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Festschrift for
Sandro Pignatti
on the occasion of his
90th birthday

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E. Feoli, F. Garbari, P. L. Nimis,
F. Pedrotti & F. M. Raimondo

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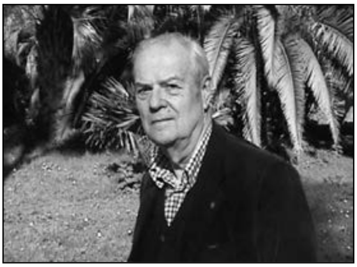
To Sandro Pignatti, on the occasion of his 90th birthday



Sandro Pignatti (Venice, 28 September 1930) began his academic career at the University of Pavia where in 1954 - immediately after graduating in Natural Sciences - Prof. Raffaele Ciferri appointed him as assistant. He then continued at the University of Padua, where in 1958 Prof. Carlo Cappelletti proposed him for the post of Systematic Botany. His academic career reached its peak in 1963 at the University of Trieste, where he was called to hold the chair of Botany, and ended at the "La Sapienza" University of Rome, where Sandro Pignatti moved in 1983 to occupy the chair of Plant Ecology, previously held by Valerio Giacomini, his friend and teacher, who died a few years earlier. Academic of the Lincei from 1999, since 2005 Sandro Pignatti is Professor Emeritus at the University of Rome "La Sapienza".

During his scientific activity, Sandro Pignatti has dealt with various botanical and ecological issues, starting with research on the phanerogamic and cryptogamic flora, to continue with the study of plant associations in various parts of Italy, and ending with the great syntheses mainly represented by the "Flora d'Italia" and "Plant Life of the Dolomites".

At the beginning of his scientifc career, Sandro Pignatti had been sent by Prof. Raffaele Ciferri to Montpellier, for a period of specialization at the phytosociological school of Josias Braun-Blanquet. After Valerio Giacomini and Ruggero Tomaselli, Pignatti was the third botanist from Pavia to go to Montpellier. Returning to Italy, he greatly contributed to the spread of Phytosociology, first in Pavia, then in Padua, Trieste and Rome. His first important phytosociological contribution, dedicated to the vegetation of the eastern Venetian Plain, has now become a classic. His research on flora allowed him to discover and describe many new species and to publish important critical revisions of some genera.

However, already since the years of Padua, Sandro Pignatti was thinking of a great work dedicated to the Italian flora. The last national Flora was that of Adriano Fiori, published between 1924 and 1926, a work which was valid for its time, but had started to appear as outdated, both because of increased floristic and taxonomic knowledge, and because the concept of species had changed considerably with respect of that adopted by Fiori. The monumental *Flora d'Italia* by Sandro Pignatti was published in 1982, in three volumes, by Edagricole of Bologna. A second edition, in four volumes, was published in 2017-2019.

Sandro Pignatti cultivated intensive contacts with other botanists and had many friends among them, both in Italy and abroad. However, beyond personal relationships, he always also had a great commitment for societal activities. In 1961, when he was in Padua, he founded - in collaboration with Erwin Aichinger (Klagenfurt) and Max Wraber (Ljubljana) - the Ostalpin-Dinarische Pflanzesoziologische Gesellschaft based in Padua, giving life to a periodical, the "Mitteilungen" , in which the communications presented at congresses organized both in Italy (Bressanone, Camerino and Trieste) and abroad (Zagreb, Zurich, Munich, Ljubljana, Vienna, etc.) were printed. This Association was very important for young Phytosociologists at the beginning of their careers, because they had the opportunity to meet and communicate at congresses, and to publish their first essays on the "Mitteilungen".

A few years later, in 1967, Sandro Pignatti was elected President of the Italian Botanical Society, where he proposed the establishment of working groups, which later became very important for the scientific growth of Italian Botany. In the international field, Sandro Pignatti regularly attended the congresses organized in Rinteln by Prof. R. Tüxen. In this context, he was also elected President of the IAVS (International Association for Vegetation Science). In those years, Sandro Pignatti was very busy both on a scientific and organizational level: every year the annual congress of the IAVS was organized in different states and regions, in Jena, Bailleul, Prague, Utrecht, Palermo and elsewhere. Of particular importance is his role in founding the Working Group for Data Processing within the IAVS, together with E. van der Maarel and L. Orloci. In an era when computers were an absolute novelty, the creation of this group - whose first meeting was held in Trieste in 1969 - was of fundamental importance in the introduction of multivariate analysis techniques in Plant Ecology. Another important fallout of Sandro Pignatti's interest in the new information technologies was the creation of the *Database on the Flora of Italy*, one of the first examples of this kind at an international level, in an era when the Internet did not yet exist.

In Montpellier, Sandro Pignatti had met a young botanist, Erika Wikus, native from Fronsburg (Wien), also a specialist under the guidance of Braun-Blanquet. After a short time, Sandro and Erika got engaged and married. From their marriage 5 children were born: Johannes, Laura, Giuseppe, Eugenio and Francesco. In addition to being a wife, Erika also became a close collaborator of Sandro in the field of vegetation studies, as is clear from their recent works on the Dolomites and on the Western Australian Deserts.

Sandro Pignatti published hundreds of important scientific contributions. The work consulted by all Italian botanists is his *Flora d'Italia*, of which he managed to provide an eagerly awaited update in its recent second edition.

On the occasion of his 90th birthday, 70 colleagues, students, friends and young botanists of various nationalities gathered in contributing to this volume, wishing Sandro Pignatti to enjoy for a long time the fruits of what he managed to sow during a life dedicated to Botany.

From their respective offices, January 6, 2022

E. Feoli, F. Garbari, P. L. Nimis, F. Pedrotti, F. M. Raimondo

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Article

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H. Walter Lack

From Ethiopia to Fiesole, Kew and Paris: The discovery, naming and typification of *Cadia purpurea* (*Fabaceae*)

Abstract

Lack, H. W.: From Ethiopia to Fiesole, Kew and Paris: The discovery, naming and typification of *Cadia purpurea* (*Fabaceae*). — Fl. Medit. 31 (Special Issue): 9-21. 2021. — ISSN: 1120-4052 printed, 2240-4538 online.

Cadia purpurea, an unarmed shrub to small tree of the tribe Podalyrieae, is native in East Africa and southern Arabia. Seeds collected by James Bruce in Eritrea or Ethiopia in 1770-1772 were raised in gardens in Fiesole, Kew and Paris. Several names were based on this cultivated material. The nomenclature is clarified, a neotype superseded and a revised typification presented.

Key words: East Africa, southern Arabia, James Bruce, nomenclature, botanical illustration.

Dedication

As a botanist and vegetation ecologist with a very broad spectrum of interests Sandro Pignatti has worked, collected, published and lectured in several parts of the world. During his tenure as professor at Trieste University he accepted the position of guest professor at Jaamacadda Ummadda Soomaaliyeed [National University of Somalia] in Mogadishu in 1982 and studied the Boscalia vegetation of the southern Somalia (Pignatti & Warfà 1983). This publication was followed by another paper on pastoralism and plant cover in southern Somalia (Barkhadle & al. 1994). During his visit in southern Somalia in 1982 Sandro Pignatti may well have encountered the member of the extremely diverse *Fabaceae* family which is the subject of this paper. On the occasion of his ninetieth birthday this paper is dedicated to him.

Introduction

Cadia purpurea is an unarmed shrub to small tree of the *Fabaceae*, subfamily *Papilionoideae*, which occurs widely from southern Saudi Arabia in the north to southern Somalia in the south and from northern Kenya in the west to southern Oman in the east. Well documented in the floristic literature (Eritrea: Thulin 1989; Ethiopia: Thulin 1989; Kenya: Gillett & al. 1971; Oman: Ghazanfar 2007; Saudi Arabia: Collenette 1999;

Somalia: Thulin 1993; Yemen: Wood 1997), *Cadia purpurea* has been reported as a common, sometimes abundant plant occurring in bushland and reaching in Yemen an altitude of c. 3500 m. For a distribution map of the species in Africa see African Plant Database (http://www.ville-ge.ch/musinfo/bd/cjb/africa/details.php?langue=an&id=62679). For recently collected specimens from the Arabian Peninsula examined by the present author see Appendix 1.

The flowers of *Cadia purpurea* with their cream petals when opening, later wine-red in colour (Gillett & al. 1971) offer the most striking character of *C. purpurea*: they are actinomorph, an anomaly in the *Papilionoideae* with otherwise almost exclusively zygomorphic flowers. This has created very considerable interest and led to molecular studies (e.g. Citerne & al. 2003, 2006) which associate *C. purpurea* to an informally delimited genistoid clade. Further work on a broader spectrum of material has clarified the phylogenetic position of the small genus *Cadia* within the now clearly circumscribed tribe *Podalyrieae* (Boatwright & al. 2008, Cardoso & al. 2013). This paper, however, does not address the phylogeny of the genus and its next relatives but deals with the discovery, naming and typification of *C. purpurea*. Admittedly the major points of this argument have already been elucidated in the monograph of the genus (van der Maesen 1970), but his choice of the neotype has to be superseded. In addition, over the last fifty years a considerable amount of new evidence has come to light, in particular in Florence, London and Paris, which necessitates this paper and results in a revised typification.

The pioneers – Forsskål and Bruce

The first to collect *Cadia purpurea* was Pehr Forsskål (1732-1763), who travelled as member of the Royal Danish Expedition in what is now Yemen in 1762-1763. His specimen, i.e. *Forsskål 1038*, has survived and is kept in C (Hepper & Friis 1994). In his posthumously published *Flora aegyptiaco-arabica* the pertinent locality is given as "Hadîe" (Forsskål 1775: 90), which has been interpreted as Al Hadiyah (14°31'N, 43°34E; Hepper & Fries 1994) and is plausible for this taxon. In his travel diary (Forsskål 1950, 2009) Forsskål does not mention *C. purpurea* and the locality "Hadîe" only in passing, but the Arab plant name "Kadi" given in the *Flora aegyptiaco-arabica* (Forsskål 1775: 90) became the basis for the generic name *Cadia* (Hepper & Friis 1994). As a consequence, the collection date remains unknown but judging from the itinerary in the "montes hadienses" (Forsskål 1775: lxxxix) it is safe to assume that this was in March 1763. Only a few months later, on 11 July 1763, Forsskål died in Yarim, probably from malaria (Hepper & Friis 1994). Carsten Niebuhr (1733-1815), the leader of the expedition and only surviving participant, managed to reach Bombay [Mumbay], from where he sent Forsskål's collections and notes to Copenhagen (Hepper & Friis 1994). Later he returned via Shiraz and Istanbul to Copenhagen and first published his travelogue (Niebuhr 1772, 1774, 1778). On the basis of Forsskål's notes and specimens, Niebuhr subsequently arranged for the publication of the *Flora aegyptiaca-arabica* which appeared in June 1775 (Hepper & Friis 1994). In this work the specimen from "Hadîe" was described and the generic name *Cadia* based on it validated (Forsskål 1775: 90), but no specific epithet was given. Even the medicinal, or rather superstitious use of the fresh leaves of this plant by local informants was mentioned (Forsskål 1775: 90).

James Bruce of Kinnaird (1730-1794), a gentleman of private means, was one of the pioneers of the exploration of what are now Ethiopia and Eritrea (Bredin 2001). Like Niebuhr he published an extensive travel account (Bruce 1790) and brought back artefacts, in particular Ethiopian manuscripts and illustrations prepared for him by Luigi Balugani (1737-1771), as well as natural history items, among them seeds. No seeds seem to have survived in a herbarium and no details are available about the locality and the date where they were collected. However, this collection must have included seeds of *Cadia purpurea* (see below). Considering Bruce's travel route and the fact that he sailed along the eastern coast of the Red Sea as far as Al Luhayya in what is now Yemen without venturing further inland in 1769, it is almost certain that he collected these seeds in Africa between 1770 and 1772. Consequently an Ethiopian or Eritrean progeny is extremely likely. Significantly no illustration of *C. purpurea* prepared by Balugani is known among his drawings kept in the Yale Center for British Art (Hepper & al. 1991).

Seeds donated to gardens in Fiesole, Kew and Paris

On the way back to his native Scotland, Bruce is known to have stopped in Paris in spring 1773 and donated seeds of *Cadia purpurea* to André Thouin (1747-1824), then the head gardener at the Jardin du Roi (Laissus 1986; Letouzey 1989). Because of illness Bruce continued from the French capital to Tuscany and donated seeds of his trophy to Giovanni Mariti (1736-1806), a correspondent of Balugani then based in Florence (Hepper & Friis 1991). The latter passed them on to Niccolò Marchese Panciatichi (1742-1811; Passerini 1858), chamberlain of Pietro Leopoldo (1747-1792), Grand Duke of Tuscany, and of the latter's brother Joseph II (1741-1790), Emperor of the Holy Roman Empire. Panciatichi was a member of the Florentine aristocracy, who cultivated botanical and horticultural interests and owned, among several other properties, La Loggia, a *villa suburbana* in Fiesole, today via Bolognese 165, just outside Florence (Passerini 1858). Panciatichi gave the seeds to Giuseppe Picciuoli [Piccioli] (- 1818), his head gardener at La Loggia (Picciuoli 1783), who was later invited by Grand Duke Ferdinand III (1769-1824) to become "giardiniere botanico" [botanical gardener] at the Regio Museo di Storia Naturale in Florence (Grifoni 1999). However, Piccuoli's manuscript catalogue of the garden at La Loggia, dated 1773-1780 (Grifoni 1999), mentions only two accessions received from Bruce (but see below).

After a stay in Bologna and Rome, Bruce returned to Paris and was back in London in June 1774 (Hulton 1991). According to a letter sent by Bruce to Joseph Banks (1743-1820), the informal supervisor of the Royal Garden at Kew soon to be elected President of the Royal Society (Carter 1988), seeds collected in Ethiopia had been previously sent to "Mr. Eaton" (Dawson 1958: 177). The recipient was clearly William Aiton (1731-1793), the head gardener at Kew (Desmond 2007). It is hypothesized that among this material were seeds of *Cadia purpurea*.

Panciatica purpurea in Fiesole

The plant cultivated in Fiesole was described by Picciuoli in his *Hortus Panciaticus*, an exceedingly rare brochure on the garden of La Loggia (Picciuoli 1783), as a species new to science. He coined the name *Panciatica purpurea* G. Piccioli, offered an extremely detailed description (Picciuoli 1783: 9-10) and included a coloured copper engraving with analysis based on a drawing of an anonymous illustrator (Fig. 1). From the contents it is clear that the plant was among those cultivated from material donated by Bruce although Picciuoli refrained from specifying an individual specimen. It is of interest that at the end of his description Picciuoli explicitly noted that the plant "appartiene alla classe decima, o decandria di Linneo, e per l'unità del pistillo dei suoi fiori, merita la medesima di essere arruolata tra le piante del primo ordine della classe stessa" "[belongs to the tenth class, or the Decandria of Linnaeus, and because of it having only one pistil in its flowers, merits to be listed among the plants of the first order of that class]" (Picciuoli 1783). The name Bruce had given to the seeds, i.e. "Acacia nova Abissinica", has also been mentioned in the protologue.

The herbarium Micheli-Tangiori, a historical herbarium kept at FI (Nepi 2009), contains a specimen of *Cadia purpurea* (FI063817) annotated in ink "Panciatica purpurea", though without a date or a provenance (Fig. 2). The paper strips fixing the specimen on the sheet carry the note in ink "Cl X O I", which stands for classis X ordo I, i.e. *Decandria monogynia* which Picciuoli had explicitly referred to in the protologue. A letter written by Picciuoli dated 28 December 1802 kept in the Archives of the Conservatoire et Jardin botaniques in Geneva shows a handwriting which indicates that FI063817 was annotated by Picciuoli. Another specimen of *C. purpurea* kept in Candolle herbarium, G-DC (G00652597) carries the pencil note "Panciatica purpurea Picciuoli hort. Flor." in the same hand. The second specimen was sent in 1808 by Giuseppe Raddi (1770-1829), then curator at the Reale Museo di fisica e di storia naturale in Florence, to Augustin-Pyramus de Candolle (1778-1841), when the latter was professor at Montpellier University. At that time Picciuoli had left the services of Niccolò Panciatichi and worked as head gardener of the garden attached to this museum (Grifoni 1999) and was, in a sense, Raddi's colleague. FI063817 is selected as lectotype of the name *Panciatica purpurea*, G00653597 could be an isolectotype.

A specimen in the Banks herbarium (BM001134363, upper specimen) merits attention. Annotated on the back of the sheet "1. Hort. Florent. 1780 2. Hort Kew without flowers" it consists of a flowering and a non-flowering branch of *C. purpurea* plus dissected flowers with the individual parts glued on oval pieces of paper attached to the herbarium sheet. Considering the rarity of the species, the flowering branch may well originate in the garden of La Loggia in Fiesole, but since there is no plant name associated with this material, the specimen cannot be used for typification.

Fig. 1. *Cadia purpurea* (Piccioli) Ait. Coloured copper engraving. – F. Picciuoli, Hortus Panciaticus, Firenze 1783. – München, Bayerische Staatsbibliothek Res/4 Phyt. 157, after p. 20.

Fig. 2. *Cadia purpurea* (Piccioli) Ait. Lectotype. Specimen annotated by G. Picciuoli. FI063817. – Firenze, Museo di Storia naturale.

Cadia purpurea at Kew and in Milan

In the *Hortus kewensis*, the first printed inventory of the Royal Garden at Kew, *Cadia purpurea* is listed with the note “Introd. 1775, by Jame Bruce, Esq.” under the addenda, and reported as cultivated in “S”, i.e. in a warm house (Aiton 1789, vol. 3: 492). The habitat is given as “Arabia”, almost certainly in error (Aiton 1789, vol. 3: 492). Although the name of William Aiton (1731-1793), then the head gardener at Kew, appears on the title-page of this work, it is largely the work of Daniel Solander (1733-1782) and Jonas Dryander (1748-1810), who in succession were librarians to Banks (Mabberley 2019). Remarkably the *Hortus Panciaticus* is listed in the bibliography of the *Hortus kewensis* (Aiton 1789, vol. 1: xxv) and appears also in the catalogue of Banks’s library (Dryander 1797). The availability of the *Hortus Panciaticus* in this library was apparently the reason why the combination *C. purpurea* (Piccioli) Aiton was formed in the *Hortus kewensis*. The existence of a living plant of this species cultivated in the Royal Garden at Kew is documented by an undated specimen annotated “Hort Kew [ink] without flowers [pencil]” kept in the Banks herbarium (BM001134363, lower specimen). When *C. purpurea* flowered for the first time at Kew, remains unknown.

Separately from Aiton, or rather Dryander, and apparently at the same time, a teacher at the Brera in Milan came to the same conclusion. This was Fulgenzio Vitman (1728-1806), the professor for botany and founder of the botanic garden at this institution (Visconti 2012), and he transferred the name *Panciatica purpurea* to the genus *Cadia* (Vitman 1789). However, the third volume of his *Summa plantarum* appeared in December 1789 or early 1790 and therefore just after the *Hortus kewensis* (Stafleu & Cowan 1976, 1986). Interestingly Vitman ascribed the *Hortus Panciaticus* to Attilio Zuccagni (1754-1807), director of the botanical garden of the Reale Museo di Fisica e Scienze naturali in Florence and physician in ordinary to Grand Duke Pietro Leopoldo (Sarchiani 1812), not to Picciuoli.

Cadia arabica in Göttingen

When Johann Friedrich Gmelin (1748-1804), since 1775 professor of philosophy and since 1778 also professor of medicine at Göttingen University (Wagenitz 1988), sat down to write the thirteenth edition of Linnaeus’s *Systema naturae* he also dealt with the genus *Cadia* Forssk. Referring to “Forsk. fl. aeg. arab. p. 90.” he published the naked name *Cadia arabica*. For good reason Gmelin is regarded as “mainly a compiler” (Stafleu & Cowan 1976) and nothing indicates that he had ever seen a specimen of this species.

Cadia varia, *Spaendoncea tamarindifolia* and *C. pendula* in Paris

The specimen in the Jardin des plantes, the re-named Jardin du Roi now belonging to the newly founded Muséum d’Histoire naturelle, flowered in 1794 at the latest, and it was definitely just one specimen (Desfontaines 1795). It immediately attracted the attention of the initiated – Pierre-Joseph Redouté (1759-1840), a free-lance illustrator who regularly received commissions from botanists based in Paris; Charles-Louis L'Héritier de Brutelle (1746-1800), a self-taught botanist who had lost his position at the Cour des Aides due to the French Revolution and was then a *commis* at the ministry of justice (Stafleu 1963); and René-Louiche Desfontaines (1750-1833), one of the professors at the Muséum. However, the precise sequence of events remains unclear.

Redouté produced a water-colour of a specimen of *Cadia purpurea* for the Collection des vélins, now conserved in the Bibliothèque centrale of the Muséum national d'Histoire naturelle in Paris (Vol. 54, f. 19). It is annotated in calligraphy "Spaendoncea tamarindifolia. (Desf:) Cadia purpurea. (Forsk:) Abissinie" and shows a flowering branch with (1) two flowers, one with the petals removed, the other with the sepals and petals removed, (2) a separate petal, (3) a separate stamen and (4) a juvenile pod. Painted on vellum and signed (though difficult to discern) outside the painted frame, this drawing is undated. However, judging from the fake gold (a paint containing copper and turning brown) in the frame, it can be dated to the period between c. 1794 and c. 1804, when good quality gold paint was difficult to obtain (Raynal-Roques & Jolinon 1998). Notably, the water-colours integrated into the Collection of vélins were intended as documents and not primarily for publication. As a matter of fact Redouté's image of *C. purpurea* was first published complete, i.e. with all details, only some 180 years after it had been made (Anonymous 1980).

For good reason an anonymous correspondent of Paul Usteri (1768-1831), a botany-minded publicist based in Zurich, wrote "die Botanicker und Liebhaber sind allhier [in Paris] nichts weniger als mittheilend, hat jemand eine seltene Planze in der Blüthe so wird sie strenger bewacht als ein Schatz bewahrt [botanists and amateurs here [in Paris] are anything but communicative, when someone has a rare plant in flower, it is guarded more closely than a treasure]" (Anonymous 1791). Four years after this statement had been published, the situation had not changed. One of the rare plants in flower was the specimen of *Cadia purpurea* raised by Thouin. At an interval of a few months it was described as new to science independently – by L'Héritier as *C. varia* L'Hér. (L'Héritier 1795) and by Desfontaines as *Spaendoncea tamarindifolia* Desf. (Desfontaines 1795). Both protologues explicitly refer to a living plant in the Jardin des plantes raised from seeds received from Bruce who had them collected in Ethiopia. Furthermore both protologues contain copper engravings, one of them with the note "del. P. Redouté" (L'Héritier 1795) the other unattributed, and both engravings show a flowering twig and an analysis. The two analyses differ only in details: one of them shows (1) two flowers, both without petals, (2) two stamens in different views, (3) a separate petal and (4) a juvenile pod (L'Héritier 1795), the other consists of a representation of (1) one flower without petals, (2) one flower without petals and sepals, (3) a separate petal, (4) one separate stamen and (5) a juvenile pod (Desfontaines 1795). A comparison of the two analyses with the analysis on the water-colour (see above) shows that the individual elements are identical and were copied, while in contrast the three twigs shown in water-colour and in the two engravings differ. No specimen annotated *Cadia varia* in L'Héritier's hand could be traced, though material annotated by Pierre-Étienne Ventenat exists (G00341938). In contrast specimens annotated by Desfontaines "Spaendoncea tamarindifolia" have been located (G00341939, P02778642).

In the years following the hot phase of the French Revolution communication among botanists was extremely quick. Only months after the publication of the names *Cadia varia* and *Spaendoncea tamarinifolia* in Paris Zuccagni in Florence realized their identity with *Cadia purpurea* (Zuccagni & al. 1796). This paper which appeared in Zurich consist of two parts: (1) Zuccagni's arguments, (2) a re-issue of the two previously published papers (L'Héritier 1795; Desfontaines 1795), albeit including only one illustration (Desfontaines 1795). Although synonymies were convincingly clarified, all three names remained in use. A few years later Jaume St.-Hilaire (1772-1845) validated one further name for this species, i.e. *Cadia pendula*, ascribing it in error to Forsskål; in the protologue no specimen is mentioned, but only the habitat "Arabie".

In May 1827, Redouté started to publish his *Choix des plus belles fleurs*, a work consisting of 144 colour stipple engravings issued in 36 instalments with 20 pages of text by Antoine Guillemin (1796-1842) issued with the last part; the work came to its conclusion in June 1833 (Stafleu & Cowan 1983). The contents is an amalgam of newly produced and previously published plates which had appeared in Redouté's earlier works, with the plates of the latter group often modified in comparison to their first issue (Lack 2018: 450-452). Both numbered and unnumbered plates are known. The engraving inscribed on the lower left hand margin "P. J. Redouté _76" had not previously been published and shows *Cadia purpurea*, more specifically the upper part of the branch depicted by Redouté for the Collection des vélins whereas the analysis was suppressed. While the engraving is inscribed *Spaendoncea tamarindifolia* Guillemin regarded in his comments the name *Cadia varia* as correct.

Nomenclatural summary

Cadia purpurea (G. Piccioli) Aiton, Hort. Kew. 3: 492 (1789).

≣ *Panciatica purpurea* G. Piccioli, Hortus Panciaticus 9 (1783). – Lectotype designated here: FI063817, image! (Fig. 2); isolectotype (?): G00653597, image!. – Note: In accordance with ICN Art. 9.19a (Turland & al. 2018) the neotype previously selected "Forskål herb. 267" (Meusen 1971: 283), i.e. *Forsskål 1038*, is herewith superseded, because FI063817 is regarded as original material of *P. purpurea*.

= *Cadia varia* L'Hér. in Mag. Encycl. 5: 22 (1795). – Lectotype here designated: Mag. Encycl. 5: plate without number following p. 20.

= *Spaendoncea tamarindifolia* Desf. in Décade Philos. 7: 259 (1795). – Lectotype here designated: G00341939, image!, P02778642 image!.

= *Cadia pendula* J. St. Hil., Exposition 2: 206 (1805).

Eponyms

The generic name *Panciatica* Picc. does not refer to Niccolò Marchese Panciatichi, the owner of La Loggia in Fiesole and Picciuoli's superior, but to the former's great uncle, cardinal Bandino Marchese Panciatichi (1629-1718), long-sitting prefect of the Congregation for the Clergy in Rome (Passerini 1858). His robe had the same colour as the flowers of this plant specifically referred to in the protologue (Picciuoli 1783), at least in their late stage. *Spaendoncea* Desf. is a tribute to the painter and plant illustrator Gerard [Gerrit] van Spaendonck (1746-1822), one of the twelve professors when the Muséum d'Histoire naturelle in Paris was founded in 1792, and therefore a colleague of Desfontaines. Van Spaendonck had Redouté as his most prominent pupil, starting from 1792 he taught botanical illustration at the Muséum and is famous for having created the logo of this institution which continues to be in use today (e.g. Spary 2000).

Epilogue

In a nutshell the fate of the generic names *Cadia*, *Panciatica* and *Spandoncea* exemplify the interdependence of taxonomic work undertaken in the late eighteenth century and the results of collaborative versus competitive approach by the botanists involved. At the same time this case story shows that not only specimens and printed texts are essential for clarifying plant names but also illustrations, both originals and prints, as well as archival material.

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References

Aiton, W. 1789: Hortus kewensis; or a catalogue of the plants cultivated in the Royal botanic garden at Kew, **1-3.** – London.

Anonymous 1791: Auszüge aus Briefen. – Ann. Bot. (Usteri) **1:** 170.

— 1980: Redouté et les vélins du Muséum National d'Histoire Naturelle. – Paris.

Barkhadle, A. M. I., Ongaro, L. & Pignatti, S. 1994: Pastoralism and plant cover in the lower Shabelle region, Southern Somalia. – Landscape Ecol. **9:** 79-88.

Boatwright, J. S., Savolainen, V., van Wyck, B.-E., Schutte-Vlok, A. L., Forest, F. & van der Bank, M. 2008: Systematic position of the anomalous genus *Cadia* and the phylogeny of the tribe Podalyrieae (*Fabaceae*). – Syst. Bot. **33:** 133-147.

Bredin, M. 2001: The pale Abyssinian: a life of James Bruce, African explorer and adventurer. – London.

Bruce, J. 1790: Travels to discover the source of the Nile in the years 1768, 1769, 1770, 1771, 1772, and 1773, **1-5.** – Edinburgh.

Cardoso, D., Pennington, R. T., Queiros, L. P. de, Boatwright, J. S., van Wyck, B.-E., Wojciachowski, M. F. & Lavin, M. 2013: Reconstructing the deep-branching relationships of the papilionoid legumes. – S. African J. Bot. **89:** 58-75.

Carter, H. B. 1988: Sir Joseph Banks 1743-1820. – London.

Citerne, H. L., Pennington, R. T. & Cronk, Q. C. B. 2006: An apparent reversal in floral symmetry in the legume *Cadia* is a homeotic transformation. – Proc. Natl. Acad. Sci. U.S.A. **103:** 12017-12020.

—, Luo, D., Pennington, R. T., Coen, E. & Cronk, Q. C. B. 2003: A phylogenetic investigation of CYCLOIDEA-like TCP genes in Leguminosae. – Pl. Physiol. **131:** 1042-1053.

Collenette, S. 1999: Wildflowers of Saudi Arabia. – Riyadh.

Dawson, W. R. (ed.) 1958: The Banks letters. – London.

Desfontaines, R.-L. 1795: Description d'un nouveau genre de plante. – Décade Philos. **7:** 259-261.

Desmond, R. 2007: The history of the Royal Botanic Gardens Kew, ed. 2. – Kew.

Dryander J. 1797: Catalogus bibliothecae historico-naturalis Josephi Banks **3.** – London.

Forsskål, P. 1950: Resa till lycklige Arabien. Petrus Forsskåls Dagbook 1761-1763. – Uppsala.

— 2009: Peter Forsskål's Journal. – Pp. 281-380 in: Hansen, L. (ed.). The Linnaeus Apostles. Global science & adventure **4.** – London.

Ghazanfar, S. 2007: Flora of the Sultanate of Oman, **2.** – Meise (= Scripta Bot. Belgica **36**).

Gillett, J. B., Polhill, R. M. & Verdcourt, B. 1971: Leguminosae (Part 3) Subfamily Papilionoideae. – Pp. 1-501 in: Milne-Readhead, E. & Polhill, R. M. (ed.). Flora of Tropical East Africa. – London.

Grifoni, T. 1999: I cataloghi botanici del giardino di Villa La Loggia fra tradizione ed innovazione. – Nuncius **19:** 583-628.

Hepper, F. N. & Friis, I. 1991: The scientific value of Balugani's plant illustrations and notes. – Pp. 61-68 in Hulton, P., Hepper, F. N. & Friis, I. (eds). Luigi Balugani's drawings of African plants. From the collection made by James Bruce of Kinnaird on his travels to discover the sources of the Nile 1767-1773. – Rotterdam.

— & — 1994: The plants of Pehr Forsskål's 'Flora aegyptiaco-arabica'. – Kew.

—, — & Hulton, P. 1991: The catalogue of plant drawings & their identifications. – Pp. 69-114 in: Hulton, P., Hepper, F. N. & Friis, I. (eds). Luigi Balugani's drawings of African plants. From the collection made by James Bruce of Kinnaird on his travels to discover the sources of the Nile 1767-1773. – Rotterdam.

Hulton, P. 1991: An outline of the life of James Bruce of Kinnaird with particular emphasis on the drawings he brought out of Africa. – Pp. 3-40 in: Hulton, P., Hepper, F. N. & Friis, I. (eds). Luigi Balugani's drawings of African plants. From the collection made by James Bruce of Kinnaird on his travels to discover the sources of the Nile 1767-1773. – Rotterdam.

Lack, H. W. 2018: Pierre-Joseph Redouté. The book of flowers/Das Buch der Blumen/Le livre des fleuurs. – Köln.

Laissus, Y. 1986: Le jardin du roi. – Pp. 287-341 in: Taton, R. (ed.). Enseignement et diffusion des sciences en France au XVIIIe siècle. – Paris (= Histoire de la pensée. École pratique des hautes études **11**).

Letouzey, Y. 1989: Le jardin des plantes à la croisée des chemins avec André Thouin: 1747-1824. – Paris.

L'Héritier de Brutelle, C.-L. 1795: Mémoire sur un nouveau genre de plantes appelé *Cadia*. – Mag. Encycl. **5:** 20-31.

Mabberley, D. J. 2019: Botanical revelation. European encounter with Australian plants before Darwin. The Peter Crossing collection. – Sydney.

Maesen, L. J. G. van der 1971: Primitiae africanae VIII. A revision of the genus *Cadia* Forskål (Caes.) and some remarks regarding *Dicraeopetalum* Harms (Pap.) and *Platycelyphium* Harms (Pap.). – Acta Bot. Neerl. **19:** 227-248.

Nepi, C. 2009: L'erbario Micheli-Targioni/The Micheli-Targioni herbarium. – Pp. 85-102 in: Raffaelli, M. (ed.). Il Museo di Storia naturale dell'Università degli Studi di Firenze 2. Le collezioni botaniche. – Firenze (= Cataloghi e collezioni **6**).

Niebuhr, C. 1772: Beschreibung von Arabien. – Kopenhagen.

— 1774: Reisebeschreibung nach Arabien und anderen umliegenden Ländern, **1.** – Hamburg.

— 1778: Reisebeschreibung nach Arabien und anderen umliegenden Ländern, **2.** – Kopenhagen.

Passerini, L. 1858: Genealogia e storia della famiglia Panciatichi. – Firenze.

Pignatti, S. & Warfà, A. M. 1983: The Boscalia vegetation complex in southern Somalia. – Tuexenia n.s. **3:** 159-168.

Picciuoli, G. 1783: Hortus Panciaticus. – Firenze. https://daten.digitale-sammlungen.de/~db/0009/bsb00092538/images

Raynal-Roques, A. & Jolinon, J. C. 1998: Les peintres de fleurs. Les vélins du Muséum. – Paris.

Sarchiani, G. 1812: Elogio del dottor Zuccagni. – Atti Imp. Soc. Econom. Firenze **7:** 38-46.

Spary, E. C. 2000: Utopia's garden. French natural history from old regime to revolution. – Chicago.

Stafleu, F. A. 1963: L'Héritier de Brutelle: the man and his work. – Pp. xiii-xliii in: L'Heritier de Brutelle, C.-L., Sertum anglicum 1788. Facsimile with critical studies and a translation. – Pittsburgh, Penns. (= Hunt Fascimile Series **1**).

Stafleu, F. A. & Cowan, R. S. 1976: Taxonomic literature, ed. 2, **1.** – Utrecht (= Regnum Veg. **94**).

— & — 1983: Taxonomic literature, ed. 2, **3.** – Utrecht (= Regnum Veg. **110**).

— & — 1986: Taxonomic literature, ed. 2, **6.** – Utrecht (= Regnum Veg. **115**).

St.-Hilaire, J. 1805: Exposition des familles naturelles et de la germination des plantes, **2.** – Paris.

Thulin, M. 1989: Subfamily 3. *Papilionoideae* (*Faboideae*). – Pp. 97-251 in: Hedberg, I. & Edwards, S. (eds), Flora of Ethiopia, **3.** – Addis Ababa.

— 1993: *Fabaceae* (*Leguminosae*). – Pp. 341-465 in: Thulin, M. (ed.). Flora of Somalia, **1.** – Kew.

Turland, N. J., Wiersema, J. H., Barrie, F. R., Greuter, W., Hawksworth, D. L., Knapp, S., Kusber, W.-H., Li, D.-Z., Marhold, K., May, T. W., McNeill, J., Monro, A. M., Jefferson, P., Price, M. J. & Smith, G. F. (eds) 2018: International Code of nomenclature for algae, fungi and plants (Shenzhen Code). – Königstein (= Regnum Veg. **159**).

Visconti, A. 2012: La fondazione dell'orto botanico di Brera e gli anni della direzione dell'abate vallombrosano Fulgenzio Vitman (1726-1806) tra assolutismo asburgico ed età napoleonica. – Atti. Soc. Ital. Sci. Nat. Mus. Civico Storia Nat. Milano **153:** 27-48.

Vitman, F. 1789-1790: Summa plantarum, **3.** – Mediolani.

Wagenitz, G. 1988: Göttinger Biologen 1737-1945. Eine biographisch-bibliographische Liste. – Göttingen (= Göttinger Universitätsschriften. Ser. C, **2**).

Wood, J. R. I. 1997: A handbook of the Yemen flora. – Kew.

Zuccagni, A., Desfontaines, L.-R. & L'Héritier, C.-L. 1796: Cadiae arabicae descriptio. – Ann. Bot. (Usteri) **19:** 10-30.

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APPENDIX

List of selected specimens of *Cadia pupurea* recently collected on the Arabian Peninsula and reexamined

Oman: **Dhofar**, Jebel Qamar, along road to Khadrafi on Mughsail-Sarfayt road, c. 2.5 km W of junction with track to Dalkut, 16°45’15”N, 53°11’40”E, 27. 9. 2002, *Meister & Oberprieler 10230* (B); Jebel Qamar, along road to Khadrafi on Mughsail-Sarfayt road, c. 17.3 km W of junction with track to Dalkut, 1060 m, 16°42’ 16”N, 53°07’44”E, 27. 9. 2002, *Meister & Oberprieler 10231* (B).

Yemen: Gov. **Dhamar**, western escarpment, Jabal Uthmar, near village Mrisa’a, ca. 5 km SW of village Uthmar, 14°28’07.7”N, 44°00’20.0”E 1620-1720 m, 12.8.2002, *Kilian, Hein & Al-Naggan YP2611* (B, P); Gov. **Lahaj**, Jebel Eraf, between 13°06’44.1”N, 44°14’57.4°E and 13°06’32,4”, 44°15’14.5”E, 1430 , *Kilian, Hein, Kürschner, Shaber, Habib & Hubaishan YP1444* (B, P); Gov. **Abyan**, escarpment W of Lawdar, near the serpentine road E of the pass Naqil Thirah, 1650-1750 m. 13°53’N, 45°46’E, 26. 3. 1997, *Hein 3635* (B, W); Gov. **Hadramout**, Kor Seiban, 14°49’37.2”N, 48°48’21.3”E, 1900-1950m, 16. 10. 2001, *Kilian, Meister & Hubaishan YP1267* (B); Jol Plateau, 2 km S of Bayn al Jibál, Kor Seyban escarpment, upper Mawla Matar gorge, 1800-1930 m, 14°48’N, 48°46’E, 30. 10. 2000, *Kilian, Bahah, Bin Nesr, Hein & Hubaishan NK 6550* (B), *Hein 7805* (B); Jol Berka, 14°36’N, 48°40’E, on the track from village As Safal in the upper Wadi Fuwwah = Wadi Al Muhammedin, 1350 m, 14. 11. 1999, *Kilian, El-Mashjary & Hein NK 6013* (B); Jol Berka plateau above the Wadi Muhammedin, 1200 – 1400 m, 14°36’N, 48°40’E, 14. 11. 1999, *Hein 6351* (B, W); Gov. **Al Mahra**, track from Hawf towards NE up to the first plateau, 16°39’N, 53°03’E, first plateau, 200-260 m, 22. 11. 1999, *Kilian, Bahah, Bashmeilah, Ghoufaly, Hein, Kodah & Al-Shameli NK 6250* (B); coastal mountains between Al Faydami and Hawf, 1.plateau, 250-500 m, 16°39’N, 53°02’E, 22. 11. 1999, *Hein 6667* (B, W); track from Hawf to the village Con, second plateau, 16°39’N, 53°02’E, 700-900 m, 22. 11. 1999, *Kilian, Bahah, Bashmeilah, Ghoufaly, Hein, Kodah & Al-Shameili NK 6281* (B); coastal mountains between Al Faydami and Hawf, plateau of the Jabal Chatan (3.plateau), 1300-1350 m, 16°40’N, 52°58’E, 23. 11. 1999, *Hein 6782* (B, W); Hawf Mts, near a locality called ‘Uteq’, 16°38’57.5”N, 52°57’39.2”E, c. 900 m, 1. 10. 2001, *N. Kilian YP628 (*B); Costal mountains between Al Faydami and Hawf, plateau and slopes N of the village Damqawt, 520 m, 16°34’N, 52°47E, 12. 11. 2000, *Hein 8078* (B, W).

Article

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Enrico Feoli & Paola Ganis

Similarity, classification and diversity “an Eternal Golden Braid” in quantitative vegetation studies

Abstract

Feoli, E. & Ganis, P.: Similarity, classification and diversity “an Eternal Golden Braid” in quantitative vegetation studies. — Fl. Medit. 31 (Special Issue): 23-41. 2021. — ISSN: 1120-4052 printed, 2240-4538 online.

The role of similarity-dissimilarity matrices is discussed within a conceptual framework that shows the strict connections between similarity, classification and diversity in vegetation studies. Examples of application of the evenness of the eigenvalues of similarity matrices ($E(\lambda)$) to define classes, to measure correlation between biological communities and environmental factors and to measure diversity of vegetation systems as a parameter δ, by the formula $\kappa\delta$, where k is the number of classes and $\delta = E(\lambda)$, are given by considering two data sets regarding beech forests of the Italian peninsula.

Key words: beech forests, correlation, eigenanalysis, evenness, fuzzy sets, matrices, Occam’s razor.

Introduction

Paraphrasing Douglas R. Hofstadter (1979, 1984) we can say that Similarity, Classification and Diversity are three concepts that in quantitative ecology constitute an “Eternal golden braid” as “Gödel, Escher and Bach” in the “world” of his book. Quantitative ecology is following Gödel when it is calculating similarity (dissimilarity) between ecosystem states (nothing is definable and explainable without comparisons), it follows Escher, when produces classes of ecosystem states (classification), sharp or fuzzy: from the indistinctiveness to distinct things (see the Escher’s pictures “Liberation”, “Methamorphosis II” and “Verbum” in the book of Hofstadter) and it follows Bach when it detects diversity, that in music is a property of a playable construct based on different notes and of combinations of different notes. It is not by chance that Pignatti (1982) introduces his flora of Italy by showing a piece of music of Bach (Concerto Italiano, Fig. 1). The definition of diversity of a system is the key to understand how the system is working or playing in the “immense game” of the nature in the sense of Margalef (1980) and Eigen & Winkler (1986).

After having quantified diversity of a given area on the basis of the species (alpha diversity) or on the basis of plant-animal communities (beta diversity), we are ready to calculate similarity between the classes of the hierarchical level for which we have calculated diversity and for defining new classes at higher hierarchical levels as new levels of diversity: we can walk up and down as in the picture of Escher at page 13 of the Italian edition of the book of Hofstadter (1984). The application of the three concepts: similarity, classification and diversity, in logical sequential loops, leads towards the knowledge generation about the ecosystems and ecosystem’s components. In this paper we reconsider in more detail the results we have obtained by Feoli & Ganis (2019) and we show how $E(\lambda)$ can be used to measure the diversity of the vegetation systems as suggested by Feoli (2018).

Similarity, classification, diversity and eigenvalues

Similarity

Similarity is a property of any object that emerges when it is compared with other objects. For the comparison we can use any set of characters that we are considering useful for a given purpose. Similarity between objects may be measured by mathematical functions called resemblance functions or similarity functions (Orlóci 1978) and it becomes a special case of data transformation: the description of a set of objects based on a set of characters is transformed in a description given by the set of similarities that each object has with the other objects in the set, i.e. the data matrix $m \times n$ is transformed in a symmetric similarity matrix $n \times n$ or $m \times m$. Similarity was introduced in sciences by Jaccard (1901, 1912) for comparing floras of different areas. It is a concept that is used in all branches of taxonomy and ecology and that had and has a prominent importance in phytosociology as defined by Bran-Blanquet (1964) (cf. Mueller-Dombois & Ellenberg 1974; Mucina & van der Maarel 1989; Podani 2000; Wildi 2017) thanks also to the contributions of Pignatti (e.g. Pignatti & Mengarda 1962; Maarel & al. 1976; Pignatti 1980). We do not enter in discussions about the similarity functions, we consider

Fig. 1. A piece of Concerto Italiano of J. S. Bach from the book of Pignatti (1982).

that their choice is a matter of the circumstances and the knowledge of the researcher (Dale 1988a), but we want to stress that the similarity matrices are the basic tools for all the multivariate methods linear or non-linear, from multiple regression analysis to non-metric multidimensional scaling, to cluster analysis. In the first case the regression coefficients β are obtained by the cross product of the independent variables in a matrix $\mathbf{X}$**,** that gives rise to the similarity matrix $\mathbf{X'X}$ that is used in the equation $\mathbf{B}=(\mathbf{X'X})^{-1}\,\mathbf{X'Y}$ where $\mathbf{B}$ is the matrix of the regression coefficients β and $\mathbf{Y}$ is the vector of the dependent variable. In the second case the similarity matrix, can be obtained from different resemblance functions, and it is used, in an iterative process, to obtain a minimum number of axes that are able to fit, in terms of distance, as much as possible the similarity (dissimilarity) between the objects. In the third case, the similarity matrices are the basis to obtain clusters by different methods of cluster analysis (Anderberg 1973; Orloci 1978; Legendre & Legendre 2012). We want also to remember that all the methods known as factor analysis, principal component analysis, principal co-ordinate analysis, canonical correlation analysis, canonical correspondence analysis, discriminant analysis are based on similarity matrices of the cross - product type. The differences between the methods rely on the data transformations, and the algorithms by which the similarity matrices are treated (see Mardia & al. 1979 and Jongman & al. 1995, for a good mathematical presentation of the methods in terms of matrix algebra).

In vegetation science similarity can be calculated between single sample units (pieces of lands or volumes of water) described by species or other characters (descriptors) or between sets of sampling units (as done by Feoli & Scoppola 1980 to quantify the dynamical pattern of the plant communities defined by Pignatti 1959, for the dunes of Venice's Lagoon) or between the descriptors in terms of their behaviour in the sample units (presence-absence or quantities), that generally is called correlation or association, or on the basis of characters that can describe the descriptors (structural, chemical, evolutive etc., cf. Feoli 2018 and references therein). In Phytosociology (Braun-Blanquet 1964) such sampling units are called relevés. They can be done on the basis of different criteria (Mueller-Dombois & Ellenberg 1974) and are the basis for the discipline called syntaxonomy that is dedicated to the hierarchical classification of plant communities (Pignatti 1980, 1990). Besides to be the basis for numerical classifications and ordinations, similarity matrices can be very useful to correlate two or more sets of characters that describe the same set of objects, as was proposed by Mantel (1967), i.e. by calculating the correlation between similarity matrices, or as was proposed by Zerihun Woldu & al. (1989), by the correlation between fuzzy sets obtained by similarity matrices, or, as was proposed by Feoli & Ganis (1986), by the autocorrelation of single or composite variables in spaces defined by the similarity matrices. These ways of finding correlations between sets (representing classes of objects and or measures on single of groups of variables), overcomes all the problems related to different scales of measuring variables that we may find in traditional "parametric" methods treated in Mardia & al. (1979) and Jongman & al. (1995), because we can use different types of similarity functions including those suitable for mixed data such Goodall's (Goodall 1964, 1966), Burnaby's (1970) and Gower's (1970, 1971) ones (see Carranza & al. 1998).

Classification and fuzzy sets

The higher is the similarity between two objects the higher is the possibility that two objects would belong to the same class of objects (Zadeh 1978). The similarity matrices of objects can be interpreted mathematically in terms of fuzzy sets theory: the similarity between two objects is, indeed, the degree of belonging of one object to the set defined by the other object (Zhao 1986; Roberts 1986; Feoli & Zuccarello 1986; Feoli & Orlóci 2011). The definition of sets (classes) is the result of a classification or of an identification process and the *k* sets (classes), that are established, represent always a classification. The degrees of belonging of objects to each of the *k* classes may be calculated by averaging their similarity in the classes or by keeping the minimum or the maximum values of their similarity within the classes, according to the three main strategies of cluster analysis, i.e. average, complete and single linkage (Anderberg 1973; Orlóci 1978; Podani 2000). In this way one object can belong to more than one set with the same or different degrees of belonging. Once we have decided the number of *k* classes on the basis of a given set of characters, we can describe the classes on the basis of other characters (external characters) suitable to infer on the causes that could have been responsible for that classification, e.g. the importance of the environmental factors in determining the *k* classes, or in general to find correlations between environmental factors and other characters that can be used to describe the classes (Feoli & Ganis 2019). The utility of defining fuzzy sets from similarity matrices after classification processes is the fact that the fuzzy sets so obtained, may be used as new variables that have the property to be correlated with the eigenvectors of the similarity matrix from which they are calculated (Feoli & Zuccarello 2013) and that allow to correlate directly classes of objects with variables measured on the objects (in the case of the example of this paper the vegetation types with the environmental indicator values describing the vegetation types).

Diversity

The higher is the number of classes (*k*) of elements we can define within one system (living or not), by a classification or an identification process, the higher is its diversity. Feoli (2018) discussed the concept of fuzzy diversity and proposed to measure it by the formula:

$$D= k\delta \qquad 1)$$

where k is the number of classes and δ a parameter ranging between 0 and 1, representing the dissimilarity within-between (or only between the classes, depending if we consider or not that the elements of one class are completely alike). The parameter δ should not to be seen as a compulsory parameter, it should be used only if we think that the similarity within-between the classes is important to be taken into consideration when measuring the diversity of a system: “the higher the similarity between its components the lower is its diversity”. If this assumption is not considered relevant, δ is placed equal to 1 and the diversity is just the richness of the system. Another alternative formula should be $D = k^{\delta}$, however, this is less sensitive to the number of classes. Feoli (2018) distinguished between crisp and fuzzy diversity according to the way by which δ is calculated. If we consider the complete homogeneity within the class (i.e. the similarity between the elements of the class is 1 and dissimilarity is 0) and we consider the similarity between the classes equal to 0, then the parameter δ is considered crisp and it will depend only by the proportion of the classes. The diversity in this case is a crisp diversity and is the one that is traditionally calculated with the Gini-Simpson index or with the Shannon's index. To clarify the matter: if we consider a vector, in which each component represents a quantity of one class of elements, the vector could be interpreted as a crisp similarity matrix with disjoint submatrices with elements $s_{ij} = 1$, representing the perfect similarity between the units that has been used to quantify the classes (components of the vector). For example, if we have a vector with three classes A, B, C with respective quantities (e.g. biomass in kg.): A=4.3, B=8.65 and C=10.68, the vector is representing a disjoint symmetric matrix of (430+865+1068) x (430+865+1068) cells (with values as decagrams) with 3 submatrices **A**, **B**, **C** full of 1s, with respectively 430 x 430, 865 x 865 and 1068 x 1068 cells. It follows that the most used diversity indices e.g. the one of Gini-Simpson and the one of Shannon, are respectively the average similarity-dissimilarity and the entropy of the eigenvalues of the crisp symmetric matrix and their evenness could be used as a crisp δ (cf. Feoli 2018).

If we are interested in considering the similarity between the classes, i.e. the fuzzy diversity, we should consider as a fuzzy δ, the evenness of the well-known index of Rao (cf. Rao 2010), when we are going to apply the Gini-Simpson index, or the evenness of the formula suggested by Ricotta & Szeidl (2006), if we are going to apply the Shannon's entropy. These indices are keeping into consideration both the proportions and the similarity between the classes represented by the components of the diversity vectors. Feoli (2018) stresses the fact that dissimilarity cannot be considered synonymous of "beta diversity". The difference between "alpha" and "beta" diversity are consisting only by the fact that alpha diversity is an individual-based diversity, while beta diversity is a community- based diversity, i.e. in the first case the objects grouped into classes are individuals of plants, animals, microbes, etc., in the second case, they are communities of plant, animals and microbes. Therefore, according to Feoli (2018) alpha diversity is the diversity of species, or other sets of characters, grouping the individuals living in a given ecosystem (these groups or classes can be defined at any hierarchical level we consider adequate for the research we are involved to, e.g. Pignatti 1960, 1980), while beta diversity is the diversity of the ecosystems (adequately defined) that are occupying a given area. In analogy with classifications and ordinations based on rows (R) and those based on columns (Q) of a matrix, when the rows represent classes of individuals defined by a certain set of characters and the columns classes of objects (with one or more elements) described by the classes in rows, we can distinguish two type of diversity of a matrix, the diversity based on rows and the diversity based on columns, i.e. R and Q diversity. Both may be fuzzy or crisp. While Q diversity could correspond to the Whittaker's beta diversity, R could include alpha diversity, when we consider the richness of the single column vector or the average richness of all the column vectors of a matrix, and the gamma diversity of Whittaker when we consider the richness of the complete matrix i.e. the number of its rows.

Feoli (2018) suggests to use the diversity measures of formula 1) to calculate the redundancy of the system by the following formula:

$$\rho = \frac{k - k\delta}{k} = 1 - \delta \qquad 2)$$

that is the complement to one of δ i.e. a measure of a relative "global" similarity within a system.

Eigenvalues

The definition of classes is the aim of any classification process. To represent a useful classification the classes should be significantly separated in order to be in line with the Occam's razor principle "Entities are not to be multiplied beyond necessity" also called principle of ontological economy, principle of parsimony, or principle of simplicity Goodall (1986). There are many methods to measure the separation between the classes that are used in ecological context (Dale 1988b; Pillar 1999a, b; Pillar & Orlóci 1996; Tichy & al. 2010). We do not want to compare all these methods here, we want just to show the use of the evenness of the eigenvalues of similarity matrices ($E(\lambda)$) to measure the separation between classes, as already done by Feoli & Ganis (2019) and to calculate fuzzy diversity of vegetation systems at different hierarchical levels. The reasoning on which the proposal is based, that underlies also nodal ordination (Noy-Meier 1971, 1973; Orlóci 1978), is the following. If a similarity matrix is filled by 1s, it corresponds to only one set of objects, while if it has 1s and 0s, it represents different sets of objects. When there is only one homogeneous set, the matrix has only one eigenvalue that is equal to the number of objects or classes *k*, i.e. the square root of *k* x *k* (Wilkinson 1965). It is enough that 1 element is different from all the others that the number of eigenvalues of the similarity matrix becomes 2. If all the *k* elements are completely different from the others, then the similarity matrix is the identity matrix (with 1s only in the diagonal and 0s outside the diagonal). In this case the number of eigenvalues is *k* and all are equal to 1. If instead of single objects we compare classes of objects, the diagonal elements of a similarity matrix may represent (if we think it useful, otherwise we consider them equal to 1) the within classes similarity, while the elements outside the diagonal represent the between classes similarity. As the elements outside the diagonal approaches to 1, the lower becomes the entropy of the eigenvalues of the similarity matrix, because the number of eigenvalues decreases and the first one becomes more and more big. It follows that the evenness of the Shannon's entropy (Shannon & Weaver 1949) of the positive (*p*) eigenvalues (λ) of the similarity matrices (**S**)

$$E(\lambda) = \frac{-\sum_i \frac{\lambda_i}{\sum_i \lambda_i} \ln \frac{\lambda_i}{\sum_i \lambda_i}}{\ln k} \qquad i= 1,..., p \qquad 3)$$

is a relative measure of the global dissimilarity between objects compared in the similarity matrices. These matrices can be defined at different hierarchical levels by grouping the classes according to some hierarchical criterion. The values of $E(\lambda)$ calculated at different hierarchical levels can be used to find the level for which the classes are significantly separated on the basis of the set of characters used to calculate the given similarity matrix **S**. The *k* classes corresponding to the highest separation i.e. to the highest $E(\lambda)$, should constitute the optimal classification. The statistical significance of the separation between the classes expressed by $E(\lambda)$ is tested by permutation techniques (cf. Biondini & al. 1991; Pesarin 2001; Pillar 1996; Pillar & Orlóci 1996). Once the classes are defined based on the similarity matrices, they can be used to obtain fuzzy sets for ordinations (Feoli & Zuccarello 1986) and for measuring correlations between them and other variables both environmental or biological, as shown in the example. The $E(\lambda)$ of a similarity matrix obtained by considering its partition in k groups (or classes) can be used also as one alternative of the non-parametric analysis of variance between-within the k groups (see the example). The definition of the classes can be based on different criteria; all those underlying the analysis of variance (Manova & Permanova e.g. Anderson 2017) can be used. Correspondence between the eigenvalues and eigenvectors with clusters have been shown by simple examples by Feoli & Zuccarello (2013).

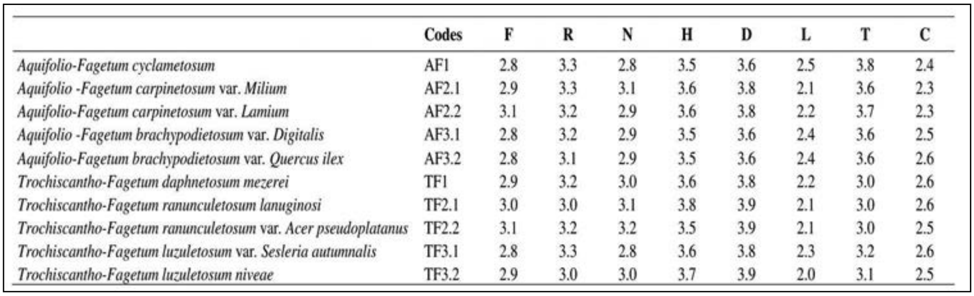
It is clear that the higher is the evenness $E(\lambda)$ of a similarity matrix the higher is the difference between the objects or between the classes of objects that are compared in the matrix, therefore the evenness $E(\lambda)$ can be properly used as δ in formula 1) in order to correct the value of richness k (number of classes), by a measure of the overall dissimilarity within the system based on the characters we want to take into consideration (Feoli 2018).

Two types of beech forests as a case study

Data

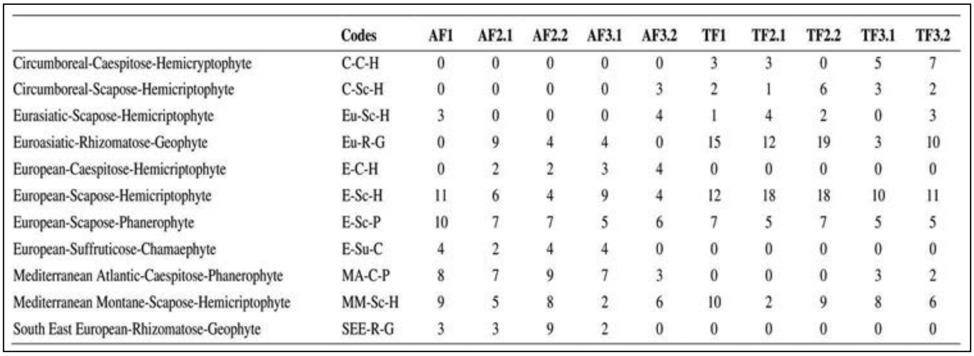
The loop "similarity, classification and diversity" is applied in a simple case study aimed to put in evidence the structural and chorological differences between two vegetation types of Apennines that represent the two opposite states of the beech forests in the Mediterranean area along a North -South gradient. The first association is *Aquifolio - Fagetum* (AF) that includes three sub-associations, two of them have two variants; the second association is *Trochiscantho - Fagetum* (TF) that also includes three sub-associations of which two are subdivided in two variants. In total there are 10 variants: 5 in the first association and 5 in the second one. The variants have been defined by clustering methods using the species as characters by Feoli & Lagonegro (1982). AF is distributed in the Southern part of the Apennines and on the mountain of Sicily where the rainfall has the maximal peaks in winter and autumn. TF is distributed on the North part of the Apennines where the rainfall has the maximal peaks of rainfall in spring and autumn (Feoli & Lagonegro 1982). The description of the 10 variants is given in two data sets represented by two very simple data matrices. The data have been extracted from the paper of Feoli & Ganis (1985). The first (Table 1) consists in the description of the 10 variants by 8 environmental factors obtained by averaging each of the 8 ecological indicator values of Landolt (1977) of the species in each type (matrix **X**). The second data set (Table 2) shows the description of the same vegetation types by the sum of frequency classes (from 1 to 5) of species in cells of a three-way contingency table given by the chorological type (i.e. the type of geographical distribution), growth forms and life forms, i.e. structural characters (matrix **Y**).

Table 1**.** Description of 10 syntaxonomical variants (vegetation types) of beech forests of Central Italy by the average values of indicator values corresponding to environmental factors according to Landolt (1977). F = Humidity, R = Reaction, N = Nutrients, H = Humus, D = Dispersion, L = Light, T = Temperature, C = Continentality.



	Codes	F	R	N	H	D	L	T	C
Aquifolio-Fagetum cyclametosum	AF1	2.8	3.3	2.8	3.5	3.6	2.5	3.8	2.4
Aquifolio -Fagetum carpinetosum var. *Milium*	AF2.1	2.9	3.3	3.1	3.6	3.8	2.1	3.6	2.3
Aquifolio-Fagetum carpinetosum var. *Lamium*	AF2.2	3.1	3.2	2.9	3.6	3.8	2.2	3.7	2.3
Aquifolio -Fagetum brachypodietosum var. *Digitalis*	AF3.1	2.8	3.2	2.9	3.5	3.6	2.4	3.6	2.5
Aquifolio-Fagetum brachypodietosum var. *Quercus ilex*	AF3.2	2.8	3.1	2.9	3.5	3.6	2.4	3.6	2.6
Trochiscantho-Fagetum daphnetosum mezerei	TF1	2.9	3.2	3.0	3.6	3.8	2.2	3.0	2.6
Trochiscantho-Fagetum ranunculetosum lanuginosi	TF2.1	3.0	3.0	3.1	3.8	3.9	2.1	3.0	2.6
Trochiscantho-Fagetum ranunculetosum var. *Acer pseudoplatanus*	TF2.2	3.1	3.2	3.2	3.5	3.9	2.1	3.0	2.5
Trochiscantho-Fagetum luzuletosum var. *Sesleria autumnalis*	TF3.1	2.8	3.3	2.8	3.6	3.8	2.3	3.2	2.6
Trochiscantho-Fagetum luzuletosum niveae	TF3.2	2.9	3.0	3.0	3.7	3.9	2.0	3.1	2.5

Table 2. Description of 10 variants of beech forests of Central Italy (listed in Table 1) by the combination of chorological types and the structural characters (Growth forms and Life forms). The numbers are the sum of Raunkier’s frequency classes of the species in the phytosociological tables given by Feoli & Lagonegro (1982) as obtained by Feoli & Ganis (1985).



	Codes	AF1	AF2.1	AF2.2	AF3.1	AF3.2	TF1	TF2.1	TF2.2	TF3.1	TF3.2
Circumboreal-Caespitose-Hemicryptophyte	C-C-H	0	0	0	0	0	3	3	0	5	7
Circumboreal-Scapose-Hemicriptophyte	C-Sc-H	0	0	0	0	3	2	1	6	3	2
Eurasiatic-Scapose-Hemicriptophyte	Eu-Sc-H	3	0	0	0	4	1	4	2	0	3
Euroasiatic-Rhizomatose-Geophyte	Eu-R-G	0	9	4	4	0	15	12	19	3	10
European-Caespitose-Hemicriptophyte	E-C-H	0	2	2	3	4	0	0	0	0	0
European-Scapose-Hemicriptophyte	E-Sc-H	11	6	4	9	4	12	18	18	10	11
European-Scapose-Phanerophyte	E-Sc-P	10	7	7	5	6	7	5	7	5	5
European-Suffruticose-Chamaephyte	E-Su-C	4	2	4	4	0	0	0	0	0	0
Mediterranean Atlantic-Caespitose-Phanerophyte	MA-C-P	8	7	9	7	3	0	0	0	3	2
Mediterranean Montane-Scapose-Hemicriptophyte	MM-Sc-H	9	5	8	2	6	10	2	9	8	6
South East European-Rhizomatose-Geophyte	SEE-R-G	3	3	9	2	0	0	0	0	0	0

Methods

With this case study we show how the use of similarity, classification, $E(\lambda)$ and fuzzy sets can answer easily the following questions:

a) Are the two plant associations, already defined by species by Feoli & Lagonegro (1982), significantly separated in the space defined by environmental factors and chorological-structural characters?

b) What is the effect of the environmental factors on the chorological and structural pattern of the two associations and of the single phytosociological variant?

c) What is the Q-diversity of the considered vegetation system at different hierarchical levels, on the basis of the similarity based on environmental factors and on that based on combination of chorological and structural characters?

To answer to the three questions, we have produced two similarity matrices **S**(X) and **S**(Y) for the 10 variants, one for matrix **X** and one for matrix **Y**. We have used the same similarity function for the two matrices. This is the complement to 1 of Euclidean distance after having transformed all the d_{ij} values of the distance matrix to range between 0 and 1 according to the following formula:

$$S_{ij} = 1 - \frac{d_{ij} - d_{min}}{d_{max} - d_{min}} \qquad 4)$$

where d_{min} and d_{max} are respectively the minimum and maximal Euclidean distance in the matrix. This transformation is suggested to relativize the distance to the maximal distance we can have between two objects in a dissimilarity matrix. As we have already said, there are many similarity functions that can be applied; we refer to Pavoine & al. (2005) for a comparison between several of them in measuring fuzzy diversity by the Rao's entropy (Rao 2010).

To answer question a) we have calculated $E(\lambda)$ with the similarity matrices **S**(X) and **S**(Y) by grouping the 10 vegetation types (variants) according to the 2 associations. We have measured the separation between the two associations also in terms of the single environmental factors and in terms of the single chorological-structural characters, in this way $E(\lambda)$ is used as an alternative of the test of Kruskal-Wallis (i.e. a univariate non-parametric analysis of variance). To do this we have obtained 8 similarity matrices by comparing the 10 vegetation types on the basis of each of the 8 environmental factors in **X** and 11 similarity matrices on the basis of the 11 characters in **Y**. The characters may be combined in several ways to test the capacity of their combinations to separate the classes, but we do not enter in such an exercise that does not add new meanings to the aims of the paper as we have said in Feoli & Ganis (2019).

To answer to question b) i.e. to define what are the environmental factors defining the chorological and structural differences between the two associations, we have calculated the corresponding fuzzy partitions. These have been obtained by averaging the similarity values of the variants within and between the two associations, based on matrix **X**, and based of matrix **Y** (Feoli & Zuccarello 1986) and then by squaring the normalized average similarity values. In this way the degrees of belonging become complementary i.e. their sum is equal to 1. With the 4 fuzzy sets, 2 for matrix **X** and 2 for matrix **Y** each corresponding to one association, we have calculated the following correlations:

- between the 4 fuzzy sets in order to have a general correlation between the environmental factors and the chorological and structural variables (in analogy of what is done in Canonical Correlation Analysis (Legendre & Legendre 2012), but conditioned by the classification of the vegetation types in two associations);
- between the 4 fuzzy sets and the 8 environmental factors in order to put in evidence the importance of the single environmental factors in defining the two fuzzy sets, i.e. the two plant associations;
- between the 4 fuzzy sets and the 11 chorological-structural variables in order to put in evidence what are, among these, the characters that are characterizing the two associations.

We have also analysed the correlation between the single variant (the vegetation type at lower hierarchical level) and the variables in **X** and in **Y** by the Pearson's and the

Spearman’s rank correlation coefficients, considering the single vectors of similarity in matrices **S**(X) and **S**(Y) and the variables in **X** and in **Y**. The single vectors of the two similarity matrices are fuzzy sets representing the degrees of belonging of each variant to the set represented by another variant (Zhao 1986; Feoli & Zuccarello 1986).

It is clear that all the correlations based on fuzzy sets are contextual correlations, i.e. they depend on the set of objects we are considering. It should be also clear that the correlation is just a measure of similarity ranging between -1 and 1 that can be easily transformed in one ranging between 0 and 1 with the formula $(r_{ij}+1)/2$, or $(r_{ij} - r_{min})/(r_{max} - r_{min})$, in analogy with formula 4).

To answer question c) we have applied the formula 1) and 2) by considering the $E(\lambda)$ of the similarity matrix 10 x 10, corresponding to the 10 vegetation variants, to the matrix 6 x 6 corresponding to the six sub-associations, to the matrix 2 x 2 corresponding to the two associations. Formula 2) has been used to measure redundancy of the two sets of characters in **X** and **Y**. We have considered the data set as representing a vegetation system that can be subdivided significantly in different vegetation types at three hierarchical levels. The redundancy (formula 2) can show how the system is going to be sharp as we pass from one level to the upper one.

Results

The results related to question a) confirm that the separation between the two associations in the space defined by environmental factors and in the space defined by the combination of chorological and structural characters is significant (Table 3).

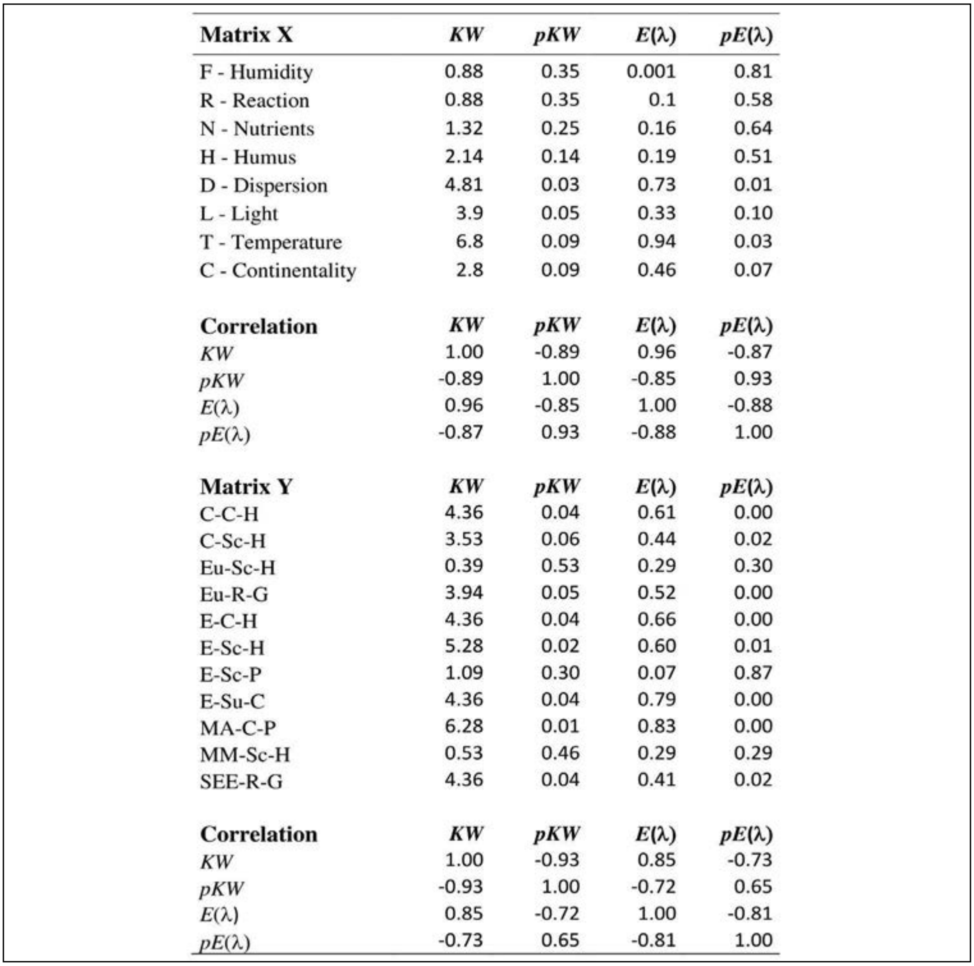
As we have stressed in Feoli & Ganis (2019), the $E(\lambda)$ is higher for the two associations when described by the environmental factors ($E(\lambda) = 0.824$), than when described by the combination chorological-structural characters ($E(\lambda) = 0.785$). However, the separation is maximal when we consider only the temperature ($E(\lambda) = 0.94$). If we consider separately the chorological characters and the structural characters, the separation is higher for the structural characters ($E(\lambda) = 0.797$ versus 0.72) (Table 3).

Table 3. Evenness ($E(\lambda)$) and its probability ($pE(\lambda)$) of the similarity matrix 2 x 2 obtained by grouping the 10 variants in two associations by averaging the similarity values of the matrix 10 x 10. X indicates the evenness ($E(\lambda)$) for the similarity matrix based on matrix **X**, Y indicates the evenness based on matrix **Y**, c indicates the evenness of the similarity matrix obtained by only the chorological data, s indicates the matrix obtained only by the structural data.

	$E(\lambda)$	$pE(\lambda)$
$E(\lambda)\ X$	0.824	0.0001
$E(\lambda)\ Y$	0.785	0.0044
$E(\lambda)\ Yc$	0.724	0.007
$E(\lambda)\ Ys$	0.797	0.00021

This means that the two associations defined on the basis of floristic data, occupy two different community niches well separated from the environmental point of view, with the temperature that is playing the most important role in differentiating the structure and the chorology of the two associations. The fact that they are more separated from the environmental point of view rather than from structural one would suggest that there is a certain convergence towards a common functionality of the beech forest. The results of the separation between the associations based on single environmental factors and on the single chorological and structural characters is given in Table 4.

Table 4. Results of application of Kruskal Wallis test (*KW*) to the original data and $E(\lambda)$ to matrices 2 x 2 obtained by the similarity matrices 10 x 10 corresponding respectively to matrices **X** and **Y,** by considering the classification of variants in two associations, *pKW* is the probability of test *KW*, $pE(\lambda)$ is the probability of the evenness test. The correlations between the two tests and their probability are also given. Symbols as in Tables 1 and 2.



Matrix X	*KW*	*pKW*	$E(\lambda)$	$pE(\lambda)$
F - Humidity	0.88	0.35	0.001	0.81
R - Reaction	0.88	0.35	0.1	0.58
N - Nutrients	1.32	0.25	0.16	0.64
H - Humus	2.14	0.14	0.19	0.51
D - Dispersion	4.81	0.03	0.73	0.01
L - Light	3.9	0.05	0.33	0.10
T - Temperature	6.8	0.09	0.94	0.03
C - Continentality	2.8	0.09	0.46	0.07

Correlation	*KW*	*pKW*	$E(\lambda)$	$pE(\lambda)$
KW	1.00	-0.89	0.96	-0.87
pKW	-0.89	1.00	-0.85	0.93
$E(\lambda)$	0.96	-0.85	1.00	-0.88
$pE(\lambda)$	-0.87	0.93	-0.88	1.00

Matrix Y	*KW*	*pKW*	$E(\lambda)$	$pE(\lambda)$
C-C-H	4.36	0.04	0.61	0.00
C-Sc-H	3.53	0.06	0.44	0.02
Eu-Sc-H	0.39	0.53	0.29	0.30
Eu-R-G	3.94	0.05	0.52	0.00
E-C-H	4.36	0.04	0.66	0.00
E-Sc-H	5.28	0.02	0.60	0.01
E-Sc-P	1.09	0.30	0.07	0.87
E-Su-C	4.36	0.04	0.79	0.00
MA-C-P	6.28	0.01	0.83	0.00
MM-Sc-H	0.53	0.46	0.29	0.29
SEE-R-G	4.36	0.04	0.41	0.02

Correlation	*KW*	*pKW*	$E(\lambda)$	$pE(\lambda)$
KW	1.00	-0.93	0.85	-0.73
pKW	-0.93	1.00	-0.72	0.65
$E(\lambda)$	0.85	-0.72	1.00	-0.81
$pE(\lambda)$	-0.73	0.65	-0.81	1.00

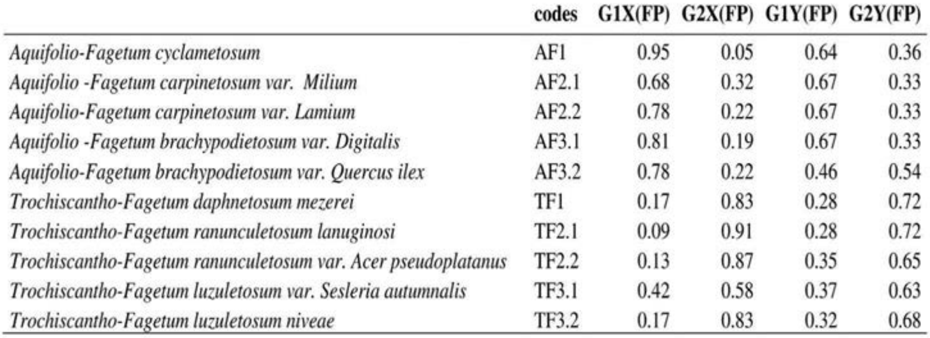
The values of the Kruskal Wallis (*KW*) test (non-parametric analysis of variance) are also reported for a comparison. The correlation between $E(\lambda)$ and the *KW* test is very high and significant (Table 4). The two tests fully agree in showing the characters that significantly separate the two associations. The temperature and the dispersion (i.e. the dimension of the soil particles), are the only two environmental factors that are strongly significant, while almost all the chorological-structural characters are significant except 3 of them (see Table 4). This means that these two environmental factors, temperature and dispersion, are influencing very strongly the structure of vegetation.

Concerning the question b) we have to say that the application of Pearson’s and Spearman’s correlation coefficients has given the same results, so we present only those of the first coefficient. Table 5 shows the fuzzy partitions corresponding to the two association.

Table 6 shows the correlations between the fuzzy sets corresponding to the two associations (*Aquifolio-Fagetum* and *Trochiscantho-Fagetum*, the environmental factors in Table 1 (matrix **X**) and the combination of chorological and structural variables in Table 2 (matrix **Y**). What is relevant from Table 4 and Table 6 is the fact that the most significant environmental factors influencing the definition of the two associations are also significantly correlated with the structure of vegetation (i.e temperature is correlated with European - Caespitose - Hemicriptophyte, European - Suffutricose - Chamaephyte, Mediterranean Atlantic - Caespitose - Phanerophyte and South East European - Rhizomatose - Geophyte).

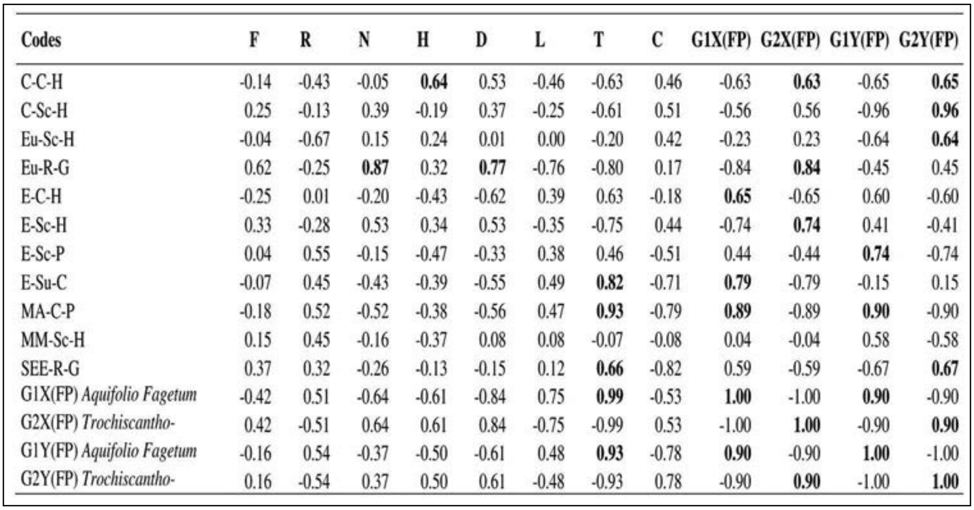
From Table 6 we can see in detail how the two associations are different in structure, since the corresponding fuzzy partition allows to see what are the environmental and chorological-structural characters that are contrasting (i.e. correlated in opposite way) among the two associations in a significant way, for example N, L, D, T and Euroasiatic - Rhizomatose - Geophyte, European - Caespitose - Hemicriptophyte, European - Scapose - Hemicriptophyte, European -Suffruticose - Cahmaephyte and Mediterranean Atlantic - Caespitose - Phanerophyte.

Table 5. Fuzzy partitions of the fuzzy sets originated by similarity matrices based on matrix **X** (G1X(FP)and G2X(FP)) and matrix **Y** (G1Y(FP)and G2Y(FP)).



	codes	G1X(FP)	G2X(FP)	G1Y(FP)	G2Y(FP)
Aquifolio-Fagetum cyclametosum	AF1	0.95	0.05	0.64	0.36
Aquifolio -Fagetum carpinetosum var. Milium	AF2.1	0.68	0.32	0.67	0.33
Aquifolio-Fagetum carpinetosum var. Lamium	AF2.2	0.78	0.22	0.67	0.33
Aquifolio -Fagetum brachypodietosum var. Digitalis	AF3.1	0.81	0.19	0.67	0.33
Aquifolio-Fagetum brachypodietosum var. Quercus ilex	AF3.2	0.78	0.22	0.46	0.54
Trochiscantho-Fagetum daphnetosum mezerei	TF1	0.17	0.83	0.28	0.72
Trochiscantho-Fagetum ranunculetosum lanuginosi	TF2.1	0.09	0.91	0.28	0.72
Trochiscantho-Fagetum ranunculetosum var. Acer pseudoplatanus	TF2.2	0.13	0.87	0.35	0.65
Trochiscantho-Fagetum luzuletosum var. Sesleria autumnalis	TF3.1	0.42	0.58	0.37	0.63
Trochiscantho-Fagetum luzuletosum niveae	TF3.2	0.17	0.83	0.32	0.68

Table 6. Matrix of correlations between the variables of **X** and **Y** and the two fuzzy sets (fuzzy partition) corresponding of the two associations based on similarity calculated with matrix **X** (G1X(FP)and G2X(FP)) and matrix **Y** (G1Y(FP)and G2Y(FP)). Significance of *r*: *p*=0.05, *r*=0.632; *p*=0.02, *r*=0.716; *p*=0.01, *r*=0.765; *p*=0.001, *r*= 0.872. Symbols as in Table 1 and Table 2.



Codes	F	R	N	H	D	L	T	C	G1X(FP)	G2X(FP)	G1Y(FP)	G2Y(FP)
C-C-H	-0.14	-0.43	-0.05	**0.64**	0.53	-0.46	-0.63	0.46	-0.63	**0.63**	-0.65	**0.65**
C-Sc-H	0.25	-0.13	0.39	-0.19	0.37	-0.25	-0.61	0.51	-0.56	0.56	-0.96	**0.96**
Eu-Sc-H	-0.04	-0.67	0.15	0.24	0.01	0.00	-0.20	0.42	-0.23	0.23	-0.64	**0.64**
Eu-R-G	0.62	-0.25	**0.87**	0.32	**0.77**	-0.76	-0.80	0.17	-0.84	**0.84**	-0.45	0.45
E-C-H	-0.25	0.01	-0.20	-0.43	-0.62	0.39	0.63	-0.18	**0.65**	-0.65	0.60	-0.60
E-Sc-H	0.33	-0.28	0.53	0.34	0.53	-0.35	-0.75	0.44	-0.74	**0.74**	0.41	-0.41
E-Sc-P	0.04	0.55	-0.15	-0.47	-0.33	0.38	0.46	-0.51	0.44	-0.44	**0.74**	-0.74
E-Su-C	-0.07	0.45	-0.43	-0.39	-0.55	0.49	**0.82**	-0.71	**0.79**	-0.79	-0.15	0.15
MA-C-P	-0.18	0.52	-0.52	-0.38	-0.56	0.47	**0.93**	-0.79	**0.89**	-0.89	**0.90**	-0.90
MM-Sc-H	0.15	0.45	-0.16	-0.37	0.08	0.08	-0.07	-0.08	0.04	-0.04	0.58	-0.58
SEE-R-G	0.37	0.32	-0.26	-0.13	-0.15	0.12	**0.66**	-0.82	0.59	-0.59	-0.67	**0.67**
G1X(FP) *Aquifolio Fagetum*	-0.42	0.51	-0.64	-0.61	-0.84	0.75	**0.99**	-0.53	**1.00**	-1.00	**0.90**	-0.90
G2X(FP) *Trochiscantho-*	0.42	-0.51	0.64	0.61	0.84	-0.75	-0.99	0.53	-1.00	**1.00**	-0.90	**0.90**
G1Y(FP) *Aquifolio Fagetum*	-0.16	0.54	-0.37	-0.50	-0.61	0.48	**0.93**	-0.78	**0.90**	-0.90	**1.00**	-1.00
G2Y(FP) *Trochiscantho-*	0.16	-0.54	0.37	0.50	0.61	-0.48	-0.93	0.78	-0.90	**0.90**	-1.00	**1.00**

In this way the two associations are quantitatively well characterized in a way that models could be easily produced about the changes in structure of the considered beech forests, due to climatic changes; e.g. we can say that by increasing temperature they will becomes richer in European - Caespitose – Hemicriptophyte, in European - Suffruticose - Chamaephyte and Mediterranean Atlantic - Caespitose - Phanerophyte, while the lost of fertility (N), and the reduction of soil dispersion (D) would reduce the frequency of Euroasiatic - Rhizomatose - Geophyte and European - Scapose - Hemicriptophyte. We can conclude that the temperature would have produced effects that have differentiated the beech forest in the two well distinguishable associations, both in terms of species and in terms of chorological structural characters. A detailed pattern of relationships between the variants, described by their similarity based on matrix **X** and on matrix **Y**, and the environmental factors and chorological - structural characters can be seen respectively in Table 7 and Table 8.

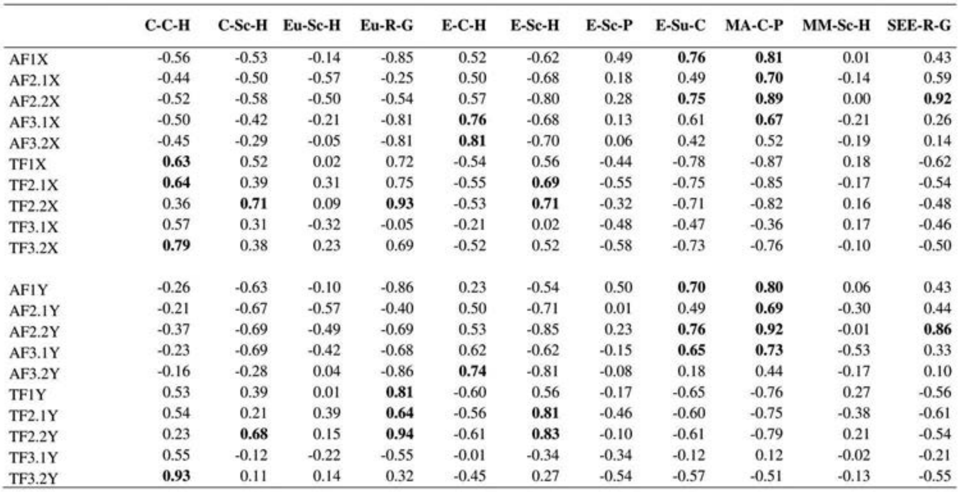
These results obtained with a very simple data set are in agreement with those obtained by a very large data set Bruelheide & al. (2018), i.e. "the trait combinations seem to be predominantly filtered by local-scale factors such as disturbance, fine-scale soil conditions, niche partitioning and biotic interactions", in fact if we consider Table 7 we can find that the correlations between the fuzzy sets of the single variants and the environmental factors are more numerous than those between the fuzzy sets of the associations and the environmental factors. For example, there are variants correlated with humidity (F) and with humus (H), factors that at hierarchical level of associations don't look to be significant. Table 8 shows that the majority of variants are highly correlated with some chorological structural characters, however the variant TF3.1 (*Trochiscantho - Fagetum luzuletosum* var. *Sesleria autumnalis*) does not show any high correlation both with environmental factors and with chorological structural characters, meaning that it has an intermediate structure in between the two associations as it is suggested also by the degrees of belonging of this variant to the sets of the two associations in Table 5.

The results related to question c) are presented in Table 9. The diversity is higher when we consider the matrix **X**, i.e. the environmental characters to calculate the similarity between the vegetation types. The redundancy ρ (formula 2) is decreasing more than twice from the lower hierarchical levels (respectively 2.3 and 2.27) to the highest ones in the case of environmental factors, while only 1.3 and 1.36 times in case of biological characters. This means that the classification at level of associations is the one that is respecting more the Occam’s razor principle when we consider the environmental rather than the chorological-structural characters. The fact that at the highest hierarchical level (two associations) the Q diversity is higher for the **X** data than for **Y** data, respectively D(X) = 1.724 and D(Y) = 1.58, would lead to the conclusion that the adaptation to the environment tends to uniformize the structure of the beech forests. If we consider just the R diversity of the two associations separately in terms of the richness of chorological-structural characters *Aquifolio - Fagetum* results slightly more diverse (k = 10) than *Trochiscantho - Fagetum* (k = 8). This confirms the general trend of biodiversity i.e. in spontaneous ecosystems the diversity is increasing as temperature is increasing provided that all the environmental factors (including temperature) remain within acceptable limits.

Table 7. Correlation between fuzzy sets defined by the single variant according to matrices **X** and **Y** and the environmental factors in matrix **X** (Significance of r: $p=0.05$, $r=0.632$; $p=0.02$, $r=0.716$; $p=0.01$, $r=0.765$; $p=0.001$, $r= 0.872$) (see Tables 1 for symbols).

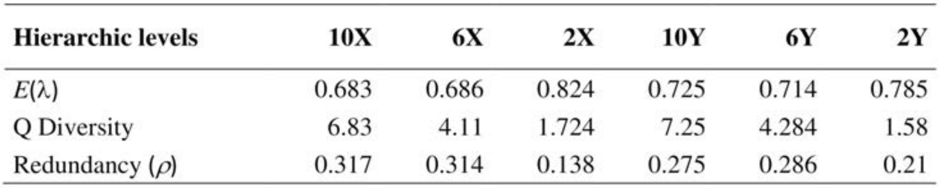
Vegetation types	F	R	N	H	D	L	T	C
AF1 X	-0.57	0.52	-0.73	-0.65	-0.92	**0.87**	**0.93**	-0.38
AF2.1 X	0.00	0.48	0.02	-0.19	-0.17	-0.04	0.62	-0.79
AF2.2 X	0.11	0.39	-0.35	-0.29	-0.35	0.24	**0.82**	-0.80
AF3.1 X	-0.65	0.38	-0.67	-0.66	-0.95	**0.83**	**0.81**	-0.15
AF3.2 X	-0.67	0.24	-0.65	-0.63	-0.93	**0.82**	**0.74**	0.00
TF1 X	0.18	-0.32	0.42	0.43	**0.64**	-0.54	-0.94	**0.66**
TF2.1 X	0.41	-0.66	0.62	**0.77**	**0.82**	-0.76	-0.93	0.53
TF2.2 X	0.58	-0.33	**0.78**	0.34	**0.82**	-0.75	-0.91	0.37
TF3.1 X	-0.42	0.19	-0.34	0.06	0.08	0.08	-0.40	0.61
TF3.2 X	0.32	-0.66	0.54	**0.72**	**0.82**	-0.83	-0.88	0.42
AF1 Y	-0.59	0.49	-0.81	-0.37	-0.74	**0.74**	**0.84**	-0.41
AF2.1 Y	-0.33	0.40	-0.20	-0.09	-0.30	0.07	0.61	-0.61
AF2.2 Y	-0.11	0.40	-0.56	-0.24	-0.45	0.35	**0.84**	-0.70
AF3.1 Y	-0.59	0.27	-0.53	-0.25	-0.65	0.49	**0.70**	-0.31
AF3.2 Y	-0.69	0.11	-0.66	-0.34	-0.72	0.60	**0.65**	0.01
TF1 Y	0.18	-0.21	0.52	0.36	0.61	-0.57	-0.84	0.44
TF2.1 Y	0.21	-0.59	0.57	**0.75**	0.64	-0.57	-0.82	0.53
TF2.2 Y	0.50	-0.22	**0.78**	0.20	0.69	-0.60	-0.85	0.35
TF3.1 Y	-0.71	0.21	-0.67	0.06	-0.20	0.27	0.09	0.26
TF3.2 Y	-0.19	-0.47	0.15	0.61	0.51	-0.55	-0.62	0.39

Table 8. Correlation between fuzzy sets defined by the single variant according to matrices **X** and **Y** and the chorological and structural characters in matrix **Y** (Significance of *r*: *p*=0.05, *r*=0.632; *p*=0.02, *r*=0.716; *p*=0.01, *r*=0.765; *p*=0.001, *r*= 0.872). Symbols as in Tables 1 and 2.



	C-C-H	C-Sc-H	Eu-Sc-H	Eu-R-G	E-C-H	E-Sc-H	E-Sc-P	E-Su-C	MA-C-P	MM-Sc-H	SEE-R-G
AF1X	-0.56	-0.53	-0.14	-0.85	0.52	-0.62	0.49	**0.76**	**0.81**	0.01	0.43
AF2.1X	-0.44	-0.50	-0.57	-0.25	0.50	-0.68	0.18	0.49	**0.70**	-0.14	0.59
AF2.2X	-0.52	-0.58	-0.50	-0.54	0.57	-0.80	0.28	**0.75**	**0.89**	0.00	**0.92**
AF3.1X	-0.50	-0.42	-0.21	-0.81	**0.76**	-0.68	0.13	0.61	**0.67**	-0.21	0.26
AF3.2X	-0.45	-0.29	-0.05	-0.81	**0.81**	-0.70	0.06	0.42	0.52	-0.19	0.14
TF1X	**0.63**	0.52	0.02	0.72	-0.54	0.56	-0.44	-0.78	-0.87	0.18	-0.62
TF2.1X	**0.64**	0.39	0.31	0.75	-0.55	**0.69**	-0.55	-0.75	-0.85	-0.17	-0.54
TF2.2X	0.36	**0.71**	0.09	**0.93**	-0.53	**0.71**	-0.32	-0.71	-0.82	0.16	-0.48
TF3.1X	0.57	0.31	-0.32	-0.05	-0.21	0.02	-0.48	-0.47	-0.36	0.17	-0.46
TF3.2X	**0.79**	0.38	0.23	0.69	-0.52	0.52	-0.58	-0.73	-0.76	-0.10	-0.50
AF1Y	-0.26	-0.63	-0.10	-0.86	0.23	-0.54	0.50	**0.70**	**0.80**	0.06	0.43
AF2.1Y	-0.21	-0.67	-0.57	-0.40	0.50	-0.71	0.01	0.49	**0.69**	-0.30	0.44
AF2.2Y	-0.37	-0.69	-0.49	-0.69	0.53	-0.85	0.23	**0.76**	**0.92**	-0.01	**0.86**
AF3.1Y	-0.23	-0.69	-0.42	-0.68	0.62	-0.62	-0.15	**0.65**	**0.73**	-0.53	0.33
AF3.2Y	-0.16	-0.28	0.04	-0.86	**0.74**	-0.81	-0.08	0.18	0.44	-0.17	0.10
TF1Y	0.53	0.39	0.01	**0.81**	-0.60	0.56	-0.17	-0.65	-0.76	0.27	-0.56
TF2.1Y	0.54	0.21	0.39	**0.64**	-0.56	**0.81**	-0.46	-0.60	-0.75	-0.38	-0.61
TF2.2Y	0.23	**0.68**	0.15	**0.94**	-0.61	**0.83**	-0.10	-0.61	-0.79	0.21	-0.54
TF3.1Y	0.55	-0.12	-0.22	-0.55	-0.01	-0.34	-0.34	-0.12	0.12	-0.02	-0.21
TF3.2Y	**0.93**	0.11	0.14	0.32	-0.45	0.27	-0.54	-0.57	-0.51	-0.13	-0.55

Table 9. Hierarchical Q-diversities based on formula 1) and corresponding values of redundancy ρ. The hierarchical levels are given respectively by the 10 variants, the 6 subassociations and the 2 associations (see text). **X** means that the similarity between the vegetation types has been calculated on the basis of ecological indicators, **Y** that similarity was calculated on the basis of chorological and structural characters.



Hierarchic levels	**10X**	**6X**	**2X**	**10Y**	**6Y**	**2Y**
$E(\lambda)$	0.683	0.686	0.824	0.725	0.714	0.785
Q Diversity	6.83	4.11	1.724	7.25	4.284	1.58
Redundancy (ρ)	0.317	0.314	0.138	0.275	0.286	0.21

Discussion and conclusion

The case study is showing how, with similarity matrices, we can analyse in detail the relationships between different kind of environmental and biological variables and the states of ecological systems as defined by types of communities and how we can reach a level of information surprisingly high by very simple mathematical tools. We used data describing plant communities, but we could have been used data from any other type of communities and ecosystems and even from other systems described by two or more sets of variables. The choice of this very simple data set was done because the results could have been easily discussed and challenged with the results of studies already done with the same data set and with knowledge already consolidated on the type of vegetation system (i.e. beech forests) in the Mediterranean basin. We think that working with similarity matrices and classification methods, leads to obtain very clear results that could be a useful step towards modelling dynamics of vegetation or other ecosystems. As a matter of fact, the usefulness of the concept of similarity becomes more and more tangible in all the disciplines that are dealing with multivariate time series analysis (Norman & Streiner 2003; Liao 2005) and in general with complex systems and artificial intelligence (AI) (e.g. Rissland 2006; Hofmann & al. 2008). The application of the similarity concept leads to important conclusions in different fields of ecology for example about the behaviour of invasive species Divíšek & al. (2018) or on the role of evolution in the relationships between different ecological communities Podani & al. (2018). In this respect if we consider a set A of k classes of objects, δ can be calculated by considering different sets of characters, if for example one set represents the mutual phylogenetic position of the k classes (i.e. the similarity matrix $\mathbf{S}(1)$ is a topological distance matrix of the evolutionary tree of the species involved, e.g. Ricotta & al. (2018), and references therein) and the same k classes are described also by a set that may represent their similarity $\mathbf{S}(2)$ in terms of structure or functional characters, then if ρ_1, corresponding to $\mathbf{S}(1)$ is larger than ρ_2, corresponding to $\mathbf{S}(2)$, it would mean that there is a structural divergence, while $\rho_1<\rho_2$ would represent a structural convergence of the k classes (obviously for the characters we have chosen). The case study presented in this paper, is answering three questions that are very important in supporting similarity theory (Feoli & Orlóci 2011; Wildi 2018). The first question is concerned with the prediction of a classification based on certain characters with respect to other characters. The second is concerned with detailed correlations analysis between characters of different nature and fuzzy sets representing classes at different hierarchical levels (see Roberts 2008, 2009 for use of fuzzy sets incorporated in traditional methods of multivariate analysis). The third question is concerned with the analysis of fuzzy diversity (i.e. diversity of ecosystems, Q diversity) at different hierarchical levels. In all the three questions it emerges the importance of classification based on similarity, and therefore of numerical taxonomy and numerical syntaxonomy, as already stressed several years ago (Mucina & van der Maarel 1989). In this context the evenness of the eigenvalues of similarity matrices, that can be calculated by different similarity functions and characters at different hierarchical levels, playing a fundamental role in class definition according the Occam’s razor principle, can be considered a key mathematical tool in the “Eternal Golden Braid” of similarity, classification and diversity in vegetation science.

References

Anderberg, M. R. 1973: Cluster analysis for applications. – New York.

Anderson, M. J. 2017: Permutational Multivariate Analysis of Variance (PERMANOVA). – https://doi.org/10.1002/9781118445112.stat07841

Biondini, M. E., Mielke, P. W. Jr. & Redente, E. F. 1991: Permutation techniques based on Euclidean analysis spaces: A new and powerful statistic method for ecological research. – Pp. 221-240 in: Feoli, E. & Orlóci, L. (eds) Computer assisted vegetation analysis. – Boston.

Braun-Blanquet, J. 1964: Pflanzensoziologie. Gründzuge der Vegetationskunde. 3th ed. – Wien.

Bruelheide, H., Dengler, J., Purschke, O., Lenoir, J., Jiménez-Alfaro, B., Hennekens, S. M., Botta-Dukát, Z., Chytrý, M., Field, R., Jansen, F. & al. 2018: Global trait–environment relationships of plant communities. – Nat. Ecol. Evol. **2:** 1906-1917.

Burnaby, T. P. 1970: On a method for character weighting a similarity coefficient, employing the concept of information. – J. Int. Ass. Math. Geol. **2:** 25-38.

Carranza, L., Feoli, E. & Ganis, P. 1998: Analysis of vegetation structural diversity by Burnaby's similarity index. – Pl. Ecol. **138:** 77-87.

Dale, M. B. 1988a: Mutational and Non-mutational similarity Measures: A Preliminary Examination. – Coenoses **3:** 121-133.

— 1988b: Knowing when to stop: cluster concept–concept cluster. – Coenoses **1:** 11-31.

Divíšek, J., Chytrý, M., Beckage, B., Gotelli, N. J., Lososová, Z., Pyšek, P., Richardson, D. M. & Molofsky, J. 2018: Similarity of introduced plant species to native ones facilitates naturalization, but differences enhance invasion success. – Nature Communications **4631**. https://doi.org/10.1038/s41467-018-06995-4

Eigen, M. & Winkler, R. 1986: Il gioco. Le leggi naturali governano il caso. – Milano.

Feoli, E. 2018: Classification of plant communities and fuzzy diversity of vegetation systems. – Community Ecology **19(2):** 186-198.

— & Ganis, P. 1985: Comparison of floristic vegetation types by multiway contingency tables. – Abstr. Bot. **9:** 1-15.

— & — 1986: Autocorrelation for measuring Predictivity in Community Ecology: An example with structural and Chorological data from Mixed Forest Types of NE Italy. – Coenoses **1:** 53-56.

— & — 2019: The use of the evenness of eigenvalues of similarity matrices to test for predictivity of ecosystem classifications. – Mathematics **7:** 245. https://doi.org/10.3390/math7030245

— & Lagonegro, M. 1982: Syntaxonomical analysis of beech woods in the Apennines (Italy) using the program package IAHOPA. – Vegetatio **50:** 129-173.

— & Orlóci, L. 2011: Can similarity theory contribute to the development of a general theory of the plant community? – Community Ecology **12:** 135-141.

— & Scoppola, A. 1980: Analisi informazionale degli schemi di dinamica della vegetazione. Un esempio sul popolamento vegetale delle dune del litorale di Venezia – Giorn. Bot. Ital. **114:** 227-236.

— & Zuccarello, V. 1986: Ordination based on classification: yet another solution?! – Abstr. Bot. **10:** 203-219.

— & — 2013: Fuzzy sets and eigenanalysis in community study: classification and ordination are two faces of the same coin. – Community Ecology **14:** 164-171.

Goodall, D. W. 1964: A probabilistic similarity index. – Nature **203:** 1098.

— 1966: A new similarity index based on probability. – Biometrics **22:** 882-907.

— 1986: Classification and ordination: their nature and role in taxonomy and community studies. – Coenoses **1:** 3-9.

Gower, J. C. 1970. A note on Burnaby's character-weighted similarity coefficient. – J. Int. Ass. Math. Geol. **2:** 39–45.

— 1971. A general coefficient of similarity and some of its properties. – Biometrics **27:** 857-871.

Hofmann, T., Schölkopf, B. & Smola, A. J. 2008: Kernel methods in machine learning. – The Annals of Statistics **36(3):** 1171-1220.

Hofstadter, D. R. 1979: Gödel, Escher, Bach an Eternal Golden Braid. – New York. (1984 Italian edition, Milano).

Jaccard, P. 1901: Distribution de la flore alpine dans le bassin des Dranses et dans quelques régions voisines. – Bull. Soc. Vaudoise Sci. Nat. **37:** 241-272.

— 1912: The distribution of the flora in the alpine zone. – New Phytologist **11(2):** 37-50.

Jongman, R. H. G., Ter Braak, C. J. F. & Van Tongheren, O. F. R. 1995: Data analysis in community and landscape ecology. – Cambridge.

Landolt, E. 1977: Okologische Zeigerwerte zur Schweizer Flora. – Ber. Geobot. Inst. ETH. **64:** 64-207.

Legendre, P. & Legendre, L. 2012. Numerical ecology; 3rd ed. – Amsterdam.

Liao, T. W. 2005: Clustering of time series data-a survey. – Pattern recognition **38:** 1857-1874.

Maarel van der, E., László Orlóci, L. & Pignatti, S. 1976: Data-processing in phytosociology, retrospect and anticipation. – Vegetatio **32:** 65-72.

Mantel, N. 1967: The detection of disease clustering and a generalized regression approach. – Cancer Res. **27:** 209-220.

Mardia, K. V., Kent, J. T. & Bibby, J. M. 1979: Multivariate analysis. – London.

Margalef, R. 1980: La biosfera entre la termodinamica y el juego. – Barcellona.

Mucina, L. & Maarel van der, E. 1989: Twenty years of numerical syntaxonomy. – Vegetatio **81:** 1-15.

Mueller-Dombois, D. & Ellenberg, H. 1974: Aims and methods of vegetation ecology. – New York.

Norman, G. R. & Streiner, D. L. 2003: Pretty Darned Quick Statistics. – Hamilton, London.

Noy-Meir, I. 1971: Multivariate analysis of the semi-arid vegetation in South-eastern Australia: nodal ordination by component analysis. – Pp. 159-193 in : Nix, N. A. (ed.) Quantifying Ecology. – Proc. Ecol. Soc. Aust. **6**.

— 1973: Data transformation in ecological ordination. I. Some advantages of non-centering. – J. Ecol. **61:** 329-341.

Orlóci, L. 1978: Multivariate analysis in vegetation research. 2nd ed. – The Hague, The Netherlands.

Pavoine, S., Ollier, S. & Pontier, D. 2005: Measuring diversity from dissimilarities with Rao's quadratic entropy: Are any dissimilarities suitable? – Theor. Popul. Biol. **67:** 231-239.

Pesarin, F. 2001: Multivariate Permutation Tests. With Applications in Biostatistics. – Chichester, Toronto.

Pignatti, S. 1959: Ricerche sull'ecologia e sul popolamento delle dune del litorale di Venezia. Il popolamento vegetale. – Boll. Mus. Civ. Venezia **12:** 61-141.

— 1960: Il significato delle specie poliploidi nelle associazioni vegetali. – Ist. Ven. Sci. Lett. Arti. **118:** 75-98.

— 1980: Reflections on the phytosociological approach and the epistemological basis of vegetation science. – Vegetatio **42:** 181-185.

— 1982: Flora d'Italia, **1-3.** – Bologna.

— 1990: Towards a prodrome of plant communities. – J. Veg. Sci. **1:** 425-426.

— & Mengarda, F. 1962: Un nuovo procedimento per l'elaborazione delle tabelle fitosociologiche. – Accad. Naz. Lincei Mem. Classe Sci. Fis. Mat. Nat. **8:** 215-222.

Pillar, V. D. 1996: A randomization-based solution for vegetation classification and homogeneity testing. – Coenoses **11:** 29-36.

— 1999a: How sharp are classifications? – Ecology **80:** 2508-2516.

— 1999b: On the identification of optimal plant functional types. – J. Veg. Sci. **10:** 631-640.

— & Orlóci, L. 1996: On randomization testing in vegetation science: Multifactor comparisons of relevé groups. – J. Veg. Sci. **7:** 585-592.

Podani, J. 2000: Introduction to the exploration of multivariate biological data. – Leiden.

—, Pavoine, S. & Ricotta, C. 2018: A Generalized Framework for Analyzing Taxonomic, Phylogenetic, and Functional Community Structure Based on Presence–Absence Data. – Mathematics **6**, 250. https://doi.org/10.3390/math6110250

Rao, C. R. 2010: Quadratic entropy and analysis of diversity. – Sankhyā: Ind. J. Stat. **72-A(1):** 70-80.

Ricotta, C. & Szeidl, L. 2006: Towards a unifying approach to diversity measures: bridging the gap between Shannon entropy and Rao's quadratic index. – Theor. Popul. Biol. **70:** 237-243.

—, Bacaro, G., Caccianiga, M., Cerabolini, B. E. L. & Pavoine, S. 2018: A new method for quantifying the phylogenetic redundancy of biological communities. – Oecologia **186:** 339-346.

Rissland, E. L. 2006: AI and Similarity. – IEEE Intelligent Systems **21(3):** 39-49.

Roberts, D. W. 1986: Ordination on the basis of fuzzy set theory. – Vegetatio **66:** 123-143.

— 2008: Statistical analysis of multidimensional fuzzy set ordinations. – Ecology **89:** 1246-1260.

— 2009: Comparison of multidimensional fuzzy set ordination with CCA and DB-RDA. – Ecology **90:** 2622-2634.

Shannon, C. E. & Weaver, W. 1949: The mathematical theory of communication. – Urbana.

Tichý, L., Chytrý, M., Hájek, M., Talbot, S. S. & Botta-Dukát, Z. 2010: OptimClass: using species-to-cluster fidelity to determine the optimal partition in classification of ecological communities. – J. Veg. Sci. **21:** 287-299.

Wildi, O. 2017: Data analysis in vegetation ecology; 3rd ed. – Oxfordshire.

— 2018: Evaluating the predictive power of ordination methods in ecological context. – Mathematics **6(12):** 295. https://doi.org/10.3390/math6120295

Wilkinson, J. H. 1965: The algebraic eigenvalue problem. – London.

Zadeh, L. A. 1978: Fuzzy sets as a basis for a theory of possibility. – Fuzzy Sets Syst. **1:** 3-28.

Woldu, Z., Feoli, E. & Nigatu, L. 1989: Partitioning an elevation gradient of vegetation from south-eastern Ethiopia by probabilistic methods. – Vegetatio **81:** 189-198.

Zhao, S. X. 1986: Discussion on fuzzy clustering. – Pp. 612-614 in: 8th Int. Conference on Pattern Recognition. – New York.

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Article

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Searching for hidden site factors – species pool and land use blurring Swiss forest vegetation types

Abstract

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A numerical analysis of data more than 50 years old shows that two zones of particularly high fuzziness appear in the as yet valid classification of forest vegetation in Switzerland. This raises the question of the causes of the phenomenon, but also that of a possible correction. The results show that the crispness of the classification is significantly improved by bypassing some dominant tree species. This is true for *Fagus sylvatica* in lower altitudes of the country, but especially for the beech forests in general. *Picea excelsa*, probably the most frequently tree species planted in the past, predominantly blurs the subalpine forest classification. For some less frequent tree species (*Castanea sativa*, *Larix decidua*) it can be shown that rare plantings were often made in locations unsuitable for the species. Many analyses are only possible with the help of a more recent, systematically collected data set, which also includes numerous environmental variables. This is now already 25 years old, which means that the species composition known today is not up do date. The general species poverty of all forests of Central Europe is likely to make them particularly vulnerable to drought events, storms and insect infestation.

Key words: classification, forest management, group similarity, heat colors,potential vegetation.

Introduction

Semi-natural vegetation is of particular interest because, in the absence of management without human control, it develops in compliance with ecological laws. This results in a new species-specific diversity, which on the one hand is highly dependent on the local "species pool" and on the other hand is modified by interactions between species such as competition and mutual support (Connell & Slatyer 1977). To what extent the vegetation cover encountered in the real world is natural is difficult to determine, because sites without human influence no longer exist on earth. In the case of forests, therefore, one speaks of "potential natural vegetation" addressing a fictitious stable final state (Tüxen 1956; Neuhäusl 1984; Kowarik 1987; Küchler 1988; Brzeziecki & al. 1993; Lindacher 1996). However, Chiarucci & al. (2010), for example, consider this concept to be too rigid and therefore fundamentally question its validity. In fact, there is no single definition of potential natural vegetation, but most authors agree that if no management is undertaken, the plant cover will generally develop in the direction of greater proximity to nature. This is not valid if irreversible environmental changes occur in the meantime, such as soil erosion or climate change. In these cases, a new species combination that has never been observed before can be expected.

There is hardly any alternative to the narrative of potential natural vegetation, as will be illustrated below using the relatively well researched forests of Switzerland as an example. With the publication of Ellenberg and Klötzli (1972) a nationwide classification exists, which is still in use after half a century - for lack of alternatives. It is based on vegetation records that are now more than fifty years old and that were made by various authors. For many of them, the place and time of the survey are unknown and the taxonomies used can hardly be reconciled with the current one. The classification method used at that time is purely heuristic and thus also not verifiable (de Caceres & al. 2015). Some recent local additions and attempts at correction hardly contribute to the nationwide representation.

A serious gap in the data situation is the lack of comprehensive data on management intensity and management type, both past and present, although a national forest inventory has been compiled in Switzerland since the 1980s. It is currently in its fourth edition (Brändli & al. 2020). This inventory provides information on the shrub and tree layer of the forests, but does not include a survey of the herb layer or an analysis of the soil. Thanks to the systematic sampling, the data allow at least an extrapolation to the whole country.

In the 1990s, a vegetation survey was carried out on a square sub-network of the National Forest Inventory, using a mesh size of 4 by 4 kilometres (Wohlgemuth & al. 2008; Wildi 2017). Despite the limited sample size of 726, it provided for the first time a representative picture of the forest ecosystem, both of the vegetation and of some environmental factors, in contrast to previous surveys. Thanks to proven interpolation methods, good quality climate data are available for all plots (Zimmermann & Kienast 1999). Of the soils, there is only a single pH measurement from the first national forest inventory. Again, data on current and historical forest management is missing, which has never been collected in a uniform way across the whole country and which is likely to significantly affect existing classifications.

The aim of the present analysis is to find and explain weaknesses in the existing vegetation classification using appropriate models. A first systematic disturbance factor could have arisen from the fact that forests at lower and flatter altitudes were more intensively managed and modified than those at higher altitudes for purely practical reasons (Brändli & al. 2020). A second factor, the general species poverty of forests in Central Europe, could have led to the fact that the ecological niches realized by some tree species are wider than those of other species due to a lack of competition (Latham & Ricklefs 1993). This could be the case for *Fagus sylvestris*, which extends like a veil over numerous vegetation types, or *Picea excelsa*, probably the most frequently planted species. And thirdly, there are a few tree species that, thanks to their efficient propagation mechanism, spread very quickly and reach less suitable sites, such as *Fraxinus excelsior*, *Acer platanoides* or *Acer pseudoplatanus*.

Data

The 2533 vegetation relevés used by Ellenberg & Klötzli (1972) and the corresponding group affiliations were first published by Keller & al. (1999). They are included in the R-package “dave” (R Development Core Team 2017) and further analysed by Wildi (2017). The vegetation data are in the file “EKv”, the corresponding group numbers in “EKs”. For these data, there is no complete information about the authors, the location and the year of recording. The classification is, as usual at that time, purely heuristic. The tree species were each treated as three independent descriptors according to their occurrence in the tree, shrub and herb layer.

The data collected in the 1990s in a systematic grid and initially analysed by Wohlgemuth & al. (2008) are also included in the package “dave”, under the object names “ws30”, “ws200” and “ws500” for the plot sizes of 30, 200 and 500 square meters respectively. The file “wssit” contains the corresponding site factors described in Wildi (2017). The sample size is n=726. Again in this data set, tree species are described by three descriptors each according to their occurrence in the tree, shrub and herb layer.

Methods

In the absence of spatial, temporal or environmental data, as is the case with the data set of Ellenberg & Klötzli (1972), the interpretability of a classification can be evaluated by comparing the similarities of equal group membership with those between groups. The resulting matrix resembles a similarity matrix, but its elements are mean values of all pair-wise groups involved. Such a representation can be found in Wildi (2017), p. 51 (Fig. 1, upper right). The method scales the similarity values to a range from 0 to 1 and converts them into heat colors. The highest value occurring in the matrix becomes a dark red, medium values become yellow and the lowest becomes white. Ideally, the diagonal of the matrix is red, which indicates a high similarity of relevés within a vegetation unit. Red cells outside the diagonal mean that vegetation units are similar and therefore difficult to distinguish.

In the graphic in Fig. 1, upper right, there are two noticeable areas besides some local problems. The units 1 to 21, upper left, are more similar than average among themselves, as can be seen from an intense red colored square. They are beech forests, which dominate in lower altitudes of the alpine country. Could it be that one species dominates all units, for example *Fagus sylvatica* or the often planted *Picea excelsa*? Or is it just a weakness of the classification method?

A similar phenomenon is to be observed in the forest communities 45 to 60, which are subalpine forests where spruce (*Picea excelsa*) probably also naturally dominates, while it can be assumed that management is less intensive.

I have decided to leave the classification unchanged, because a critical evaluation by means of environmental factors is not possible. Instead, I try to eliminate one or more tree species (always in the tree, shrub and herb layer simultaneously) in the expectation that the overly high similarity of the block will partially or completely disappear. In the results I show the influence of *Fagus sylvatica*, *Picea excelsa*, *Abies alba* and the two species *Fraxinus excelsior* and *Acer pseudoplatanus* with their particularly far-reaching wind distribution.

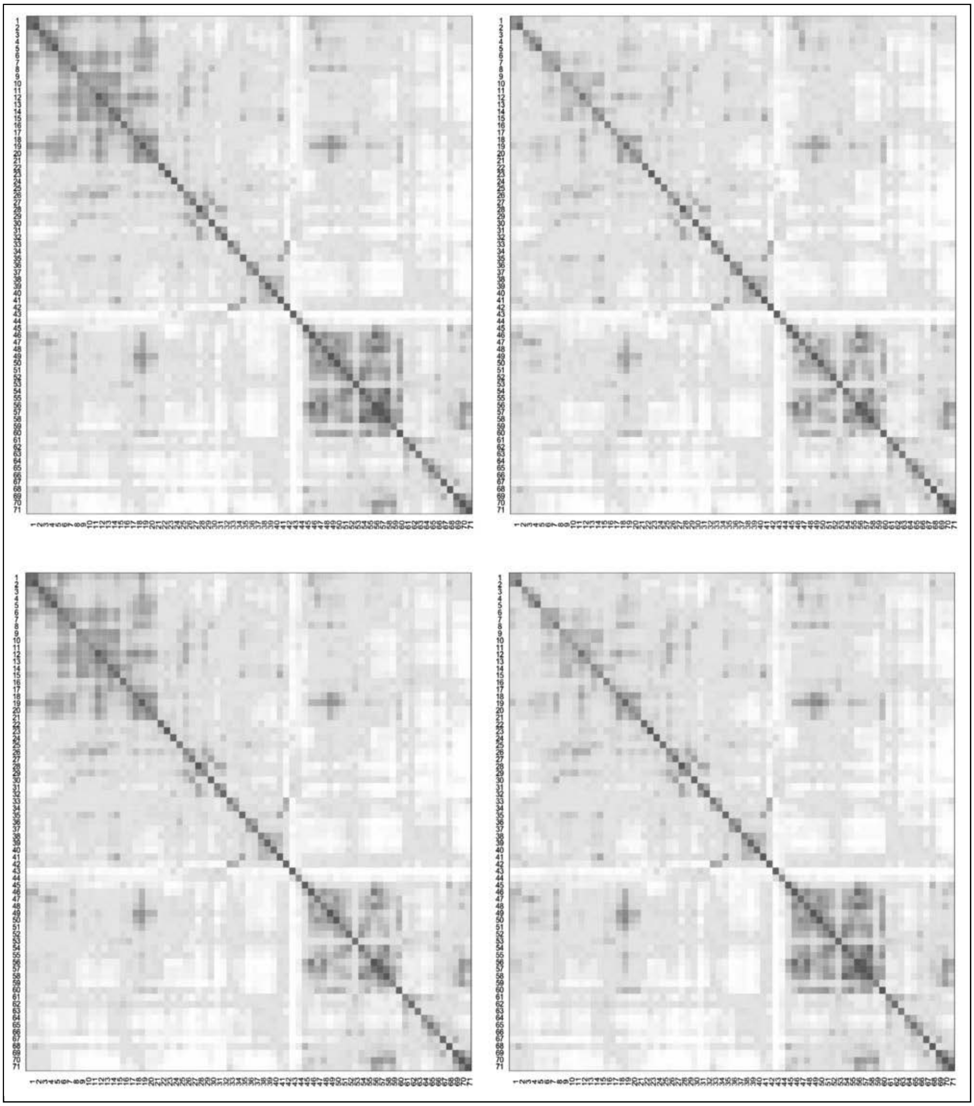

Fig. 1. Within and between similarity of 71 vegetation types of Swiss forests (Ellenberg & Klötzli 1972; Wildi 2017). Upper left: full data set. Upper right: *Fagus sylvatica, Picea abies, Acer pseudoplananus, Fraxinus excelsior* and *Abies alba* removed. Lower left: *Picea excelsa* removed. Lower right: *Fagus sylvatica* removed.

The systematically collected data set now allows to verify a possible influence of dominant tree species independently from the old classification, but also to compare the potential vegetation with the current one. No official classification of this data set exists so far. Since the sample size is very limited, I first generate a coarse classification with eight vegetation types using the total sample of 726 relevés and applying a numerical method (Ward's method, based on correlations transformed to distances), as already shown in Wildi (2017). From this I derive a matrix of mean similarities within and between the vegetation types, with and without the dominant tree species.

Since the localities of all relevant species are known, the vegetation types can be displayed as distribution maps. For this purpose I use a multinomial regression (Venables & Ripley 2010, R package "nnet") with the site factors elevation, yearly precipitation, yearly degree-days, and pH (soil), which have proven to be particularly good predictors in a previous analysis (Wildi 2017).

Tree plantations play a central role in forest management. Preference is given to planting species whose wood is economically interesting. To identify unfavourable plantations, I compare the occurrence probabilities of some species with their actual distribution. An indication for artificial occurrence are populations that can be observed on unsuitable sites. However, the method can only work if plantings are not too frequent (e.g. in *Larix decidua* or *Castanea sativa*), because otherwise they influence the determination of the potential distribution too much. To determine the probability of occurrence I use a generalized linear model (Venables & Ripley 2010; Wildi 2017) with the same site factors as in the multinomial regression.

Results

Fig. 1 shows that the two blurred areas, the forest communities 1 to 21 and 45 to 60 respectively (graph upper right) largely disappear when the species *Fagus sylvatica*, *Picea abies*, *Abies alba*, *Fraxinus excelsior* and *Acer pseudoplatanus* are eliminated from the data set (graph upper left). The raw data for the graphs (not shown here) indicate, as expected, that the similarities of all forest communities are reduced when species are omitted, but that those between them (outside the diagonal) are reduced more strongly than those within (diagonal elements). If only *Picea excelsa* is suppressed, the crispness in the range of forest types 45 to 60 is improved (Fig. 1, bottom left). If only *Fagus sylvatica* is suppressed, crispness improves in the range 1 to 21.

Fig. 2 shows the same effects in the much smaller, systematic sample. The classification involved is generated numerically (Ward's method). If the full data set is used (graphic above left), for example, units 1, 2 and 3 are difficult to distinguish from each other, but also units 5 to 7. The resolution improves considerably if the above-mentioned 5 tree species are omitted (Fig. 2, graph upper right). If only Picea excelsa is suppressed (graphic bottom left), the crispness improves in the lower right part of the matrix with the forests of the subalpine area. The lower right graphic again shows that it is primarily the suppression of *Fagus sylvatica* improving the crispness of the classification.

The systematic sampling data set not only allows generating a coarse classification of forest types, but also the spatial distribution of occurrence probability (Fig. 3). Just by coincidence the first 3 forest types encompass the natural range of Fagus sylvestris. Then follow the ones of the higher altitudinal zones and ending with the same of the Southern Alps. Fig. 3 also suggests the similarity pattern being a continuum in which the edges of the forest types are arbitrary.

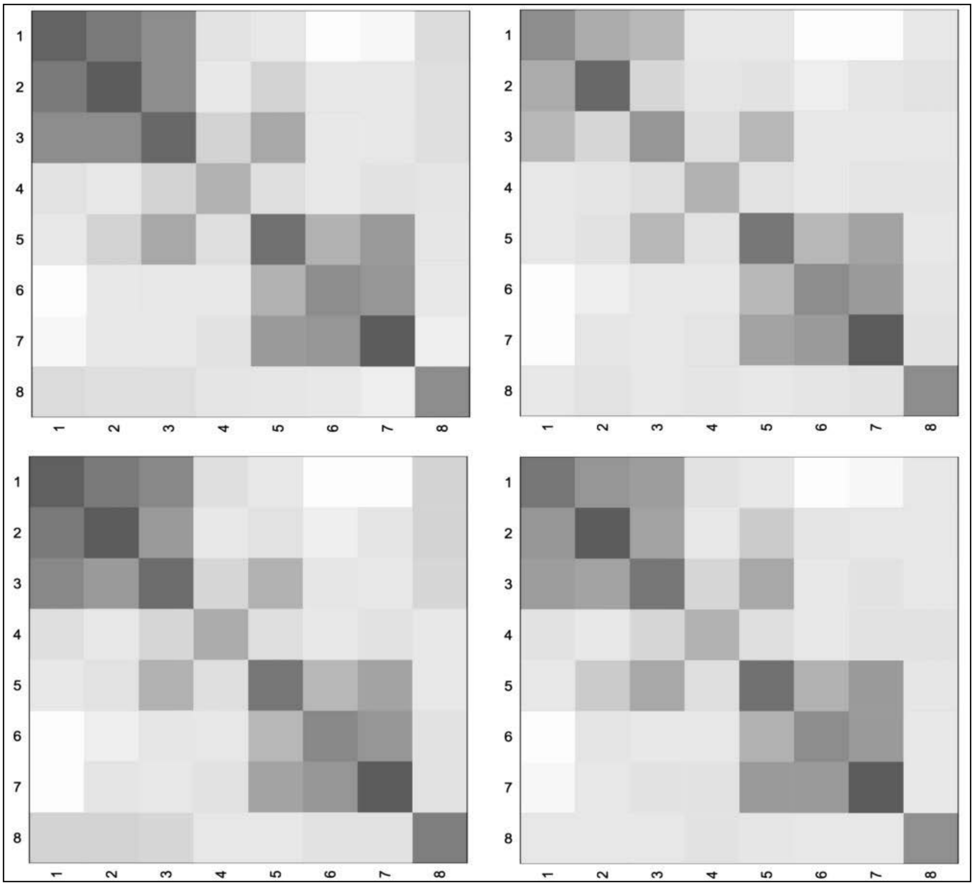

Fig. 2. Within and between similarity of 8 vegetation types derived from the systematic Swiss forests survey (Wohlgemuth & al. 2008; Wildi 2017). Upper left: full data set. Upper right: *Fagus sylvatica, Picea abies, Acer pseudoplananus, Fraxinus excelsior* and *Abies alba* removed. Lower left: *Picea abies* removed. Lower right: *Fagus sylvatica* removed.

Fig. 4 shows the observed (left column) and potential distribution (right column) of 4 selected tree species. *Fagus sylvatica* (first row) is distributed over the whole country, with the exception of the high subalpine areas and the southern side of the Alps. *Picea excelsa* (second line) is very dominant, probably planted in the lower altitudes, but naturally occurring in the higher ones. In *Larix decidua* (third line) the artificial plantings north of the Alps are recognizable (Fig. 4). The species occurs mainly in the central Alps. The few populations north of the Alps are on ecologically unsuitable sites. An analogous situation is shown by *Castanea sativa*, which is normally restricted to southern Switzerland, but occasionally occurs in western Switzerland as well. Here, too, it is evident that the ecological conditions are not really suitable.

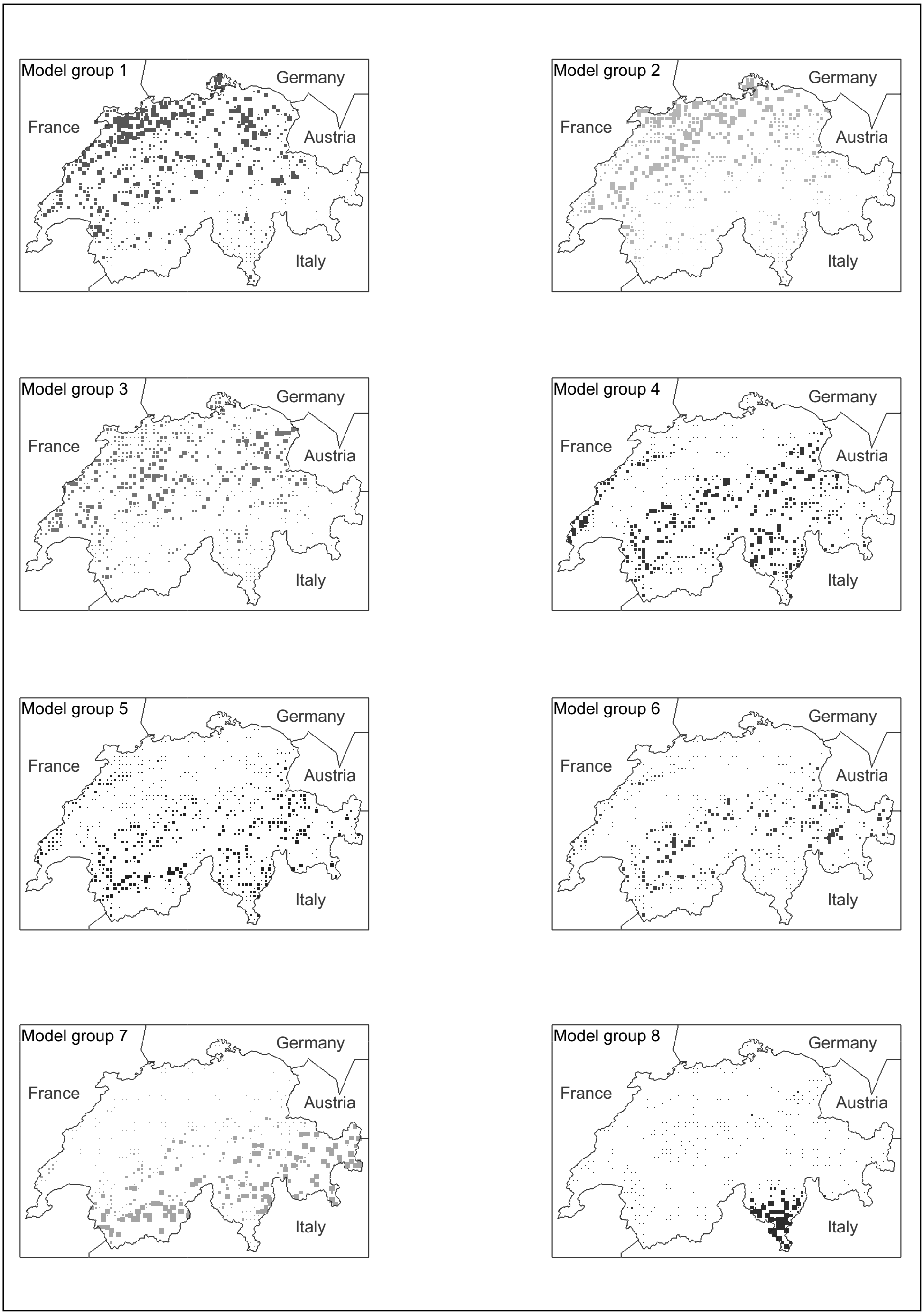

Fig. 3. Spatial distribution of 8 vegetation types derived by numerical classification of the Swiss systematic survey. The occurrence probability bases on 5 site variables (Wildi 2017, p. 291).

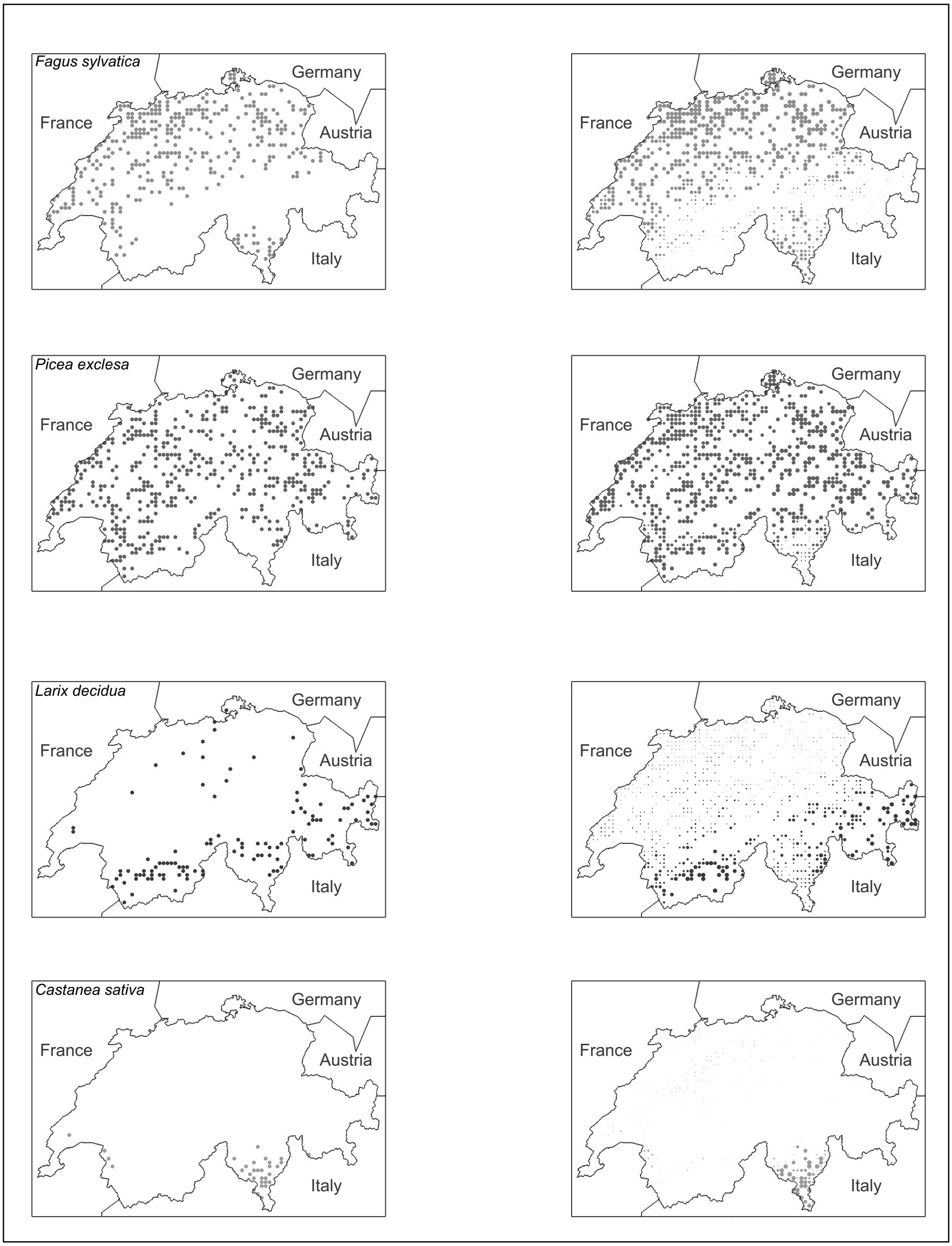

Fig. 4. Occurrence of 4 selected tree species (left hand row) compared to the occurrence probability of the same based on a generalized linear model using 5 site factors. *Fagus sylvatica* (first row) is hardly ever planted, but it has a wide ecological niche. *Picea excelsa*, second row, has been planted almost everywhere for economic reasons. *Larix decidua*, typical for central Alps, has frequently been planted in the northern parts of the country and the few populations hit by the sampling grid all occur on unsuitable sites. The same holds for *Castanea sativa* with suitable sites only south of the Alps.

Conclusion

The issue of the analysis is the occurrence of inconsistencies in the classification of Swiss forest types. Traditionally, shilouette plots are used to identify contradicting delineation of vegetation types (Everitt & al. 2011). These offer a more compact representation of group structure than dendrograms, but they are still too voluminous for overviewing very large data sets. With the proposed visualization of mean similarities within and between groups, even extensive classification systems can be surveyed. Trying to evaluate classification methods with this method is not recommended (nor would it be by silhouette plots), because the mean similarity coefficients are transformed to a range from zero to one and thus may encompass a very narrow range. However, entire blocks of groups that differ from all others with respect to consistency are detected. In the present case this concerns the very widespread beech and spruce forest types.

Whether an overall improvement in the crispness of the classification can be achieved by omitting certain species is one more question not further explored here. As Feoli & Ganis (2019) mention, different analyses of variance could provide answers, alternatively also the evenness of the eigenvalues of the similarity of the groups.

Although it can be shown that the shrub and herb layer of the examined forests behave differently than the tree layer, I have merged all three for the purpose of the analysis. Seedlings can also occur more frequently when their mother trees are found under unsuitable conditions. This is true for many changed stands, some of which dating back far into the past, because forestry has always focused on the promotion of economically interesting tree species (Brändli & al. 2020). This fact is evidenced by the wide distribution of *Picea excelsa* (Ellenberg & Klötzli 1972), but also of *Fagus sylvatica*, which has a broad realized niche by nature. If five frequently occurring tree species from all layers are removed from the data set, the zone of blurring between the forest communities disappears to a high extent.

Thanks to a systematically collected sample from recent times (Wohlgemuth & al. 2008; Wildi 2017), it can be shown that the influence of dominant species on the classification of forests is general. Thus, the observed uncertainties are not due to a lack of data quality or an insufficient grouping analysis by Ellenberg & Klötzli (1972). However, the interpretation that the undifferentiated behavior of common tree species is due to centuries of cultivation is difficult to prove. Historical sources on tree plantations are only available sporadically, on a local to regional scale.

In favourable individual cases (*Larix decidua*, *Castanea sativa*) it can be shown that tree plantings were occasionally made on unsuitable sites. Thanks to the availability of numerous site factors, the systematically collected data set allows the regression-based simulation of the regional distribution of potentially suitable sites. Tree groups planted at unsuitable sites can thus be identified. However, if a tree species is very common and plantations are widespread (*Picea excelsa*, *Fagus silvatica*), this method is not applicable because the tree species-site model is distorted by the uncontrolled management.

Fig. 1 suggests that the classification of Ellenberg & Klötzli (1972) in the realm of beech forests is somewhat too high in resolution, because different plant communities show a low degree of homogeneity internally, recognizable by rather light red coloured diagonal elements. If one merges very similar forest communities, the zone of blurring does not disappear. And in the systematic sample, where the majority of beech forests is represented by only three groups, the influence of *Fagus sylvatica* and *Picea excelsa* is equally visible. This in turn indicates that the causes of the blurring are not to be found either in the classification method or in the data quality.

The dominance of few tree species, and thus the lack of diversity of tree species overall, represents one of the risks associated with climate change (Gehrig-Fasel & al. 2005). In the case of beech, it is the susceptibility to drought in extreme sites (Brändli & al. 2020), while in the case of spruce it is the susceptibility to pests such as bark beetle as well as storm damage. A preventive measure would involve reducing this species poverty by changing the cultivation regime. The recipe is to narrow the realized niche of *Fagus* and *Picea*. This might be difficult due to the lack of better suited species.

As Latham & Ricklefs (1993) explain, the relative poverty of tree species applies to the whole of Europe. To confirm this would require a statistically satisfactory survey of the forest vegetation combined with adequate ecological information. However, as shown for Switzerland, the data situation is unsatisfactory throughout the whole continent. There is a lack of a sufficiently large sample, which would have to be up-to-date to reflect changes.

References

Brändli, U. B., Abegg, M., Allgaier Leuch, B. (eds) 2020: Schweizerisches Landesforstinventar. Eidgenössische Anstalt für Wald, Schnee und Landschaft WSL. – Bern.

Brzeziecki, B., Kienast, F. & Wildi, O. 1993: A simulated map of the potential natural forest vegetation of Switzerland. – J. Veg. Sci. **4:** 499-508.

De Cáceres, M., Chytrý, M., Agrillo E., Attorre, F., Botta-Dukát, Z., Capelo, J., Czúcz, B., Dengler, J., Ewald, J. & Wiser, S. K. 2015: A comparative framework for broad-scale plot based vegetation classification. – Appl. Veg. Sci. **18:** 543-560.

Chiarucci, A., Araújo, M. B., Decocq, G., Beierkuhnlein, C. & Fernández-Palacios, J. M. 2010: The concept of potential natural vegetation: an epitaph? – J. Veg. Sci. **21:** 1172-1187.

Connell, H. J. & Slatyer, R. O. 1977: Mechanisms of succession in natural communities and their role in community stability and organisation. – Amer. Naturalist **111:** 1119-1144.

Ellenberg, H. & Klötzli, F. 1972: Waldgesellschaften und Waldstandorte der Schweiz. – Mitteilungen der Eidgenössischen Anstalt für das forstliche Versuchswesen, **48.** – Zürich.

Everitt, B. S., Landau, S., Leese, M. & Stahl, D. 2011: Cluster Analysis, 5° Ed. – Chichester.

Feoli, E. & Ganis, P. 2019: The Use of the Evenness of Eigenvalues of Similarity Matrices to Test for Predictivity of Ecosystem Classifications. – Mathematics **7:** 245.

Gehrig-Fasel, J., Zimmermann, N., Guisan, A. & Brändli, U. B. 2005: Climate change or land abandonment? Analysis of treeline change in the Swiss Alps. – 90th ESA Annual Meeting / IX International Congress of Ecology, Montreal, Canada.

Kowarik, I. 1987: Kritische Anmerkungen zum theoretischen Konzept der potentiellen natürlichen Vegetation mit Anregungen zu einer zeitgemässen Modifikation. – Tüxenia **7:** 53-67.

Küchler, A. W. 1988: Mapping dynamic vegetation. – In: Küchler, A.W. & Zonneveld, I. S. (eds), Vegetation Mapping. Handbook of Vegetation Science **10:** 13-23.

Latham, R. E. & Ricklefs, R. E. 1993: Continental Comparisons of Temperate-Zone Tree Species Diversity. – In: Ricklefs, R. E. & Schluter, D. (eds). Species Diversity in Ecological Communities: Historical and Geographical Perspectives: 294-317. – Chicago .

Lindacher, R. 1996: Verifikation der potentiellen natürlichen Vegetation mittels Vegetationssimulation am Beispiel der TK 6434 "Hersbruck". – Hoppea **57:** 5-143.

Neuhäusl, R. 1984: Umweltgemässe natürliche Vegetation, ihre Kartierung und Nutzung für den Umweltschutz. – Preslia **56:** 205-212.
R Development Core Team 2017: A Language Environment for Statistical Computing. – R version 3.3.3. R Foundation for Statistical Computing 2017, Vienna.
Tüxen, R. 1956: Die heutige potentielle Vegetation von Oberfranken. – Angewandte Pflanzensoziologie (Stolzenau) **13:** 5-42.
Venables, W. N. & Ripley, B. D. 2010: Modern Applied Statistics with S, 4th Ed. – Berlin.
Wildi, O. 2017: Data Analysis in Vegetation Ecology. – 3rd Ed., Boston.
Wohlgemuth, T., Moser, B., Brändli, U.-B., Kull, P. & Schütz, M. 2008: Diversity of forest plant species at the community and landscape scales in Switzerland. – Pl. Biosyst. **142:** 604-613. https://doi.org/10.1080/11263500802410975
Zimmermann, N. E. & Kienast, F. 1999: Predictive mapping of alpine grassland in Switzerland: species versus community approach. – J. Veg. Sci. **10:** 469-482.

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Article

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The genus *Solenopsora* (Lichenized Ascomycetes, *Leprocaulaceae*) in Italy

Abstract

Guttová, A. & Nimis, P. L.: The genus *Solenopsora* (Lichenized Ascomycetes, *Leprocaulaceae*) in Italy. — Fl. Medit. 31 (Special Issue): 55-65. 2021. — ISSN: 1120-4052 printed, 2240-4538 online.

This paper includes a dichotomous key, descriptions and predictive distributional maps for all of the 9 infrageneric taxa of the lichen genus *Solenopsora* (*Leprocaulaceae*) known to occur in Italy. The genus includes obligatory saxicolous lichens with the main centre of diversity in the Mediterranean, Macaronesian, and Madrean biogeographical regions. All taxa have their optima below the montane belt. Most of them have a distinctly Thyrrenian-Mediterranen distribution pattern in Italy, being most frequent in areas with a mild, suboceanic climate.

Key words: Biogeography, dichotomous key, flora, lichens, Southern Europe.

Introduction

After the completion of a new checklist of the lichens of Italy (Nimis 2016), and its incorporation into ITALIC, the online information system on the lichens of Italy (Nimis & Martellos 2002; Martellos 2012), work has started on the preparation of a computer-aided lichen flora of the country, containing keys and descriptions (Nimis & Martellos 2020). A first comprehensive key, including all species known from Northern Italy (2.240 infrageneric taxa) has been already published online for testing (Nimis 2021). Separate, nationwide dichotomous keys to given families and/or genera are also being produced, which will be eventually integrated into a complete national key.

This paper is dedicated to the genus *Solenopsora* in Italy. It includes a key, descriptions and predictive distributional maps for all taxa known to occur in the country. The genus, for a long time listed under the *Catillariaceae*, was recently found to belong into the *Leprocaulaceae* (Miadlikowska & al. 2014, Fačkovcová & al. 2020). It mainly occurs in temperate and subtropical regions, the centre of diversity being in the Mediterranean, Macaronesian, and Madrean biogeographical regions (Fačkovcová & al. 2020). European species were treated by Guttová & al. (2014; see also Fačkovcová & al. 2019), who recognised 9 infrageneric taxa, all of which do occur in Italy (see Nimis 2016; Guttová & al. 2019).

Data and Methods

The key, which is also available online in an illustrated, interactive version, was produced using FRIDA (FRiendly IDentificAtion, see Martellos 2010), a software package for producing digital identification keys, developed since 2003 at the Department of Life Sciences of the University of Trieste. Contrary to most available software for the creation of identification tools, FRIDA is mainly focused on the optimization of classical dichotomous keys, although it also includes the possibility of adding a multi-entry query interface. FRIDA allows to store and organise characters and their states, names of taxa, descriptions, digital images, and textual notes into a unified system. These resources are used for generating digital identification keys, which can be edited, refined, enriched by further content, and published online, or used through an app for mobile devices (Martellos & Nimis 2015; Nimis & Martellos 2020). To allow collaborative efforts in the development of identification keys, FRIDA is based on a double-level architecture, which permits several authors to contribute to a common project, while maintaining a high degree of independence (Martellos 2010).

The distribution of species in the administrative regions of Italy is based on the data provided by Nimis (2016), integrated with data from Fačkovcová & al. (2019; 2020), and Guttová & al. (2019). Commonness/rarity of species was assessed on the basis of the number of literature citations for the different administrative regions of Italy (from Nimis 1993, 2016), and from the number of herbarium samples revised by Guttová & al. (2019).

The predictive distribution maps are based on the presence/absence in the administrative regions of Italy, and on commonness-rarity values (see Nimis & al. 2018) in 9 ecoregions (see Nimis 2016; Martellos & al. 2020), delimited on the basis of several thematic maps (altitude, precipitation, urbanization, etc.), also taking into account the difference between the Tyrrhenian (humid) and Adriatic (dry) part of the Italian Peninsula, which is relevant in influencing lichen distribution in Italy (Nimis & Tretiach 1995, 2004; Nimis 2016). The maps show the probability of finding a species in a given climatic area, and point to further exploration in some regions (when a species was never recorded from a region, that region remains blank). The actual distribution of species is likely to be narrower than that depicted in the maps, because these do not take into account the occurrence of the main types of rocks on which *Solenopsora*-species grow (calcareous, siliceous, and ultrabasic rocks).

Results

The species

Solenopsora A. Massal.
Framm. Lichenogr.: 20, 1855.

Thallus crustose or squamulose, sometimes placodioid, the upper surface corticate, with a trebouxioid photobiont. Apothecia lecanorine, the thalline margin sometimes becoming excluded. Asci 8-spored, clavate, *Catillaria*-type (but sometimes with a small ocular chamber). Ascospores (0-)1-septate, hyaline, without a thick epispore. Conidia simple, bacilliform. Medulla with orcinol and β-orcinol depsidones, triterpenes and different unidentified substances. Type species: *S. requienii* A. Massal. (= *S. holophaea*).

Solenopsora candicans (Dicks.) J. Steiner

Österr. bot. Z., 65: 288, 1915. Basionym: *Lichen candicans* Dicks., Fasc. Plant. Crypt. Brit., 3: 15, 1793.

Synonyms: *Caloplaca candicans* (Dicks.) Flagey; *Diphratora candicans* (Dicks.) Jatta; *Lecania candicans* (Dicks.) Stizenb.; *Lecanora candicans* (Dicks.) Schaer.; *Placodium candicans* (Dicks.) Duby; *Placodium epigaeum* (Ach.) Gray; *Placolecania candicans* (Dicks.) Zahlbr.; *Ricasolia candicans* (Dicks.) A. Massal.

Description: Thallus crustose-placodioid, epilithic, forming orbicular to irregular, strongly white-pruinose, 2-5 cm wide rosettes. Lobes mostly flattened, contiguous, radiating, 0.4-0.8(-1.4) mm wide, chalky white, sometimes glaucous-white at margins. Cortex colourless, with abundant crystals not soluble in K; medulla white, with a few crystals only. Apothecia frequent, subsessile, 0.8-2 mm across, with a flat, dark brown to black, usually slightly pruinose disc and a thin, white-pruinose, finally sometimes excluded thalline margin. Epithecium brownish; hymenium colourless, 50-70 µm high, K/I+ blue; paraphyses simple, not markedly capitate; hypothecium colourless, 110-140 µm high. Ascospores 1-septate, narrowly ellipsoid to almost acicular, sometimes slightly curved, (10-)12-17(-20) × 2.5-5 µm. Spot tests: thallus K-, C-, KC-, P-, UV+ greenish grey; medulla P+ orange-red. Chemistry: medulla with pannarin and zeorin (both major).

Note: a Mediterranean-Atlantic, to mild-temperate species found on calcareous rocks, most often on horizontal faces. Widespread throughout Italy (Fig. 1a), with optimum below the montane belt; more heliophilous in northern than in southern Italy, where it often occurs in sheltered situations.

Solenopsora cesatii (A. Massal.) Zahlbr.

Österr. bot. Z., 68: 303, 1919. Basionym: *Ricasolia cesatii* A. Massal., Mem. Lichenogr.: 47, 1853.

Synonyms: *Berengeria cesatii* (A. Massal.) Trevis.; *Diphratora cesatii* (A. Massal.) Jatta; *Lecania cesatii* (A. Massal.) Bagl.; *Placolecania cesatii* (A. Massal.) Zahlbr.; *Solenopsora carpatica* Pišút & Vězda

Description: Thallus crustose-placodioid, epilithic, blue-grey to grey when dry, bright green when wet, often white-pruinose in marginal parts, forming either single rosettes (up to 2 cm across) or concentric radiating circles or arcs (up to 15 cm across), squamulose-lobulate in central parts, irregularly lobed at margins. Lobes 0.4-0.8 mm wide, flat to usually slightly convex, undulate, folded and crisped, with round, entire margins. Apothecia sessile, 0.5-1.5(-3) mm across, with a dark brown to black, sometimes pruinose disc and a persistent thalline margin. Epithecium brownish; hymenium colourless, K/I+ blue, 40-60 µm high; paraphyses simple, coherent; hypothecium colourless, 100-110 µm high. Ascospores (0-)1-septate, narrowly ellipsoid, (7-)8-11 × 2.5-4 µm. Spot tests: thallus C-, K-, KC-, P-; medulla P+ orange-red. Chemistry: medulla with pannarin and zeorin (both major), plus minor unidentified substances.

Note: a lichen with optimum in the submediterranean belt, found in fissures of calcareous boulders in rather sheltered situations. Widespread throughout Italy (to be looked for in Umbria), but most frequent outside the Tyrrhenian ecoregion (Fig. 1b).

Solenopsora grisea (Bagl.) Kotlov

Nov. Sist. Niz. Rast., 37: 251, 2004. Basionym: *Ricasolia cesatii* var. *grisea* Bagl., Comm. Soc. Critt. Ital., 1, 3: 121, 1862.

Synonyms: *Solenopsora bagliettoana* Tav. ined.

Description: Thallus crustose-placodioid, epilithic, forming continuous, irregular patches (up to 8-10 cm across), the central parts glaucous grey-green, the marginal lobes up to 1 mm wide, white-pruinose at margins. Central part of thallus with raised lobules producing blastidia or breaking into soralia-like structures. Apothecia infrequent, up to 1.5 mm across, with an initially flat, then strongly convex, brown, pruinose or epruinose disc, and a crenulate, but often finally excluded thalline margin. Epithecium brownish; hymenium colourless, 60-70 µm high, K/I+ blue; paraphyses simple, coherent; hypothecium colourless, 80-100 µm high. Ascospores (0-)1-septate, narrowly ellipsoid, (10-)14-18 × 2.5-4 µm. Spot tests: thallus and medulla C-, K-, KC-, P-. Chemistry: medulla with terpenoids and unidentified substances, rarely with atranorin.

Note: on calcareous rocks in open to sheltered situations. Most probably widespread throughout Italy (to be looked for in several regions), with optimum below the montane belt in the Tyrrhenian part of the country (Fig.1c). For further details see Guttová & al. (2014).

Solenopsora holophaea (Mont.) Samp.

Broteria, ser. bot., 19: 26, 1921. Basionym: *Parmelia holophaea* Mont., in Webb & Berthelot, Hist. des Iles Canaries, 3, 2, 4, 51: 113, 1840.

Synonyms: *Lecania holophaea* (Mont.) A. L. Sm.; *Lecania requienii* (A. Massal.) Zahlbr.; *Lecanora holophaea* (Mont.) Nyl.; *Massalongia requienii* (A. Massal.) Jatta; *Pannaria holophaea* (Mont.) B. de Lesd.; *Solenopsora requienii* A. Massal.; *Thalloidima holophaeum* (Mont.) Arnold

Description: Thallus squamulose, olive-green to olive-brown, epruinose, rather glossy. Squamules 1-3 mm wide, rounded, concave to flat, contiguous or imbricate, with entire to crenulate or flexuose, raised margins; lower surface somewhat paler, attached by sparse, mostly centrally located, pale rhizines. Upper cortex of anticlinally oriented, gelatinized hyphae; medulla white. Apothecia 0.5-1.5 mm across, sessile to shortly stipitate, with a dark brown to blackish, flat disc, and a smooth, finally sometimes excluded thalline margin. Epithecium reddish brown; hymenium colourless or pale reddish brown, 50-60 µm high, I+ blue; paraphyses coherent, swollen at apices; hypothecium colourless or pale brown, 130-140 µm high. Ascospores 1-septate, ellipsoid-elongate to slightly fusiform, 11-18(-24) × 4-5(-6) µm. Spot tests: thallus and medulla K-, C-, KC-, P-, UV-. Chemistry: terpenoids, unidentified substances.

Note: a Mediterranean-Atlantic lichen found in sheltered crevices of basic siliceous rocks and on soil, especially along the coast; rare, and exclusively Tyrrhenian in Italy, to be looked for in Latium (Fig. 1d).

Solenopsora liparina (Nyl.) Zahlbr.

Öst. bot. Z., 68: 304, 1919. Basionym: *Lecanora liparina* Nyl., Flora, 59: 305, 1876.

Synonyms: *Ricasolia cesatii* var. *olivacea* Bagl.; *Ricasolia liparina* (Nyl.) Flagey; *Solenopsora cesatii* f. *liparina* (Nyl.) Clauzade & Cl. Roux

Description: Thallus crustose-placodioid, epilithic, forming up to 2.5 cm wide, orbicular rosettes, the central parts sometimes falling off, leaving semicircular arcs of lobes. Lobes 0.3-0.6 mm wide, flat to slightly convex, olivaceous grey or grey-green, with rounded, white-pruinose ends. Apothecia sessile, to 1 mm across, with a brown, bluish-white-pruinose disc, and a smooth to scabrid, persistent to finally excluded thalline margin. Epithecium brown, granular, the granules not dissolving in K; hymenium colourless, 60-70 µm high; paraphyses coherent, swollen at apices; hypothecium colourless, 80-90 µm high. Ascospores 1-septate, hyaline, straight or slightly curved, 13-16 × 3-4 µm. Spot tests: thallus K-, C-, KC-, P-, UV-; medulla P+ orange-red. Chemistry: medulla with pannarin and zeorin (both major).

Note: on inclined surfaces of ultrabasic rocks (e.g. serpentine), often in fissures, in shaded situations also on vertical faces, mostly in the Mediterranean belt; so far recorded from Liguria and Tuscany (Fig. 1e).

Solenopsora marina (Zahlbr.) Zahlbr.

Cat. Lich. Univ., 5: 756, 1828. Basionym: *Placolecania marina* Zahlbr., Österr. Bot. Z., 57: 396, 1907.

Description: Thallus squamulose, pale green to glaucous green, up to 0.4 mm thick, forming rosettes or irregular patches up to 5-6 cm in diam. Outer squamules elongate, loosely attached by sparse rhizines, flexuose, folded, with white-pruinose margins; central parts of thallus crustose-areolate. Upper cortex paraplectenchymatous 40-50 µm thick; medulla white. Apothecia sessile, up to 0.5(-1) mm across, with a brownish, initially flat, finally strongly convex disc, and a thin, often white-pruinose, finally excluded thalline margin. Proper exciple of radially arranged hyphae; epithecium brownish; hymenium colourless, 60-90 µm high; paraphyses filiform, conglutinated, mostly simple; hypothecium colourless, 90-100 µm high. Ascospores 1-septate, hyaline, narrowly ellipsoid to fusiform, 9-16 × 3-3.5 µm. Pycnidia black, immersed. Conidia hyaline, simple, bacilliform, 3.5-4,5 × 0.5-1 µm. Spot tests: medulla K- C-, KC-, P-. Chemistry: different terpenoids and unidentified substances.

Note: on calcareous substrata, mostly in rock fissures and in humid and shaded situations in the Mediterranean belt; so far reported only from Tuscany and Basilicata (Fig. 1f), also known from e. g. the Dalmatian coasts, Turkey, Eastern Mediterranean (Jordan), and from the Ukraine (Guttová & al. 2019).

Solenopsora olivacea (Fr.) H. Kilias subsp. ***olivacea***

Herzogia, 5: 399, 1981. Basionym: *Biatora olivacea* Dufour ex Fr., Syst. Orb. Veget., 1: 285, 1825.

Synonyms: *Biatorina michelettiana* A. Massal.; *Biatorina olivacea* (Fr.) Anzi; *Catillaria olivacea* (Fr.) Zahlbr.; *Lecanora olivacea* (Fr.) Nyl.; *Placodiella olivacea* (Fr.) Szatala; *Ricasolia olivacea* (Fr.) Bagl.; *Toninia olivacea* (Fr.) Clauzade

Description: Thallus crustose, epilithic, brown-green to olive-green, epruinose, forming irregular, sometimes confluent, up to 10 cm wide patches, the central part often warted-areolate, the marginal part often lobulate, the lobes usually short and flat, sometimes not well developed. Apothecia sessile, 0.3-0.5(-0.8) mm across, with a pale to dark brown, flat to finally convex disc and a thin, poorly visible and often finally excluded thalline margin. Epithecium colourless to pale brown; hymenium colourless, 35-40 μm high: paraphyses coherent, simple, clavate; hypothecium colourless, 50-90 μm high. Ascospores 1-septate, narrowly ellipsoid with rounded ends, (10-)12.16 × 2.5-4 μm. Pycnidia immersed in the thallus. Conidia bacilliform, 3.5-4.5 × 0.5-0.9 μm. Spot tests: thallus K-, C-, KC-, P-; medulla P+ orange-red. Chemistry: medulla with pannarin and zeorin (both major).

Note: a Mediterranean species found on calcareous rocks, especially in open woodlands, with optimum below the montane belt in the Tyrrhenian part of the country (Fig. 1g).

Solenopsora olivacea subsp. ***olbiensis*** (Nyl.) Clauzade & Cl. Roux

in Roux, Bull. Soc. Bot. Centre-Ouest, n. sér. 13: 226, 1982. Basionym: *Lecanora olbiensis* Nyl., Flora, 59: 306, 1876.

Synonyms: *Catillaria olivacea* var. *soredifera* Zahlbr.; *Toninia olivacea* var. *olbiensis* (Nyl.) Clauzade

Description: Thallus crustose, episubstratic, sorediate, green, brown-green, epruinose, forming irregular, sometimes confluent, up to 10 cm wide patches, the central part often warted-areolate, the marginal part often lobulate, with short, sometimes not well-developed lobes. Soralia laminal, round, excavate, pale green, turning yellowish in the herbarium. Apothecia usually absent. Spot tests: thallus K-, C-, KC-, P-; medulla P+ orange-red. Chemistry: medulla with pannarin and zeorin (both major).

Note: on calcareous rocks, often associated with the typical subspecies, but rarer, and bound to more humid and shaded situations, with optimum below the montane belt in the Tyrrhenian part of the country (Fig. 1h).

Solenopsora vulturiensis A. Massal.

Lotos, 6: 75, 1856.

Synonyms: *Lecania holophaea* var. *glaucospora* (Nyl.) A.L. Sm.; *Lecania leucospeirea* (Nyl.) A.L. Sm.; *Lecanora holophaea* var. *glaucospora* Nyl.; *Lecanora leucospeirea* Nyl.; *Lecanora subdisparata* Nyl.; *Solenopsora leucospeirea* (Nyl.) Zahlbr.; *Solenopsora subdisparata* (Nyl.) Samp.; *Thalloidima leucospeireum* (Nyl.) Arnold

Description: Thallus crustose-subsquamulose, epilithic, pale grey to olive-grey, sorediate-blastidiate, consisting of single, crowded or scattered, rarely radiating, 0.2-0.5 mm wide, squamule-like lobules with white-pruinose margins, forming irregular patches; central lobules raised and subcoralloid (1-3 mm high) when producing blastidia, apically breaking into soralia-like structures; peripheral lobules adpressed and the whole finally appearing as a subleprose crust. Apothecia rare, 0.3-0.6 mm across, with an epruinose to faintly pruinose, pinkish brown to finally brown-black, flat to convex disc, and a crenulate, finally often excluded thalline margin. Epithecium brown or reddish brown; hymenium colourless, 50-60 μm high; paraphyses mostly simple, 1.5-2 μm thick, the apical cells 4-5 μm wide, often with an internal brown cap; hypothecium colourless to orange-brown, 80-110 μm high. Ascospores at first 1-celled, later 1-septate, hyaline, ellipsoid, 9-11(-14) × 4-5(-6) μm. Spot tests: thallus K+ faintly yellow, C-, KC+ faintly yellow, P- or P+ yellow-orange, UV-. Chemistry: terpenoids, unidentified substances, occasionally atranorin in low quantities,

Note: a Mediterranean-Atlantic lichen found on basic siliceous substrata, including brick walls, in open to most often sheltered situations; so far reported only from Tyrrhenian Italy (Fig. 1i).

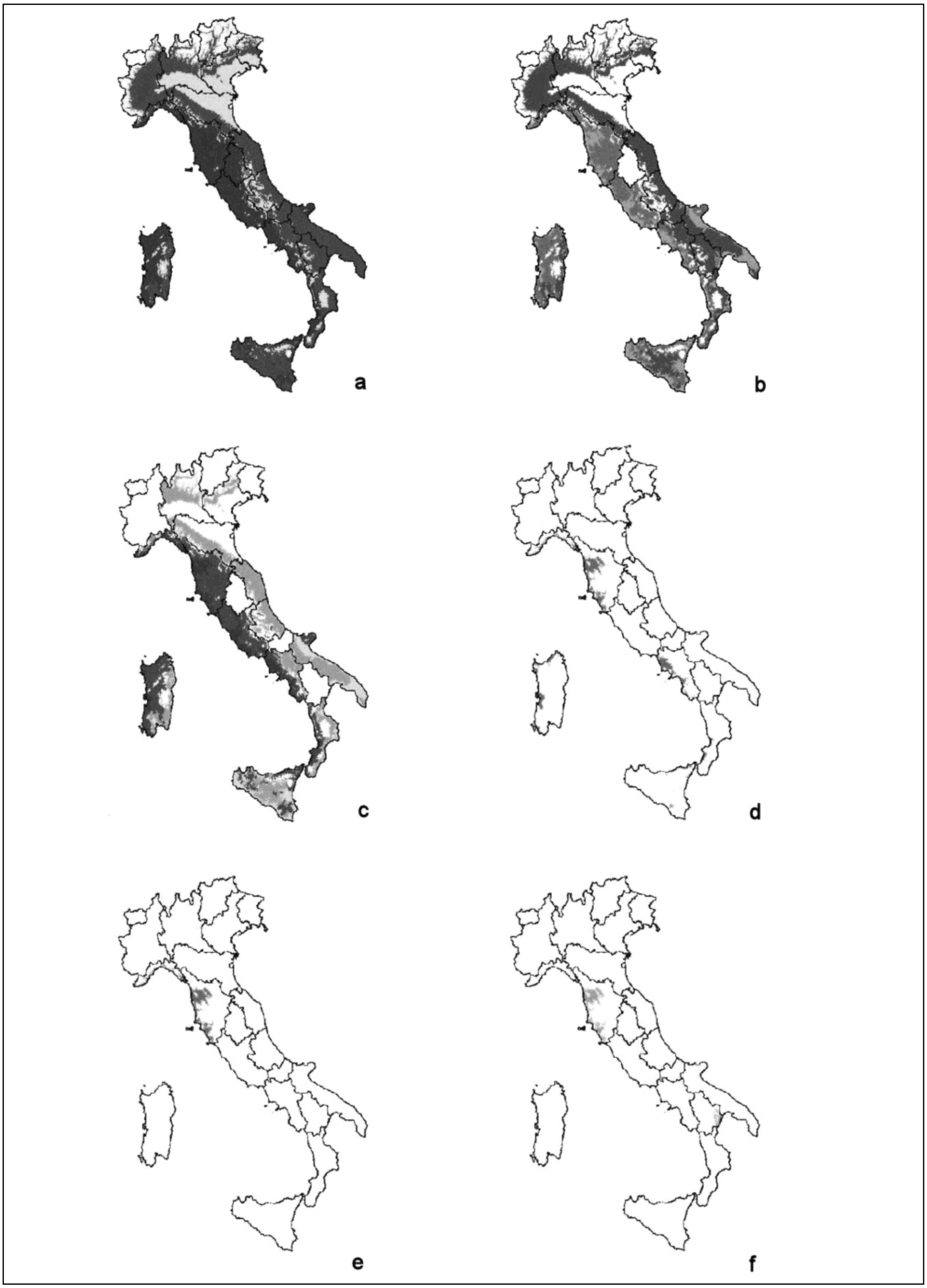

Fig. 1. Predictive distribution maps of the infrageneric taxa of *Solenopsora* occurring in Italy: a) *S. candicans*, b) *S. cesatii*, c) *S. grisea*, d) *S. holophaea*, e) *S. liparina*, f) *S. marina*.

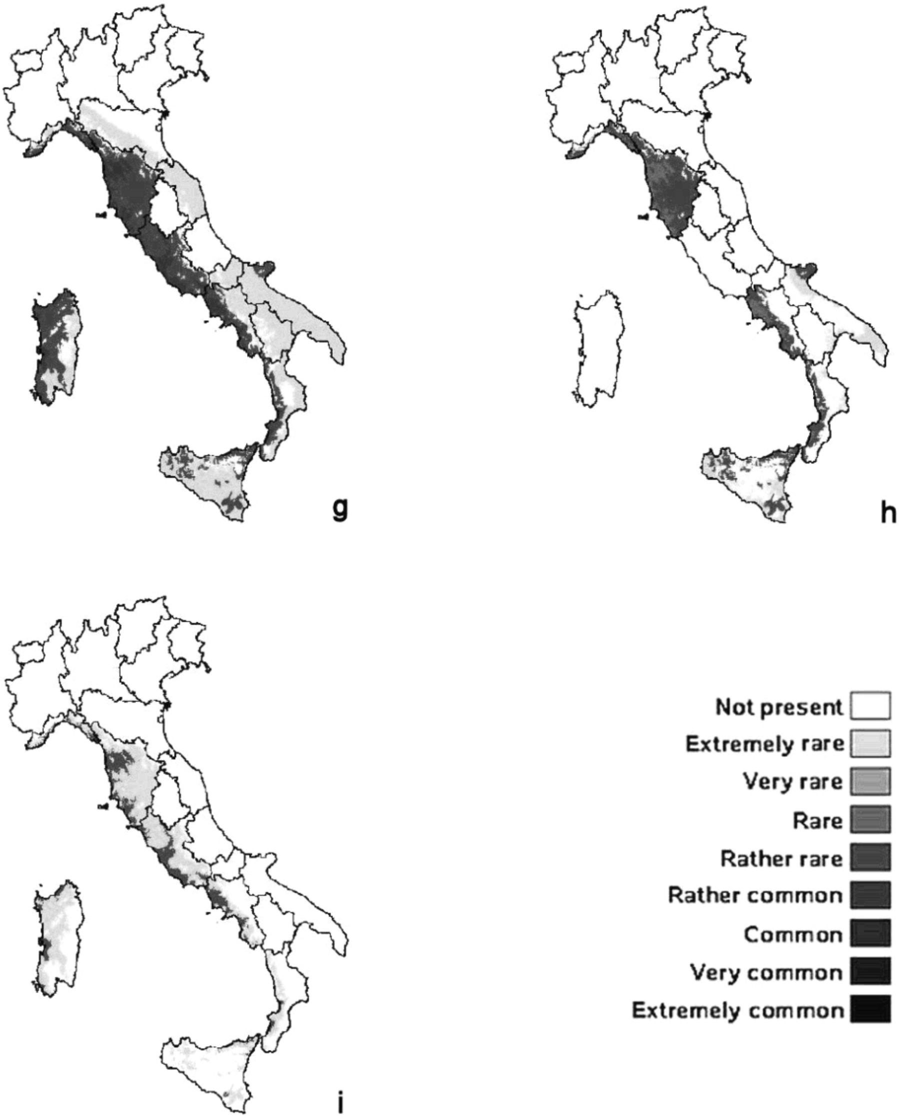

Fig. 1. (Continuation). Predictive distribution maps of the infrageneric taxa of *Solenopsora* occurring in Italy: g) *S. olivacea* subsp. *olivacea*, h) *S. olivacea* subsp. *olbiensis*, i) *S. vulturiensis*.

Dichotomous key

1. Soredia or blastidia present. Apothecia rare *2*

1. Soredia or blastidia absent. Apothecia usually abundant *4*

2. On siliceous substrata, central lobules raised and subcoralloid (1-3 mm high) when producing blastidia, apically breaking into soralia-like structures; peripheral lobules adpressed .... ***S. vulturiensis***

2. On calcareous substrata. Thallus different *3*

3. Thallus indistinctly placodioid, epruinose. In humid, sheltered situations ***S. olivacea* subsp. *olbiensis***

3. Thallus distinctly placodioid, the margin of lobes white-pruinose. In both open/sunny and sheltered situations ....***S. grisea***

4. Thallus squamulose to subfoliose, greenish or brown *5*

4. Thallus crustose-placodioid, white to grey, rarely greenish- brown *6*

5. Squamules pale greenish to glaucous green, not glossy, white-pruinose at margins. Upper cortex paraplectenchymatous. Apothecia pale/medium brown, sessile, with a finally convex disc. On calcareous substrata in humid-sheltered situations ***S. marina***

5. Squamules red-brown to greenish brown, glossy, epruinose, with rounded, entire margins. Upper cortex of anticlinally oriented, gelatinized hyphae. Apothecia dark red-brown to blackish, with a flat disc. On basic siliceous substrata in open situations ***S. holophaea***

6. On ultrabasic rocks (e.g. serpentine) .... ***S. liparina***

6. On calcareous rocks 7

7. Thallus not placodioid, brown-green to olive-green, epruinose ***S. olivacea* subsp. *olivacea***

7. Thallus placodioid, white to pale grey, at least in part white-pruinose *8*

8. Thallus blue-grey, white-pruinose only in marginal parts, forming either single rosettes (up to 2 cm across) or concentric radiating circles or arcs (up to 15 cm across), with undulate, folded-crisped lobes. Mostly in sheltered situations .... ***S. cesatii***

8. Thallus entirely white-pruinose, chalk-white, forming single rosettes (up to 5 cm across), with flattened, closely adpressed, isotomically branched lobes. In both exposed and sheltered situations .... ***S. candicans***

Discussion

All of the 9 infrageneric taxa of *Solenopsora* known to occur in Europe are present in Italy. All of them are saxicolous, one being specialized on ultrabasic rocks such as serpentine (*S. liparina*), two growing on siliceous rocks (*S. holophaea*, *S. vulturiensis*), the others on calcareous rocks. Their relative commonness/rarity was assessed from the total number of literature references (from Nimis 1993, 2016), and of Italian herbarium samples revised by Guttová & al. (2019). Out of a total of 339 citations and 236 herbarium samples, the species can be ranked, in order of decreasing commonness, as follows (number of citations/number of TSB samples): *S. candicans* (118/73), *S. cesatii* (68/40), *S. olivacea* subsp.

olivacea (51/33), *S. grisea* (33/33), *S. holophaea* (29/17), *S. vulturiensis* (20/18), *S. olivacea* subsp. *olbiensis* (13/11), *S. liparina* (4/10), *S. marina* (3/1). The most commonly collected/recorded species are those which are not restricted to the eu-Mediterranean belt, the rarer species are strictly Mediterranean and often coastal, or, as in the case of *S. liparina*, restricted to a rather rare type of rocks (ultrabasic siliceous rocks). The species of *Solenopsora* have a remarkable similarity in their climatic requirements, with more specific requirements in terms of microclimate. All of them have the optima below the montane belt; only *S. candicans*, *S. cesatii* and *S. grisea* occasionally occur above 1.000 m. Furthermore, 75% of the total number of citations, and 73% of herbarium samples are from administrative regions facing the Thyrrenian sea, the majority of species being most frequent in Thyrrenian Italy, an ecoregion characterized by a milder, more suboceanic climate than the one prevalent in northern Italy and along the Adriatic side of the Peninsula at comparable altitudes (the most relevant exception being *S. cesatii*, which is most frequent outside Tyrrhenian Italy). This agrees well with the model based on climatic and geological data developed by Guttová & al. (2019), suggesting that the occurrence of *Solenopsora*-taxa seems to be mainly governed by low variability in diurnal temperature and tolerance to dryness, with precipitation in the range of 0–20 mm in the driest month and a minimum temperature of >5 °C in the coldest month. The predictive distribution maps of Fig.1 also highlight exploration bias, as most of the taxa are undercollected. Further sampling will contribute to a better knowledge of the geographic as well as climatic areas occupied by these taxa in Italy.

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References

Fačkovcová, Z., Lőkös, L., Farkas, E. & Guttová, A. 2019: New Records of Species of the Lichen Genus *Solenopsora* A. Massal. in the Balkan Peninsula and Adjacent Islands. – Herzogia **32:** 101-110. https://doi.org/10.13158/heia.32.1.2019.101

—, Slovák, M., Vďačný, P., Melichárková, A., Zozomová-Lihová, J. & Guttová, A. 2020: Spatiotemporal formation of the genetic diversity in the Mediterranean dwelling lichen during the Neogene and Quaternary epochs. – Molec Phylog. Evol. **44**. https://doi.org/10.1016/j.ympev.2019.106704

Guttová, A., Sosomová-Lihová, J., Timdal, E., Kučera, J., Slovák, M., Piknová, K. & Paoli, L. 2014: First insights into genetic diversity and relationships of European taxa of *Solenopsora* (*Catillariaceae*, Ascomycota) with implications for their delimitation. – Bot. J. Linn. Soc. **176:** 203-223. https://doi.org/10.1111/boj.12200

—, Fačkovcová, Z., Martellos, S., Paoli, L., Munzi, S., Pittao, E. & Ongaro, S. 2019: Ecological specialization of lichen congeners with a strong link to Mediterranean-type climate: a case study of the genus *Solenopsora* in the Apennine Peninsula. – Lichenologist **51:** 75-88. https://doi.org/10.1017/s0024282918000543

Martellos, S. 2010: Multi-authored interactive identification keys: The FRIDA (Friendly IDentificAtion) package. – Taxon **59:** 922-929. https://doi.org/10.1002/tax.593020

— 2012: From a textual checklist to an information system: The case study of ITALIC, the Information System on Italian Lichens. – Pl. Biosyst. **146:** 764-770. https://doi.org/10.1080/11263504.2012.740088

— & Nimis, P. L. 2015: From Local Checklists to Online Identification Portals: A Case Study on Vascular Plants. – plosOne **103:** 1-18.

—, d'Agostino, M., Chiarucci, A., Nimis, P. L., & Nascimbene, J. 2020: Lichen distribution patterns in the ecoregions of Italy. – Diversity **12:** 1-21. https://doi.org/10.3390/d12080294

Miadlikowska, J., Kauff, F., Högnabba, F., Oliver, J. C., Molnár, K., Fraker, E., Gaya, E., Hafellner, J., Hofstetter, V., Gueidan, C., Otálora, M. A. G., Hodkinson, B., Kukwa, M., Lücking, R., Björk, C., Sipman, H. J. M., Burgaz, A. R., Thell, A., Passo, A., Myllys, L., Goward, T., Fernández-Brime, S., Hestmark, G., Lendemer, J., Lumbsch, H. T., Schmull, M., Schoch, C. L. Sérusiaux, E., Maddison, D. R., Arnold, A. E., Lutzoni, F., Stenroos, S. 2014: A multigene phylogenetic synthesis for the class Lecanoromycetes (Ascomycota): 1307 fungi representing 1139 infrageneric taxa, 317 genera and 66 families. – Mol. Phylogenet. Evol. **79:** 132-168. https://doi.org/10.1016/j.ympev.2014.04.003

Nimis, P. L. 1993: The Lichens of Italy. An Annotated Catalogue. – Mus. Reg. Sci. Nat. Torino, Monogr. XII, 897 pp.

— 2016: The Lichens of Italy. A Second Annotated Catalogue. – Trieste.

— 2021: The lichens of Northern Italy. An interactive guide. – Continuously updated online at: http://italic.units.it/flora/index.php?procedure=ext_key_home&key_id=241 [Last accessed 23/3/2021].

— & Martellos, S. 2002: ITALIC, the information system on Italian lichens. – Bibl. Lichenol. **82:** 271-823.

— & — 2020: Towards a digital key to the lichens of Italy. – Symbiosis **82:** 149-155.

— & Tretiach, M. 1995: The lichens of Italy. A phytoclimatic outline. – Crypt. Bot. **5:** 199-208.

— & — 2004: Delimiting Tyrrhenian Italy: A lichen foray in the SW of the peninsula. – Bibl. Lichenol. **88:** 456-478.

—, Martellos, S., Spitale, D. & Nascimbene, J. 2018: Exploring patterns of commonness and rarity in lichens: a case study from Italy (Southern Europe). – Lichenologist **50:** 385-396. https://doi.org/10.1017/s0024282917000731

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Article

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The "London" Australian natural history drawings of Ferdinand Bauer (1760-1826) - revisited

Abstract

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Since the catalogues of the zoological (1994) and botanical and landscape (1999) drawings of Ferdinand Bauer in the Natural History Museum, London were published, it has been possible to refine the attributions of the "finished" watercolours held there through examination of more of the original field drawings held at the Archiv, Naturhistorisches Museum Wien. As a result, locality and chronology information for many zoological and botanical drawings held in London are updated here. Such precision has bearing on phenology of the germane plant species in light of climate-change and distributions now reduced through European land-use practices. In an appendix there is discussion of the drawings attributed to Bauer and now held in the Linnean Society of London; some are possibly the work of Franz Bauer.

Key words: Ferdinand Bauer, London watercolours, Australian biota.

Introduction

The enormous scientific output of Sandro Pignatti (and Erika Pignatti-Wikus) extends from the Mediterranean to Australia and includes an important comparison of the ecosystems of the Mediterranean with those of Western Australia (Pignatti-Wikus & al. 2002). In celebrating Sandro's ninetieth birthday, it seems appropriate, then, to discuss the work of another whose ambit similarly spanned the Mediterranean and Australia, namely the Austrian natural history painter, Ferdinand Bauer (1760-1826), coincidentally another of Erika's subjects of research (Pignatti-Wikus & al. 2000a, 2000b; Mabberley & al. 2007).

Ferdinand Bauer's work on Mediterranean plants and animals in the field and studio (1786-99) leading to the monumental *Flora graeca* (1806-40) of John Sibthorp and James Edward Smith is well documented (Lack with Mabberley 1999; Mabberley 2017: 22-57) and is a relatively straightforward topic of research, as most of the germane materials are held in one place, namely Oxford, England. By comparison, Bauer's Australian work is much less so, because his materials are in both London and Vienna, with the latter yet to be completely catalogued and digitised.

Ferdinand Bauer in Australia

In 1800 Bauer was recruited by Sir Joseph Banks to be natural history painter on the *Investigator* voyage (1801-05) of Matthew Flinders to Australia (Britten 1909; Stearn 1960; Mander-Jones 1965; Bauer 1976; Mabberley 1985 passim; Norst 1989; Watts & al. 1997; Mabberley & Moore 1999; Mabberley 1999 passim; Pignatti-Wikus & al. 2000a, 2000b; Mabberley 2002; Lack 2003, 2015 passim; Mabberley 2017: 76-173, 2019: 175-217, 232-43). As in the Mediterranean, Bauer used a colour-coding system ("painting by numbers") to capture the natural appearance of both plants and animals of Madeira, South Africa, Australia and Indonesia (Timor). Each tone was assigned a number used in pencil sketches made in the field, allowing the true coloration to be recovered in Europe later. This system had been used by Bauer and his brothers in childhood when they were required to copy coloured illustrations of expensive plate-books in the library of a local monastery in what is now Valtice (Czechia). It would appear that such coding used on pencil sketches of images copied from the books allowed the boys to complete their watercolours elsewhere, thereby avoiding possible paint-damage to the originals (Mabberley 2017: 6). According to Riedl-Dorn & Riedl (2019), such numbering was used at this time by children colouring maps, so it was likely not a novelty in Valtice, but, with the exception (Mabberley & San Pío Aladrén 2012) of the Bohemian Thaddaeus Haenke (1761-1816) in South America (1789-1816), Ferdinand Bauer was the only significant artist so far known ever to use it such a system in the field. Among those colour-charts in use in Central Europe by the end of the eighteenth century, Franz Estner's *Versuch einer Mineralogie* (1794; Fig. 1) was certainly employed in some circumstances by Bauer, notably in drawing a sea-slug (Bauer MS: "see of Estners Mineral Tables for all of this", "Norfolk Island Dec 21 1804") but also noted on drawings of some subjects from northern Australia before that – and his copy of the book was still amongst his chattels when he died (Mabberley 2017: 10-11, 153, 219). Although a "Bauer'sche Farbtabelle" was reportedly used in 1860 to "interpret" a pencil sketch made by Bauer of the now extinct Norfolk kaka (*Nestor productus* (Gould)), a bird drawn on Norfolk Island in January 1805 (Mabberley 2017: 160-61, Riedl-Dorn & Riedl 2019), it has yet to be demonstrated that Bauer's system of 1000 colour-shades (200 of green alone) used in Australia was generally based on Estner's scheme, or another (lost) system Bauer may have elaborated – or, in view of the speed with which he worked, was in practice, partly or even wholly, just in his head in any case - rather in the way composers use musical notation (Mabberley & San Pío Aladrén 2012). That any chart available after Bauer's death must have been difficult to use is shown by the singularly unfaithful results in a half-finished watercolour of the Western Australian *Stylidium nymphaeum* Wege (Mabberley 2017: 66-89), elaborated in Vienna, possibly by the Zehner brothers, who may have also prepared the rather gaudy watercolours of at least some of Bauer's Australian fungi there, so different from the germane finished watercolours of Bauer in London, yet both elaborated from Bauer's field drawings. Certainly, no such Bauer chart survives at W today. Nonetheless, using the colours of living plants in Western Australia, it has been possible to crack Bauer's Australian code by assigning colours to the numbers on Bauer's pencil drawings made there in 1801-2 and now preserved in the Naturhistorisches Museum Wien (Pignatti-Wikus & al. 2000a, 2000b). Moreover, using "reverse engineering" it has been possible for a modern Australian botanical artist, Marion Westmacott, to use the reconstructed code to produce a watercolour from Bauer's numbered pencil drawings (Fig. 2) of a now-extinct tree, *Solanum bauerianum* Endl.

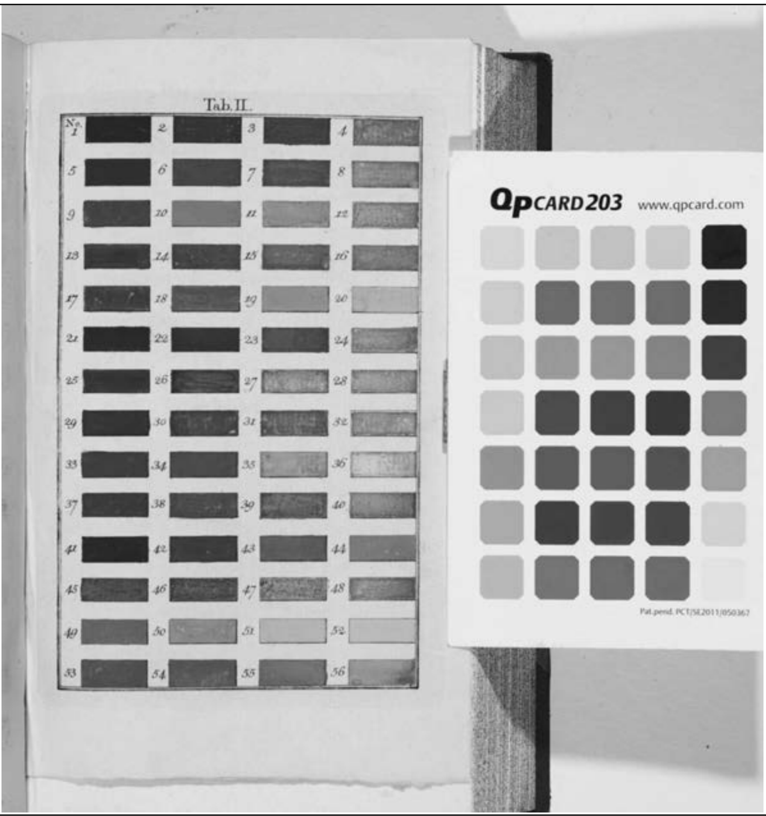

Fig. 1. Franz Estner’s Versuch einer Mineralogie (1794) (Natural History Museum, London).

(*Solanaceae*; Mabberley & al. 2007; Mabberley 2017: 156-159), so that modern biologists now know what looked like (Fig. 3).

Although Bauer was technically “line-managed” by Flinders’s naturalist, the Scottish botanist, Robert Brown (1773-1858), in *Investigator*’s circumnavigation of Australia (1801-03), he often worked independently and made his own herbarium, most of which survives in Vienna (W), with some Norfolk Is. duplicates owned by Brown now at Kew (K; not with Brown’s own herbarium now at the Natural History Museum in London (BM), which includes a small number of Bauer’s Australian duplicates; Mabberley 1985 passim; Mabberley & Moore 2021). In general, the W specimens are the bases for Bauer’s surviving field-drawings in W, though it is clear that he sometimes used Brown’s or even other collectors’ material, as this is sometimes noted in his often idiosyncratic English on the Vienna drawings (e.g. unidentified pencil sketches with numbers (HPV[1] 384) “Sydney Sept 10 1803 by [Alexander] Gordon [see Mabberley 2019: 186]” “No 1341” and (HPV 391) “No 1318” “Duck Bruch [Duck River Bridge] Parramatta [New South Wales] M^r Brown Ap[ril] 12 1805”). Besides localities, Bauer seems to have started adding dates from “North Coast” in December 1802, after Gulf of Carpentaria “Island h [North Island or Barranyi, Northern Territory]” to his sketches, but there

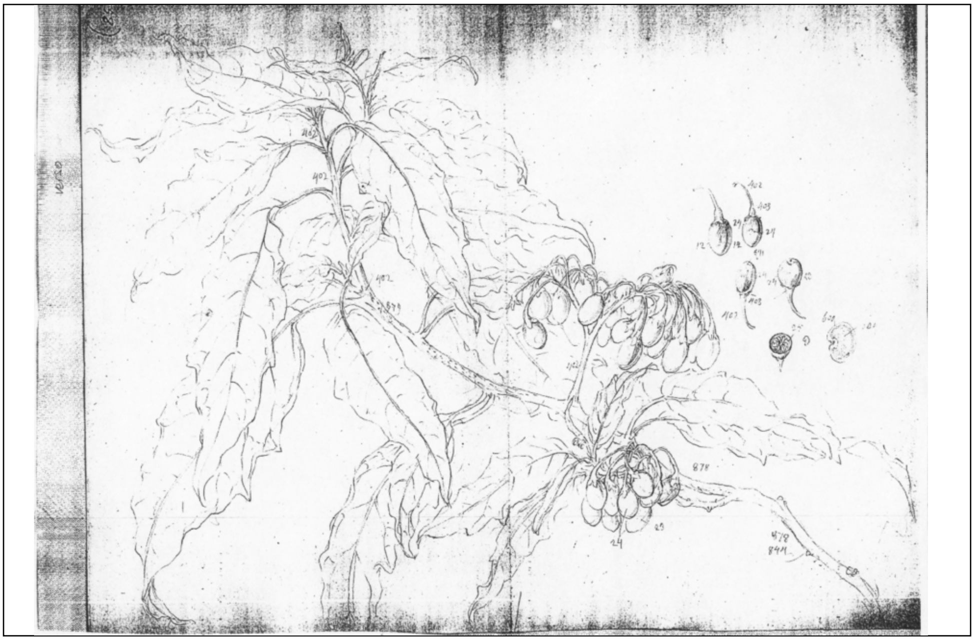

Fig. 2. *Solanum bauerianum* Endl. (*Solanaceae*). Field drawing of fruiting branches by Ferdinand Bauer, Norfolk Island, 1804-05 (Archiv, Naturhistorisches Museum Wien).

is no record of why he did this, but, in using his records, it is possible, by using referring to Brown's diary (Vallance & al. 2001), to know precisely where Bauer's drawings were made.

Ferdinand Bauer in London

Besides amassing his own herbarium, Bauer also collected seeds, some of which subsequently germinated at Kew Gardens, where, after the voyage, he also made colour-coded pencil drawings of plants grown from seeds collected by Brown's whole team. Such include as yet unidentified legumes (HPV 1721) "Van Dimons I [sic = Tasmania, which Bauer never visited, so raised from seeds collected by Brown himself] Kew April 14 1809" [part enlarged "magnifit", i.e. "magnified"] and (HPV 1766), "Van Diemans Islan [sic = Tasmania] M^{r} Brown Kew May 3th 1808", while that of what is likely a *Pelargonium* (HPV 1557) has "May 3 1808 Kew Port Jackson No X [Port Lincoln, South Australia] South Coast", which were raised from seeds collected by Peter Good (d. 1803) the gardener on *Investigator*. Sometimes Bauer made such "Kew" drawings on the verso of his field ones, e.g. unidentified HPV 942, though very often in the field, especially on Norfolk Is. (as with *Solanum bauerianum*) he drew the fruits (Fig. 2) on that side, the flowers being on the recto. Bauer also made drawings with colour-code numbers elsewhere as in the great London nursery of Conrad Loddiges (Mabberley 2019: 249, 292, 298), e.g. an unidentified legume (HPV 1767), "Loddige [sic] June 5th 1807".

Fig. 3. *Solanum bauerianum* Endl. (*Solanaceae*). Watercolour by Marion Westmacott (Katoomba, New South Wales), “reverse-engineered” from Bauer’s field-drawings interpreted according to the code cracked by Pignatti-Wikus & al. (2001a, b). Courtesy the artist.

Bauer’s drawings were intended to be the basis for illustrations for a grand Flora of Australia in the style of *Flora Graeca*, to be written by Brown. After Brown’s and Bauer’s return to England in 1805, the British Admiralty paid their salaries, in Bauer’s case until the end of 1811. Bauer worked up watercolours (some of the so-called “duplicates” possibly in Sydney before leaving Australia), using his colour-coded sketches.

Some, at least, were elaborated with details from his own herbarium specimens (Mabberley 2017: 108-111). During that time, Brown, in the mode of J. E. Smith’s *Prodromus* (1806-07) for *Flora Graeca*, produced the first (and only) part of his *Prodromus florae novae hollandiae* (1810), but the ending of state support meant that the main Flora project was aborted and none of the 235 watercolours Bauer made for it was to be published until the 1960s. Nonetheless, Brown used them in his work, notable being that of *Prasophyllum baueri* (R. Br.) Poir. (*Orchidaceae*), nowadays an endangered species (Grimm & al. 2020), Bauer’s finished watercolour being the sole basis for Brown’s description and therefore the holotype of Brown’s then monospecific genus *Genoplesium*. The field-drawing in Vienna (Fig. 4) reveals that the material drawn was from Farm Cove, now the site of the Royal Botanic Garden Sydney.

Later, several of Bauer’s completed drawings of Australian fish were again the sole basis for the descriptions, by John Richardson (see Appendix 3), and these holotype drawings are also preserved in London (Mabberley 2017: 96-97). Even in the mid-twentieth century, one of Bauer’s Australian plant pencil sketches in Vienna became a holotype, namely that of *Clerodendrum heterophyllum* var. *baueri* Moldenke (i.e. ?*Volkameria inermis* L., *Labiatae/Lamiaceae*) in Phytologia 4: 127 (1952), which was based on HPV[i] 968a, drawn at Keppel Bay, Queensland in August 1802.

With the abandonment of the grand Flora project, Bauer, with Brown’s help, himself began to publish fascicles of new versions of his drawings of Australian plants, his *Illustrationes florae Novae Hollandiae* (1813-16). He also made illustrations for Matthew Flinders’s *Voyage to Terra Australis* of 1814, while, after Bauer’s death, his field drawings were used by yet others, especially Stephan Endlicher (Mabberley & Moore 1999: 206-221). In 1814 Bauer returned to Vienna and issued the third and final fascicle (each fascicle comprising five plates) of his *Illustrationes*; Brown was effectively his agent for sales in Britain (Mabberley 2017: 194-196, 2019: 236-237; Watt 2004). Again, sometimes the localities can be ascertained from the annotated colour-coded field drawings in Vienna. Examples include: *Pterostylis grandiflora* (*Orchidaceae*; HPV 389) “Wallamula [Woolloomooloo] Sydney Jan 17 1804” “No 1317”, likely the basis for his t. 2; *Levenhookia pusilla* (*Stylidiaceae*; HPV 813) [King George Sound; drawn from a Brown specimen (Mabberley & Moore 1999: 84)], the basis for his t. 15 (bottom); *Stylidium calcaratum* (*Stylidiaceae*; HPV 824) “King George III S” the basis for his t. 15 (top left; Mabberley, 2017: 198).

Bauer also made for himself watercolours (on paper with watermarks from 1811) based on his drawings of animals he had sketched in the Pacific (Mabberley 2019: 232). These drawings he bequeathed to his brother Franz, in London, and are now in the Natural History Museum there. After Ferdinand’s death, when his field-drawings of plants and animals were bought by the Emperor, some of those from both the Australian mainland and also Norfolk Is. and Timor were traced and lithographs made in Vienna, some (a few unpublished ones surviving) apparently for an aborted Flora of Norfolk Island of which

Fig. 4. *Prasophyllum baueri* (R. Br.) Poir. (*Orchidaceae*). Field drawing by Ferdinand Bauer, Farm Cove, Sydney, 29 April 1804. Previously unpublished, it is the basis for the London watercolour which is the holotype of *Genoplesium baueri* R. Br. (Archiv, Naturhistorisches Museum Wien).

Endlicher published a *Prodromus* (1833; Mabberley 2017: 210-12), others being used in his *Iconographia* and *Atakta* (Mabberley & Moore 1999). Such field drawings revealing precise type localities include *Morgania pubescens* R. Br. (Endl., Iconographia t. 103 (1840); without HPV no.; i.e. *Stemodia pubescens* (R. Br.) W. R. Barker, *Scrophulariaceae*) - partly inked pencil tracing without numbers "Broad Sound 16. 1647.)" "Morgania"; *Mazus pumilio* R. Br. (*Mazaceae*; Endl., Iconographia t. 102 (1840); without HPV no.) - partly inked pencil tracing without numbers "1644"; [*Dentella repens* J.R.

Forst., *Rubiaceae*] (Endl., Atakta: t. 13 (1834); HPV 867) - pencil drawing with numbers "No 457" "Gulf of Carpentaria Isl h" [North Island] (Mabberley & Moore 1999: 210). In such cases, where new species were being described, Bauer's field drawings, sometimes backed by surviving herbarium specimens can be part of the original material in the context of typification matters.

The Natural History Museum London drawings

Although Bauer's 203 bound Admiralty drawings (three volumes) were used as "conversation pieces" (at least one drawing had by then already been lost), they eventually came to the British Museum in 1843 and into the care of Brown (Mabberley & Moore 1999: 87-88), who had also personally acquired the finished botanical and zoological watercolours from Bauer's brother Franz's sale in 1841. After Brown's death in 1858, these 49 (of which 16 were "duplicates" of the Admiralty set) also came to the collections of what is now the Natural History Museum, London and all the "finished" drawings were thus forever divorced from the original field-drawings of Australian animals and plants in Vienna. As it is usually only the field drawings that indicate the provenance of the finished watercolours in London, the value of the latter is diminished. This is particularly pertinent where, as in the case of a number of fish and at least one orchid (see above), descriptions of new species were based solely on the unpublished watercolours.

The aim of this study is to begin to reconcile these resources.

Published catalogues of the "London" drawings

Wheeler & Moore (1994) presented a catalogue of the 52 zoological drawings held at the Natural History Museum in London; Mabberley & Moore (1999) presented one of botanical (236 with a and b series for some orchids etc., though 219 & 220 are not by Bauer) and landscape (4 of Norfolk Is.) ones held there. The localisations in both papers were, in the main, based on MSS and specimens in the Natural History Museum London, though Mabberley & Moore (1999) cited a number of original field drawings, by then seen in Vienna or whilst they were on loan in Australia. As Mabberley & Moore (1999: 83-84) pointed out, these are the critical sources of dates and localities for the subjects depicted in the finished drawings. In connexion with a number of other projects (e.g. Mabberley 2017, 2019) the author has had the opportunity to examine all the Ferdinand Bauer materials held in the Naturhistorisches Museum Wien, where most are housed in the Archiv.

The fate of the field drawings

It would appear that almost all of the zoological field drawings survive in the Archiv, including the originals from which the "finished" drawings now in London were prepared, but most are unnamed. For the botanical drawings the situation is much more unsatisfactory, which is why no accurate number of Bauer's output can be arrived at (see Appendix 1). In 1889, many of the botanical field drawings were attached to Bauer specimens in the herbarium, because otherwise they, as artworks, were to be removed from the Botany Department to the Kunsthistorisches Museum in Vienna. Along with the original field drawings (all given HPV numbers in series according to the country where made) there were the tracings made for the production of a number of published and unpublished plates (see above) made from them (given “a”, “b” etc. suffixes to the HPV numbers). Where more than one taxon was on a drawing, this was of course problematical in terms of its placing in the herbarium.

In 1945, some days after the armistice in World War II, a fire broke out in one of the rooms in an otherwise empty country house in Lower Austria, where part of the Vienna herbarium had been evacuated. No-one has recorded who was responsible, though there have been rumours of people burning the collections to keep warm (but it was summer) or for cooking, or even of vandalism by drunken Russian soldiery occupying that area. Certainly not only that room was burnt out, but the hall of the Schloss was also damaged. Riedl (1981) listed the “destroyed families” in that disaster and these include most of the Monocotyledones (though the orchids were kept separate, so did not suffer), the gymnosperms and many “Dicot” families such as important Australian ones like *Proteaceae*. On the face of it, then, all the drawings in the “destroyed families” were lost, but this is not so.

Examination of surviving drawings in the Archiv shows that some from the “destroyed” families survive, so were either apparently never added to specimens, or, as some herbarium material from these families has also survived, the drawings filed with them were not burnt (see Appendix 2 for germane examples related to the London drawings). Others include some *Piperaceae*, *Casuarinaceae* (Mabberley 2017: 134-35), *Hydrocharitaceae* (Mabberley 2017: 143) and even *Proteaceae*, as with [*Persoonia pinifolia*] (HPV 507: “Sydney Jan 1 1804” “No 166”; [verso, fr.] “Sydney Sep 1803”. This may not be unconnected with the fact that in the Archiv today, some drawings are filed in very old paper folders, apparently their contents having been arranged by family, suggesting that some drawings at least were long ago retrieved from (or never added to) the herbarium. Again, those field drawings of such plants depicted on the same sheets as species not in “destroyed” families sometimes also survive (if they were filed under the latter). Others may have been on loan to workers outside Vienna during the war.

In the late twentieth century, an effort was made to extract the Bauer drawings and associated artwork from the herbarium collection for proper conservation in the Archiv, sadly without either recording where in the herbarium they had come from or leaving photographs of them in place in the collection. Most (but not all – see below) of the drawings etc. bear “HPV” numbers which would have been traceable through the acquisitions register, which would also have revealed how many drawings there were, as, where more than one taxon appeared on a sheet, each was given a number so that the HPV ticket bears e.g. “747-49”. Very regrettably this invaluable document is lost.

In view of that, one has to turn to the problematic Brown list of Bauer’s drawings (B. 97) in the Natural History Museum, London (Appendix 1), when it becomes clear that a number of drawings of taxa, at least from non-“destroyed” families (though possibly some of those too - see above), must still be in the collection. However, yet again, this is not straightforward, because the numbers Brown used for e.g. *Compositae/Asteraceae*, *Labiatae/Lamiaceae* [incl. “*Verbenaceae*” sensu auctt.], *Myoporaceae* [= *Scrophulariaceae*], *Campanulaceae* [incl. *Lobeliaceae*], *Stylidiaceae, Violaceae,* most *Malvaceae* and *Dilleniaceae* are on none of the surviving drawings of plants in those families found in the Archiv, so that it will be very difficult, using surviving resources, to track down such drawings unless every herbarium folder of those families containing material from the germane countries is examined.

On the other hand, scrutiny of Brown MSS (B.65 of Moore 2021) has thrown light on the precise localities of some of Bauer’s drawings where the originals were lost in the fire (Mabberley & Moore 1999 passim), but, for some others, it will never be possible to improve on the tentative attributions already published, unless citations of these are published in literature or manuscripts yet to be identified.

Conclusion

The new findings are set out in Appendix 2 and 3. Bearing in mind that many of the botanical field drawings were of plants in the “destroyed families” (but see caveats above), a very high proportion of the drawings which were the bases for Bauer’s published drawings, besides the Admiralty watercolours unpublished in his lifetime, have now been found.

What is needed next is a joint Austrian/Australian project to digitize all the Bauer field-drawings in W and identify them: they represent important cultural heritage of both Austria and Australia. Only with the successful execution of such an international co-operative effort, of the kind championed by Sandro and Erika Pignatti, can the full scientific importance of the Vienna drawings be appreciated.

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References

Bauer, F. L. 1976: The Australian flower paintings of Ferdinand Bauer. – in: Stearn,W. T. & Blunt, W. (eds). – London.

Britten, J. 1909: Ferdinand Bauer’s drawings of Australian plants. – J. Bot., London **47:** 140-147.

Clarkson, J. R. & Mabberley, D. J. 2005: Under the watchful eye of centinels: Robert Brown at the Pennefather River. – Roy. Geogr. Soc. Qld, Geogr. Monog. **10:** 109-131.

Grimm, W. A., Weston, P. H., Manea, A. & Leishman, M. R.: 2020: Life-cycle and natural history of the endangered terrestrial orchid *Genoplesium baueri* in eastern New South Wales. – Cunninghamia **20:** 265-271.

Lack, H. W. 1998: Recording form in early nineteenth[-]century botanical drawing. Ferdinand Bauer’s “cameras”. – Curtis’s Bot. Mag. **15:** 254-274.

— 2003: Ferdinand, Joseph und Franz Bauer: Testamente, Verlassenschaften und deren Schicksale. – Ann. Naturhist. Mus. Wien **104B:** 479-551.
— 2015: The Bauers: masters of botanical illustration. – London.
— with Mabberley, D. J. 1999: The *Flora Graeca* story: Sibthorp, Bauer and Hawkins in the Levant. – Oxford.
Mabberley, D. J. 1985: Jupiter botanicus. Robert Brown of the British Museum. – London.
— 1999: Ferdinand Bauer: the nature of discovery. – London.
— 2002: Ferdinand Bauer. – Pp. 50-68 in Thomas, S. (ed.) The Encounter, 1802: art of the Flinders and Baudin voyages. – Adelaide.
— 2017: Painting by numbers: the life and work of Ferdinand Bauer. – Sydney.
— 2018: An inconvenient truth? Notes on Australian plants in Persoon's *Synopsis Plantarum* (1806-7). – Austral. Syst. Bot. Newsl. **174:** 7-10.
— 2019: Botanical Revelation: European encounters with Australian plants before Darwin. The Peter Crossing Collection. – Sydney.
— & Moore, D. T. 1999: Catalogue of the holdings in The Natural History Museum (London) of the Australian botanical drawings of Ferdinand Bauer (1760-1826) and cognate materials relating to the *Investigator* voyage of 1801-1805. – Bull. Natur. Hist Mus., Bot. Ser. **29:** 81-226.
— & — 2021 (in proof): The Robert Brown Handbook: a guide to the life and work of Robert Brown (1773-1858), Scottish botanist [Regnum Vegetabile **160**]. – Glashütten.
— & San Pío Aladrén, M. P. 2012: La carta de colores de Haenke de la Expedición Malaspina: un enigma - Haenke's Malaspina colour-chart: an enigma. – Madrid.
—, Pignatti-Wikus, E. & Riedl-Dorn, C.: 2007: An extinct tree "revived". – Curtis's Bot. Mag. **24:** 190-196.
Mander-Jones, P. 1965: The artists who sailed with Bauer and Flinders. – Proc. Roy. Soc. Australasia, South Aus. Br. **66:** 17-31.
†Moore., D. T. 2021 (in proof). Robert Brown's botanical manuscripts at the Natural History Museum London. – In: Mabberley, D. J. & †Moore, D. T.: The Robert Brown Handbook: a guide to the life and work of Robert Brown (1773-1858), Scottish botanist [Regnum Vegetabile **160**]. – Glashütten.
Norst, M. J. 1989: Ferdinand Bauer; the Australian natural history paintings. – London.
Pignatti, E., Pignatti, S. &. Ladd, P. G. 2002: Comparison of ecosystems in the Mediterranean Basin and Western Australia. – Pl. Ecol. **163:** 177-186.
Pignatti-Wikus, E., Riedl-Dorn, C. & Mabberley, D. J. 2000a: Ferdinand Bauer's field drawings of endemic Western Australian plants made at King George Sound and Lucky Bay, December 1801 - January 1802. I. – Rend. Fis. Acc. Lincei ser. 9, **11:** 69 –108.
—, — & — 2000b: Ferdinand Bauer's field drawings of endemic Western Australian plants made at King George Sound and Lucky Bay, December 1801 – January 1802. II. – Rend. Fis. Acc. Lincei ser. 9, **11:** 201-244.
Riedl, H. 1981: Families destroyed in World War II at the Vienna Herbarium (W). – Taxon **30:** 727-728.
Riedl-Dorn, C. & Riedl, M. 2019: Ferdinand Bauer or Johann and Joseph Knapp? A rectification. – Gard. Bull., Singapore **71** suppl. **2:** 123-142.
Stearn, W. T. 1960: Franz & Ferdinand Bauer, masters of botanical illustration. – Endeavour **19:** 27-35.
Thomas, S. (ed.) 2002: The Encounter, 1802: Art of the Flinders and Baudin voyages – Adelaide.
Vallance, T. G., Moore, D. T. & Groves, E. W. (eds) 2001: Nature's Investigator the diary of Robert Brown in Australia, 1801-1805 – Canberra.
Watt, A. 2004: Notes on the Robert Brown letter to Dawson Turner. – Int. Dendrol. Soc. Austral. Br. Newsl. **2(12):** 5-7.
Watts, P., Pomfrett, J. A. & Mabberley, D. J. 1997: An exquisite eye: the Australian flora and fauna drawings 1801-1820 of Ferdinand Bauer. – Glebe.

Wheeler, A. & Moore, D. T. 1994: The animal drawings of Ferdinand Bauer in the Natural History Museum, London. – Arch. Nat. Hist. **21:** 309-344.

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[1] HPV
= Herbarium Palatinum Vindobonense is the prefix used on most of Bauer's Vienna drawings.

APPENDIX 1

Robert Brown MS B. 97 (Natural History Museum London) and its ramifications

This manuscript, entitled "List of sketches of Plants and Animals made during the Voyage of his Majesties [sic] Ship Investigator and subsequently at Port Jackson & Norfolk Island by Ferdinand Bauer" (Moore 2021) appears at face value to be very straightforward - but it is full of pitfalls.

The contents are a numbered list of animal and plant drawings, the latter arranged according to Linnaeus's Sexual System, but it is not clear when the list was compiled, the title-page being watermarked "SHARP 1804", so it is likely after *Investigator* reached England in 1805 and was probably an aide-memoire for Brown's work. Importantly, it also includes information about drawings made in South Africa and Timor (Indonesia), as well as at sea (animals). A number of authors have used it to calculate the number of drawings Bauer made during his time on the expedition but, as will be explained below, this is by no means straightforward - and such numbers are likely to be gross underestimates.

For ease of use, the Australian plant drawings were arranged according to the Linnaean system, beginning with Monandria and ending with Polygamia, followed by "Palmae" and then "Cryptogamia" [of which there are merely 10, comprising just two fern entries ("Marsilea", "Ophioglossum", with a later interpolated unnumbered "Azolla") and eight fungal ones, so almost no pteridophytes and no algae, lichens, or bryophytes were drawn. The sequence ends with nos 1530-1541 "Incert: sed florib: incognit:". There follow the plants from Norfolk Island similarly arranged with palms before cryptogams at the end, the total being 80. Next are Timor plants (60) and those from "Cape of Good Hope" (79).

The animals follow, firstly from Norfolk Island (40 entries) beginning with Birds, then Fish and finally "Insects", which term includes all invertebrates, and then "New Holland" (263 entries beginning with mammals and ending with "Insects"). None of the animal drawings from South Africa or Timor is included.

On the face of it, Bauer would therefore have appeared to have made 2163 drawings (as well as the unlisted Indonesian and African animals). However, examination of the holdings in the Archiv of the Naturhistorisches Museum, Vienna shows that very often there are separate drawings of different plants but of the same species being given the same number. i.e., as far as Brown was concerned, this list represents a **species** not **drawing** list.

Moreover, very many of the surviving field drawings do not bear “Brown” numbers, which were added to his drawings by Bauer himself, suggesting that he may have overlooked or withheld certain drawings, but see below, where species in certain families of plants were given numbers but these are not found on the drawings. When analysis of the Vienna findings is complete it may be possible to estimate the overall numbers of drawings Bauer made. However, it is not a simple matter of adding up the numbers of pieces of paper (and extrapolating - see below), because Bauer often sketched more than one plant on a single folio. This was particularly true in southern Australia, less so in the north where single subjects indeed often cover very large sheets.

As the entries in B. 97 bear tentative identifications by Brown (a few of which Bauer added to drawings) and later pencil amendments and additions, such that those near the beginning for example often have species-level names, Brown must have examined the drawings as the list was made and later updated it as he worked through his *Investigator* material and compared it with the drawings that were always in Bauer’s possession. And it is important to emphasize “his” herbarium material, because only rarely does he seem to have had access to Bauer’s own substantial herbarium, though there are several entries in his *Prodromus* (1810) where he cites “D[ominus] Bauer”. Sometimes such material is in his own herbarium, though Bauer’s “top set” is in W, with duplicates of Norfolk Island materials now at K (Brown bought them at the sale of Franz Bauer’s effects in the 1840s and, in turn, but still unmounted, were sold on Brown’s death (1858). There are also Bauer specimens (e.g. Norfolk Island *Meliaceae*) in Budapest and likely elsewhere. Generally, it is his specimens that are associated with the drawings; only very occasionally does Bauer add “Mr Brown” as the source of material for his sketch (see above). In short, the two worked far more independently of one another than has been generally supposed. On top of this, of course, Bauer (with his servant) collected alone in Newcastle, New South Wales, and on Norfolk Island, Brown (with his) alone in Tasmania.

Again, amongst the surviving drawings are many drawn by Bauer after the voyage from material grown at Kew from expedition materials, largely seeds sent back by Peter Good, the horticulturist on the voyage (see above). Bauer’s sketches of these date from 1806 to 1811, at the end of which year he ceased being employed by the Admiralty (Brown ceasing at the end of 1810).

APPENDIX 2

Botanical drawings

This must be read in conjunction with Mabberley & Moore (1999), which numbering is followed here, with correct(ed) identification or nomenclature (if any) in bold and original attribution with the new information after “**W**:”. N.B. The non-HPV numbers cited on the W drawings refer to B.97 numbers – see Appendix 1.

1 ***Hibbertia dealbata***

W: (HPV 1255) pencil drawing with numbers “A” “N 78” “Gulf of Carpentar I p I y S Arnhem Bay & N Arnhem Bay [sign] Feb 16 1803 [Bauer and Brown were on Strath Is., Melville Bay, Northern Territory, that day (Vallance & al. 2001: 367-368)]”; (HPV 1255-a) inked tracing with numbers.

2 *Pachynema complanatum* = ***Hibbertia persquamata*** Toelken
W: (HPV 1254) pencil drawing with numbers “Gulf of Carpentaria [sign] Jan 26 1803 [Bauer and Brown were at Cape Shield north of Blue Mud Bay, Northern Territory, that day]” “A 19” “No 675” “Brachystema” - (HPV 1244. [sic]) inked tracing with numbers.

4 ***Cochlospermum gillivraei***
W: (HPV 1370-a) pencil drawing (quarto) without numbers “Gulf of Carpentaria” Prince of Wales Island [= Goods Is. (Pallilag), Torres Strait, Queensland] No 20 A No 890 (460).

5 *Citriobatus pauciflorus* = ***Pittosporum multiflorum*** (Benth.) Cayzer & al.
W: no drawing recognized.

6 *Pronaya fraseri* = ***Billardiera fraseri*** (Hook.) Cayzer & al.
W: no drawing recognised.

7 ***Tremandra stelligera***
W: (HPV 1854/55) pencil drawings [also of a legume] with numbers “Kig [sic] Georg S [King George Sound, Western Australia]” “No 734”; “No 627”.

13, 14 ***Brachychiton paradoxus***
W: (HPV 1364-a) partly inked pencil tracing “453” “Carpentaria” - associated with original for London watercolour, but re-arranged.

15 *Rulingia hermanniifolia* = ***Commersonia hermanniifolia*** J. Gay ex Kunth
W: (HPV 1374) pencil drawing with numbers “South Head [Sydney Harbour] Aug 27 1803 & Farm Coav [Cove, Sydney]” “A” “No 447”, but with branches added, likely from a herbarium specimen; (HPV 1373a) inked tracing with numbers.

16 *Keraudrenia hookeriana* = ***Seringia hookeriana*** (Walp.) F. Muell.
W: no drawing recognised.

17 *Tribulus brownii* = ***Tribulopis pentandra*** R. Br.
W: no drawing recognised.

21 ***Turraea pubescens***
W: (HPV 1943-a) partly inked tracing “ Kappel [Keppel] Bay [Queensland] East coast”.

22 ***Toona ciliata***
W: (HPV 1394) pencil drawing with numbers “No 445” “A” “Paterson [i.e. Hunter] River April 11 1804” (Fig. 5).

Fig. 5. *Toona ciliata* M. Roem. (red cedar, *Meliaceae*). (Archiv, Naturhistorisches Museum Wien). Previously unpublished.

24 ***Stackhousia nuda***

W: (HPV 1452) pencil drawing with numbers “No 520” “Sydney Jan 9 1804”; “[verso] “A” “No 520” “No 66”; (HPV 1452-a) proof plate (imprint 22.5 x 17.5 cm); (HPV 1453) pencil drawing with numbers “[verso]”No 73” “A” “North shor[e] Port Jackson Jun 1803” “common at Sydney Jan 7 1804”; (HPV 1453-a) inked tracing with numbers; (HPV 1453 -b) partly inked pencil tracing without numbers.

25 ***Tripterococcus brunonis***

W: (HPV 1456) “K Georg[e] III Sound [Western Australia]” “A” N 67” “No 524”.

28 *Distichostemon hispidulus* = ***Dodonaea hispidula*** Endl.

W: no drawing recognised.

31 ***Templetonia hookeri***

W: (HPV 1746), pencil drawing with numbers “Gulf of Carpentaria Isl h [North Is., Edward Pellow Group, Northern Territory]” “A” “N 41” “No 1039”.

32 ***Hovea longifolia***

W: (HPV 1802), pencil drawing with numbers “Bay II East Coast [Port Clinton, Queensland]” “A N. 0[dot]” “No 1045”. First published, with finished watercolour in Mabberley (2017: 116-17).

34 ***Crotalaria medicaginea***
W: (HPV 1803) pencil drawing with numbers “Facing I[sland; 07-08 August 1802] Bay I Kappel [Keppel] Bay [Queensland] East Coast” “A” “N. 37”) “No 1048”.

35 ***Aeschynomene falcata***
W: (HPV 1801) pencil drawing with numbers “Broad Sound & Northumberland Isl [Queensland]” “A” “N 1106” “N 72” - at least part of watercolour image likely augmented with details from herbarium material.

37 ***Senna artemisioides***
W: (HPV 1881), pencil drawing with numbers “N° XII South coast [Spencer Gulf, South Australia] 1802” “N 64” “A” No 749”.

45 *Drosera binata* = ***Drosera pedata*** Pers.
W: no drawing recognised. See Mabberley (2018) for nomenclature.

52 *Agonis marginata* = ***Taxandria marginata*** (Labill.) J. Wheeler & N. Marchant
W: no drawing recognised.

54 *Calothamnus gracilis* = ***Melaleuca gracilis*** (R. Br.) Craven & R.D. Edwards
W: no drawing recognised.

55 ***Eucalyptus conferruminata*** D.J. Carr & S.G.M. Carr (*“E. lehmannii*”)
W: no drawing recognised.

59 *Myrtella obtusa* = ? ***Lithomyrtus obtusa*** (Endl.) N. Snow & Guymer
W: (HPV 1650) pencil drawing with numbers “N Co[a]st Isl y 2 [Pobassoo Is., English Company Is., Northern Territory] Feb 22 1803” “No 823” – basis of Endl., Atakta: t. 18 (1834), but this is *L. retusa* (Endl.) N. Snow & Guymer; pencil tracing (1650a).

60 ***Adenia heterophylla***
W: (flowers; HPV 1318) pencil sketch with numbers “Gulf of Carpentaria Jan 16 1803 [Bauer was on Winchelsea Is., Northern Territory that day (Vallance & al. 2001: 342)]”- (fruits on verso; HPV 1319) pencil sketch with numbers “Gulf of Carpentaria “- also bases for Endl., Ic. Gen. Plant.: tt. 114, 115 (1841); (HPV 1319-a) - proof plate.

67 ***Mackinlaya macrosciadea***
Likely Mount Westall Passage, Queensland, 26 August 1802 (Mabberley 2017: 122-123 – field drawing at W).

68 ***Sambucus gaudichaudiana***
W: field drawing seen 2014.

69 ***Gardenia megasperma***

W: (HPV 843) pencil drawing (fruit) with numbers; verso (flowers) “No 461” “Gulf of Carpentaria Island H [North Is., Edward Pellew Group, Northern Territory]”.

70 ***Scyphiphora hydrophylacea***

W: (HPV 863, fruit [& attached seed drawing] on verso) pencil drawing with numbers “No 183” “Gulf of Carpent N Arnhem Bay [female sign] Feb 16 1803 [Bauer was on Strath Is., Melville Bay, Northern Territory that day]”; HPV 863a) - inked pencil tracing with numbers.

72 *Canthium attenuatum* = ***Psydrax attenuatus*** (Benth.) S. Reynolds & R. Henderson

W: no drawing recognised.

75 ***Calotis dentex***

W: (HPV 725) pencil drawing with numbers “Poart [Port] Jackson Parramatta [New South Wales] 1802”; (HPV 725/a) inked tracing with numbers.

77 ***Pterocaulon serrulatum***

W: (HPV 727) pencil drawing with numbers “Facing Isl [Queensland] East Coast” “No 46” “A Q No 5” though watercolour has added branches from Bauer’s herbarium material; (HPV 727/a) inked tracing with numbers. First published in Mabberley (2017: 108-111).

78 ***Ammobium alatum***

W: (HPV 652) “No 63” “New Castle [Newcastle, New South Wales] March 30 1804”.

80 *Helichrysum scorpioides* = ***Coronidium scorpioides*** (Labill.) Paul G. Wilson

W: no drawing recognised.

82 ***Stylidium nymphaeum*** Wege (*“S. scandens”*)

Bald Head, King George Sound, Western Australia (see Mabberley 2017: 86-89).

83 ***Stylidium fasciculatum***

W: (HPV 836) pencil drawing with numbers “No 8” “P [Bald] Head K G III Sound [King George Sound, Western Australia]”.

88 ***Scaevola spinescens***

W: (HPV 762-764) - pencil drawings “Bay No III [Fowlers Bay] South coast “No 264” “A”; “No III” “No 255”; “[verso] No 254” “No V [Spencer Gulf] South coast”. See Vallance & al. (2001: 159).

89 *Diaspasis filifolia* = ***Scaevola filifolia*** (R. Br.) K. Sheph.

W: no drawing recognised.

91 ***Brunonia australis***

W: “Shoal Bay Island A [Port Clinton, Queensland]”. Bauer reworked his field drawing for his Illustrationes: t. 10 (1813-14). See Mabberley & Moore (1999: 132, 207); Mabberley (2017: 118-19).

92 ***Lysinema ciliatum***

W: (HPV 1170/71) pencil drawings with numbers “Bay I [Lucky Bay, Western Australia] South coast” “No 378” “a” (but watercolour elaborated, likely from herbarium material); “No 407” “b”.

93 ***Cosmelia rubra***

W: (HPV 1173) pencil drawing (very small) with numbers “K G S [King George Sound, Western Australia] No 409” “b”. See Mabberley 2017: 90-91).

95 ***Andersonia sprengelioides***

W: (HPV 1132) pencil drawing with numbers “K.G.III Sound Kew May 31^{t} 1806” “A No I”. Drawn from material grown at Kew Gardens from seeds collected at King George Sound, Western Australia (Mabberley 2017: 176-177).

96 ***Andersonia caerulea***

W: (HPV 1154-a) inked tracing with numbers “K G III Sond [King George Sound, Western Australia] No 408. (1496.) “b”; (HPV 1145/1146) pencil drawings with numbers “K George III Sond” “B” “No 408” “a”; “b” “No 401”; (HPV 1145-a) inked tracing with numbers of “a”.

97 ***Dracophyllum secundum***

W: (HPV 1174) pencil drawing with numbers “Port J [...] Paramata [Parramatta, New South Wales] 1802” “No 423”.

100 ***Parsonsia straminea***

W: (HPV 889) pencil drawing with numbers “Paterson river [Hunter River] April 11” “1804” “No 479” “A”.

101 ***Wrightia pubescens***

W: (HPV 890) pencil sketch with numbers “in the Gulf of Carpentaria” “No 465” + fr on verso.

102 ***Gymnanthera oblonga***

W: (HPV 882): pencil sketch with numbers “No 467” “Gulf of Carpentaria Isl IIII [? one of the South Wellesley Islands, Queensland]...”

104 *Sarcostemma viminale* = ***Cynanchum viminale*** (L.) Bassi subsp. ***australe*** (R. Br.) Meve & Liede

W: no drawing recognised.

105 *Brachystelma glabriflorum* = ***Ceropegia glabriflora*** (F. Muell.) Bruyns
W: no drawing recognised.

106 *Logania pusilla* = ***Orianthera pusilla*** (R. Br.) C.S.P. Foster & Conn
W: no drawing recognised.

107 ? ***Solanum hystrix***
W: (HPV 1047) pencil drawing with numbers "No 344" "A" "No V [Spencer Gulf, South Australia] South coast"; "Facing Isl Keppel Bay Shoal Bay [Queensland]".

(HPV 1047-a) inked tracing with numbers; (HPV no no.) partly inked pencil tracing without numbers ".. 344... 1656". These localities do not match the distribution of *S. hystrix*.

109 ***Anthocercis viscosa***
W: [*Anthocercis viscosa*/*Eremophila glabra*] (HPV 973/974) pencil drawings with numbers "K G" "K George III sound [King George Sound, Western Australia]" "No 21" "a" "No 947"; "No III" "No III South coast [Fowlers Bay, South Australia]" "942" No 22" "A" "b" (see Lack 1998: 257-261)

113 ***Eremophila glabra***
W: [*Anthocercis viscosa*/*Eremophila glabra*] (HPV 973/974) pencil drawings with numbers "K G" "K George III sound [King George Sound, Western Australia]" "No 21" "a" "No 947"; "No III" "No III South coast [Fowlers Bay, South Australia]" "942" No 22" "A" "b"; [*Eremophila glabra*] (HPV 973-a) inked tracing for Endl., Ic. Gen. Pl. t. 92 (1839).

115 ***Pityrodia salviifolia***
W: (HPV no no.) inked tracing with numbers "Bay East Coast [Queensland]No 25 (1589)"

117 *Hemigenia purpurea* = ***Westringia*** sp.
W: no drawing recognised.

121 ***Enchylaena tomentosa*** [? = *Maireana* sp.)
BM: According to Brown's descriptive slip B. 65. 50/71 "Ic Bauer Enchylaena {ab Inlet XII [Spencer Gulf, South Australia]}". N.B. *Chenopodiacea/Amaranthaceae*, a "destroyed family" (Riedl 1981).

123 ***Gyrostemon sheathii*** Fitzg. (*"G. ramulosus"*)
See Mabberley & Moore (1999: 84).

146 ***Decaisnina brittenii*** (Blakely) Barlow (*"Amyema pendulum*")
Likely Point Blane, Blue Mud Bay, Northern Territory, 28 January 1803. See Thomas (2002: 94-95), Clarkson & Mabberley (2005: 130). N.B. *Loranthaceae*, a "destroyed family" (Riedl 1981).

156 ***Allocasuarina torulosa***

W: (HPV 455) "Sydney to Parramatta July 20 1804". See Mabberley (2017: 134-135). N.B. *Casuarinaceae*, a "destroyed family" (Riedl 1981).

161 ***Ottelia ovalifolia***

W: (HPV 333) - pencil drawing with numbers [enlargements of seq.]" No 900"; (HPV 334) - pencil drawing with numbers "A" "No 898" "(760)" "from Tungaby [Toongabbie] to Hawkesbury [River, New South Wales] Nov 21" "1803", [verso] "No VIII [?Spencer Gulf, South Australia]". See Mabberley (2017: 143). N.B. *Hydrocharitaceae*, a "destroyed family" (Riedl 1981).

162 *Dendrobium discolor* = ***D. brownii*** F. Dietr.

W: (HPV 367) – pencil drawing with numbers but without locality (Mabberley 2017: 114-115; 2019: 192-93). See Mabberley & Moore (2021) for nomenclature.

165 ***Spiranthes sinensis*** subsp. ***australis***

W: (HPV 424) pencil sketch with numbers "1273" "(813)" "Farm Cove Sydney Feb 21 1804".

166 ***Thelymitra ixioides***

W: (HPV 411) pencil sketch (incl. verso) with numbers, "Sydney Aug 11 1803" "No 1296" "(800)"; pencil tracings with numbers, re-arranged (HPV 411.a, 411.c)

167 ***Thelymitra canaliculata***

W: (HPV 433) pencil sketch with numbers "No 1300 King G III Sound [King George Sound, Western Australia]" "(1441)".

169 ***Thelymitra tigrina***

W: (HPV 434) pencil sketch with numbers "(1442)" "No 1301" "K George III Sound [King George Sound, Western Australia]".

170 ***Thelymitra carnosa***

W: (HPV 428) pencil sketch with numbers "Sydney Farm Cove" "No 1299" "(817)" "Georges River Sep 29 1803"; (HPV 428a) inked tracing with numbers "Sydney Fawn Count N 1299 (817)".

171 ***Thelymitra fuscolutea***

W: (HPV 435) pencil drawing with numbers "K G III Sound [King George Sound, Western Australia]" "No 1302" (1443)".

172: ***Thelymitra venosa***

W: (HPV 412) pencil sketch with numbers "No 1298" (801)" "Sydney Nov 12 1803".

173 ***Epiblema grandiflorum***

W: (HPV 437) pencil sketch with numbers “K G III Sound [King George Sound, Western Australia]” “(1445)” “No 1303”.

176: ***Diuris aurea***

W: (HPV 413) pencil sketch with numbers”No X” “Sydney Sep 25 1803” “(802)”.

177: ***Diuris maculata***

W: (HPV 371 - folded sheet) pencil drawing with numbers “Port Jackson Sydney 1802” (a second, epiphytic, species on verso)

178: ***Diuris pedunculata***

W: (HPV 419) pencil sketch with numbers “No IX” “Sep 8th 1803 from Paramata [Paramatta] to Hawksb [Hawkesbury River, New South Wales]” “(803)” plus image on verso.

180 ***Diuris emarginata*** var. ***pauciflora***

W: (HPV 436) pencil drawing with numbers “No VI.” “K. G III Soud [sic; King George Sound, Western Australia]”.

182: ***Cryptostylis ovata***

W: (HPV 380) pencil sketch with numbers “No X[?] K G III S [King George Sound, Western Australia]” “(758.b.)”.

183 ***Cryptostylis erecta***

W: (HPV 416) pencil sketch with numbers “No 1330” “Sydney April 30 1805”.

184 ***Prasophyllum striatum***

W: (HPV 417) pencil sketch with numbers “No 1275” “Sydney Molamola [?Woolloomooloo] May 21 1804”.

189 ***Pterostylis nutans***

W: (HPV 394) pencil sketch with numbers “No 1313” “Sydney White Farm [White’s farm, Petersham, Sydney – see Vallance & al. 2001: 520] July 6th 1804” [great detail on verso].

190 ***Pterostylis gibbosa***

W: (HPV 390) pencil sketch with numbers “No 1320” “Cow Pastras [Cowpastures, southwest Sydney] Oct 9th 1803” [verso] “No 1321” Prospect [Hill] Oct 8 1803”.

191 ***Caleana major***

W: (HPV 386) pencil sketch with numbers “No 329” “Caleana major” “Sydney Sept 22[?]” “Sydney Oct 17” “1802”.

193 ***Acianthus fornicatus***
W: (HPV 440) pencil sketch with numbers “Port Jackson Sydney 1802” “No 1327” “(1448)”.

194 ***Acianthus exsertus***
W: (HPV 409) pencil drawing with numbers “N 1324” “(798)” “North Rock[s] Paramatta [New South Wales] May 12 1804”.

197 ***Cyrtostylis reniformis***
W: (HPV 439) pencil sketch with numbers “(1447)” “No 1328” “Port Jackson 1802”.

198 ***Lyperanthus suaveolens***
W: (HPV 369) pencil drawing with numbers “Sydney Aug 27 1803”**,** image verso “No XI [sic]”; inked tracings with numbers (HPV 369a, 369b)

199 ***Caladenia testacea***
W: (HPV 403) pencil sketch with numbers “Sydney Sep 2 1803”, “No 1289A” “(792)”.

202 ***Chiloglottis reflexa*** sensu lato
W: (HPV 388) pencil sketch with numbers including magnified seed “Duk Bruge [Duck Bridge] R. Parramatta [New South Wales] July 20 1804” [orig. for 202A and therefore part of 202B (middle plant new)]

203 ***Calochilus campestris***
W: (HPV 441 mounted on herbarium sheet, pencil sketch with numbers “Shaol Water Bay [male sign; Shoalwater Bay, Queensland]” “(1449)” “No 1285”.

207 ***Habenaria ochroleuca***
W: (HPV 427) pencil sketch with numbers “No 1271” “North Cost [sic] I y2 [female sign; Pobassoo Is., English Company Is., Northern Territory] Feb 18 1803”.

221 ***Calectasia cyanea***
W: (HPV 279) pencil drawing with numbers “King Georg III Sound [King George Sound, western Australia]” “A” “No 589”; also the basis for engraving in M. Flinders Voyage Terra Australia, atlas t. 10 (1814). N.B. *Dasypogonaceae*, a “destroyed family” (cf. Riedl 1981).

229 ***Azolla pinnata***
W: (HPV 231) pencil drawing with numbers, also the basis for Sansom’s engraving in Flinders, Voy. Terra Australis Atlas t. 10 (upper) (See Mabberley 2017: 140-141).

230 ***Aseroe rubra***
W: (HPV 225) pencil drawing with numbers “Parramatta [New South Wales]” “May 12th1804”.

233 *Comarophyllus lilacinus* = ***Cantharellus lilacinus*** Cleland & Cheel
W: Field drawing seen 2014.

234 (upper) ? ***Entoloma* sp.**
W: (HPV 224a) – watercolour (?by Zehner brothers) arranged differently from the London watercolour but based on same Bauer field drawing.

234 (lower) ? ***Entoloma* sp.**
W: (HPV 222a) – watercolour (?by Zehner brothers) arranged differently from the London watercolour but based on same Bauer field drawing.

235 (upper) ? ***Hygrocybe* sp.**
W: (HPV 223a) – watercolour (?by Zehner brothers) arranged differently from the London watercolour but based on same Bauer field drawing.

236 *Clavulinopsis miniata* = ***Clavaria miniata*** Berk.; ***Geoglossum* sp.**
W: field drawing seen 2014; (HPV 223a) – watercolour (?by Zehner brothers) arranged differently from the London watercolour but based on same Bauer field drawing.

APPENDIX 3

Zoological drawings

This must be read in conjunction with Wheeler & Moore (1994), which numbering and nomenclature are followed here, with corrected identification (if any) in bold and original attribution with the new information after "**W**:". N.B. The numbers cited on the W drawings refer to B.97 numbers – see Appendix 1.

1(1), 2(1A) ***Hydromys chrysogaster***
W: "Port Jackson 1802". See Mabberley (2017: 105).

3(2), 4(2A) ***Perameles bougainville***
W: "South coast 1802" "no III [Fowlers Bay, South Australia]". See Thomas (2002: 72-73); Mabberley (2017: 94-95).

5(3), 6(4), 7(5), 8(6), 9(7) ***Phascolarctos cinereus***
W: "from the south of Port Jackson Aug 15 1803". See Mabberley (2017: 138-139).

10(8), 11(9) ***Vombatus ursinus***
W: "Kings Island [King Island, Tasmania] 1802".

16(14) ***Psephotus dissimilis***
W: “No 46” “Gulf of Carpent [Caledon Bay, Mount Caledon]…. Feb. 6 1803”.

21(19) ***Platycercus venustus venustus***
Northern Territory, 6 Feb. 1803 (Mabberley & Moore 2021). Robert Brown MS descriptive slip (**BM**) Z1 f. 323 has “Psittacus venustus Brownii Temminck in Linn. Soc. Trans. … Arnheim [sic] Bay Feb^{y} 6th 1803 [likely Mount Caledon, Caledon Bay, Arnhem Land, Northern Territory] desc d^{o} d^{o}”, “Fig. Pict. Ferd. Bauer. N^{o} 19”. This is likely also the “Psittacus splendidus” of Robert Brown’s diary (Vallance & al. 2001: 366).

22(20), 23(21) *P. zonarius zonarius* = ***Barnardius zonarius zonarius*** (Shaw)
W: “No 39” “N IX South coast [Memory Cove, South Australia]”. See Mabberley 2017: 100-101).

26(24) *Trichoglossus haematodus moluccanus* = ***T. moluccanus moluccanus*** (Gmelin)
W: “No 44” “I Broad Sound [Queensland] 1802”.

27(25) ***Philemon corniculatus***
W: “No 68” “Shoal Water Bay [Queensland] 18[02]”.

28(26) ***Litoria raniformis*** (Keferstein) (*“L. aurea”*)
King Island, Tasmania. See Thomas (2002: 74).

29(27) ***Egernia cunninghami***
W: “Egernia kingii” - pencil sketch with numbers + “C”, “D”, “E”, “G”; Bauer MS: “No 187” “South Coast”.

30(28), 31 (28A) *Brachaluteres baueri* = ***B. jacksonianus*** **(**Quoy & Gaimard)
W: “South Coast [perhaps Petrel Bay, St Francis Is., Nuyts Archipelago, South Australia]” (Mabberley 2017: 92-93).

32(29), 33(29A) ***Anoplocapros inermis***
W: “No 235” “South coast”.

34(30), 35(30A) *Bigener brownii* = ***Acanthaluteres brownii*** (Richardson)
W: mounted pencil drawing numbers incl. Roman numbers + X, “with gold”, “No 226”, “South Coast”; the finished watercolour the sole basis (and therefore holotype) for Richardson’s description.

36(31), 37 (31A) ***Periophthalmus* sp.**
W: “No 239”, “Gulf of Carpentaria”.

38(32), 39(32A) ***Favonigobius*? sp.**

W: "No 240" "Gulf of Carpentaria Isl I [Maria Is., Sir Edward Pellew Group, Northern Territory; see Vallance & al. (2001: 335)]".

40(33) ***Pterois* sp.**

W: "Shall W [= Shoalwater] Bay [Queensland]" "No 224". See Mabberley (2017: 120-121).

41(34), 42(34A) ***Enoplosus armatus***

W: "No IIII [= Petrel Bay, St Francis Is., Nuyts Archipelago, South Australia] South coast" "No 243".

43(35), 44(35A) *Odax acroptilus* = ***Heteroscarus acroptilus*** (Richardson)

W: "No 230; "South coast". The watercolour was the sole basis (and therefore holotype) for Richardson's description.

45(36) ***Siphonognathus radiatus***

W: "No IIII South Coast" "N IIII [= Petrel Bay, St Francis Is., Nuyts Archipelago, South Australia]" "No 244".

46(37), 47(37A) ***Exocoetus* sp.**

W: "[female (Venus) sign] May 6 1803 Lat 20˚ [?30˚; at sea off Western Australia] No 234".

48(38) ***Phyllopteryx taeniolatus***

W: "South coast" "N 215"; fins re-arranged for finished watercolour. See Mabberley (2017: 92-93).

49(39), 50(40), 51(40A) *Portunus pelagicus* = ***P. armatus*** (L.)

W: field drawing with numbers "[anchorage] XIII [Kangaroo Is., South Australia]" (see Lack 1998: 268; Thomas 2002: 22-23).

52(41) *Gasteracantha minax* = ***Austracantha minax*** (Thorell)

W: "No 259" & "No 260" -"Norfolk Island Jan 10 1805"; "Norfolk Isl Jan 14 1805". See Mabberley (2017: 162-163).

APPENDIX 4

Watercolours of Australian plants and animals attributed to Ferdinand Bauer and held in the Linnean Society of London

Also in London are other drawing attributed to Bauer. The Linnean Society of London has a handful of other Australian plant watercolours (and also one of arthropods) attributed to him. How they came to the Society is unclear, but it is conceivable they ultimately originate from the sale of Aylmer Bourke

Lambert’s library in 1842 or possibly from Bauer’s early, and somewhat eccentric, biographer, Jan Lhotzky. One, likely coloured by Bauer himself, is of *Lambertia formosa* Sm. (*Proteaceae*), the mountain devil of eastern Australia, named after Lambert by J. E. Smith; Bauer’s drawing was redrawn from a sketch made in New South Wales, “corrected from wild Specimens” in Smith’s herbarium (LINN-SM), both likely sent from Sydney by Surgeon John White in the late 1780s (Mabberley 2017: 62, 2019: 238). Based on this, an engraving by Joseph Banks’s engraver, Daniel Mackenzie, was published in the *Transactions of the Linnean Society* in 1798. Part of the original illustration was later engraved by J. Watts and published in the *Botanical Register* in 1821, when the watercolour was still in Lambert’s hands.

Enigmatic drawings attributed to Bauer

Much less known is a smaller watercolour (MS 622 f. 5, 332 x 236 mm; no watermark; Fig. 6) of an emu-bush from Australia, *Eremophila longifolia* (R. Br.) F. Muell. (*Scrophulariaceae*). Marked by the late Gavin Bridson as the work of “F Bauer” and catalogued as the work of Ferdinand Bauer, the subject of this unpublished drawing was identified by Bob Chinnock of Adelaide Botanic Garden only in 2017.

Bauer made a colour-coded, pencil field sketch of this species whilst working with Robert Brown on what is now Mount Brown in the Flinders Ranges, South Australia, in March 1802. If that was the basis for the watercolour, its small size, perhaps reflecting the dearth of paper during his time in Australia, suggests that Bauer would have completed the watercolour there before returning to Britain with Brown in 1805 (Mabberley 2017: 152-53). If this were to be so, he would likely have made the watercolour, then therefore the first made of any South Australian plant by a European, in a rented house on the site of today’s Royal Botanic Garden Sydney, using a locally made travelling desk (now preserved in the Economic Botany Collection at the Royal Botanic Gardens, Kew), one of the oldest surviving pieces of Australian colonial furniture (Mabberley 2017: 152).

However, the drawing is “No. 5”, one of a series (MS 622) of plants, 1-2, 4-5 with the sixth being the arthropods, all of the same size. Some of these are less accomplished and some are notable for shadows (unusual in Bauer’s work, though found in his Dali-esque fungal drawings done for the Admiralty – see above) depicted underneath sprigs of leaves, “No 1”, of a species of *Myoporum* (also *Scrophulariaceae*) bearing in pencil in an unknown early hand “App. F. Bauer del.”. The quality of the work suggests that if it was by Bauer, it must have been in his old age. However, any attribution to Bauer at all has now been thrown seriously into doubt through the examination, in another context (Mabberley 2019: 268, 270-73), of the papers of the Australian Surveyor General, Sir Thomas Mitchell (1792-1855), papers preserved in the State Library of New South Wales in Sydney.

Among the drawings filed there as PXD 627 f. 12 (Fig. 7) is the same image of a “cucumber” (an undescribed species) as “No. 4” in the “Bauer” series (both with shadows drawn) in London (Fig. 8). One is a copy of the other, but which is the original, who made the copy and, more importantly, who was the original artist? The image is of a species of “*Cucumis”* (*Cucurbitaceae*) and the Sydney drawing has an inscription, “Cucumber – banks of the Gwydir & flat rich ground S of it bet^{w} it & the first chain of Ponds. (There is a variety with a yellow flower and dark green streaks on the cucumber like a melon -)”. Mitchell was on the Gwydir River (New South Wales) early in 1832 (after Bauer’s death), when he wrote in his *Three expeditions into the interior of Australia*, vol. 1: 88 (1838), “We found a new species of cucumber in the rich soil near the water, of about the size of a plum, the flower being of a purple colour…..the latitude of this camp was 29 ^{o} 28” 34” S”. Moreover, he here discussed spiders which match those in the arthropod drawing in London.

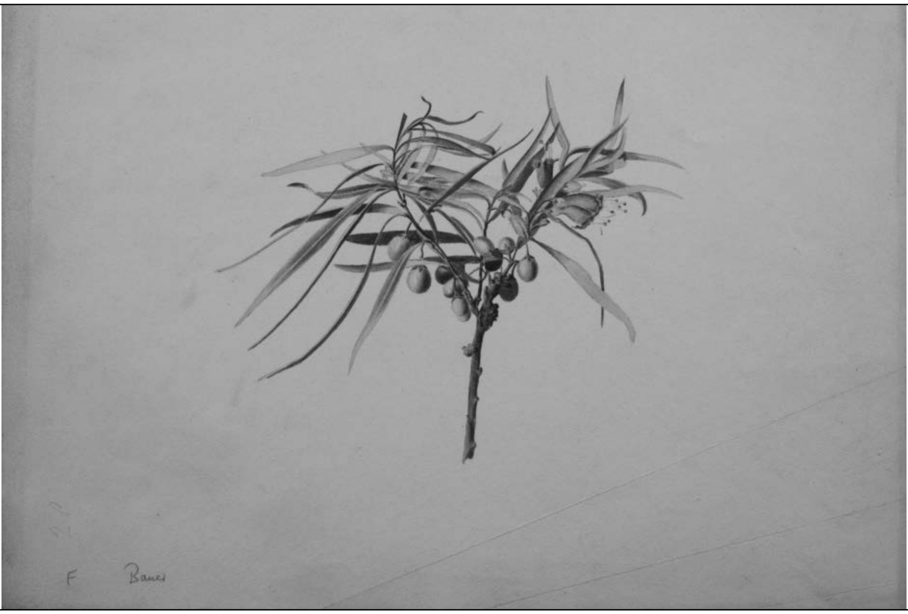

Fig. 6. *Eremophila longifolia* (R. Br.) F. Muell. (*Scrophulariaceae*). Watercolour by unknown artist. Linnean Society of London MS 622 f. 5.

In his preface (pp. iii-iv), Mitchell wrote “neither his pencil nor his pen has been allowed to pass the bounds of truth”, suggesting the artist was Mitchell himself; indeed, the book is illustrated with plates lithographed from his original drawings. However, Mitchell's original watercolours (see Mabberley 2019: 272-3) are nowhere near as accomplished as these, strongly suggesting the Linnean Society drawings are by another hand. John Lindley wrote up the plants for Mitchell's book and, at the same time, was collaborating with Franz Bauer, Ferdinand's brother (Lack 2015: 373-5). Perhaps, then, the “F Bauer” on the drawings is Franz Bauer, the Sydney version of the Cucumis being a copy annotated by Mitchell. This needs further work by one immersed in the oeuvre of Franz Bauer - but, certainly, Ferdinand Bauer seems to have had nothing to do with it.

This is not the first mis-attribution of drawings to Bauer, as a set of 60 watercolours in Naturhistorisches Museum Vienna so attributed since 1832 have recently been convincingly shown to be the work of Joseph Knapp (1810-67) with two possibly by Knapp’s father, Johann (1778-1833), court painters to the Archdukes Anton Viktor and Johann (Mabberley 2017: 216-18, 220-21: Riedl-Dorn & Riedl 2019; cf. Lack 2003). But there is still a niggling problem with two of these “Knapp” drawings in that they are on different paper from that used for the others and were painted in a different way (Mabberley 2017: 216; Riedl-Dorn & Riedl 2019). Perhaps they were merely the property of Bauer when he died. He seems to have been an intimate of the Knapps, and it was he who proposed that the elder Knapp be commemorated in “Knappia” for what is now *Rhynchoglossum* Blume (*Gesneriaceae*), Bauer’s Timor drawing of which was incorporated in Knapp’s famous monumental painting, *Huldingung an Jacquin* (*Jacquin’s Denkmal*) now hanging in the Belvedere Palace in Vienna. But Brown plumped for *Antonia* instead, commemorating one of the archdukes (Mabberley & Moore 1999: 210; Mabberley 2017: 199-201), though that was a later homonym of *Antonia* Pohl (*Loganiaceae*, South America).

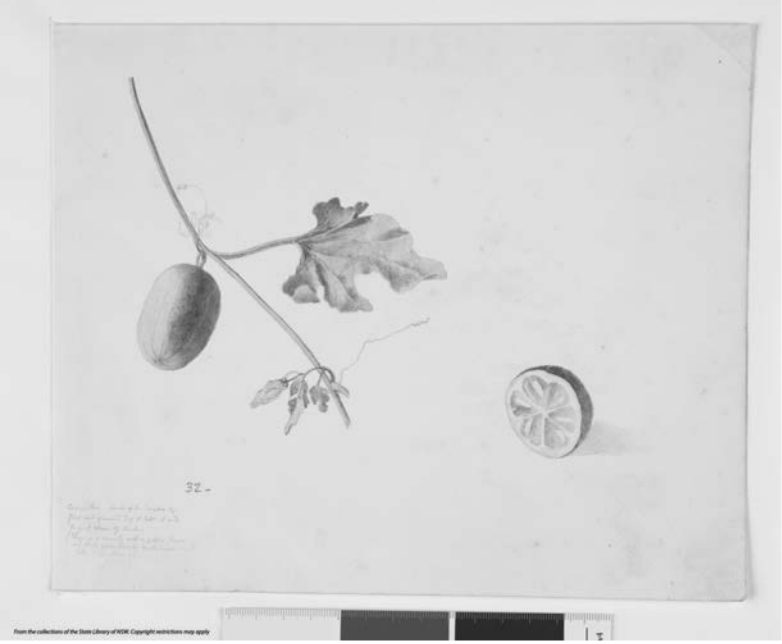

Fig. 7. *Cucumis* sp. (*Cucurbitaceae*) by unknown artist (State Library of New South Wales PXD 627 f. 12).

Fig 8. *Cucumis* sp. (*Cucurbitaceae*) by unknown artist (Linnean Society of London MS 622 f. 4).

Article

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Contribution to the Syntaxonomy of Rare Tall Sedge Community in Central Apennine (Umbria-Italy): I. *Caricetum buxbaumii*

Abstract

Venanzoni, R., Praleskouskaya, S. & Ciaschetti, G.: Contribution to the Syntaxonomy of Rare Tall Sedge Community in Central Apennine (Umbria-Italy): I. *Caricetum buxbaumii*. — Fl. Medit. 31 (Special Issue): 95-104. 2021. — ISSN: 1120-4052 printed, 2240-4538 online.

This contribution describes a new plant association of marshy meadows, named *Deschampsio cespitosae-Caricetum buxbaumii ass. nova hoc loco*, occurring in the karstic basins of Sibillini Mountains (Pian Grande, Pian Piccolo and Savelli-Castel S. Maria, Umbria Region) between 1000-1350 m above sea level. The new association is distinguished from *Ranunculo-Caricetum buxbaumii* Pedrotti 2016 and *Galio palustris-Caricetum buxbaumii* Ciaschetti & al. 2020 for its floristic and ecological features. After the comparison with the original tables of Issler's *Caricetum buxbaumii* and Ritter-Studnicka's *Valeriano-Caricetum buxbaumii*, all Apennine associations belong to *Caricion gracilis* alliance, and are southern synvicariants of the *Caricetum buxbaumii* Issler 1933 of Central Europe.

Key words: *Carex buxbaumii* communities, *Caricion gracilis*, Apennine Karstic plains, Central Italy.

Introduction

The vegetation of the *Magnocaricetalia elatae* Pignatti 1953 Order has been the subject in recent years of numerous studies aimed at finding common traits for classification at the European level (Mucina & al. 2016, Landucci & al. 2020) or to look for distinctive elements that characterize these plant communities distributed on a continental scale at the local level (Gigante & Venanzoni 2000; Pedrotti 2015, 2016b; Ciaschetti & al. 2020, Landucci & al. 2013; Lastrucci & al. 2012, 2014). Swamps, with large sedges, have now almost all disappeared or deeply transformed throughout the Italian plains and hilly territory due to reclamations and anthropic pressure. In this context, the karstic plains, which range along the Apennine ridge at an altitude of 900-1300 m from the Umbro-Marchigiano Apennines, up to the Abruzzo and Molise Regions (Pedrotti 1976), represent a very important subsystem of the Apennine ecoregional Province (Blasi & al. 2018) and an exceptional reservoir of biodiversity hosting almost all the species that characterize the vegetation of the *Magnocaricetetalia* (Ciaschetti & al. 2020).

Carex buxbaumii Wahlenb. is an amphiatlantic boreal species with a still unknown range of distribution (Segal & Westhoff 1959). It is a rare and threatened species in Europe (Sotek 2006; e.g. Grulich 2012; Bernátová & al. 2018). It is rare also in Italy (Pedrotti 1971) and included in the Read Lists of The Italian Flora as Endangered (Rossi & al. 2013); The EEC Habitat Directive 92/43 does not include any rare tall sedge communities. Only Poland and some other Nordic countries (Estonia, Latvia, etc.), where *Caricetum buxbaumi* is attributed to *Caricion davallianae*, can protect this association by including it in Habitat 7210* "Calcareous fens with *Cladium mariscus* and species of the *Caricion davallianae*" and in Habitat 7230 "Alkaline fens" (Wolejko & al. 2005; Bacieczko & Kaszycka 2015; Stanko & al. 2018) though it has been stated for this association a severe reduction (Wolejko & al. 2005). The aim of this paper is to present a comparison of the communities of *Caricetum buxbaumii* of the Apennines with those analyzed in the recent European literature (e.g. Landucci & al. 2020).

Materials and methods

We have considered 34 phytosociological relevés (according to Braun-Blanquet 1964) from Umbria and Abruzzo Regions (Fig. 1): 10 unpublished (made in the Sibillini Mountains) and 24 taken from the literature (Gigante & Venanzoni 2005; Pedrotti 2015 and Ciaschetti & al. 2020) were rearranged in order to compare the classification with recent European literature (e.g. Landucci & al. 2020). Floristic nomenclature follows Pignatti (2017-2019) and Bartolucci & al. (2018) for vascular plants; Aleffi & al. (2020) for mosses.

We have applied cluster analysis by complete linkage using similarity ratio as resemblance function by the Matedit software (Burba & al. 1992, downloadable at www.vegitaly.it). Relevés are stored in the free botanical database http://www.anachive.it (Landucci & al. 2012; Gigante & al. 2012; Lucarini & al. 2015).

Results

Deschampsio caespitosae-Caricetum buxbaumii ass. nova. hoc. loco (Table 1, holotypus: rel. 5 of Table 1)

Floristic analysis

The new association is characterized by a general depletion of species of the *Magnocaricetalia* Order (evidenced for all communities also in Landucci & al. 2013, 2020; Venanzoni & al. 2018; Ciaschetti & al. 2020) and the presence of transitional meadows species such as *Deschampsia caespitosa*, *Ranunculus repens* and *Potentilla reptans* (typical and diagnostic species are highlighted in Table 1). The comparison with the relevés of central Italy (Table 1) shows a clear separation between that of the proposed association and those described as *Ranunculo pedrotti-Caricetum buxbaumii* Pedrotti 2015 and *Galio palustris-Caricetum buxbaumii* Ciaschetti & al. 2020; the cluster analysis (Table 1) confirms a sharp classification that not made possible to include all relevés in one association.

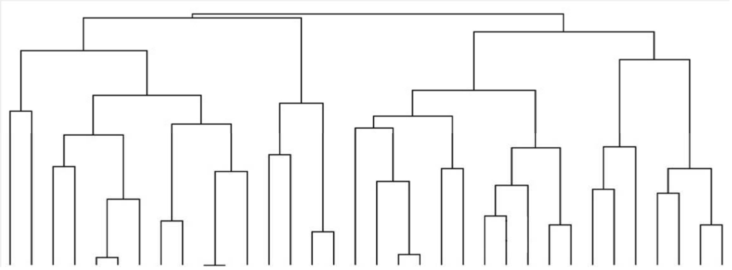
Fig. 1. Distribution of *Carex buxbaumii* in Italy (source www.anarchive.it) and study area.

Lastly, the relevés have been compared with the original tables of Issler's *Caricetum buxbaumii* and Ritter-Studnicka's *Valeriano-Caricetum buxbaumi* (results are shown in the Electronic Supplemetary File 1). Both *Caricetum buxbaumii* and *Valeriano-Caricetum buxbaumii* are characterized by species of *Molinietalia cerulae* and *Caricetalia davallianae* due to vegetational catenal contact with peaty vegetation that does not happen in Central Italy where we found only catenal contacts with transitional meadows of *Potentilletalia anserinae* and *Trifolio-Hordeetalia secalini*. Same conclusion may be assumed also by comparing Table 2 with Table 1 in Segal & Westhof (1959); in fact, these authors define the *Caricetum buxbaumii* as a transitional association between the *Molinietalia* and the *Schuchzerio-Caricetea fuscae*.

Synecology

Deschampsio-Caricetum buxbaumii develops in stations with high water excursion and summer water stress conditions that occur in the karst bassin of Savelli-Castel Santa Maria (where it forms extensive populations, Fig. 2) and in the Pian Piccolo of Castelluccio.

Table 1. Dendrogram & Classification of the 34 relevés: Legenda: PP (Pian Piccolo di Norcia - PG), PG (Pian Grande di Norcia - PG), AB (Abruzzo), SM (Savelli-Castel S. Maria - PG)
Source of data: Rel. 2-7, 9-12 (original data), rel. 1-8, 17, 28-30 (Gigante & Venanzoni 2005), rel. 17-27, 31-34 (Pedrotti 2015); rel. 13-16 (Ciaschetti & al. 2020).



N. of Relevé	1	**2**	**3**	**4**	**5***	**6**	**7**	8	**9**	**10**	**11**	**12**	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	Presences
Main locality	PP	PP	PP	PP	SM	SM	SM	PP	SM	SM	SM	SM	AB	AB	AB	AB	PP	PG	PG	PG	PG	PG	PG	PG	PG	PG	PG	PP	PP	PP	PG	PG	PG	PG	
Characteristic & differential species	*Deschampsio-Caricetum buxbaumii*												*Galio-Caricetum-buxbaumii* Ciaschetti & al. 2020																						
																	Ranunculo-Caricetum buxbaumii Pedrotti														Var. with *E. quinqeflora*				
Carex buxbaumii Wahlenb.	**5.5**	**5.5**	**5.5**	**5.5**	**5.5**	**5.4**	**4.4**	**5.5**	**5.5**	**5.5**	**5.5**	**5.5**	**5.5**	**5.5**	**5.5**	**4.4**	**5.5**	**4.4**	**3.3**	**3.3**	**4.4**	**3.3**	**2.2**	**2.2**	**5.3**	**3.4**	**2.2**	**5.5**	**5.5**	**4.4**	**1.2**	**3.3**	**1.2**	**2.2**	34
Deschampsia cespitosa (L.) P. Beauv.	+.2	2.2	1.2	2.2	+.2	1.2	+	+	+.2	1.2	1.1	2.2	.	.	1	+	1.2	+	1.1	+.2	+	.	+.2	+	+.2	1.2	1.1	1.2	1.2	.	+	+	+	+	30
Ranunculus repens L.	1.1	3.3	2.2	1.1	2.2	2.2	2.2	+	1.1	1.1	1.1	1.1	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	+.2	.	.	.	.	14
Potentilla reptans L.	.	+	.	+	+	1.1	1.1	.	1.1	1.1	2.2	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	9
Lathyrus pratensis L.	.	.	1.1	+	+	.	+	.	.	.	+	1.1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	8
Galium palustre L. subsp. *palustre*	.	.	.	.	.	.	.	.	.	.	.	.	1.2	1.1	1.1	3.3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4
Alopecurus pratensis L. subsp. *pratensis*	.	.	.	.	.	.	.	.	.	.	.	.	2.2	.	+	+	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4
Ranunculus pedrottii Spinosi ex Dunkel	+	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	+	1.1	.	+	+	.	1.1	.	1.1	+.2	1.1	+	+	+	1.1	16
Ranunculus apenninus (Chiov.) Pignatti	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	+	.	.	+	1.1	1.2	+	1.1	.	.	.	1.1	+	2.2	1.1	12
Scorzoneroides autumnalis (L.) Moench	.	.	.	.	.	.	+	.	.	.	.	.	.	+	.	1.1	1.1	+	2.2	2.2	1.1	1.1	1.1	1.1	1.1	2.2	1.1	1.1	1.1	2.1	2.2	1.1	2.2	2.2	21
Sanguisorba officinalis L.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	.	.	+.2	.	+	+	.	.	+	1.1	.	+	1.1	1.3	2.3	+	.	.	+	.	13
Agrostis canina L.	.	.	.	.	.	.	.	.	.	.	.	.	1.1	+	.	1.1	.	.	+	1.1	1.1	1.2	2.2	.	1.1	1.1	+	.	1.1	+	+	.	+	+	16
Eleocharis quinqueflora (Hartmann) O. Schwarz	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1.2	1.2	1.2	1.1	4
Higher ranks species																																			
Carex acuta L.	.	.	1.1	1.1	1.1	+	2.2	+	2.2	1.1	1.2	1.1	1.1	.	.	.	+.2	+	+	+	1.2	+	1.1	2.2	1.1	+	2.2	+.2	.	1.1	.	.	+	.	25
Galium debile Desv.	1.1	.	+	.	+	+	1.1	.	.	.	.	.	.	.	.	.	+	+	+	+	.	.	.	.	.	.	.	+	.	1.1	.	+	+	+	14
Ranunculus flammula L.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	2.3	+	1.1	+	+	1.1	1.1	1.1	+	+	1.1	1.3	.	.	.	.	.	.	13
Mentha aquatica L.	.	.	.	+	+	+	+	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	6
Molionio-Arrhenatheretea species																																			
Ranunculus acris L.	+	.	+	.	+	1.1	.	.	.	+	+	.	.	.	1.1	1.1	1.1	.	.	.	.	.	.	.	.	.	.	1.1	2.2	.	.	.	.	.	11
Danthonia decumbens (L.) DC.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	+	.	+	*1.1*	+	*1.1*	+	+	+	.	10
Carex hirta L.	+	.	.	.	+	+.2	+	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	1.1	.	.	.	.	.	+	+	+	+	10
Carex leporina L.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	+.2	+	.	+	+.2	1.2	1.2	1.2	1.2	.	.	.	.	.	.	.	9
Trifolium spadiceum L.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	.	.	.	.	1.1	+	1.1	.	+	+	.	+	.	+	9
Agrostis stolonifera L.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	+	.	.	.	1.1	.	+	.	.	.	.	.	.	+	+	8
Anthoxanthum odoratum L.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	+	+	.	+.2	.	.	.	+	.	6
Carex pallescens L.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	+	.	.	.	.	.	.	+.2	+.2	2.2	2.3	.	.	.	.	.	6
Bistorta officinalis Delarbre	+	.	1.1	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	4
Rumex acetosa L.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	.	.	.	.	+	.	.	.	.	4
Festuca rubra subsp. *juncea* (Hack.) K. Richt.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	+	+	+	4
Phleum nodosum L.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	+	+	3
Trifolium pratense L.	.	.	.	.	.	1.1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	+	.	+	+	5
Scheuchzerio-Caricetea fusce species																																			
Veronica scutellata L.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	+	+	+	2.2	+	1.1	1.1	+	+	.	.	1.1	.	.	.	.	12
Potentilla erecta (L.) Raeusch.	1.1	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+.2	.	.	.	+.2	.	+	1.1	.	1.1	+	1.2	3.3	2.2	.	.	+	.	12
Carex panicea L.	.	+.2	+	1.1	+	1.1	+	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	+	.	.	.	.	1.1	+	1.1	+	12
Aulacomnium palustre (Hedw.) Schwägr.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+.2	+	+.2	.	.	.	.	.	.	.	3
Carex davalliana Sm.	+.2	+.2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2
Blysmus compressus (L.) Link	+.2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Carex echinata Murray	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+.2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Companions																																			
Nardus stricta L.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+.2	1.2	+.2	1.2	2.2	2.3	1.1	.	.	.	.	8
Juncus inflexus L.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+.2	+.2	.	1.2	.	.	.	+	+	+	+	7
Juncus acutiflorus Ehrh.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+.2	1.1	+	+	.	.	.	.	.	.	.	.	.	4
Narcissus poëticus L.	.	.	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	1.1	+	.	.	.	.	5
Luzula multiflora (Ehrh.) Lej.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	+	+	.	.	.	.	.	.	.	3
Serratula tinctoria L.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3
Mosses (were not included in statistical analysis)																																			
Drepanocladus aduncus (Hedw.) Warnstorf	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4.4	2.3	3.4	2.1	3.4	4.4	1.2	2.1	3.3	1.2	.	.	.	2.3	1.2	1.2	1.2	14
Acrocladium cuspidatum (Hedw.) Lindb.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+.2	1.2	.	.	.	.	.	.	.	2.3	2.3	1.3	5
Polytrichum commune Hedw.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+.2	+.2	+.2	+.2	.	.	.	.	.	.	.	4

* *Holotypus*

Fig. 2. Schematic representation of the vegetation in the study area (Savelli/S. Maria Karstic plain). A: general view with 1 *Trifolio-Hordeetalia*, 2 *Deschampsio-Caricetum buxbaumii,* 3 *Caricetum gracilis.* 4 *Caricetum vesicariae*, 4 Sinkhole. B: *Carex buxbaumii*. C: life forms of *C. buxbaumi*, D: *Deschampsio-Caricetum buxbaumii.*

Synchorology

Deschampsio caespitosae-Caricetum buxbumii is present in the Karstic bassin of Savelli-Castel Santa Maria and Piani di Castelluccio, *Ranunculo pedrotti-Caricetum buxbaumii* only in the Piani di Castelluccio (Pedrotti 2015) and, finally, *Galio palustris-Caricetum buxbaumii* in the Major Highlands of Abruzzo (Ciaschetti & al 2020).

Final Remarks

The *Carex buxbaumii* populations of Central Italy constitute a distinct and isolated post glacial relict nucleus with distinct floristic, ecological, and historical characteristics that allow us to include them in the *Caricion gracilis* Alliance. The *Caricetum buxbaumii* Issler 1932 can be considered present only in the southern slope of the Italian Alps (where the species is reported) in contact with the peaty meadows vegetation of *Molinietalia* and *Scheucherio-Caricetea fuscae*. On the contrary, the *Carex buxbaumii* communities of the Apennine karstic plains, in catenal contact with the transition meadows of *Deschampsion caespitosae* and *Potentillion anserinae,* attributable to the habitat 3180* "Turloughs" not currently present in the Italian Interpretation Manual (http://vnr.unipg.it/habitat), are included into the *Caricion gracilis* Alliance. The present research highlights that the Habitat Directive 92/43 does not include any Habitat with the vegetation of the *Phragmiti-Magnocaricetea*

Class and therefore there are no tools of protection neither at the National nor at the European level for the very rare associations *Caricetum buxbaumii* - treated in this work - and others such as *Caricetum vulpinae* and *Caricetum distichae*.

Syntaxomic scheme

SCHEUCHZERIO PALUSTRIS-CARICETEA NIGRAE NOM. MUT. PROPOS. EX STEINER 1992
  Caricetalia davallianae Br.-Bl 1949
    Caricion davallianae
      Valeriano simplicifoliae-Caricetum buxbaumii Ritter-Studnicka 1972

PHRAGMITI-MAGNOCARICETEA ELATAE KLIKA IN KLIKA & NOVÁK 1941
  Magnocaricetalia elatae Pignatti 1953
    Caricion elatae Koch 1926
      Caricetum buxbaumii Issler 1932

    Caricion gracilis Gèhu 1961
      Ranunculo pedrotti-Caricetum buxbaumii Pedrotti 2016
      Galio palustris-Caricetum buxbaumii Ciaschetti, Pirone & Venanzoni 2020
      Deschampsio cespitosae-Caricetum buxbaumii Venanzoni, Praleskouskaya & Ciaschetti 2021

References

Aleffi, M., Tacchi, R. & Poponessi, S. 2020: New Checklist of the Bryophytes of Italy. – Cryptog. Bryol. **41(13):** 147-195. https://doi.org/10.5252/cryptogamie-bryologie2020v41a13.

Bacieczko, W. & Kaszycka, E. 2015: The conservation requirements of rare and threatened vascular plants of Natura 2000 habitats of the Dolina Płoni i Jezioro Miedwie (Płonia valley and Miedwie lake) special area of conservation. – Folia Pomeranae Univ. Technol. Stetinensis **316(33):** 15-32.

Balatova-Tulackova, E. 1972: Flachmoorwiesen im mittleren und unteren Opava-Tal (Schlesien). – Academia-Verlag Tschechoslow, Akad. Wissen. – Prague.

Bartolucci, F., Peruzzi, L., Galasso, G., Albano, A., Alessandrini, A., Ardenghi, N. M. G., Astuti, G., Bacchetta, G., Ballelli, S., Banfi, E., Barberis, G., Bernardo, L., Bouvet, D., Bovio, M., Cecchi, L., Di Pietro, R., Domina, G., Fascetti, S., Fenu, G., Festi, F., Foggi, B., Gallo, L., Gottschlich, G., Gubellini, L., Iamonico, D., Iberite, M., Jiménez-Mejías, P., Lattanzi, E., Marchetti, D., Martinetto, E., Masin, R. R., Medagli, P., Passalacqua, N. G., Peccenini, S., Pennesi, R., Pierini, B., Poldini, L., Prosser, F., Raimondo, F. M., Roma-Marzio, F., Rosati, L., Santangelo, A., Scoppola, A., Scortegagna, S., Selvaggi, A., Selvi, F., Soldano, A., Stinca, A., Wagensommer, R. P., Wilhalm, T. & Conti, F. 2018: An updated checklist of the vascular flora native to Italy. – Pl. Biosyst. **152(2):** 179-303. https://doi.org/10.1080/11263504.2017.1419996

Bernátová, D., Kliment, J., Topercer, J. 2018: Buxbaum's sedge – a hot candidate for extinction in Slovakia. – Bull. Slov. Bot. Spoločn. **40(2):** 171-180.

Blasi, C., Capotorti, G., Copiz, R. & Mollo, B. 2018: A first revision of the Italian Ecoregion map. – Pl. Biosyst. **152(6):** 1201-1204. https://doi.org/10.1080/11263504.2018.1492996

Braun-Blanquet, J. 1964: Pflanzensoziologie – Grundzuge der Vegetationkunde. – Wien, New York.

Burba N., De Paoli, D., Feoli, E., Malaroda, M., Oriolo, G. & Zuccarello, V. 1992: Un sistema informativo per la vegetazione. Calcolo degli indici ecologici. – Coll. Quad. C.E.T.A., **2.** – Gorizia.

Ciaschetti, G., Pirone, G. & Venanzoni, R. 2020: Sedge Vegetation of the "Major Highlands of Abruzzo" (Central Italy): Updated Knowledge After New Discoveries. – Pl. Biosyst. **155(3):** 647-662. https://doi.org/10.1080/11263504.2020.1801876

Conti, F., Pedrotti, F. & Pirone, G. 1990: Su alcune piante notevoli rinvenute in Abruzzo, Molise e Basilicata. – Arch. Bot. Ital. **66(3/4):** 1-15.

Cortini Pedrotti, C., Orsomando, E., Pedrotti, F. & Sanesi, G. 1973: La vegetazione e i suoli del Pian Grande di Castelluccio di Norcia (Appennino centrale). – Atti Ist. Bot. Lab. Critt. Univ. Pavia **9:** 155-249.

Dunkel, F. G. 2011: The *Ranunculus auricomus* L. complex (*Ranunculaceae*) in Central and Southern Italy, with addition to north Italian taxa. – Webbia **66(2):** 165-193. https://doi.org/10.1080/00837792.2011.10670895

Ferrez, Y. 2005: Connaissance de la flore rare ou menacée de Franche-Comté, *Carex buxbaumii* Wahlenb. – Besançon.

Gallandat, J.-D. 1982: Prairies marécageuses du Haut-Jura (*Molinietalia, Scheuchzerio-Caricetea fuscae* et *Phragmitetea*). – Matér. Levé Géobot. Suisse **58:** 1-180.

Gigante, D. & Venanzoni, R. 2000: Contributo alla conoscenza della vegetazione degli ambienti umidi dell'Umbria (Italia). – Fitosociologia **37(2):** 13-63.

— & — 2005: Habitat umidi di rilevante interesse botanico e vegetazionale nel Pian Piccolo di Castelluccio (PG). – In: Guida all'escursione della Società Italiana di Scienza della Vegetazione.

—, Acosta, A. T. R., Agrillo, E., Attorre, F., Cambria, V. E., Casavecchia, S., Chiarucci, A., Del Vico, E., De Sanctis, M., Facioni, L., Geri, F., Guarino, R., Landi, S., Landucci, F., Lucarini, D., Panfili, E., Pesaresi, S., Prisco, I., Rosati, L., Spada, F. & Venanzoni, R. 2012: VegItaly: Technical features, crucial issues and some solutions. – Pl. Sociol. **49(2):** 71-79. https://doi.org/10.7338/pls2012492/05

Grulich, V. 2012: Red List of vascular plants of the Czech Republic: 3rd edition. – Preslia **84:** 631-645.

Issler, E. 1933: Les prairies non fumées du Ried Ello-rhénan et le Mesobrometum du Haut-Rhin. – Bull. Soc. Hist. Nat. Colmar **23:** 43-129.

Jutrzenka-Trzebiatowski, A. & Szarejko, T. 2001: Zespol *Caricetum buxbaumii* w Wigierskim Parku Narodowym. – Fragm. Flor. Geobot. Polonica **8:** 149-171.

Keller, L. 1969-1970: Étude des groupements végétaux de la réserve de Cheyres. – Bull. Soc. Fribourgeoise Sc. Nat. Neuchâtel **59:** 47-59.

Klötzli, F. 1969: Die Grundwasserbeziehungen der Streu- und Moorwiesen in nördlichen Schweizer Mittelland. – Beitr. Geobot. Landesaufnahme Schweiz **52:** 1-296.

— 1973: Übersicht über die walfreien Nassstandorte der Schweiz. Veröff. Geobot. – Inst. Eidg. Techn. Hochschule, Stift. Rübel, Zürich **51:** 15-39.

Korneck, D. 1962: Die Pfeifengraswiesen und ihre wichtigsten Kontaktgesellschaften in der nördlichen Oberrheinebene und in Schweinfurter Trockengebiet I. – Beitr. Naturk. Forsch. SW-Deutschl. **21(1):** 55-77.

Korneck, D. 1963: Die Pfeifengraswiesen und ihre wichtigsten Kontaktgesellschaften in der nördlichen Oberrheinebene und in Schweinfurter Trockengebiet III. – Beitr. Naturk. Forsch. SW-Deutschl. **22(1):** 19-44.

Landucci, F., Acosta, A. T. R., Agrillo, E., Attorre, F., Biondi, E., Cambria, V. M., Chiarucci, A., Del Vico, E., De Sanctis, M., Facioni, L., Geri, F., Gigante, D., Guarino, R., Landi, S., Lucarini, D., Panfili, E., Pesaresi, S., Prisco, I., Rosati, L., Spada, F. & Venanzoni, R. 2012: VegItaly: The Italian collaborative project for a national vegetation database. – Pl. Biosyst. **146(4):** 756–763. https://doi.org/10.1080/11263504.2012.740093

—, Gigante, D., Venanzoni, R. & Chytrý, M. 2013: Wetland vegetation of the class *Phragmito-Magnocaricetea* in Central Italy. – Phytocoenologia **43(1-2):** 67-100, https://doi.org/10.1127/0340-269X/2013/0043- 0545

—, Šumberová, K., Tichý, L., Hennekens, S., Aunina, L., Biță-Nicolae, C., Borsukevych, L., Bobrov, A., Čarni A., De Bie, E., Golub V., Hrivnák, R., Iemelianova, S., Jandt, U., Jansen, F., Kącki, Z., Lájer, K., Papastergiadou, E., Šilc, U., Sinkevičienė, Z., Stančić, Z., Stepanovič, J., Teteryuk, B., Tzonev, R., Venanzoni, R., Zelnik, I. & Chytrý, M. 2020: Classification of the European marsh vegetation (*Phragmito-Magnocaricetea*) to the association level. – Appl. Veg. Sci. **23:** 297-316, https://doi.org/10.1111/avsc.12484

Lastrucci, L., Landucci, F., Gonnelli, V., Barocco, R., Foggi, B. & Venanzoni, R. 2012: The vegetation of the upper and middle River Tiber (Central Italy). – Pl. Sociol. **49(2):** 29-48.

—, Bonari, G., Angiolini, C., Casini, F., Giallonardo, T., Gigante, D., Landi, M., Landucci, F., Venanzoni, R. & Viciani, D. 2014: Vegetation of Lakes Chiusi and Montepulciano (Siena, Central Italy). – Plant Sociology **51:** 29-55. https://doi.org/10.7338/pls2014512/03

Lucarini, D., Gigante, D., Landucci, F., Panfili, E. & Venanzoni, R. 2015: The anArchive taxonomic Checklist for Italian botanical data banking and vegetation analysis: Theoretical basis and advantages. – Pl. Biosyst. **149(6):** 958-965. https://doi.org/10.1080/11263504.2014.984010

Mucina, L., Bültmann, H., Dierßen, K., Theurillat, J.-P., Raus, T., Čarni, A., Šumberová, K., Willner, W., Dengler, J., García, R. G., Chytrý, M., Hàjek, M., Di Pietro, R., Iakushenko, D., Pallas, J., Daniëls, F. J. A., Bergmeier, E., Guerra, A. S., Ermakov, N., Valachovič, M., Schaminée, J. H. J., Lysenko, T., Didukh, Y. P., Pignatti, S., Rodwell, J. S., Capelo, J., Weber, H. E., Solomeshch, A., Dimopoulos, P., Aguiar, C., Hennekens, S. M. & Tichý, L. 2016. Vegetation of Europe: Hierarchical floristic classification system of vascular plant bryophyte lichen and algal communities. – Appl. Veg. Sci. **19(S1):** 3-264.

Oberdorfer, E. 1957: Süddeutsche Pflanzengesellschaften. – Jena.

— 1983: Pflanzensoziologische Exkursionsflora. – Stuttgart.

Pedrotti, F. 1971: *Carex buxbaumii*, relitto glaciale: prima segnalazione per l'Italia peninsulare. – Arch. Bot. Biogeogr. Ital. **15(1):** 21-28.

— 1976: Les prairies permanentes humides de l’Apennin central: phytosociologie et cartographie. – Coll. Phytosoc. **5:** 181-187.

— 1982: La végétation du Pian Grande. – Pp. 347-360 in: Guide-Itinéraire Excursion Internat. Phytosociologie Italie centrale (2-11 juillet 1982). – Camerino.

— 2015: A new plant association of *Caricion gracilis* alliance of the Central Apennines (Italy). – Contrib. Bot. **50:** 137-152.

— 2016a: ERRATUM. A new plant association of *Caricion gracilis* alliance of the central Apennines (Italy). – Contrib. Bot. **51:** 155.

— 2016b: The *Caricetum distichae* Association in Italy. – Pp. 357–362 in: Vegetation structure and function at multiple spatial, temporal and conceptual scales. Geobotany studies – New York.

— & Sanesi, G. 1969: Resoconto delle escursioni sull'Appennino umbro-marchigiano (25-27 giugno 1968). – Mitt. ostalp.-din. pflanzensoz. Arbeitsgem. Camerino **9:** 365-388.

—, Aleffi, M. & Cortini Pedrotti, C. 2004: La vegetazione attuale dei depositi quaternari dell’Umbria e delle Marche (Italia centrale). – Coll. Phytosoc. **28:** 1073-1084.

Philippi, G. 1960: Zur Gliederung der Pfeifengraswiesen im südlichen und mittleren Oberrheingebiet. – Beitr. Naturk. Forsch. Südw.-Dtld. **19:** 138-187.

— 1971: Beiträge zur Flora der nordbadischen Rheinebene und der angrenzenden Gebiete. – Beitr. Naturk. Forsch. Südw.-Dtld. **30:** 9-47.

Pignatti, S., Guarino, R. & La Rosa, M. 2017-19. Flora d’Italia, 1-4, 2° ed, & Flora Digitale. – Milano.

Ritter-Studnicka, H. 1972: Neue Pflanzengesellschaften aus den Karstfeldern Bosniens und der Hercegovina. – Bot. Jahrb. Syst. Stuttgart **92:** 108-154.

Rossi, G., Montagnani, C., Gargano, D., Peruzzi, L., Abeli, T., Ravera, S., Cogoni, A., Fenu, G., Magrini, S., Gennai, M., Foggi, B., Wagensommer, R. P., Venturella, G., Blasi, C., Raimondo, F. M. & Orsenigo, S. (eds) 2013: Lista Rossa della Flora Italiana. 1. Policy Species e altre specie minacciate. – Roma.

Salmina, L. 2005: New fen communities in Latvia. – Latvijas Univ. Raksti **685:** 96-111.

— 2006: Limnogenous, mire vegetation of Latvia. – Summary of the PhD thesis, University of Latvia - Riga.

Segal, S., Westhoff, V. & Dijk, J. (van) 1959: Die Vegetationskundliche Stellung von Carex buxbaumii Wahlenb. in Europa, besonders in den Niederlanden. – Acta Bot. Neerl. **8:** 304-329.

Sotek, Z. 2006: The distribution of *Carex buxbaumii* Wahlenb. in Poland. – Acta Societatis Botanicorum Poloniae **75(4):** 293-296.

Stańko, R., Wołejko, L. & Pawlaczyk, P. (eds) 2018: A Guidebook on Good Practices of alkaline fen conservation. – Świebodzin.

Tomaszevic, H. 1979: Roslinnosc wodna i szuwarowa Polski. – Warsaw.

Venanzoni, R., Properzi, A., Bricchi, E., Landucci, F. & Gigante D. 2018: The Magnocaricetalia Pignatti 1953 (*Phragmito- Magnocaricetea* Klika in Klika et Novák 1941) Plant Communities of Italy. – Pp. 135-173 in: Pedrotti F. (ed.), Climate Gradients and Biodiversity in Mountains of Italy. – Geobotany Studies, Berlin. https://doi.org/10.1007/978-3-319- 67967-9_8

Wolejko, I., Herbichowa, M. & Potocka, J. 2005: Typological differentiation and status of Natura 2000 mire habitats in Poland. – Stapfia 85, zugleich Kataloge der Ö. Landesmuseen Neue Serie **35:** 175-219.

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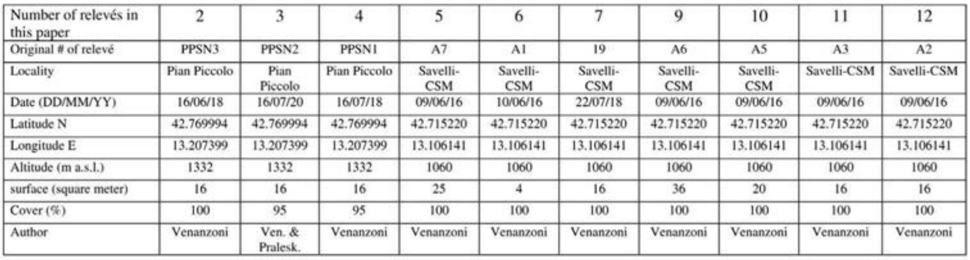
Annex 1 - Sporadic species of Tab. 1 [specie, value (relevés)].

Ophioglossum vulgatum L., 1,1 (21), +(26); *Schedonorus arundinaceus* (Schreb.) Dumort. + (5), +.2(6); *Galium mollugo* L. 1.1 (11), 2.2 (12); *Trifolium repens* L. 1.1 (6), +(34); *Alopecurus rendlei* Eig. 2.2(15), +(16); *Briza media* L. +(1), +.2(2); *Taraxacum officinale* Weber (aggr.), +(12), +(26); *Cerastium holosteoides* Fr., +(5), +(6); *Lathyrus pannonicus* (Jacq.) Garcke +(15), +(16); *Bellevalia romana* (L.) Sweet + (14), + (16); *Vicia cracca* L. + (27), + (34); *Rhinanthus minor* L. + (29) + (31); *Carex vulpina* L. + (34); *Equisetum palustre* L. + (20); *Trifolium fragiferum* L. 1.1 (6); *Cardamine amporitana* Sennen et Pau + (1); *Rubus caesius* L. + (5); *Carex disticha* Huds. + (13); *Cruciata pedemontana* (Bellardi) Ehrend. + 2; *Galium verum* L. +.2 (30); *Oenanthe fistulosa* L. + (14); *Veronica chamaedrys* L. + (1) + (2); *Euphrasia stricta* J. P. Wolff ex J.F. Lehm. + (21); *Cynosurus cristatus* L. + (31); *Centaurea jacea* L. + (33); *Dicranum bonjeanii* De Not. +.2(4); *Campylium polygamum* (Schimp.) CEO Jensen + (31); *Luzula spicata* (L.) DC. + (29); *Juncus articulatus* L. +.2 (1); *Juncus conglomeratus* L. +.2 (29); *Ornithogalum gussonei* Ten. + (29); *Rumex acetosella* L. + (30).

Annex 2 - Locality and data of unpublish relevés.



Number of relevés in this paper	2	3	4	5	6	7	9	10	11	12
Original # of relevé	PPSN3	PPSN2	PPSN1	A7	A1	19	A6	A5	A3	A2
Locality	Pian Piccolo	Pian Piccolo	Pian Piccolo	Savelli-CSM	Savelli-CSM	Savelli-CSM	Savelli-CSM	Savelli-CSM	Savelli-CSM	Savelli-CSM
Date (DD/MM/YY)	16/06/18	16/07/20	16/07/18	09/06/16	10/06/16	22/07/18	09/06/16	09/06/16	09/06/16	09/06/16
Latitude N	42.769994	42.769994	42.769994	42.715220	42.715220	42.715220	42.715220	42.715220	42.715220	42.715220
Longitude E	13.207399	13.207399	13.207399	13.106141	13.106141	13.106141	13.106141	13.106141	13.106141	13.106141
Altitude (m a.s.l.)	1332	1332	1332	1060	1060	1060	1060	1060	1060	1060
surface (square meter)	16	16	16	25	4	16	36	20	16	16
Cover (%)	100	95	95	100	100	100	100	100	100	100
Author	Venanzoni	Ven. & Pralesk.	Venanzoni	Venanzoni	Venanzoni	Venanzoni	Venanzoni	Venanzoni	Venanzoni	Venanzoni

Article

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The wonder of the Jaccard coefficient: from alpine floras to bipartite networks

Abstract

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The similarity index suggested by Paul Jaccard 120 years ago has been one of the best-known coefficients in statistical ecology and other research fields in which the objects to be compared are described in terms of the presence or absence of many characters. Jaccard and his immediate followers used the coefficient for the comparison of floras of different localities and phytosociological relevés, based on the list of constituting species. A historical and mathematical overview reveals that, in addition to applications in ordinations and classifications, partitioning the coefficient into additive fractions opens unlimited opportunities for evaluating taxonomic, phylogenetic and functional diversity and related phenomena of ecological communities.

Key words: beta diversity, contingency table, data structure, similarity, simplex diagrams.

The inventor

Paul Jaccard, to whom we generally acknowledge the coefficient discussed in this paper, was born on 18 November 1868 in Sainte-Croix, canton Vaud, Switzerland (Frey-Wyssling 1944). During his school days, he started to collect fossils under the influence of his teacher of natural history, H. Golliez. At age 15 he visited the paleontological exhibition of the Swiss Federal Polytechnic (ETH) in Zurich; it was a trip which completely determined his future. Greatly impressed by what he saw, the young boy decided to study science, but his family could not provide sufficient financial support. Therefore, he first attended a teacher's training college in Lausanne and then worked as a primary school teacher in the same town. His interest in natural sciences continued to increase in the meantime, and he developed contact with noted geologists and plant scientists of the time. As a second most influential event in his life, he made excursions to the Alps together with the famous botanist, L. Favrat. As Frey-Wyssling (1944) put it: "his enthusiasm knew no boundaries". A position of plant preparator was offered to him in the Musée Botanique de Lausanne. While employed there, he worked hard and got his BSc degree. He then started to study natural sciences at the University of Lausanne in 1889, received the degree *licentia docendi* two years later, and finally obtained a doctoral degree at ETH, Zurich, in 1893.

His richly illustrated thesis on the embryology of *Ephedra helvetica* (Jaccard 1894) appeared the next year in the natural history journal of his beloved canton, *Bulletin de la Société Vaudoise des Sciences Naturelles*. Later, Jaccard published many of his papers in this local journal, which has become known worldwide much later, thanks primarily to his achievements.

These early papers reflect the expertise of a young, intelligent researcher whose interest extended from plant embryology, teratology, medicinal plants to floristics, and vegetation ecology. As a less widely known contribution to the history of evolutionary theory, he devoted his inaugural lecture held at the University of Lausanne to Darwinism (Jaccard 1895). In this, he takes the view that the theory cannot give satisfactory explanation to many aspects of plant evolution. The reason, according to him, lies primarily in the incompleteness of the highly fragmented paleontological material, and the lack of intermediate forms in the fossil record. However, he did not engage into further dispute over this subject and turned towards the study of alpine flora. Articles published around the turn of the 20th century clearly show this shift together with a new, and an even more important aspect of his research: the development of two coefficients by which he established statistical thinking in plant ecology. These are the *coefficient of floral community* ("coefficient de communauté florale" or "Gemeinschafts-coefficient") and the *generic coefficient* ("coefficient générique"). The first one is the subject matter of the present paper. The second formula is the ratio of the number of genera to the number of species, intended to reflect the ecological diversity of a given area. The generic coefficient evoked considerable interest and triggered long discussions over its applicability to vegetation ecology (Maillefer 1928, 1929; Williams 1949). Although it has not been used any longer, thanks partly to the obvious arbitrariness of genus level taxonomy, the idea that taxonomic (and then phylogenetic) relationships should be accounted for in diversity calculations persists in more complex conceptual frameworks.

In addition to the high mountains in his homeland, Jaccard travelled to other countries in Europe and participated in expeditions to exotic places, such as the Caucasus and Turkestan. In 1903, he was appointed as a professor of botany at ETH and remained there until his retirement in 1938. As a professor, he taught microscopy for 2500 students, and supervised 15 dissertations (Frey-Wyssling 1944). His portrait reproduced in Figure 1 was taken during these happy times. At ETH he developed interest in sylviculture and forest trees and the majority of his publications dealt with wood anatomy, mycorrhiza, plant morphology and physiology. Although many of these studies were reported in *Journal Forestier Suisse*, he continued to publish in the *Bulletin* as well as in other journals from his narrow homeland. One of these papers (Jaccard 1926) reports application of the generic coefficient to the Moroccan flora he investigated in a field trip organized by J. Braun-Blanquet. According to the obituary by Frey-Wyssling (1944), Jaccard has written 126 papers and book chapters, 89 in French and 37 in German. This list is obviously incomplete, however, because two papers that are extremely relevant to the present paper are missing, namely Jaccard (1907) and its translation, Jaccard (1912), supposedly his only publication in English. Jaccard continued to work hard after his retirement and took care of the wood collection of the university. His later years were made difficult not only by deteriorating health conditions but also by the escalating World War II. He passed away on 5 May 1944 in Zurich.

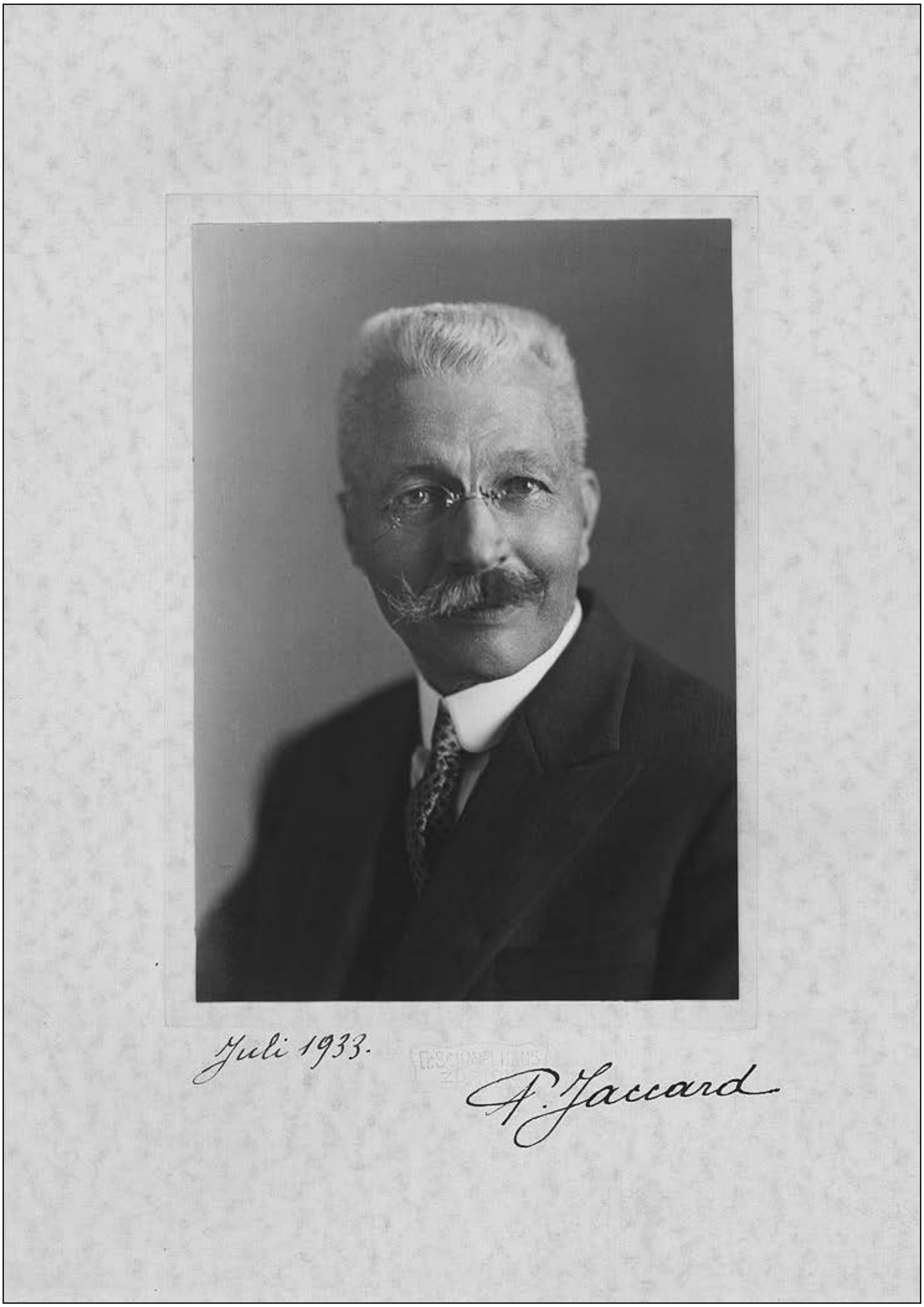

Fig. 1. Photograph and signature of Paul Jaccard from July 1933. Source: https://de.wikipedia.org/wiki/Paul_Jaccard.

Early history of a remarkable idea

References to the origin of the Jaccard coefficient are inconsistent in the ecological and statistical literature, by mentioning his papers from 1900 to 1912 almost haphazardly. This is because the *Bulletin* and other journals in which his early papers appeared were hardly available to most authors, especially in the 20th century[1]. Given that more recently Jaccard's all publications have been available electronically for the wide public, thanks especially to ETH Bibliotek in Zurich (http://retro.seals.ch), we can trace back precisely how and where his coefficient was developed.

The idea that the flora of two localities may be compared by counting the number of species occurring in both places arose first in Jaccard's mind in a study of the alpine flora of three regions in the Swiss Alps: the Wildhorn Massif (W), the Trient Basin (T) and the Bagnes Valley (B) (Jaccard 1900). In addition to three tables that list and count the shared species for the three possible pairs of these localities, no other numerical manipulations were made with the data. Yet. In a subsequent publication, Jaccard (1901a) goes one step further and describes shortly – in a footnote (!) – the method of how to compare two floras in a standardized way. On p. 249-250, he compares several districts and subdistricts in various combinations, and calculates the ratio of the number of shared species by the number of all species for T and W (Fig. 2a), with explanation given in his Footnote 1: T has 470 species, W has 350, whereas the number of common species is 295. Distracting the latter number from 470+350 = 820 yields the total number of species present in T and W, namely 525. Then, 295 divided by 525 provides the relative proportion of shared species, which is around 56/100. Actually, a more precise value of this ratio, the first ever published, is 0.5619 for four decimal digits. He gives the name of this ratio, "*coefficient de communauté florale*" only on p. 251, without presenting an explicit formula, and uses it as a percentage similarity throughout the paper.

Initially, Jaccard did not restrict the use of his new method to pairwise comparisons. He goes further on and calculates the ratio for several localities simultaneously, implicitly giving the first instance of a multiple site similarity coefficient. On p. 250, five localities are first evaluated together, producing a ratio of 0.30, which increases to 0.37 and 0.43 after successive removal of two localities (Fig. 2b)[2]. The occurrence of the first semimatrix of similarities is another remarkable achievement of this paper. On pages 253-257, the author gives complete details for the comparison of ten localities in every possible pair (partly reproduced in Fig. 3a). Based on this information it is easy to compile the semimatrix, which is presented here in dissimilarity form (Fig. 3b) for further analysis which Jaccard could not even dream of. The results of principal coordinates analysis and group average clustering (Fig. 3c-d) demonstrate the relationships between the ten regions.

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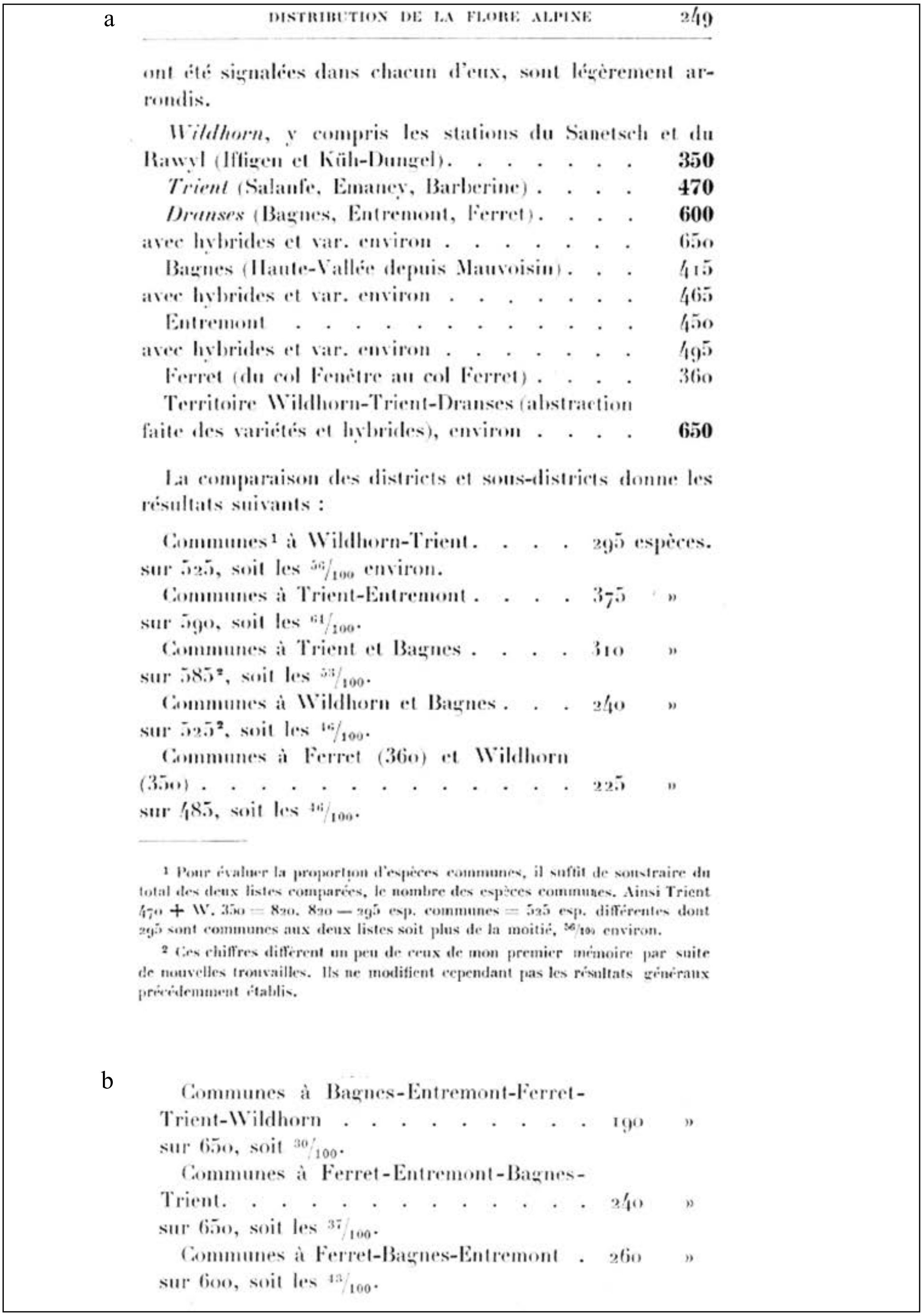
[1] Even Francey (1941) in the same *Bulletin* does not refer properly to the first occurrence of the coefficient, by mentioning Jaccard (1902a).

[2] Unfortunately, this latter idea was never expanded any further. Instead, Jaccard adapted the practice of averaging pairwise indices calculated for relevé data.



DISTRIBUTION DE LA FLORE ALPINE 249

ont été signalées dans chacun d'eux, sont légèrement arrondis.

Wildhorn, y compris les stations du Sanetsch et du Rawyl (Iffigen et Küh-Dungel)	**350**
Trient (Salanfe, Emaney, Barberine)	**470**
Dranses (Bagnes, Entremont, Ferret)	**600**
avec hybrides et var. environ	650
Bagnes (Haute-Vallée depuis Mauvoisin) . . .	415
avec hybrides et var. environ	465
Entremont	450
avec hybrides et var. environ	495
Ferret (du col Fenêtre au col Ferret)	360
Territoire Wildhorn-Trient-Dranses (abstraction faite des variétés et hybrides), environ	**650**

La comparaison des districts et sous-districts donne les résultats suivants :

Communes[1] à Wildhorn-Trient . . . . 295 espèces.
sur 525, soit les $^{56}/_{100}$ environ.
Communes à Trient-Entremont . . . . 375 »
sur 590, soit les $^{64}/_{100}$.
Communes à Trient et Bagnes . . . . 310 »
sur 585[2], soit les $^{53}/_{100}$.
Communes à Wildhorn et Bagnes . . . 240 »
sur 525[2], soit les $^{46}/_{100}$.
Communes à Ferret (360) et Wildhorn (350) . . . . 225 »
sur 485, soit les $^{46}/_{100}$.

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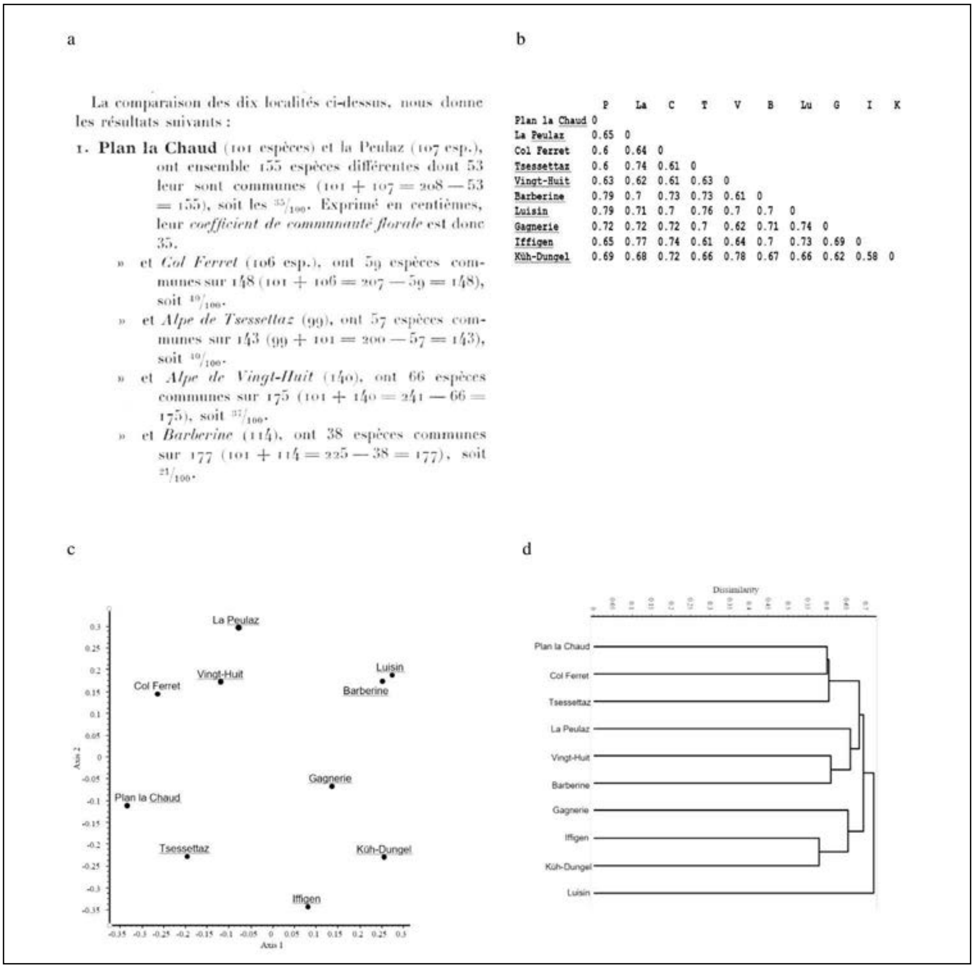
[1] Pour évaluer la proportion d'espèces communes, il suffit de soustraire du total des deux listes comparées, le nombre des espèces communes. Ainsi Trient 470 + W. 350 = 820. 820 — 295 esp. communes = 525 esp. différentes dont 295 sont communes aux deux listes soit plus de la moitié, $^{56}/_{100}$ environ.

[2] Ces chiffres diffèrent un peu de ceux de mon premier mémoire par suite de nouvelles trouvailles. Ils ne modifient cependant pas les résultats généraux précédemment établis.

Communes à Bagnes-Entremont-Ferret-Trient-Wildhorn . . . . 190 »
sur 650, soit $^{30}/_{100}$.
Communes à Ferret-Entremont-Bagnes-Trient. . . . . 240 »
sur 650, soit les $^{37}/_{100}$.
Communes à Ferret-Bagnes-Entremont . 260 »
sur 600, soit les $^{43}/_{100}$.

Fig. 2. Extracts from Jaccard (1901a) illustrating the first example of his "coefficient de communauté florale" (**a**) and its application to multiple sites (**b**).

The ordination axes have relatively low explanatory power, with percentage eigenvalues decreasing gradually (the first three being 19, 18 and 14%). The points are dispersed relatively evenly in the ordination space, and the closeness of Barberine and Luisin is misleading, as the dendrogram demonstrates. The dissimilarities fall into a narrow range, the smallest being 0.58, which suggest high floristic diversity of these mountainous areas. In subsequent publications (Jaccard 1901b, 1902a, b, d), calculations were demonstrated partly on the same dataset, that is, still at the biogeographical level. In Jaccard (1902c, p. 362) the same upper semimatrix is listed by rows. These papers also use artificial examples to demonstrate the calculations.



a

La comparaison des dix localités ci-dessus, nous donne les résultats suivants :

1. **Plan la Chaud** (101 espèces) et la Peulaz (107 esp.), ont ensemble 155 espèces différentes dont 53 leur sont communes (101 + 107 = 208 — 53 = 155), soit les $^{35}/_{100}$. Exprimé en centièmes, leur *coefficient de communauté florale* est donc 35.

» et *Col Ferret* (106 esp.), ont 59 espèces communes sur 148 (101 + 106 = 207 — 59 = 148), soit $^{40}/_{100}$.

» et *Alpe de Tsessettaz* (99), ont 57 espèces communes sur 143 (99 + 101 = 200 — 57 = 143), soit $^{40}/_{100}$.

» et *Alpe de Vingt-Huit* (140), ont 66 espèces communes sur 175 (101 + 140 = 241 — 66 = 175), soit $^{37}/_{100}$.

» et *Barberine* (114), ont 38 espèces communes sur 177 (101 + 114 = 225 — 38 = 177), soit $^{21}/_{100}$.

b

	P	La	C	T	V	B	Lu	G	I	K
Plan la Chaud	0									
La Peulaz	0.65	0								
Col Ferret	0.6	0.64	0							
Tsessettaz	0.6	0.74	0.61	0						
Vingt-Huit	0.63	0.62	0.61	0.63	0					
Barberine	0.79	0.7	0.73	0.73	0.61	0				
Luisin	0.79	0.71	0.7	0.76	0.7	0.7	0			
Gagnerie	0.72	0.72	0.72	0.7	0.62	0.71	0.74	0		
Iffigen	0.65	0.77	0.74	0.61	0.64	0.7	0.73	0.69	0	
Küh-Dungel	0.69	0.68	0.72	0.66	0.78	0.67	0.66	0.62	0.58	0

Fig. 3. Extract from Jaccard (1901a) showing the first part of his calculations of the semimatrix of similarities for ten alpine localities in Switzerland (**a**), the entire lower semimatrix converted to dissimilarities (**b**), results of PCoA from this matrix (**c**) and the dendrogram obtained by group average clustering (**d**).

Metamorphosis of an index

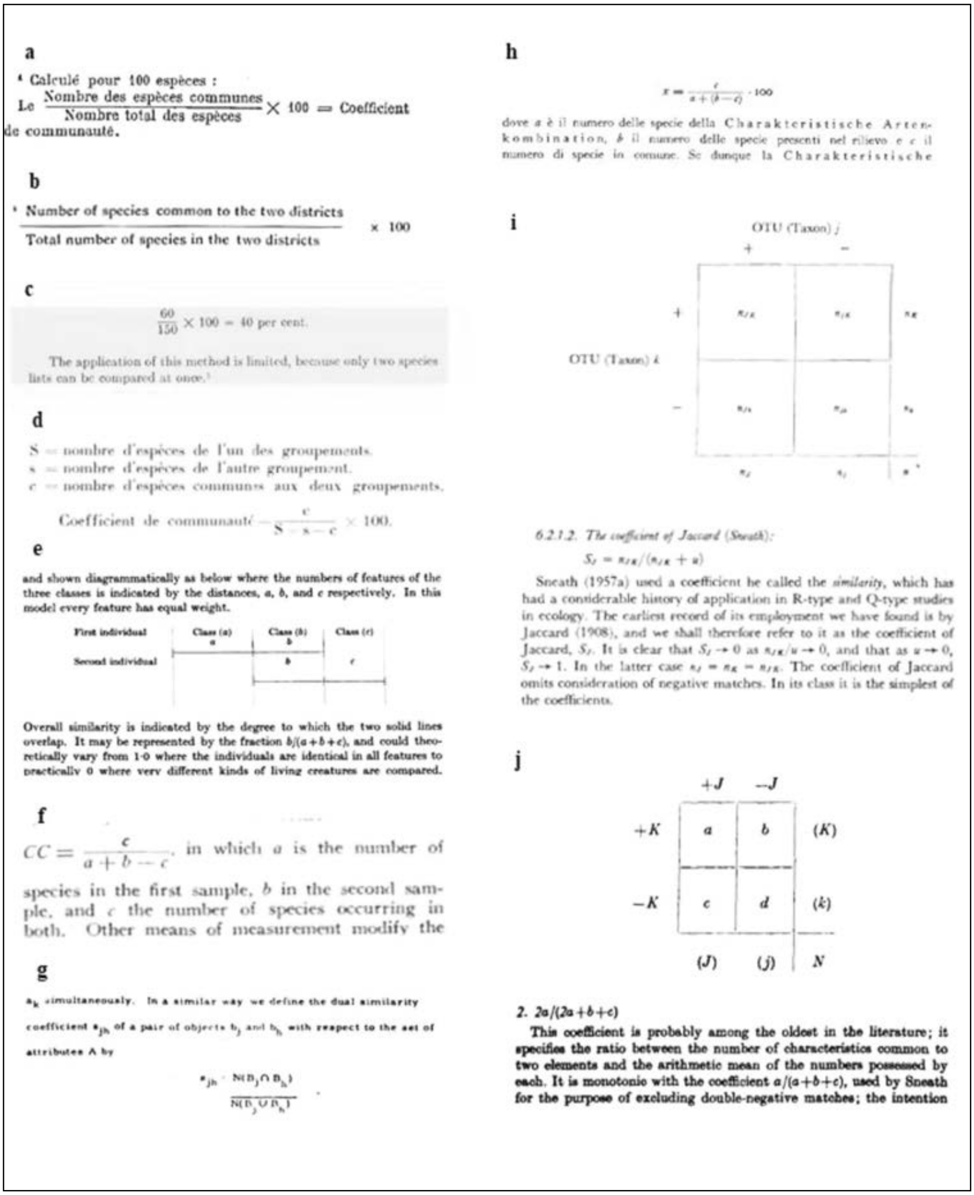
Having investigated Jaccard's publications thoroughly, I can safely say that he never gave an explicit mathematical formula (i.e., one with symbols) for the *coefficient de communauté florale*. At best, Jaccard (1907, p. 962) presents a verbal version of his index in a footnote (Fig. 4a), and the text explains that this index is understood for a pair of localities. In the English translation (Jaccard 1912, p. 39), this information is given in the ratio itself (Fig. 4b).

The coefficient gained popularity relatively rapidly, thanks to Braun-Blanquet's seminal book on plant sociology (in German: 1927, in English: 1932), in which an example, rather than a general formula (Fig. 4c) was used to introduce the method. As the author adds, the index is applicable to pairwise comparisons. It was perhaps Francey (1941) who first suggested a truly mathematical formula for the coefficient, based on the same logic as the original: the number of common species (c) is divided by the sum of the species richness values of the two localities ($S + s$) from which the number of shared species is subtracted (Fig. 4d). Later, symbols a, b and c started to appear with various meanings and combinations. For Sneath (1957) b was the number of shared attributes in numerical taxonomic context, with an illustration which is almost set-theoretical (Fig. 4e). Whittaker and Fairbanks (1958) used c again to refer to the number of common species, whereas a is the number of species in the first sample unit, b in the second (Fig. 4f). Tanimoto (1958), apparently independently from Jaccard, suggested the same coefficient with set theoretical definition. If sets B_j and B_h contain the attributes possessed by objects b_j and b_h, respectively, then the index is the number of shared attributes (intersection of the two sets) divided by the cardinality of the union of the two sets (Fig. 4g).

Pignatti & Mengarda (1962) were the first to break with the traditional usage of the coefficient. Rather than contrasting the flora of two localities or sample units, they proposed to use the index for the comparison of each sample unit (relevé) to a set of characteristic species typical of the community ("Charakteristiche Artenkombination"). That is, one object was a real observation while the other was an abstraction. The formula itself did not change, however, the authors used the same symbols as Whittaker & Fairbanks (1958) with c being the number of characteristic species occurring in the relevé (Fig. 4h).

The notations of a 2×2 contingency table were first adapted to this index by Sokal & Sneath (1963), with n_{JK} referring to the number of attributes shared by objects (OTU's, in their terminology) j and k, and u denoting the number of attributes possessed only by either object j or k, that is, $u = n_{jK} + n_{Jk}$ (Fig. 4i).

In a milestone communication, Williams & Dale (1965) proposed the use of parameters a, b, c and d of the 2×2 contingency table, a simple scheme previously used in statistical texts, for writing presence-absence resemblance coefficients. In this, a is the number of characteristics common to both objects, J and K, being compared, b is the number of attributes pertaining only to K, c is the number of attributes present only in J, and d is the number of characters missing from both (double zeros). This is the first paper that published the Jaccard index written in terms of these symbols. However, the formula appears only in a commentary to another index (Sörensen's) and the authors attribute the formula to Sneath (Fig. 4j) even though Sokal & Sneath (1963, cited also by Williams and Dale) already realized that Jaccard was the originator.



a

[1] Calculé pour 100 espèces :

Le $\frac{\text{Nombre des espèces communes}}{\text{Nombre total des espèces}} \times 100 =$ Coefficient de communauté.

b

[1] $\frac{\text{Number of species common to the two districts}}{\text{Total number of species in the two districts}} \times 100$

c

$\frac{60}{150} \times 100 = 40$ per cent.

The application of this method is limited, because only two species lists can be compared at once.[1]

d

S = nombre d'espèces de l'un des groupements.
s = nombre d'espèces de l'autre groupement.
c = nombre d'espèces communes aux deux groupements.

Coefficient de communauté $= \frac{c}{S + s - c} \times 100.$

e

and shown diagrammatically as below where the numbers of features of the three classes is indicated by the distances, *a*, *b*, and *c* respectively. In this model every feature has equal weight.

Overall similarity is indicated by the degree to which the two solid lines overlap. It may be represented by the fraction $b/(a+b+c)$, and could theoretically vary from 1·0 where the individuals are identical in all features to practically 0 where very different kinds of living creatures are compared.

f

$CC = \frac{c}{a+b-c}$, in which *a* is the number of species in the first sample, *b* in the second sample, and *c* the number of species occurring in both. Other means of measurement modify the

g

a_k simultaneously. In a similar way we define the dual similarity coefficient s_{jh} of a pair of objects b_j and b_h with respect to the set of attributes A by

$$s_{jh} = \frac{N(B_j \cap B_h)}{N(B_j \cup B_h)}$$

h

$$x = \frac{c}{a+(b-c)} \cdot 100$$

dove *a* è il numero delle specie della Charakteristische Artenkombination, *b* il numero delle specie presenti nel rilievo e *c* il numero di specie in comune. Se dunque la Charakteristische

i

OTU (Taxon) *j*

OTU (Taxon) *k*	+	−	
+	n_{JK}	n_{jK}	n_K
−	n_{Jk}	n_{jk}	n_k
	n_J	n_j	n

6.2.1.2. The coefficient of Jaccard (Sneath):

$S_J = n_{JK}/(n_{JK} + u)$

Sneath (1957a) used a coefficient he called the *similarity*, which has had a considerable history of application in R-type and Q-type studies in ecology. The earliest record of its employment we have found is by Jaccard (1908), and we shall therefore refer to it as the coefficient of Jaccard, S_J. It is clear that $S_J \to 0$ as $n_{JK}/u \to 0$, and that as $u \to 0$, $S_J \to 1$. In the latter case $n_J = n_K = n_{JK}$. The coefficient of Jaccard omits consideration of negative matches. In its class it is the simplest of the coefficients.

j

	$+J$	$-J$	
$+K$	*a*	*b*	(K)
$-K$	*c*	*d*	(k)
	(J)	(j)	N

2. $2a/(2a+b+c)$

This coefficient is probably among the oldest in the literature; it specifies the ratio between the number of characteristics common to two elements and the arithmetic mean of the numbers possessed by each. It is monotonic with the coefficient $a/(a+b+c)$, used by Sneath for the purpose of excluding double-negative matches; the intention

Fig. 4. A brief history of different textual and algebraic expressions of the Jaccard index. **a.** The first occurrence in Jaccard (1907, p. 962), **b.** the first version in English (Jaccard 1912, p. 39), **c.** Jaccard index was still “defined” by an example by Braun-Blanquet (1932, p. 363), **d.** the first mathematical formula (Francey 1941, p. 298), **e.** graphical illustration by Sneath (1957, p. 202), **f.** the formula of Whittaker & Fairbanks (1958, p. 54), **g.** set-theoretical definition by Tanimoto (1958, p. 5), **h.** description of the formula by Pignatti & Mengarda (1962, p. 216), **i.** denotation based on the 2×2 contingency table (Sokal & Sneath 1963, p. 133), **j.** the use of symbols *a, b, c,* and *d* as suggested by Williams & Dale (1965, p. 36 and p. 49).

Later, thanks to Goodall (1973) and Sneath & Sokal (1973), this notation and the term *Jaccard index* have become widely known in statistical ecology and numerical taxonomy, respectively. A rapid check of most influential textbooks and review papers of vegetation ecology demonstrates that Jaccard index has been treated as a similarity coefficient in the form $S = a / (a + b + c)$ and, less commonly, in dissimilarity form $DIS = (b + c) / (a + b + c)$ as well. Since the coefficient has been used in a very wide variety of disciplines, it is not surprising that several alternatives continue to exist and even new versions arise. For example, Verma & Aggarwal (2020) list five different, set theoretical alternatives, one of which being identical to Tanimoto's ratio.

Irrespective of mathematical formalism, as said, the index has been widely known not only in vegetation ecology but also in computer science, genomics, humanities, and other fields in which data may take binary (presence/absence) form. Widespread usage was greatly facilitated by commercial ordination and cluster analysis packages: practically all of them offer the option of the index for calculating (dis)similarity. In the Web of Science database, which goes back to 1975, the search terms "Jaccard index" and "Jaccard coefficient" appear in the title of 18 articles, and in the abstract or keywords of 1155 papers. Jaccard's early works from 1901-1910 have been cited by at least 7000 times, so they have become true citation classics. Remarkably, the citing papers are not always mere applications. The index was incorporated by Gower (1971) into his general coefficient of similarity. Being the ratio of the intersection and the union of two sets, the coefficient was chosen by Feoli & Lagonegro (1979) to maximize the monothetic criterion in clustering via intersection analysis. The mathematical and statistical properties of Jaccard's formula were evaluated by Gower & Legendre (1986), Li (2015), Chung & al. (2019), Kosub (2019) and Verma & Aggarwal (2020), among others. Most importantly, it has been shown by several authors that several coefficients developed to abundance data reduce to Jaccard similarity (Ruzicka index and the similarity ratio) or Jaccard dissimilarity (Marczewski-Steinhaus coefficient) in the binary case.

Dismantling the coefficient

Jaccard index did not remain intact, its components were modified or partitioned in several ways to exhaust more information and to increase interpretability of results. More precisely, only parameters b and c have been subject to change in two conceptual schemes in ecology since there is not much to do with parameter a reflecting absolute agreement or overlap.

Incorporating taxonomic, phylogenetic or functional distinctness

Jaccard index, just like all other (dis)similarity coefficients developed for presence-absence data consider every species (attribute, in general) equally important. Izsák & Price (2001) raised first the idea that the taxonomic relationships among species should also be considered in calculating similarity. They suggested to redefine the Sörensen index ($2a/(2a + b + c)$) with parameters b and c diminished according to the position of the nearest differential species in the Linnaean hierarchy. Species i present in site X and absent from site

Y contributes to the value of b by 1 only if it is separated from all species of site Y at the maximum rank in the entire sample (e.g., if it is a fern in site X, whereas site Y has only angiosperms which is a phylum-level separation in the Linnaean system). In all other cases, these contributions are proportionally smaller depending on the taxonomic distinctness (for example, 0.2 at genus, 0.4 at family, 0.6 at order, and 0.8 at class level) of species i from the closest relative species present in site Y. That is, b as well as c are replaced by the sum of taxonomic distinctness values, leading to an increased similarity (decreased dissimilarity) between the sites. Ricotta & al. (2016b) proposed that any other meaningful form of distinctness between species may also be considered in modulating b and c, so that functional and phylogenetic relationships may also be incorporated in the calculations. More formally, the Jaccard dissimilarity index is rewritten as

$$DIS' = \frac{B+C}{a+b+c} \qquad \text{where} \qquad B = \sum_{i \in X, i \notin Y} \min_{j \in Y}\{d_{ij}\} \text{ and } C = \sum_{j \in Y, j \notin X} \min_{i \in X}\{d_{ij}\}$$

In the above equations, $0 \leq d_{ij} \leq 1$ represents the taxonomic, phylogenetic or functional distinctness between species i and j, whereas a, b and c in the denominator retain their original meaning. It follows that $A = a + b + c - B - C$ is the absolute taxonomic, phylogenetic or functional overlap of the two sites. This general scheme applies to all other presence-absence resemblance coefficients and the modified forms can be used in ordinations and classifications that are not taxon- (mostly species-) based.

Beta diversity and its partitioning

The dissimilarity form of the index ($DIS = (b + c) / (a + b + c)$) was considered first by Colwell & Coddington (1994) as the β-diversity of a pair of sample units, starting a new field of its application and new possibilities of interpretation[3]. Two years later, Williams (1996) proposed another measure with the same denominator, $\min\{b, c\}/(a + b + c)$ for the same purpose. Since the latter coefficient is not bounded between 0 and 1, which is otherwise the case for dissimilarity coefficients, Cardoso & al. (2009) suggested to multiply the numerator by 2. The index thus obtained reflects the relative proportion of the number of species that are replaced by each other in a comparison of two sites. Podani & Schmera (2011) have shown that this is only part of beta diversity, a measure of relative species turnover, whereas the other component is $|b - c|/(a + b + c)$ which was called the relative richness difference. These two terms together comprise Jaccard dissimilarity. Podani and Schmera called attention to the obvious relationship:

$$1 = a/(a+b+c) + |b-c|/(a+b+c) + 2\min\{b,c\})/(a+b+c) = S + D + R.$$

In words, similarity, richness difference and replacement, if relativized by the total number of species, always add to 1, and as such, these three components can be illustrated using a 2D simplex diagram, an equilateral triangle. In this, a pair of sites is represented by a point, its position within the triangle depending on the three additive components. For

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[3] In fact, Whittaker (1960) was the first to suggest the use of a presence-absence dissimilarity coefficient (again, the Sörensen index) as a measure of beta diversity.

example, if $S = D = R = 0.33$, then the corresponding point will be in the centroid of the plot. If the two sites are identical in species composition ($b + c = 0$) then $S = 1$ and the point will be on the S, bottom right corner of the triangle. If $a = 0$ and $b = c$, there is only turnover and the point will fall onto R, the top corner of the triangle. The third corner, D, is taken when richness difference is the maximum, i.e. $a = b = 0$, which means that one site is empty, a situation usually avoided deliberately during vegetation surveys (e.g., pure sand or rock surfaces). In addition to the corners, the three edges are also meaningful. A point falls onto the left edge if $S = 0$, so $D + R = 1$, indicating maximum beta diversity. If there is no replacement, i.e. $\min\{b,c\} = 0$, then $S + D = 1$ and one site is nested within the other (with the condition that $a > 0$) and the point will be on the bottom edge. If the third combination of the two components, $S + R$ is 1, then there is complete richness agreement and the point falls onto the right edge (see Fig. 5a for illustration). In general, the distance of a point from a corner is inversely proportional to the value of the respective index.

An advantage of the SDR simplex approach is its ability to demonstrate pattern in presence/absence data matrices. The coefficients are calculated for all pairs of objects, and the shape of the point cloud in the SDR plot will be informative about internal data structure. For example, if the matrix is entirely nested, then all pairs of objects (columns) will exhibit zero replacement, and all points will fall onto the nestedness side (Fig. 5b). In case of high beta diversity, the point cloud will be near the left edge. Data for the pairwise comparisons presented by Jaccard (1901a) for ten localities in the Swiss Alps allowed to calculate the S, D and R scores, and the results – after a latency of 120 years! – are shown in Fig. 5c. Almost all points (each of them representing a pair of localities) fall into the upper third of the triangle demonstrating that replacement (species turnover) is the dominant process in affecting beta diversity the alpine flora at the geographic scale used by Jaccard: the mean of 45 R values is 0.52. The second major feature is overall similarity, with $\bar{S} = 0.32$ while richness difference is relatively small, $\bar{D} = 0.16$.

This agrees well with the ordination and classification results (Fig. 3c-d): the ten points are evenly arranged in the ordination space and the fusion levels in the dendrogram fall into a narrow range of high dissimilarity values. Similar result is obtained at an even higher geographical level. If we compare the flora of the 20 regions if Italy based on a total of more than 6000 species (Pignatti 1982; Conti & al. 2005), we get a point cloud more closely attached to the richness agreement side of the plot, with a balanced contribution by replacement and similarity (Fig. 5d). This pattern is typical when the flora of the localities follows a gradient, in this case a biogeographical one largely from north to the south, with the alpine regions at one end and the two big islands (Sicily and Sardinia) at the other.

Combined approach

A most natural suggestion is to combine the above two approaches by constructing a simplex diagram based on the Jaccard coefficient as modified to incorporate taxonomic, phylogenetic or functional distinctness of species (Podani & al. 2018a). In this way, the conceptual scheme developed for taxon-based data (i.e., species by localities matrices) is extended to three other areas of application. In addition to raw data, we also need three species by species matrices of distinctness values standardized to the range [0,1]. This condition must satisfy for the modified Jaccard index to allow comparison of data structures

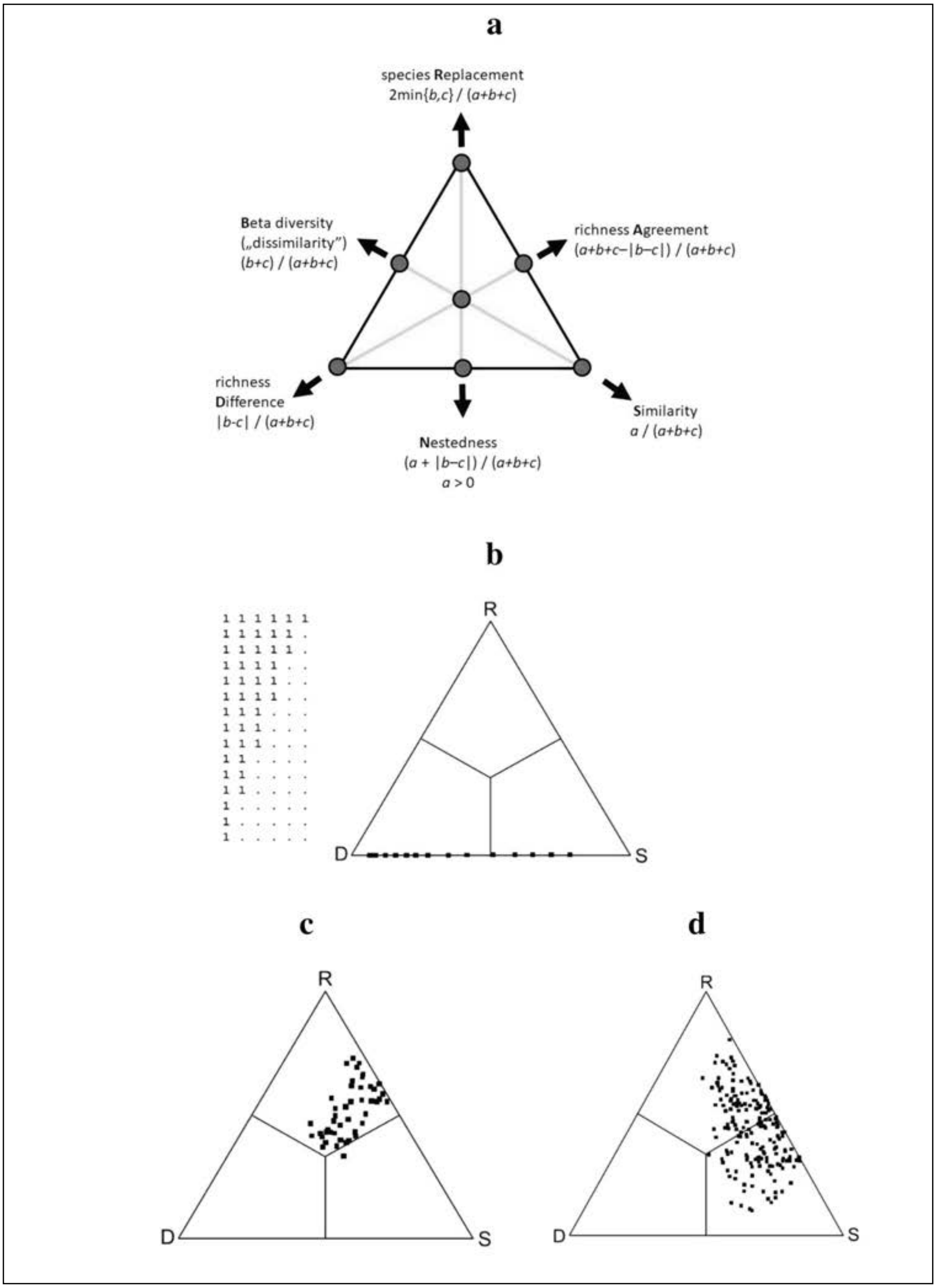

Fig. 5. **a.** Components of the SDR simplex diagram (with explanations in text); **b.** the SDR simplex plot for an artificial data matrix with complete nestedness; **c.** the SDR simplex for the alpine flora data of Jaccard (1901a); **d.** the SDR simplex for the flora of 20 Italian regions.

based on four different schemes. The approach is illustrated using plot data from pioneer successional stages of alpine meadows above the timberline in the Aosta Valley, Italian Alps (Ricotta & al. 2016b). The simplex diagrams (Fig. 6a-d) demonstrate relatively high beta diversity at the species level, with replacement as the dominating background factor. Its average $\bar{S} = 0.52$ is almost identical to the value presented above for Jaccard's data from the Swiss Alps even though the scale of the two surveys is radically different! In this case, however, the point cloud has different shape, many pairs of plots show remarkable similarity and richness difference as well – reflecting extreme heterogeneity of sample plots. After switching to taxonomy, similarity becomes dominant because during succession many species are replaced by close relatives in the Linnaean system. When phylogeny is accounted for, similarity is further increased because phylogenetic relationships are in fact closer than what the use of Linnaean ranks forces upon the system. The points become highly concentrated near the S corner when functional distinctness is considered in calculating the Jaccard indices. This means that species in the alpine meadow differ very little functionally along the entire successional sere. We found similar trends in SDR simplices in further two cases (rock grasslands, coastal marshes) and therefore put forward the *beta-redundancy hypothesis*: beta diversity of ecological communities decreases in the following order: taxon (species)-level – taxonomic – phylogenetic – functional. Further studies in a wide range of community types would be welcome to confirm this proposition.

Multiple comparison of several data matrices

The SDR diagrams reflect internal structure of presence-absence data matrices, offering the possibility for comparing data matrices indirectly, through the comparison of point patterns within the plots (Podani & al. 2018b). Such comparisons are necessary to extract information on background factors that influence community pattern or beta diversity at different ecological or biogeographical scales. The summary of the method is as follows. Each diagram is dissected into 100 small equilateral triangles (inset in Fig. 7), within which the number of points is calculated. Then, these numbers are converted into relative frequencies, and two simplex diagrams are compared by the Manhattan distance function based on the corresponding relative frequency values. The advantage of the approach is that two matrices can be compared even though they differ in the number of rows and columns.

It is illustrated by presence-absence data of various animal groups of animals (butterflies, centipedes, isopods, reptiles, land snails, tenebrionids) from two groups of islands in the Mediterranean Sea (Anatolian Islands and the Cyclades). Sources of information are described in the Electronic Supplement to Podani & al. (2018a). Data matrices pertaining to the 12 combinations of animal and island groups were compared in every possible pair, providing a distance matrix of data matrices, which was in turn subjected to group average clustering (Fig. 7). The dendrogram reveals succinctly the similarities and dissimilarities in the distributional pattern of these animal groups, as influenced by their dispersal ability, local extinction, and past colonization through land bridges between islands. Note, for example, the closeness of the two butterfly faunas, as well as that of the land snail faunas, and the disparity of the reptile composition of the two island groups.

Bipartite networks

All applications of the Jaccard index discussed above are based on standard species by localities presence-absence matrices. The coefficient also applies to computing interaction similarity in pollination networks as suggested by Olesen & al. (2007). Consequently, the SDR scheme can also be extended and generalized to explore and quantify structure in any type of bipartite ecological networks (Podani & al. 2014). In these systems, the mutualistic relationships between two groups of organisms are summarized by data matrices in which 1 indicates the presence of mutualism (link in the graph), and 0 refers to absence (no link). In addition to plant–pollinator schemes, further examples are host–parasite, plant–disperser or plant–ant networks (Bascompte 2009).

Dissimilarities between all species pairs in either group are calculated based on their interactions with the other group using the Jaccard index, and then decomposed into additive fractions. These components are derived mathematically in the same way as for regular presence-absence data, while the meaning of the components is different, for example, species replacement changes to link replacement (Fig. 8). An advantage of the approach is that interaction pattern is visualized better by the SDR plots than by bipartite graphs or the data matrices themselves, especially if the data set is large.

The method is illustrated using plant–pollinator network data taken by Bartomeus & al. (2008) in coastal plant communities in Catalonia to compare undisturbed sites with those invaded by either *Carpobrotus affine* or *Opuntia stricta,* both species with large, attractive flowers. The data sets were obtained from the Interaction Web DataBase (https://iwdb.nceas.ucsb.edu). The numbers of plant species versus pollinator taxa were 27

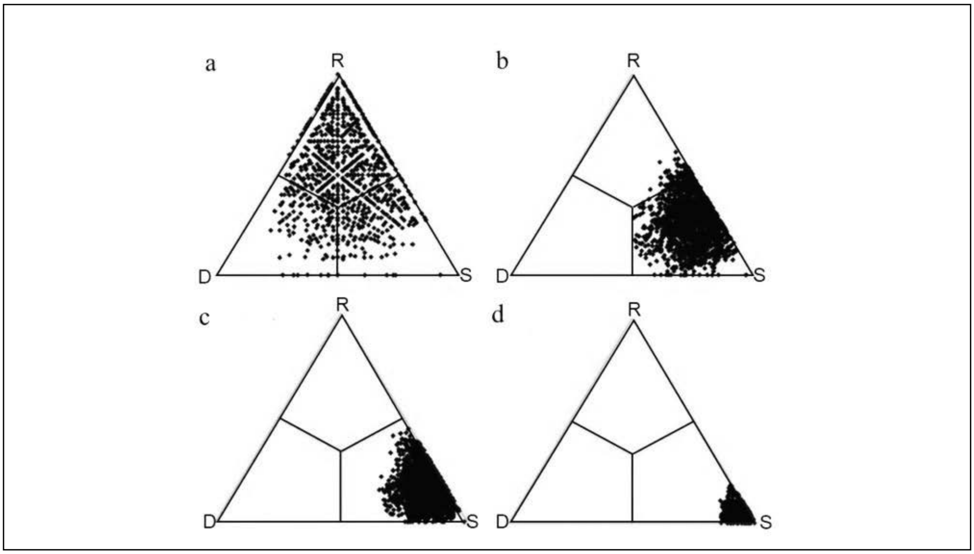

Fig. 6. SDR simplex diagrams for the alpine meadow vegetation from the Italian Alps. **a.** species, **b.** taxonomic, **c.** phylogenetic, **d.** functional. Redrawn after Podani & al. (2018b).

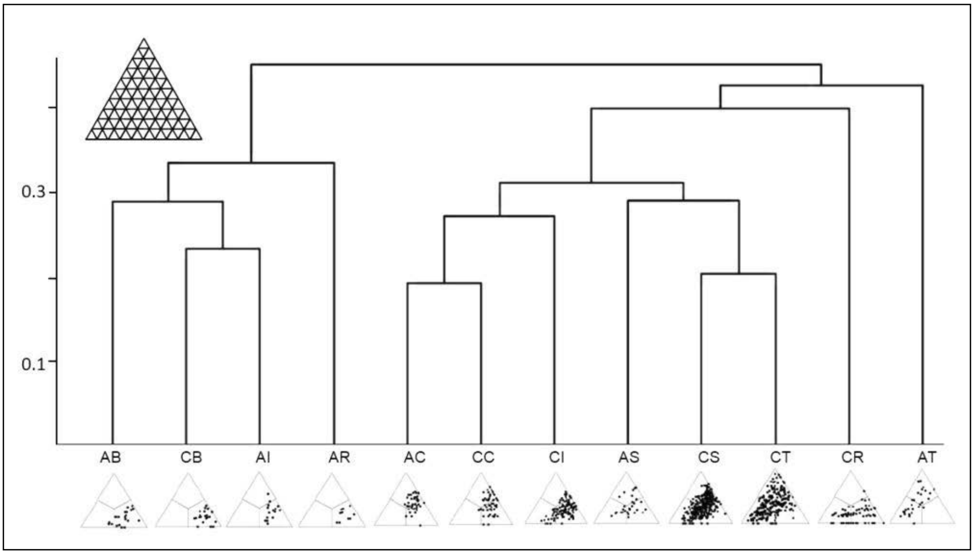

Fig. 7. Classification of biogeographical presence-absence data matrices from two groups of Mediterranean islands (first letter: A-Anatolian islands, C-Cyclades) for six taxonomic groups (second letter: B-butterflies, C-centipedes, I-isopods, R-reptiles, S-land snails, T-tenebrionids) (modified from Podani & al. 2018a). SDR simplex diagrams pertaining to each data matrix are shown on bottom. Inset: ternary plot subdivided into 100 equilateral triangles.

× 85, 18 × 70 and 13 × 47, respectively. Although the number of points in the plots differ and many of them overlap one another, the decrease of pollinator interaction diversity in that direction is clear from the SDR plots (Fig. 9), confirming the current hypothesis on the influence of invasive plants. Numerically, the fractions are 91%, 88% and 86%, respectively. Correspondingly, isolatedness of pollinators (i.e., when two species have no pollinated plant in common) also decreases in this direction (20%, 18% and 14%) while nestedness increases (22%, 30% and 29%) when spectacular invader plants occur in the community, which certainly have homogenizing effect on the plant – pollinator networks.

Conclusions

Jaccard never published a bona fide mathematical formula, an equation with symbols, for his coefficient; he introduced his index by examples and later presented a ratio with verbal terms. Nevertheless, the correct reference to the first use of the method is Jaccard (1901a). In the past century, the coefficient appeared in various forms with different systems of algebraic symbols. It seems now that the use of the parameters of the 2 × 2 contingency table, namely *a, b*, and *c* has been generally accepted and used.

Although originally suggested to compare two items described by the number of shared and differentiating attributes, the index offers many other opportunities. Quantities reflecting

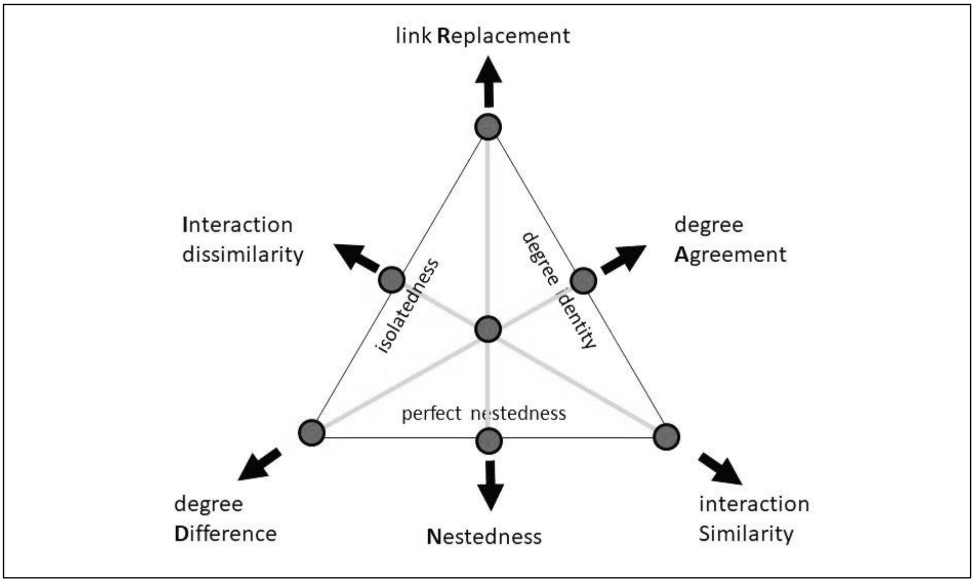

Fig. 8. Adapting the SDR simplex to bipartite interaction networks.

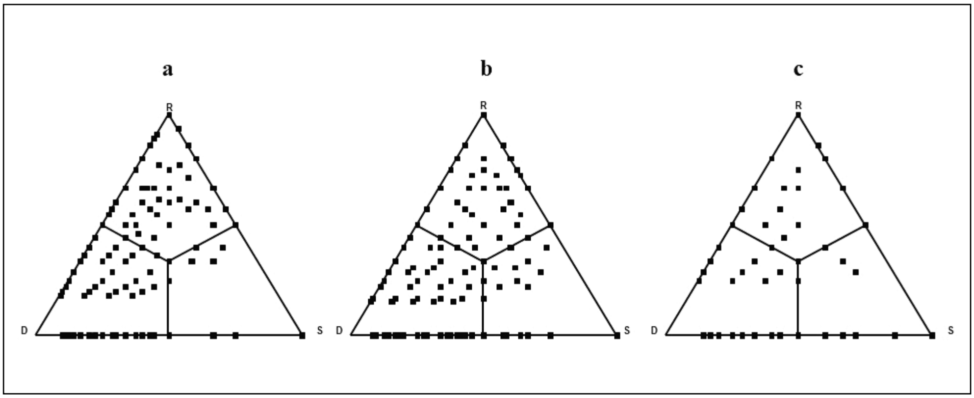

Fig. 9. SDR simplex plots for insects in plant-pollinator networks of uninvaded (**a**), *Carpobrotus*-invaded (**b**) and *Opuntia*-invaded (**c**) Mediterranean coastal plant communities.

disagreement between the two items (i.e., b and c) can be modified to consider taxonomic, phylogenetic or functional distinctness between species in calculating dissimilarity between sites. Furthermore, $b + c$ can be decomposed into additive components, $|b–c| + 2\min\{b,c\}$ which may be used in relativized forms to explore pattern in presence-absence data via twodimensional simplex diagrams. In this way, well-known ecological phenomena, such as beta diversity, nestedness, similarity, richness difference and species turnover are integrated into the same conceptual scheme. These two techniques may be combined into a single, multifaceted approach to the evaluate data structure in a more complex way. The most indirect use of the Jaccard coefficient is in the comparison of data matrices of different size, which reduces this problem to the comparison of point patterns within the ternary plots. Another promising field of application is the study of bipartite ecological networks, in which links between two sets of organisms (usually species) correspond to presence – allowing generalization of the SDR simplexes to the analysis of these complex ecological systems.

References

Bartomeus, I., Vilà, M. & Santamaria, L. 2008: Contrasting effects of invasive plants in plant-pollinator networks. – Oecologia **155:** 761-770. https://doi.org/10.1007/s00442-007-0946-1

Bascompte, J. 2009: Mutualistic networks. – Frontiers Ecol. Environ. **2009:** 7. https://doi.org/10.1890/080026

Braun-Blanquet, J. 1927: Pflanzensoziologie. – Wien.

— 1932: Plant Sociology. – Translated, revised, and edited by Fuller, G. D. & Conard, H. S. – New York and London.

Cardoso, P., Borges, P. A. V. & Veech, J. A. 2009: Testing the performance of beta diversity measures based on incidence data: the robustness to undersampling. – Div. Distrib. **6:** 1081-1090. https://doi.org/10.1111/j.1472-4642.2009.00607.x

Chung, N. C., Miasojedow, B., Startek, M. & Gambin, A. 2019: Jaccard/Tanimoto similarity test and estimation methods for biological presence-absence data. – BMC Bioinformatics **20:** 644. https://doi.org/10.1186/s12859-019-3118-5

Colwell, R. K. & Coddington, J. A. 1994: Estimating terrestrial biodiversity through extrapolation. – Philos. Trans. Roy. Soc., London B **345:** 101-118.

Conti, F., Abbate, G., Alessandrini, A. & Blasi, C. (eds) 2005: An annotated checklist of the Italian vascular flora. – Roma.

Feoli, E. & Lagonegro, M. 1979: Intersection analysis in phytosociology: computer program and application. – Vegetatio **40:** 55-59. https://doi.org/10.1007/bf00052016

Francey, P. 1941: Le coefficient de communauté de P. Jaccard. – Bull. Soc. Vaudoise Sci. Nat. **61:** 297-316.

Frey-Wyssling, A. 1944: Paul Jaccard. 1868-1944. – Verh. Schweiz. Naturf. Ges. **124:** 339-346.

Goodall, D. W. 1973. Sample similarity and species correlation. – Pp. 107-156 in: Whittaker, R. H (ed.), Ordination and Classification of Communities. – The Hague.

Gower, J. C. 1971: A general coefficient of similarity and some of its properties. – Biometrics **27:** 857-871.

— & Legendre, P. 1986: Metric and Euclidean properties of dissimilarity coefficients. – J. Classification **3:** 5-48.

Izsak, C. & Price, A. R. G. 2001: Measuring β-diversity using a taxonomic similarity index, and its relation to spatial scale. — Marine Ecol. Progr. Ser. **215:** 69-77. https://doi.org/10.3354/meps215069

Jaccard, P. 1894: Recherches embryologiques sur l'*Ephédra helvetica* C. A. Meyer. – Bull. Soc. Vaudoise Sci. Nat. **30:** 46-84.

— 1895: Considérations critiques sur les bases du darwinisme appliquées au monde vegetal. – Bull. Soc. Vaudoise Sci. Nat. **31:** 295-311.

— 1900: Contribution au problème de l'immigration post-glaciaire de la flore alpine: étude comparative de la flore alpine du massif de Wildhorn, du haut bassin du Trient et de la haute vallée de Bagnes. – Bull. Soc. Vaudoise Sci. Nat. **36:** 87-130.

— 1901a: Distribution de la flore alpine dans le Bassin des Dranses et dans quelques régions voisines. – Bull. Soc. Vaudoise Sci. Nat. **37:** 241-272.

— 1901b: Étude comparative de la distribution florale dans une portion des Alpes et du Jura. – Bull. Soc. Vaudoise Sci. Nat. **37:** 547-579.

— 1902a: Lois de distribution florale dans la zone alpine. – Bull. Soc. Vaudoise Sci. Nat. **38:** 69-155.

— 1902b: Distribution comparée de la flore alpine dans quelques régions des Aples occidentales et orientales. – Bull. Murithienne Soc. Valaisanne Sci. Nat. **31:** 81-92.

— 1902c: Gesetze der Pflanzenvertheilung in der alpinen region: auf Grund statistich-floristischer Untersuchungen. – Flora **90:** 349-377.

— 1902d: Vergleichende Untersuchungen über die Verbreitung der alpinen Flora in einigen Regionen der westlichen und östlichen Alpen. – Jahresb. Naturf. Ges. Graubünden **45:** 121-132.

— 1907: La distribution de la flore dans la zone Alpine. – Rev. Gén. Sci. Pures Appl. **18(23):** 961-967.

— 1908: Nouvelles recherches sur la distribution florale. – Bull. Murithienne Soc. Valaisanne Sci. Nat. **44:** 223-270.

— 1912: The distribution of the flora in the Alpine zone. – New Phytologist **11(2):** 37-50. https://doi.org/10.1111/j.1469-8137.1912.tb05611.x [English translation of Jaccard (1907)].

— 1926: Le coefficient générique et le coefficient de communauté dans la flore marocaine. – Mém. Soc. Vaudoise Sci. Nat. **2:** 385-403.

Kosub, S. 2019: A note on the triangle inequality for the Jaccard distance. – Pattern Recognition Lett. **120:** 36-38. https://doi.org/10.1016/j.patrec.2018.12.007

Li, W. 2015: Estimating Jaccard index with missing observations: a matrix calibration approach. – In: Cortes, C., Lawrence, N., Lee, D., Sugiyama, M. & Garnett, R. (eds), Advances in Neural Information Processing Systems **28:** 1-7.

Maillefer, A. 1928: Les courbes de Willis: répartition des espèces dans les genres de différente etendue. — Bulletin de la Société Vaudoise des Sciences Naturelles **56:** 617-632.

— 1929: Le Coefficient générique de P. Jaccard et sa signification. — Mémoires de la Société Vaudoise de Sciences Naturelles **3:** 113-183.

Olesen, J. M., Bascompte, J., Dupont, Y. L. & Jordano, P. 2007: The modularity of pollination networks. – Proc. Nat. Acad. Sci. USA **104:** 19891-19896. https://doi.org/10.1073/pnas.0706375104

Pignatti, S. 1982: Flora d'Italia 1-3. — Bologna.

— & Mengarda, F. 1962: Un nuovo procedimento per l'elaborazione delle tabelle fitosociologiche. – Accad Naz. Lincei. Rend. Classe Sci. Fis. Mat. Nat., ser. 8, **32(2):** 215-222.

Podani, J. & Schmera, D. 2011: A new conceptual and methodological framework for exploring and explaining pattern in presence-absence data. – Oikos **120:** 1625-1638. https://doi.org/10.1111/j.1600-0706.2011.19451.x

—, Jordán, F. & Schmera, D. 2014: A new approach to exploring architecture of bipartite (interaction) ecological networks. – J. Complex Networks **2:** 168-186. https://doi.org/10.1093/comnet/cnu002

—, Pavoine, S. & Ricotta, C. 2018a: A generalized framework for analyzing taxonomic, phylogenetic, and functional community structure based on presence–absence data. – Mathematics **6(11):** 250. https://doi.org/10.3390/math6110250

—, Ódor, P., Fattorini, S., Strona, G., Heino, J. & Schmera, D. 2018b: Exploring multiple presence-absence data structures in ecology. – Ecol. Modelling **383:** 41-51. Electronic supplement available at: https://ars.els-cdn.com/content/image/1-s2.0-S0304380018301674-mmc1.doc

Ricotta, C., Podani, J. & Pavoine, S. 2016a: A family of functional dissimilarity measures for presence and absence data. – Ecol. Evol. **6(15):** 5383-5389. https://doi.org/10.1002/ece3.2214
—, Luzzaro, A., Pierce, S., Ceriani, R. M. & Cerabolini, B. 2016b: Measuring the functional redundancy of biological communities: A quantitative guide. – Meth. Ecol. Evol. **7:** 1386-1395.
Sneath, P. H. A. 1957: The application of computers to taxonomy. – J. Gen. Microbiol. **17:** 201-226.
— & Sokal, R. R. 1973: Numerical Taxonomy. – San Francisco.
Sokal, R. R. & Sneath, P. H. A. 1963: Numerical Taxonomy. – San Francisco.
Tanimoto, T. T. 1958: An elementary mathematical theory of classification and prediction. Internal IBM Technical Report. – New York.
Verma, V. & Aggarwal, R. K. 2020: A comparative analysis of similarity measures akin to the Jaccard index in collaborative recommendations: empirical and theoretical perspective. – Social Network Analysis Mining 10, Article number: 43. https://doi.org/10.1007/s13278-020-00660-9
Whittaker, R. H. 1960: Vegetation of the Siskiyou Mountains, Oregon and California. – Ecol. Monogr. **30:** 279-338.
— & Fairbanks, C. W. 1958: A study of plankton copepod communities in the Columbia Basin, Southeastern Washington. – Ecology **39:** 46-65.
Williams, C. B. 1949: Jaccard's generic coefficient and coefficient of floral community, in relation to the logarithmic series and the index of diversity. – Ann. Bot. **13(49):** 53-58.
Williams, P. H. 1996: Mapping variations in the strength and breadth of biogeographic transition zones using species turnover. – Proc. Roy. Soc., London B, **263:** 579-588. https://doi.org/10.1098/rspb.1996.0087
Williams, W. T. & Dale, M. B. 1965: Fundamental problems in numerical taxonomy. – Advances Bot. Res. **2:** 35-68.

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Article

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Introduction to the study of the bryological flora of the Batumi Botanical Garden (Georgia)

Abstract

Campisi, P., Dia, M. G. & Varshanidze, D.: Introduction to the study of the bryological flora of the Batumi Botanical Garden (Georgia). — Fl. Medit. 31 (Special Issue): 125-130. 2021. — ISSN: 1120-4052 printed, 2240-4538 online.

A preliminary list of 22 bryophytes growing in the Batumi Botanical garden is provided. From chorological point of view, temperate and boreo-temperate taxa prevail while with regard to ecological behaviour, mesophilous taxa are the most numerous and with respect to light requirements equivalently sciaphilous and eliophilous taxa are represented The mosses *Fissidens dubius* and *Cyrtomnium hymenophylloides* are recorded for the first time in Georgia.

Key words: Bryophytes, Botanical gardens, Caucasus.

Introduction

In 2018 one of the authors (D. V.), to introduce herself to the taxonomic study of Bryophytes, particularly widespread in Georgia, where she lives and works (at the Botanical Garden of Batumi), asked to attend the Bryology Laboratory at the University of Palermo. Thanks to the support of the “International Foundation pro Herbario Mediterraneo” the visit was possible. As study material, a small collection of bryophytes in the Botanical Garden of Batumi, on the shores of the Black Sea, was recommended. The specimens for the formative experience were collected in several sectors of the extensive Botanical Garden.

In this contribution we report the list of taxa surveyed on the basis of the collections carried out.

The study, although not very representative of the richness and floristic diversity of the extensive Georgian Botanical Garden, allowed to introduce to the collection and study of bryophytes and moreover to provide some new data for the Georgian bryoflora.

Notes on the collection site of the material studied

Officially open in 1912, the Batumi Botanical Garden, with its current 108 hectares, is the main botanical garden in the Caucasus. Up today 1,800 taxa are cultivated in this site that is of very considerable interest not only from a horticultural and botanical research point of view, but also as an important green area for the entire city. It extends from sea level up to 220 m a.s.l. and hosts a unique dendroflora of many different phytogeographic regions. The climate of the site is characterized by highly humid and warm subtropical conditions with average rainfall between 2400 and 2700 mm per year, air humidity around 70-80% and average temperature around 13.8 - 14.4 °C.

In order to acquire data on the biodiversity of bryophytes that spontaneously grow on the different substrates of the botanical garden, some collections of samples of bryophytes were carried out.

The following list of taxa represents an initial contribution of knowledge of the brioflora of the Batumi botanical garden also to provide useful data for the characterization of the floristic biodiversity of the entire urban area, in consideration of the notable expansion with consequent environmental transformations occurred in the last century (Mikeladze &, Sharabidze, 2020). Moreover, this work contribute to the knowledge of bryoflora of Georgia that, as reported in the Sixth National Report to the Convention on Biological Diversity 2014-2018, according to the checklists of Chikovani, & Svanidze (2004) and Bakalin & al. (2016), is composed of 675 species and 152 intra-specific taxa.

Materials and methods

The specimens were collected in the sites indicated in Fig. 1. These sites (nn. 1-11) are located in the Phytogeographical sector of “Transcaucasia humid subtropics” and one site (n. 12) in “North American” phytogeographical sector.

The list of taxa, in alphabetical order, is shown in Table 1 where for each taxon taxonomic data as well as chorological and ecological behavior concerning light and moisture are reported. For the nomenclature of taxa and taxonomy we have followed Hodgetts & al. (2020) while for the geographic distribution and ecological behavior Hill & al (2007) have been taken into account. As regards light, values range from 0 (plant in darkness) to 9 (plant in full light); about moisture, the scale varies from 1 (extreme dryness) to 12 (normally submerged).

The specimens are deposited at the *Herbarium Mediterraneum Panormitanum* (PAL) and at the Herbarium of the Botanical Garden of Batumi (BATU).

Results and discussion

This is a first contribution to the knowledge of the brioflora of the Batumi Botanical Garden, never recorded so far, which highlights the presence in this site of some interesting taxa. In particular, the presence of two moss so far not reported for

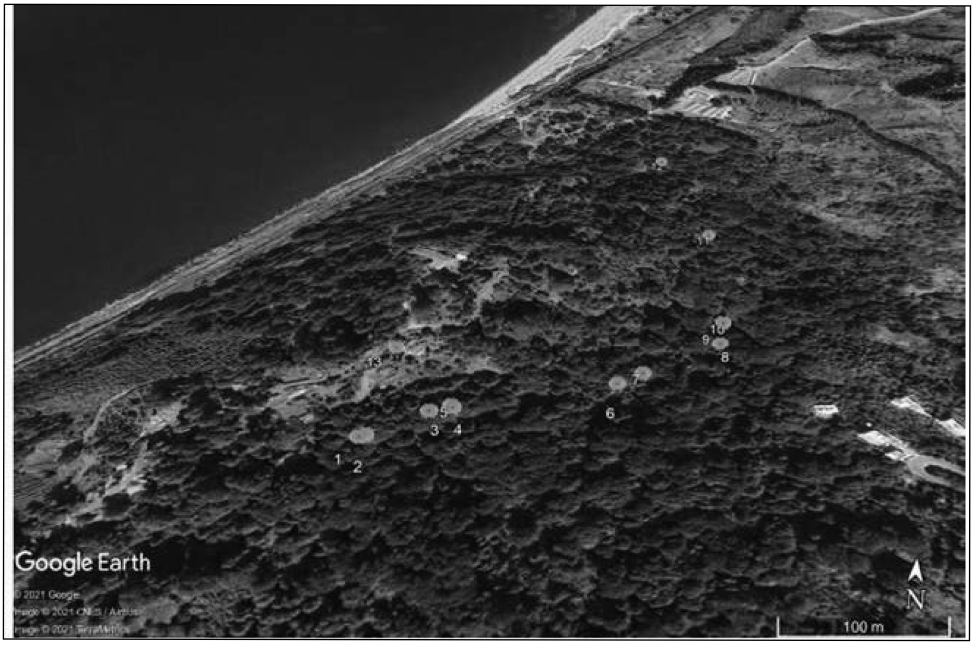


Fig. 1. Localization of sampling sites in the area of Batumi Botanical Garden.

Georgia is emphasized. They are *Fissidens dubius* and *Cyrtomnium hymenophylloides* (Fig. 2). This latter, known in North America and Eurasia, is a circumboreal taxon with an interesting fragmented distribution and an arctic-alpine disjunction (Blockell & al. 2009; Özdemir & Batan 2014).

Overall, a list of 22 taxa is provided, of which 2 liverworts and 20 mosses (Table 1). From a taxonomic point of view there is a clear diversification as 15 families are represented.

Most of these taxa have a temperate distribution and also boreo-temperate taxa such as *Ctenidium molluscum* are quite numerous. From the ecological point of view, an almost equivalent presence of sciaphilous and more heliophilous taxa is so far observed with a slight prevalence of these latter. Moreover, most of taxa reflect, as expected, well-drained or moist substrate conditions.

Overall, the data acquired, even if preliminary, seem to reflect the role of a floristic crossroads played by the Botanical Garden of Batumi in consideration of its geographical position, and suggest the presence of a rich brioflora. Therefore, it will certainly be of interest to acquire a better knowledge of the brioflora of this site since probably it will be, a refuge for many interesting species such as the taxa most sensitive to the effects of anthropization, as it has been evidenced for several other botanical gardens (Aiello & al. 2003; Godovičová 2017). Moreover, a census of bryoflora will be also useful to monitoring the possible floristic changes more or less correlated to urban transformations of Batumi city.

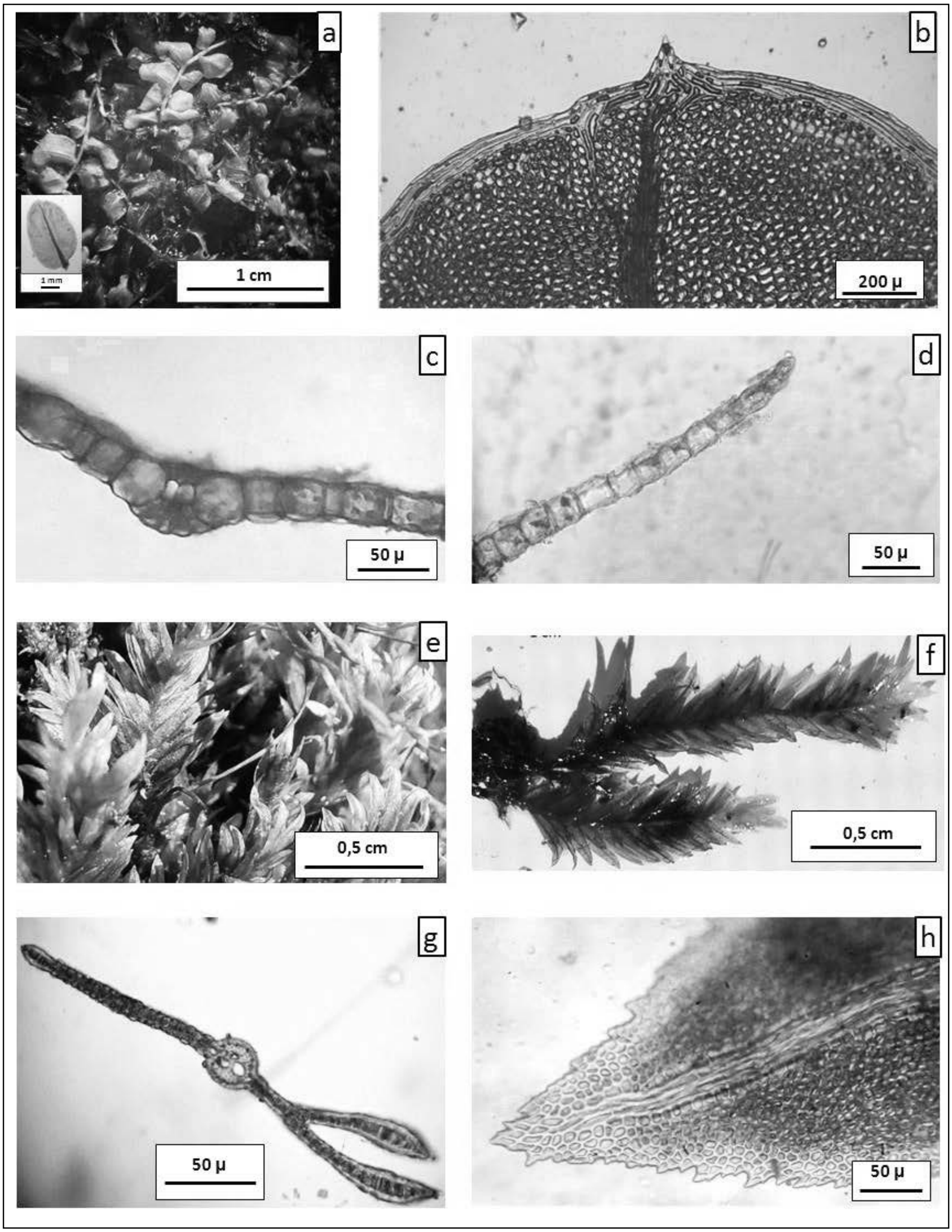
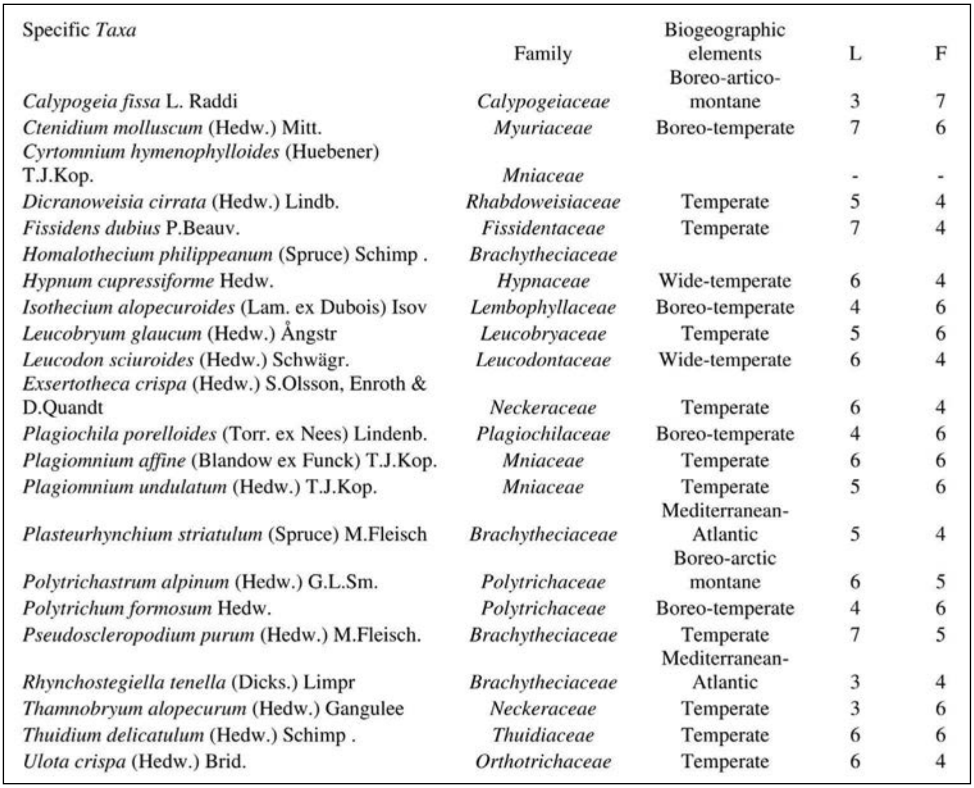


Fig. 2. Colonies and microscopic details from specimens of *Cyrtomnium hymenophylloides* (a-d) and *Fissidens dubius* (e-h) of Batumi Botanical Garden. a: plants with a leaf in detail; b: leaf apex; c and d: leaf transversal section; e and f: plants; g: leaf transversal section; h: leaf apex.

Table 1. List of taxa and their taxonomical, chorological and ecological features. L: Ellenberg value for light; F: Ellenberg value for moisture.



Specific *Taxa*	Family	Biogeographic elements	L	F
Calypogeia fissa L. Raddi	*Calypogeiaceae*	Boreo-artico-montane	3	7
Ctenidium molluscum (Hedw.) Mitt.	*Myuriaceae*	Boreo-temperate	7	6
Cyrtomnium hymenophylloides (Huebener) T.J.Kop.	*Mniaceae*		-	-
Dicranoweisia cirrata (Hedw.) Lindb.	*Rhabdoweisiaceae*	Temperate	5	4
Fissidens dubius P.Beauv.	*Fissidentaceae*	Temperate	7	4
Homalothecium philippeanum (Spruce) Schimp .	*Brachytheciaceae*			
Hypnum cupressiforme Hedw.	*Hypnaceae*	Wide-temperate	6	4
Isothecium alopecuroides (Lam. ex Dubois) Isov	*Lembophyllaceae*	Boreo-temperate	4	6
Leucobryum glaucum (Hedw.) Ångstr	*Leucobryaceae*	Temperate	5	6
Leucodon sciuroides (Hedw.) Schwägr.	*Leucodontaceae*	Wide-temperate	6	4
Exsertotheca crispa (Hedw.) S.Olsson, Enroth & D.Quandt	*Neckeraceae*	Temperate	6	4
Plagiochila porelloides (Torr. ex Nees) Lindenb.	*Plagiochilaceae*	Boreo-temperate	4	6
Plagiomnium affine (Blandow ex Funck) T.J.Kop.	*Mniaceae*	Temperate	6	6
Plagiomnium undulatum (Hedw.) T.J.Kop.	*Mniaceae*	Temperate	5	6
Plasteurhynchium striatulum (Spruce) M.Fleisch	*Brachytheciaceae*	Mediterranean-Atlantic	5	4
Polytrichastrum alpinum (Hedw.) G.L.Sm.	*Polytrichaceae*	Boreo-arctic montane	6	5
Polytrichum formosum Hedw.	*Polytrichaceae*	Boreo-temperate	4	6
Pseudoscleropodium purum (Hedw.) M.Fleisch.	*Brachytheciaceae*	Temperate	7	5
Rhynchostegiella tenella (Dicks.) Limpr	*Brachytheciaceae*	Mediterranean-Atlantic	3	4
Thamnobryum alopecurum (Hedw.) Gangulee	*Neckeraceae*	Temperate	3	6
Thuidium delicatulum (Hedw.) Schimp .	*Thuidiaceae*	Temperate	6	6
Ulota crispa (Hedw.) Brid.	*Orthotrichaceae*	Temperate	6	4

Concluding remarks

The extensive and articulated Batumi Botanical Garden does not only host collections of vascular plants together with expressions of natural vegetation of interest to the thousands of visitors who visit it annually. Alongside the plants included in the various systems and sectors, dozens of cryptogams species live, including various species of ferns and macromycetes, the latter recognizable only when the carpophores appear. Like ferns, the numerous forms of thalli and seedlings of various species of bryophytes - liverworts and mosses in particular - are constantly evident, whose correct presentation to visitors, in a scientific garden with educational functions, can represent an important innovative element. In this perspective, having started the systematic collection on site of study material and then the corresponding identification, constitutes a start in this direction. Although quantitatively insignificant, the finds identified and presented here are evidence of the start of the project that will be carried out in collaboration between the authors. The discovery of two unpublished species for the Georgian bryological flora - *Fissidens dubius* and *Cyrtomnium hymenophylloides* - in such a limited number of analyzed reports, allows us to hypothesize the finding of other unpublished taxa, thus contributing to improve the taxonomic knowledge of the bryological flora not only of the Batumi Botanical Garden but of the whole country.

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References

Aiello, P., Campisi, P. & Provenzano, F. 2003: Diversità briofitica nell'Orto botanico di Palermo. – Quad. Bot. Amb. Appl. **14 (2003):** 203-210.

Bakalin, V., Tigishvili, K. & Arutinov, G. 2016: A new checklist of the liverworts and hornworts of Georgia (Caucasus). – Bot. Pacifica **5(1):** 69-78.

Blockeel, T. L., Passos Bastos, C. J., Bednarek-Ochyra, H., Ochyra, R., Dulin, M. V., Fovet, L., Garcia, C., Hedenäs, L., Hugonnot, V., Kırmacı, M., Koponen, T., Lebouvier, M., Martins, A., Müller, F., Sabovljević, M., Lakušić, D., Schäfer-Verwimp, A., Sérgio, C., Surina, B. & Yayintaş, Ö. T. 2009: New national and regional bryophyte records, 22. – J. Bryol. **31(3):** 201-210, doi 1179: 10. /037366809X12469790518367

Chikovani, N. & Svanidze, T. 2004: Checklist of bryophyte species of Georgia. — Braun-Blanquetia **34:** 97-116.

Godovičová, K. 2017: Bryophytes of the Botanical Garden of the Comenius University in Bratislava. – Acta Bot. Univ. Comenianae **52:** 29-34.

Hill, M. O., Preston, C. D., Bosanquet, S. D. S. & Roy, D. B. 2007: BRYOATT Attributes of British and Irish Mosses, Liverworts and Hornworts — Spreadsheet. – Huntingdon.

Hodgetts, N. G., Söderström, L., Blockeel, T. L., Caspari, S., Ignatov, M. S., Konstantinova, N. A., Lockhart, N., Papp, B., Schröck, C., Sim-Sim, M., Bell, D., Bell, N. E., Blom, H. H., Bruggeman-Nannenga, M. A., Brugués, M., Enroth, J., Flatberg, K. I., Garilleti, R., Hedenäs, L., Holyoak, D. T., Hugonnot, V., Kariyawasam, I., Köckinger, H., Kučera, J., Lara, F. & Porley, R. D. 2020: An annotated checklist of bryophytes of Europe, Macaronesia and Cyprus. – J. Bryol. **42(1):** 1-116, doi: 10.1080/03736687.2019.1694329

Mikeladze, I. Sh. & Sharabidze, A. Sh. 2020: The flora of the Batumi landfill (Adjara, Georgia). – Ukrainian Bot. J. **77(6):** 428-433.

Özdemir, T. & Batan, N. 2014: New and noteworthy moss records for Turkey and Southwest Asia. – Telopea **17:** 35-42.

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Article

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Comparing flower biology in five species of *Gagea* (*Liliaceae*) from southern Italy

Abstract

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The reproductive traits in *Gagea* are affected by both abiotic and biotic environmental factors. However, further intrinsic drivers, like the ploidy level, could also have a significant influence on the sexual efficiency of these geophytes. Here, we present a comparative study involving the reproductive biology of five species of *Gagea* occurring in southern Italy, and representing different ploidy levels. The experimental investigations included flower phenology, pollen quality (i.e., morphology, viability, and germination), and stigma receptivity. Such data were then combined with information on seed-set available from previous work. All the studied species showed a gradual pollen presentation, and an early and durable stigma receptivity. Such traits represent effective functional adaptations to prevent pollen limitation under the unpredictable weather dynamics typical of the early blooming season of these plants. The use of a diluted substrate favoured the rate of pollen germination in vitro and, likely, it represents a further adaptation versus adverse environmental conditions (i.e., rain damage on exposed pollen). However, the rates of pollen viability and germination were generally low and appeared related to the ploidy level. Data inherent pollen quality (i.e. morphology, viability and germination) and seed-set indicated the hexaploid *G. lutea* as the most fertile species, while the heptaploid *G. fragifera* had the lowest scores for all the considered traits. Finally, by considering the isolation and reduced size of the studied population, the unexpected low fertility found in the diploid *G. minima* was possibly due to inbreeding depression related to the relict status of this species in southern Italy.

Key words: *Gagea*, Early-flowering plants, Inbreeding depression, Ploidy level, Pollen germination, Pollen presentation, Pollen viability, S Italy, Stigma receptivity.

Introduction

The reproductive success of early-flowering herbs is strongly constrained by the physical conditions characterizing their habitat at blooming time. These plants should cope with two opposite needs. Indeed, they should flower during the first suitable period, in order to limit competition for resource and pollinators but, on the other hand, they are also forced to flower under still unpredictable weather dynamics (Schemske & al. 1978).

The occurrence of unsuitable weather can affect the sexual performance of plant species in different ways, e.g., causing damage to reproductive structures (Percival 1955; Eisikowitch & Woodell 1975; Jones 1976; Eisikowitch 1979; Pacini & Franchi 1984; Corbet & Plumridge 1985; Corbet 1990), or inhibiting pollinator activity and efficiency (Pacini & Franchi 1984; Eisikowitch & al. 1992; Dafni 1996). Furthermore, habitat features may influence the flowering rates within the populations (Eisikowitch 1979; Dafni & al. 1981; Gargano & al. 2007), as well as patterns and effectiveness of plant-pollinator interactions (Gargano & al. 2017). As a consequence, ecologists and evolutionary biologists often considered these constraints as relevant drivers of phenological (Dafni & al. 1981; Harder & Thomson 1989; Thomson & Thomson 1992; Petanidou & al. 1995), morphological (Nishikawa & Kudo 1995; Nishikawa 1998), and physiological (Eisikowitch & Woodell 1975; Corbet 1990; Beardsell & al. 1993; Dafni & Firmage 2000) adaptations in early-flowering, as well as in late-flowering (Dafni 1996), plants. The role played by hybridity, polyploidy, and vegetative propagation in regulating the sexual fertility of flowering plants should be also considered (Wells 1979; Ness & al. 1990; Sato & al. 1993; Burton & Husband 2000; Nepi & Franchi 2000).

Elsewhere, we evaluated the possible relationships between habitat features and reproductive behaviour of some early-flowering species belonging to the genus *Gagea* from Calabria (southern Italy) (Gargano & al. 2007). This fieldwork provided evidences that agreed with the above reported considerations. In fact, most of the evaluated reproductive traits (phenology, amount of clonality, and seed production) affected by abiotic and biotic environmental factors. Furthermore, although a poor efficiency of sexual processes characterized all the studied species, the levels of sexual recruitment were connected to the ploidy level of the species. Artioploids, such as triploid (*G. lojaconoi*, *G. granatellii*) and heptaploid (*G. fragifera*) species, showed pollen malformed in higher rates and lower seed-set than the perissoploids, such as tetraploid (*G. peruzzii*) and hexaploid (*G. lutea*) plants.

In this paper, we present the results of further research carried out on the same target species, with the addition of *G. minima*, a diploid (Peruzzi & Aquaro 2005) and biogeographically interesting species (Peruzzi & Gargano 2005), and the exclusion of *G. granatellii* because of its very low flowering rates. This work is focused on pollen and stigma biology, which often reflect the pressure of genetic, environmental and/or conservation constraints (Thomson & Thomson 1992; Beardsell & al. 1993; Willis 1993; Thomson & al. 1994; Dafni 1996; Carr & Dudash 1997; Dieringer 1999; Dafni & Firmage 2000; Nepi & Franchi 2000). We carried out experimental investigations aiming to compare flower phenology, pollen quality (morphology, viability, and *in vitro*/on stigma germination), and stigma receptivity among the five selected species.

Materials and Methods

Studied species

All the considered species are small bulbous geophytes with yellow, mainly erect, radiate flowers.

Gagea sect. *Didymobulbos* (K. Koch) Boiss.

G. fragifera (Vill.) Ehr. Bayer & G. López – Pedunculate suprabasal axillary bulbils are present only in young (not yet flowering) individuals, while one basal bulblet occurs over its whole life cycle. It is an Eurasiatic species (Peruzzi & al. 2011), growing in mountainous to subalpine meadows and at the margins of beech forests from 1,000 to 1,900 m a.s.l. (Peruzzi & Gargano 2005; Gargano & al. 2007). The studied population (at ca. 1,200 m a.s.l.) is heptaploid, with $2n = 84$ chromosomes (Peruzzi & Aquaro 2005).

G. lojaconoi Peruzzi – There is only one basal bulblet during its whole life cycle. It is a Central Mediterranean species (Tison & al. 2013), growing in garrigues from 100 to 1000 m a.s.l., which was formerly misidentified with *G. chrysantha* Schult. & Schult. f. (Peruzzi & Gargano 2005; Gargano & al. 2007). The studied population (at. ca. 200 m a.s.l.) is triploid, with $2n = 36$ chromosomes (Peruzzi 2003, under the name *G. chrysantha*).

G. peruzzii J.-M. Tison – Sometimes a single axillary suprabasal bulbil is present. On the contrary, there is always a single basal bulblet for each individual. It is a species endemic to the Pollino National Park (Tison & al. 2013; Roma-Marzio & al. 2016), growing in rocky habitats from 500 to 1300 m a.s.l., which was formerly misidentified with *G. bohemica* (Zauschn.) Schulf. & Schult. f. by Peruzzi & Gargano (2005) and by Gargano & al. (2007). The studied population (at ca. 1,000 m a.s.l.) is tetraploid, with $2n = 48$ chromosomes (Peruzzi 2003, under the name *G. bohemica*).

Gagea Salisb. sect. *Gagea*

G. lutea (L.) Ker Gawl. – Many basal bulbils are present only in young (flowering) individuals, while adult flowering plants are unable for vegetative propagation (Schnittler & al. 2009). It is an Eurosiberian species, becoming rare southwards along the Italian peninsula. It grows in meadows at the margins of beech forests, from 900 to 1,500 m a.s.l. (Peruzzi & Gargano 2005; Gargano & al. 2007). The studied population (at ca. 1,200 m a.s.l.) is hexaploid, with $2n = 72$ chromosomes (Peruzzi & Aquaro 2005).

Gagea sect. *Minimae* (Pascher) Davlian.

G. minima (L.) Ker Gawl. – In this species, many basal bulbils occur only in young (not yet flowering) individuals, while one basal bulblet is present over its whole life cycle. It is an Eurosiberian species, showing a scattered distribution in peninsular Italy (Bernardo & al. 2013; Falcinelli & al. 2016) and reaching the southern limit of its range in Calabria, where it is currently known for a couple of populations (Roma-Marzio & al. 2016). It grows in cold places, rich in nitrates, from 950 to 1,900 m a.s.l. (Peruzzi & Gargano 2005). The studied population (at ca. 1,900 m a.s.l.) is diploid, with $2n = 24$ chromosomes (Peruzzi & Aquaro 2005).

Experimental protocols for studying flower biology

The flower phenology was monitored from the flower opening to its wilting, in order to record data related to the timing of pollen exposure and stigma morphology. Preliminary observations allowed us to identify three different flower phases related to anther dehiscence: F1) pollen not yet exposed, F2) pollen exposed on the anthers of the first stamens whorl, and F3) pollen exposed on all the anthers. Such flower phases were used as reference for further experiments on flower biology.

Data about pollen malformation were derived from Gargano & al. (2007), who studied the same populations, for four out the five taxa. This data-set was completed by carrying out qualitative observations under light microscope on about 600 pollen grains of *G. minima*.

Pollen viability was checked for each flower phase by the MTT test (Norton 1966; Khatun & Flowers 1995), which detects the presence of dehydrogenase. For each species, pollen from different anthers was placed on microscope slides, and it was covered by a drop of stain. The stained grains were checked after 50 minutes. For each species, an amount of 100 pollen grains × 5 replicates was collected on different flowers for each flower phase.

According to Brewbaker & Kwack (1963), *in vitro* pollen germination was checked by a solution composed by boric acid (100 mg/l), calcium nitrate (300 mg/l), magnesium sulfate heptahydrate (200 ml/l), and potassium nitrate (100 mg/l). A variable amount of sucrose was added to this base-solution to create a series of six different sucrose concentrations (5, 10, 20, 30, 40, and 50%), in order to investigate pollen germination under different osmotic regimes. The germinated grains were counted after 24 hours of treatment and the experiment was composed by 12 trials for each test. In *G. fragifera*, *G. lutea*, *G. minima*, and *G. peruzzii* the test was carried out on pollen from all the three flower phases, while for *G. lojaconoi* only indiscriminate pollen was used, because of the low number of available flowers.

Following Macior (1983), the presence of pollen grains on the stigma of flowers at different phases was identified by using a mixture of methyl green and phloxine-B (in 50% of alcoholic solutions). Once stained, grains with pollen tube were counted as germinated. For each species, this procedure was repeated for six flowers per flower phase.

Finally, the tests of stigma receptivity were performed directly in the field by means of the Perex test (Dafni & Maues 1998); by evaluating the occurrence and concentration of peroxides on the stigma surface, this test allows to check the receptive area of the stigma and its level of receptivity. For each species, the tests of stigma receptivity were repeated on six flowers per flower phase, with the only exception of *G. peruzzii*, since the flowers of this species wilted very quickly.

Data analysis

Analyses of variance (One-way ANOVA and Two-way ANOVA) were carried out for each variable (pollen viability, pollen germination *in vitro*, stigma receptivity and pollen germination on the stigma) by considering the species, the flower phase, and the sucrose concentration (for *in vitro* pollen germination) as factors. A Pearson correlation with two-tailed test of significance was applied in order to highlight the relationships between pollen/stigma traits and flower phases. All statistical tests were performed by using the package SPSS® 26.0 for Windows.

Results

Three main phases, related to anther dehiscence, were identified in all species (Fig. 1). The first phase (F1) concerned open flowers with pollen not yet exposed (Fig. 1A); an intermediate phase (F2) was characterized by the dehiscence of the three most external anthers (Fig. 1B); finally, in the third phase (F3), the pollen was exposed in all the six anthers (Fig. 1C). The stigma appeared to be yellowish in all the phases, but during F2 and F3 its surface assumed a papillose and glutinous appearance.

The results of the MTT test are provided in Table 1. The mean amount of viable pollen had the highest score in *G. lutea*, followed by *G. lojaconoi* and *G. peruzzii*, while the lowest viability was recorded in *G. minima* and *G. fragifera*. Significant negative correlations between pollen viability and flower phase resulted in *G. minima* (r = -0.918; P < 0.001), *G. lojaconoi* (r = -0.618; P = 0.014), and *G. fragifera* (r = -0.570; P = 0.027), while no significant relationships was found in *G. peruzzii* (r = 0.503; P = 0.056) and *G. lutea* (r = -0.144; P = 0.608). The two-way ANOVA performed for pollen viability (Table 2) revealed that the difference among the species for pollen viability (F = 18.992; P ≤ 0.0001) was only marginally influenced by flower phase (F = 4.339; P = 0.0168). According to correlation tests, the one-way ANOVA showed that the largest variation of pollen across flower phases occurred in *G. minima* (F = 32.308; P ≤ 0.0001); anyway, significant variations of pollen among flower phases were detected in all the taxa (Table 2).

The results of *in vitro* pollen germination tests are summarized in Table 4. The amount of germinated pollen was lower than the fraction resulted potentially viable by MTT staining. Pollen germination rates significantly varied among species (F = 6.483; P ≤ 0.0001; Table 4). Also in this experiment, *G. lutea* reached the highest values of fertility and *G. fragifera* the lowest (Table 3). Instead, in contrast to the MTT test, *G. peruzzii* showed pollen germination higher than *G. lojaconoi*.

As expected, the sucrose concentration of germination solutions severely affected the rate of pollen germination (F = 20.406; P ≤ 0.0001; Table 4). In fact, 95% of germinations occurred at sucrose concentration between 5 and 30% (Table 3). The two-way ANOVA (Table 4) indicated that the species have different pollen germination patterns in relation to sucrose concentration (F = 22.672; P ≤ 0.0001). Indeed, *G. fragifera* reached the germination peak at 5% of sucrose, *G. lutea* and *G. lojaconoi* at 10%, *G. minima* and *G. peruzzii* at 20% (Table 3). Furthermore, in *G. lutea* the pollen germinated only in a narrow range of sugar concentration, as no germination at all occurred at sucrose concentration > 30% (Table 3).

Also the flower phase strongly influenced pollen germinations *in vitro* (F = 27.633; P ≤ 0.0001; Table 4). Two-way ANOVA highlighted different patterns among species (F = 29.691; P ≤ 0.0001; Table 4). Strong negative correlations between in vitro pollen germination rates and flower phase were found in *G. minima* (r = -0.395; P < 0.001) and *G. lutea* (r = -0.352; P < 0.001), while no significant pattern was detected in *G. peruzzii* (r = -0.059; P = 0.392) and *G. fragifera* (r = -0.011; P = 0.869).

The stained area and the disposition of the papillae suggested that the receptive stigmatic surface was restricted to the stigma apex. In all the specimens, the stigma was receptive over the whole flowering period (Table 1). However, the two-way ANOVA evidenced significant differences in terms of receptivity level among species (F = 28.08; P ≤ 0.0001) and flower phases (F = 4.125; P = 0.0198). As showed in Table 1, the lowest stigma receptivity was found in *G. minima*; while in *G. lutea* the receptivity was strongly linked to the flower aging, as it gradually increased from F1 to F3 (*r* = 0.682; P = 0.002).

Fig. 1. Flowers of *Gagea lojaconoi* in phase 1 (FP1), with no pollen exposed (A); phase 2 (FP2), with pollen exposed in the three most external anthers only (B); phase 3 (FP3), with pollen exposed in all the six anthers (C). Pictures shot 19 February 2006 by L. Peruzzi.

In the two-way ANOVA, the amount of germinated pollen on the stigma significantly varied among the species (F = 15.727; P ≤ 0.0001), and the highest amount of germinated pollen was found on stigmas of *G. lutea* (Table 1). Instead, no effect was induced by the flower phase (F = 0.961; P = 0.3869), with the only exception of *G. minima*, in which the fraction of germinated grains were strongly related to the flower phase (*r* = -0.652; P = 0.003; Table 1).

Discussion

Flower phenology: ecological and evolutionary implications

The sequential anther dehiscence observed in the studied species could be interpreted as a strategy aiming to extend the temporal pollen availability. Many authors highlighted that early-flowering plants often share various adaptations to face pollen limitation, such as anthesis extension (Nishikawa & Kudo 1995; Nishikawa 1998), long-lived pollen, early and durable stigma receptivity (Beardsell & al. 1993; Dafni & Firmage 2000). Although Harder & Thomson (1989) reported that simultaneous pollen presentation can be expected if pollinator visits are infrequent, it was argued that pollen longevity plays a basic role in the adoption of a gradual or simultaneous pollen presentation (Thomson & al. 1994). Indeed, Thomson & Thomson (1992) highlighted that a gradual pollen presentation can be a successful strategy under low frequency of pollinators, in plants with short pollen longevity. The low scores of pollen viability (Table 1) and pollen germination (Table 3) suggested a rather low pollen fertility in the studied species. In addition, the exposed pollen (collected from flower phases F2-F3) often expressed lower viability and germination than pollen collected just before exposure (flower phase F1) (Tables 1, 2, 3). Furthermore, only a little fraction of germinated pollen was detected on the analysed stigmas (Table 1). All these results suggest that environmental conditions severely affect pollen viability in *Gagea*. Our results also agree with Thomson & al. (1994), which see a gradual pollen presentation as the best adaptation in facing pollen limitation in case of short pollen longevity.

Pollen and stigma biology: ecological and evolutionary implications

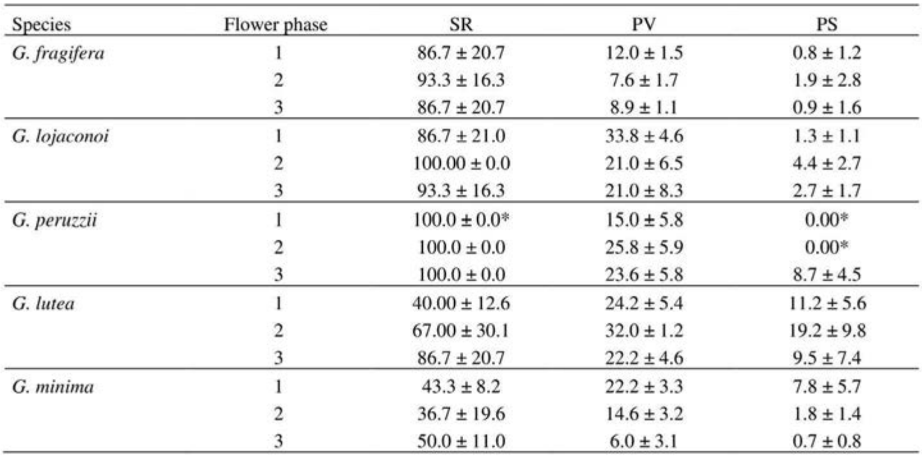
As found in other early-flowering geophytes (Peruzzi & al. 2012), the studied species showed highest pollen germination at low sugar concentration, with absence of pollen bursting (Tables 3-4). According to Dafni (1996), such patterns are congruent to an adaptation versus mechanic and osmotic damage caused by the frequent rainfalls typical of the spring Mediterranean season. Indeed, rain is known as a potentially limiting factor for different aspects of plant sexual reproduction, due to its direct (Percival 1955; Eisikowitch & Woodell 1975; Jones 1976; Eisikowitch 1979; Pacini & Franchi 1984; Corbet & Plumridge 1985; Corbet 1990) and indirect (Pacini & Franchi 1984; Eisikowitch & al. 1992; Dafni 1996) effects on reproductive structures.

Our data on stigma receptivity and *in vivo* pollen germination evidenced that the stigma of the investigated species has an early (simultaneous to flower opening) and durable receptive phase (Table 1). This finding has a particular interest if we consider that the genus *Gagea* is proterandrous, given that male gametophytes develop earlier than embryo sacs (Caparelli & al. 2006 and literature cited therein). According to Beardsell & al. (1993) and Dafni & Firmage (2000), these traits of stigma biology could also reflect adaptations to optimize pollination processes in early-flowering plants.

Genetic influence on the observed fertility patterns

A general low pollen viability was evident in all the taxa (Table 1), being the mean viable pollen never higher than 33.8 ± 4.6%. The levels of pollen fertility further decreased in the procedures of *in vitro* pollen germination, where the highest score (reached by *G. minima*) was 21.00 ± 7.7% (Table 3). The discrepancy between pollen viability and germination tests suggest that the MTT can overestimate pollen fertility.

Table 1. Mean scores (%) ± Standard deviation for stigma receptivity (SR), pollen viability (PV) and pollen germination on the stigma (PS) in the studied *Gagea* species. * = incomplete data (see the text).



Species	Flower phase	SR	PV	PS
G. fragifera	1	86.7 ± 20.7	12.0 ± 1.5	0.8 ± 1.2
	2	93.3 ± 16.3	7.6 ± 1.7	1.9 ± 2.8
	3	86.7 ± 20.7	8.9 ± 1.1	0.9 ± 1.6
G. lojaconoi	1	86.7 ± 21.0	33.8 ± 4.6	1.3 ± 1.1
	2	100.00 ± 0.0	21.0 ± 6.5	4.4 ± 2.7
	3	93.3 ± 16.3	21.0 ± 8.3	2.7 ± 1.7
G. peruzzii	1	100.0 ± 0.0*	15.0 ± 5.8	0.00*
	2	100.0 ± 0.0	25.8 ± 5.9	0.00*
	3	100.0 ± 0.0	23.6 ± 5.8	8.7 ± 4.5
G. lutea	1	40.00 ± 12.6	24.2 ± 5.4	11.2 ± 5.6
	2	67.00 ± 30.1	32.0 ± 1.2	19.2 ± 9.8
	3	86.7 ± 20.7	22.2 ± 4.6	9.5 ± 7.4
G. minima	1	43.3 ± 8.2	22.2 ± 3.3	7.8 ± 5.7
	2	36.7 ± 19.6	14.6 ± 3.2	1.8 ± 1.4
	3	50.0 ± 11.0	6.0 ± 3.1	0.7 ± 0.8

Table 2. Variance analyses of pollen viability among the studied *Gagea* species and flower phases. PV = pollen viability (%).

Analysis type	Target	Factor	Dependent variable	F	P
Two-Way ANOVA	all species	species	PV	18.992	≤ 0.0001
		flower phase		4.3394	0.0168
One-Way ANOVA	*G. fragifera*	flower phase	PV	13.057	0.001
	G. lojaconoi			6.211	0.014
	G. peruzzii			4.814	0.029
	G. lutea			7.603	0.007
	G. minima			32.308	≤ 0.0001

Table 3. Mean pollen germination (%) ± standard deviation in relation to the flower phase (FP) and sucrose concentration in the studied *Gagea* species; in *G. lojaconoi* relationships between pollen germination and flower phase are not considered.

Species	FP	[5]	[10]	[20]	[30]	[40]	[50]
G. fragifera	1	1.4 ± 0.9	1.5 ± 1.1	0.3 ± 0.3	0.4 ± 0.4	0.00	0.00
	2	2.4 ± 1.7	1.0 ± 0.8	0.8 ± 0.5	0.3 ± 0.3	0.3 ± 0.3	0.2 ± 0.2
	3	2.3 ± 1.1	0.3 ± 0.5	0.4 ± 0.5	0.1 ± 0.3	0.2 ± 0.4	0.00
G. lojaconoi		0.5 ± 0.8	8.4 ± 2.6	0.4 ± 0.7	0.33 ± 0.4	0.1 ± 0.5	0.2 ± 0.8
G. peruzzii	1	5.7 ± 4.4	3.9 ± 1.7	9.8 ± 5.2	1.5 ± 1.4	0.8 ± 1.3	0.00
	2	8.8 ± 5.0	5.3 ± 2.6	4.0 ± 1.8	2.3 ± 1.6	0.2 ± 0.4	0.1 ± 0.4
	3	8.9 ± 3.8	4.4 ± 2.7	3.1 ± 2.7	0.9 ± 0.9	0.5 ± 1.1	0.4 ± 1.0
G. lutea	1	16.9 ± 2.9	19.4 ± 8.6	7.0 ± 3.8	0.2 ± 0.5	0.00	0.00
	2	7.8 ± 3.8	6.4 ± 3.2	5.3 ± 2.7	0.2 ± 0.5	0.00	0.00
	3	5.2 ± 2.3	3.9 ± 1.2	1.8 ± 2.2	0.1 ± 0.3	0.00	0.00
G. minima	1	10.3 ± 5.8	5.4 ± 4.3	21.0 ± 7.7	1.5 ± 2.3	0.6 ± 1.3	0.3 ± 1.0
	2	1.1 ± 2.5	8.8 ± 5.9	4.4 ± 3.1	0.00	0.00	0.00
	3	0.4 ± 0.9	1.5 ± 2.2	1.9 ± 2.1	0.00	0.00	0.00

Overall, the cytoplasmatic staining techniques allow the evaluation of some structural features of pollen, but not its real physiological adequateness. As a consequence, part of the stained pollen can be unviable (Nepi & Franchi 2000).

However, significant differences occurred among species, in terms of both pollen viability and *in vitro* germination (Table 2 and Table 4). Both pollen traits agreed in indicating highest and lowest pollen fertility respectively in *G. lutea*, on one side, and *G. minima*/*G. fragifera*, on the other side. Instead, for *G. lojaconoi* and *G. peruzzii* the patterns of pollen viability and pollen germination disagreed. This discordance even increased when comparing the outcome of MTT test with those related to pollen germination on the stigma (Table 1), as the two protocols produced congruent patterns only for *G. lutea* and *G. fragifera*. This is not surprising, because each test is related to different aspects of pollen fitness, but none of them can evaluate simultaneously all of its components

(Thomson & al. 1994; Dafni & Firmage 2000). *In vitro* and on stigma pollen germination produced comparable scores in all species, with the exception of *G. minima*.

Our results on pollen viability in *G. lutea* are congruent with those reported by Zhang & al. (1995), and with data from one of the two populations studied by Zarrei & Zarre (2005). The generally scarce pollen fertility observed in the studied species can be also related to their overall low sexual efficiency and frequent vegetative propagation (Gargano & al. 2007). In particular, contrasting patterns of sexual vs. clonal propagation are particularly frequent in the genus *Gagea*, and usually are species-specific (Schnittler & al. 2009; Pfeiffer & al. 2012; Schnittler & al. 2013; Beisenova & al. 2015).

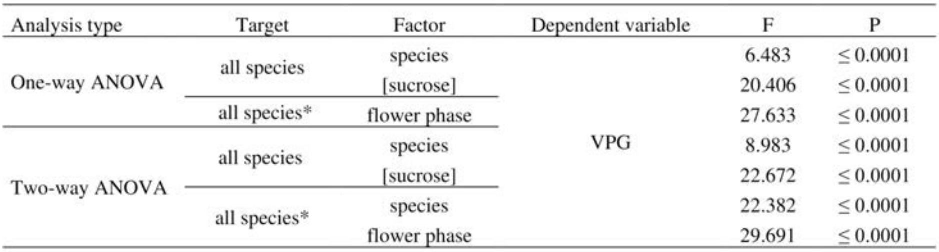
In addition, variations in the ploidy level among the studied species can provide further explanations for the detected fertility patterns. Indeed, data on pollen viability and seed-set indicated the hexaploid *G. lutea* and the heptaploid *G. fragifera* as the highest and lowest fertile species, respectively (Table 5). When comparing *G. peruzzii* (tetraploid) and *G. lojaconoi* (triploid), although the former species showed higher pollen quality, the latter actually produces more seeds (Gargano & al. 2007). Therefore, the sexual fitness in *G. peruzzii* seems to be limited by factors differing from pollen fertility that could involve problems in the development of female gametophytes (Caparelli & al. 2006, under the name *G. bohemica*). A possible explanation for that could rely also on the allopolyploid hybrid origin of this species (Peterson & al. 2009; Tison & al. 2013). Moreover, as suggested by our difficulties in finding pollinated stigmas, pollen limitation may have contributed in limiting the seed-set of *G. peruzzii*. Finally, as previously hypothesized (Gargano & al. 2007), the fruit ripening of *G. peruzzii* could be affected by resource limitation due to its quickly-drying habitat. Such a habitat feature is recognized to promote vegetative propagation (Dafni & al. 1981). Accordingly, vegetative individuals in the *G. peruzzii* population were more numerous than in the population of *G. lojaconoi* (Gargano & al. 2007).

Overall, our data also agree on previous work on the influence of ploidy level on sexual fertility in *Gagea* (Zarrei & Zarre 2005). The observed fertility patterns are also congruent with further relevant biological and evolutionary features of the genus *Gagea*, including the frequency of vegetative propagation and the role played by hybridization events in its evolutionary history (Peruzzi 2008; Peterson & al. 2009, 2011, 2016; Tison & al. 2013). Substantially, our findings evidenced that the studied species undergo common genetic constraints on male fertility, such as hybridization (e.g. Wells 1979; Ness & al. 1990), polyploidy (Burton & Husband 2000; Sato & al. 1993) and high rate of vegetative propagation (Nepi & Franchi 2000).

Conservation implications of the observed fertility patterns

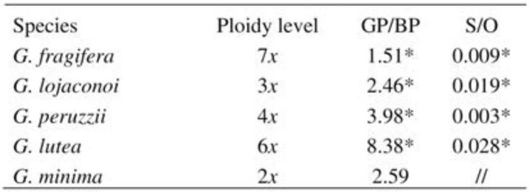
Overall, all the studied species may suffer for environmental variations, because the frequent vegetative propagation can reduce their evolutionary flexibility against habitat changes. However, our data emphasized higher concerns for *G. minima*. In spite it was the only diploid species in our study, it produced a high amount of malformed pollen (Table 5), and pollen viability/germination were strongly influenced by flower phase (Table 2, 5), as its pollen fertility severally decreased after pollen exposure. Because during the phase F1 pollen is not available for pollinators, such data justifies the reduced amount of germi-

Table 4. Analyses of variance for *in vitro* pollen germination among studied *Gagea* species in relation to the % of sucrose and flower phase. VPG = *in vitro* pollen germination (%); * = *G. lojaconoi* is excluded from this analysis.



Analysis type	Target	Factor	Dependent variable	F	P
One-way ANOVA	all species	species	VPG	6.483	≤ 0.0001
		[sucrose]		20.406	≤ 0.0001
	all species*	flower phase		27.633	≤ 0.0001
Two-way ANOVA	all species	species		8.983	≤ 0.0001
		[sucrose]		22.672	≤ 0.0001
	all species*	species		22.382	≤ 0.0001
		flower phase		29.691	≤ 0.0001

Table 5. Ploidy levels, pollen gross morphology and seed-set data for the studied *Gagea* species. *Data from Gargano & al. (2007). GP = good pollen; BP = evidently malformed pollen; S/O = seeds/ovules ratio.



Species	Ploidy level	GP/BP	S/O
G. fragifera	7*x*	1.51*	0.009*
G. lojaconoi	3*x*	2.46*	0.019*
G. peruzzii	4*x*	3.98*	0.003*
G. lutea	6*x*	8.38*	0.028*
G. minima	2*x*	2.59	//

nated pollen detected on the stigmas (Table 1). In addition, *G. minima* had the lowest scores of stigma receptivity, which was also affected by flower aging, as the germinated pollen grains drastically decreased on stigma of F2/F3 flowers. Because the studied *G. minima* population occurs in a high-mountain context, the reduced fertility found in this species could be partially due to severe environment conditions (temperature, water availability), as found in *G. lutea* (Bohdanowicz & al. 2005). On the other hand, the relict status of this species in southern Italy may also play a role. Indeed, the isolation and small size of the studied population may promote the rise inbreeding depression, whose detrimental effects were demonstrated also on pollen fertility (e.g. Willis 1993; Carr & Dudash 1997; Gargano & al. 2011).

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References

Beardsell, D. V., Knox, R. B. & Williams, E. G. 1993: Breeding system and reproductive success of *Tryptomene calycina* (*Myrtaceae*). – Austral. J. Bot. **41:** 333-353. https://doi.org/10.1071/bt9930333

Beisenova, S., Peterson, A., Peterson, J., Bersimbaev, R. I., Klahr, A. & Schnittler, M. 2015: On the limits of drought - Life history of *Gagea bulbifera* (*Liliaceae*). – Flora **210:** 72-79. https://doi.org/10.1016/j.flora.2014.10.004

Bernardo, L., Gargano, D., Marchianò, V. & Peruzzi, L. 2013: Notulae: 1971. *Gagea minima* (*Liliaceae*). – In: Barberis, G., Nepi, C., Peccenini, S. & Peruzzi, L. (eds), Notulae alla Checklist della flora italiana: 15. – Inform. Bot. Ital. **45(1):** 97-98.

Bohdanowicz, J., Szczuka, E., Świerczyńska, J., Sobieska, J. & Kościńska-Pająk, M. 2005: Distribution of microtubules during regular and disturbed microsporogenesis and pollen grain development in *Gagea lutea* (L.) Ker-Gaw. – Acta Biol. Cracov. ser. Bot. **47(2):** 89-96. https://doi.org/10.5586/aa.2006.007

Brewbaker, J. L. & Kwack, B. H. 1963: The essential role of calcium ion in pollen germination and pollen tube growth. – Amer. J. Bot. **50(9):** 859-865. https://doi.org/10.1002/j.1537-2197.1963.tb06564.x

Burton, T. L. & Husband, B. C. 2000: Fitness differences among diploids, tetraploids and their triploid progeny in *Chamerion angustifolium*: mechanism of inviability and implications for polyploid evolution. – Evolution **54(4):** 1182-1191. https://doi.org/10.1111/j.0014-3820.2000.tb00553.x

Caparelli, K. F., Peruzzi, L. & Cesca, G. 2006: A comparative analysis of embryo-sac development in three closely-related *Gagea* species (*Liliaceae*), with some consideration on their reproductive strategies. – Pl. Biosyst. **140(2):** 115-122. https://doi.org/10.1080/11263500600756090

Carr, D. E. & Dudash, M. R. 1997: The effects of five generations of enforced selfing on potential male and female function in *Mimulus guttatus*. – Evolution **51(6):** 1797-1807. https://doi.org/10.1111/j.1558-5646.1997.tb05103.x

Corbet, S. A. 1990: Pollination and the weather. – Israel J. Bot. **39:** 13-30.

— & Plumridge, J. R. 1985: Hydrodynamics and the germination of oil-seed rape pollen. – J. Agr. Res. **104:** 445-451. https://doi.org/10.1017/s0021859600044154

Dafni, A. 1996: Autumnal and winter pollination adaptations under Mediterranean conditions. – Bocconea **5(1):** 171-181.

— & Firmage, D. 2000: Pollen viability and longevity: practical, ecological and evolutionary implications. – Pl. Syst. Evol. **222(1-4):** 113-132. https://doi.org/10.1007/bf00984098

— & Maues, M. M. 1998: A rapid and simple procedure to determine stigma receptivity. – Sexual Pl. Rep. **11(3):** 177-180. https://doi.org/10.1007/s004970050138

—, Cohen, D. & Noy-Meir, I. 1981: Life-cycle variations in geophytes. – Ann. Missouri Bot. Gard. **68:** 652-660.

Eisikowitch, D. 1979: “Patents” for flowering in rain. – Salit **7:** 20-22.

— & Woodell, S. R. J. 1975: The effect of water on pollen germination in two species of *Primula*. – Evolution **28:** 692-694. https://doi.org/10.1111/j.1558-5646.1974.tb00802.x

Falcinelli, F., Roma-Marzio, F., Donnini, D. & Peruzzi, L. 2016: Nuovi dati distributivi per il genere *Gagea* (Liliaceae) in Umbria, Marche e Lazio. – Atti Soc. Tosc. Sci. Nat., Mem., serie B **122(2015):** 19-29.

—, Gat, Z., Karni, O., Chekik, F. & Rag, D. 1992: Almond blooming under adverse conditions. A compromise between various forces. – Pp. 234-240 in: Thanos, C. A. (ed.), Proceedings of the 6th International Conference on Mediterranean Climate Ecosystems. – Athens.

Gargano, D., Fenu, G. & Bernardo, L., 2017: Local shifts in floral biotic interactions in habitat edges and their effect on quantity and quality of plant offspring. – AoB Plants **9:** plx031. https://doi.org/10.1093/aobpla/plx031

—, Gullo, T. & Bernardo, L. 2011: Fitness drivers in the threatened *Dianthus guliae* Janka (*Caryophyllaceae*): disentangling effects of growth context, maternal influence and inbreeding depression. – Pl. Biol. **13(s1):** 96-103. https://doi.org/10.1111/j.1438-8677.2010.00392.x

—, Peruzzi, L., Caparelli, K. F. & Cesca, G. 2007: Preliminary observations on reproductive strategies in five early-flowering species of *Gagea* Salisb. (*Liliaceae*). – Bocconea **21:** 349-358.

Harder, L. D. & Thomson, J. D. 1989: Evolutionary options for maximizing pollen dispersal of animal-pollinated plants. – Amer. Nat. **133:** 323-344. https://doi.org/10.1086/284922

Jones, A. G. 1976: Environmental effects on the percentage of stainable and presumed normal pollen in *Aster* (Compositae). – Amer. J. Bot. **63(5):** 657-663. https://doi.org/10.1002/j.1537-2197.1976.tb11853.x

Khatun, S. & Flowers, T. J. 1995: The estimation of pollen viability in rice. – J. Exp. Bot. **46:** 151-154. https://doi.org/10.1093/jxb/46.1.151

Macior, L. W. 1983: The pollination dynamics of sympatric species of *Pedicularis* (*Scrophulariaceae*). – Amer. J. Bot. **70(6):** 844-853. https://doi.org/10.1002/j.1537-2197.1983.tb06422.x

Nepi, M. & Franchi, G. G. 2000: Cytochemistry of mature angiosperm pollen. – Pl. Syst. Evol. **222(1-4):** 45-62. https://doi.org/10.1007/bf00984095

Ness, B. D., Soltis, D. E. & Soltis P. S. 1990: An examination of polyploidy and putative introgression in *Calochortus* subsection *Nudi* (Liliaceae). – Amer. J. Bot. **77(12):** 1519-1531. https://doi.org/10.1002/j.1537-2197.1990.tb11393.x

Nishikawa, Y. 1998: The function of multiple flowers of a spring ephemeral, *Gagea lutea* (*Liliaceae*), with reference to blooming order. – Canad. J. Bot. **76:** 1404-1411. https://doi.org/10.1139/b98-120

— & Kudo, G. 1995: Relationships between flower number and reproductive success of a spring ephemeral herb, *Anemone flaccida* (*Ranunculaceae*). – Pl. Sp. Biol. **10:** 111-118. https://doi.org/10.1111/j.1442-1984.1995.tb00129.x

Norton, J. D. 1966: Testing of plum pollen viability with tetrazolium salts. – Amer. Soc. Hort. Sci. Proc. **89:** 132-134.

Pacini, E. & Franchi, G. G. 1984: Reproduction in Mediterranean plants. – Webbia **38:** 93-104. https://doi.org/10.1080/00837792.1984.10670301

Percival, M. S. 1955: The presentation of pollen in certain angiosperms. – New Phytol. **54:** 345-368.

Peruzzi, L. 2003: Contribution to the cytotaxonomical knowledge of *Gagea* Salisb. (*Liliaceae*) sect. *Foliatae* A. Terracc. and synthesis of karyological data. – Caryologia **56(1):** 115-128. https://doi.org/10.1080/00087114.2003.10589314

— 2008: Hybridity as a main evolutionary force in the genus *Gagea* Salisb. (*Liliaceae*). – Pl. Biosyst. **142(1):** 179-183.

— & Aquaro, G. 2005: Contribution to the cytotaxonomical knowledge of *Gagea* Salisb. (*Liliaceae*). II. Further karyological studies on Italian populations. – Candollea **60(1):** 237-253.

— & Gargano, D. 2005: Distribuzione del genere *Gagea* Salisb. (*Liliaceae*) in Calabria. – Inform. Bot. Ital. **37(2):** 61-68.

—, Mancuso, E. & Gargano, D. 2012: Males are cheaper, or the extreme consequence of size/age-dependent sex allocation: sexist gender diphasy in *Fritillaria montana* (*Liliaceae*). – Bot. J. Linn. Soc. **168:** 323-333. https://doi.org/10.1111/j.1095-8339.2011.01204.x

—, Peterson, A., Tison, J.-M. & Harpke, D. 2011: New light on phylogeny and taxonomy of the Eurasian *Gagea villosa–G. fragifera* complex (*Liliaceae*). – Nord. J. Bot. **29(6):** 722-733. https://doi.org/10.1111/j.1756-1051.2011.01187.x

Petanidou, T., Ellis, W. N., Margaris, N. S. & Vokou, D. 1995: Constraints on flowering phenology in a phryganic (East Mediterranean shrub) community. – Amer. J. Bot. **82(5):** 607-620. https://doi.org/10.1002/j.1537-2197.1995.tb11505.x

Peterson, A., Harpke, D., Peruzzi, L., Levichev, I. G., Tison. J.-M. & Peterson. J. 2009: Hybridization drives speciation in *Gagea* (*Liliaceae*). – Pl. Syst. Evol. **278(3-4):** 133-148. https://doi.org/10.1007/s00606-008-0102-3

—, —, Levichev, I. G., Beisenova, S., Schnittler, M. & Peterson, J. 2016: Morphological and molecular investigations of *Gagea* (*Liliaceae*) in southeastern Kazakhstan with special reference to putative altitudinal hybrid zones. – Pl. Syst. Evol. **302(8):** 985-1007. https://doi.org/10.1007/s00606-016-1313-7

—, Levichev, I. G., Peterson, J., Harpke, D. & Schnittler, M. 2011: New insights into the phylogeny and taxonomy of Chinese species of *Gagea* (*Liliaceae*) – speciation through hybridization. – Organ. Div. Evol. **11(5):** 387-407. https://doi.org/10.1007/s13127-011-0059-x

Pfeiffer, T., Klahr, A., Peterson, A., Levichev, I. G. & Schnittler, M. 2012: No sex at all? Extremely low genetic diversity in *Gagea spathacea* (*Liliaceae*) across Europe. – Flora **207(5):** 372-378. https://doi.org/10.1016/j.flora.2012.03.002

Roma-Marzio, F., Bernardo, L., Liguori, P. & Peruzzi, L. 2015: Vascular flora of Monte Sparviere (southern Italy, Pollino Massif). – Atti Soc. Tosc. Sci. Nat., Mem., ser. B **122(2015):** 79-94.

Sato, T., Maceira, M., Lumaret, R. & Jacquard, P. 1993: Flowering characteristics and fertility of interploidy progeny from normal and 2n gametes in *Dactylis glomerata* L. – New Phytol. **124(2):** 309-319. https://doi.org/10.1111/j.1469-8137.1993.tb03821.x

Schemske, D. W., Willson, M. F., Melampy, M. N., Miller, M. J., Verner, L., Schemske, K. M. & Best, L. B. 1978: Flowering ecology of some spring woodlands herbs. – Ecology **59(2):** 351-366. https://doi.org/10.2307/1936379

Schnittler, M., Pfeiffer, T., Harter, D. & Hamann, A. 2009: Bulbils contra seeds: reproductive investment in two species of *Gagea* (Liliaceae). – Pl. Syst. Evol. **279:** 29-40. https://doi.org/10.1007/s00606-008-0143-7

—, Peterson, A., Peterson, J., Beisenova, S., Bersimbaev, R. I. & Pfeiffer, T. 2013: Minor differences with big consequences: reproductive patterns in the genus *Gagea* (*Liliaceae*). – Flora **208(10-12):** 591-598. https://doi.org/10.1016/j.flora.2013.09.002

Thomson, J. D. & Thomson, B. A. 1992: Pollen presentation and viability schedules in animal-pollinated plants: consequences for reproductive success. – Pp. 1-24 in: Wyatt, R. (ed.), Ecology and evolution of plant reproduction: new approaches. – Chapman and Hall. New York.

—, Rignev, L. P., Karoly, K. M. & Thomson, B. A. 1994: Pollen viability, vigor and competitive ability in *Erythronium grandiflorum* (*Liliaceae*). – Amer. J. Bot. **81(10):** 1257-1266. https://doi.org/10.2307/2445401

Tison, J-M., Peterson, A., Harpke, D. & Peruzzi, L. 2013: Reticulate evolution of the critical Mediterranean *Gagea* sect. *Didymobulbos* (*Liliaceae*), and its taxonomic implications. – Pl. Syst. Evol. **299(2):** 413-438. https://doi.org/10.1007/s00606-012-0731-4

Wells, E. F. 1979: Interspecific hybridization in eastern north America *Heuchera* (*Saxifragaceae*). – Syst. Bot. **4(4):** 319-338. https://doi.org/10.2307/2418808

Willis, J. H. 1993: Effects of different levels of inbreeding on fitness components in *Mimulus guttatus*. – Evolution **47(3):** 864-876. https://doi.org/10.1111/j.1558-5646.1993.tb01240.x

Zarrei, M. & Zarre, S. 2005: Pollen morphology of the genus *Gagea* (*Liliaceae*) in Iran. – Flora **200:** 96-108. https://doi.org/10.1016/j.flora.2004.04.001

—, Wilkin, P., Ingrouille, M. J., Leitch, I. J., Buerki, S., Fay, M. F. & Chase, M. W. 2012: Speciation and evolution in the *Gagea reticulata* species complex (*Tulipeae*; *Liliaceae*). – Mol. Phylog. Evol. **62(2)**: 624-639. https://doi.org/10.1016/j.ympev.2011.11.003

Zhang, H., Bohdanowicz, J., Pierson, E. S., Li, Y., Tiezzi, A. & Cresti, M. 1995: Microtubular organization during asymmetrical division of the generative cell in *Gagea lutea*. – J. Pl. Res. **108:** 269-276. https://doi.org/10.1007/bf02344352

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Article

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Unpublished aspects of hygrophilous wood vegetation from Nebrodi Mountains (N-E Sicily)

Abstract

Raimondo, F. M., Domina, G., Di Gristina, E.: Unpublished aspects of hygrophilous wood vegetation from Nebrodi Mountains (N-E Sicily). — Fl. Medit. 31 (Special Issue): 145-167. 2021. — ISSN: 1120-4052 printed, 2240-4538 online.

In this paper we report the results of a study done on the vegetation of hygrophilous woods and shrubs occurring along the sub montane and montane small rivers of the Alcantara watershed located in the Nebrodi Mountains (N-E Sicily). We have described two new associations: *Alno glutinosae-Salicetum rubentis* and *Euonymo europaei-Salicetum lambertianae*, both belonging to the class *Salici purpureae-Populetea nigrae*. The forest association would belong to the alliance *Populion albae* of the order *Populetalia albae*, while the shrubs of pebbly streams would give origin to communities that would belong to the alliance *Salicion albae* of the order *Salicetalia purpureae*. The study gave the occasion to produce a new syntaxonomic framework of this vegetation.

Key words: riparian vegetation, plant sociology, syntaxonomy, *Salici purpureae-Populetea nigrae*, Sicily, Italy.

Introduction

Nebrodi Mountains are the largest mountain system in Sicily. They represent the southward extension of the Apennine chain. The system goes from east to west along the Tyrrhenian coast of the island and culminates with Mount Soro (1847 m a.s.l.). Climatically the area is subjected to temperate variations of the Mediterranean climate. In particular, over 1000 m a.s.l. the sub-Mediterranean subclimate prevails, with annual rainfall above 1000 mm and with recurring snowfall in January-February. Forest vegetation - still well represented – is distributed in altitudinal belts. The first belt is constituted by Mediterranean maquis (*Pistacio-Rhamnetalia alaterni*), the second by the temperate Mediterranean forest with *Quercus ilex* or *Q. suber* (*Quercetalia ilicis*), the third by the submontane forest with deciduous oaks (*Quercetalia pubescentis-petraeae*), to last by the mountain forest with *Fagus sylvatica* and *Acer pseudoplatanus* (*Fagetalia sylvaticae*). It is the same physiognomic vegetation occurring in Mediterranean and Apennine Italy, but in Sicily the species of local flora substitute the species of southern Europe and many of those of the South Italian

Peninsula.In their study on the arboreal and arborescent vegetation of the margins of water courses of Sicily Brullo & Spampinato (1990), considered also the Nebrodi Mountains, however, submontane and mountain areas still remained unexplored. This vegetation is characterized by species of willows (*Salix* sp. pl.), poplars (*Populus nigra*) and the black alder (*Alnus glutinosa*), the latter in Sicily assumes a considerable role in the Nebrodi Mountains. Thanks to its presence, the submontane and montane riparian formations of Nebrodi Mountains resulted physionomically very similar to the associations described by Barbagallo & al. (1982) for the southern Apennines and in particular to those described by Brullo & Spampinato (1997) and Brullo & al. (2001) in Calabria. With this study we wanted to analyse in deep the phytosociology and the syntaxonomy of the hygrophilous vegetation characterized by these species. We examined not only the tree formations traditionally referred to the order *Populetalia albae*, but also those arborescent dominated by *Salix purpurea* subsp. *lambertiana* and, therefore, referred to the order *Salicetalia purpureae.* Since this hygrophilous vegetation in Sicily is found exclusively in the submontane and mountainous belt of the Alcantara river basin of the Nebrodi Mountains and since for this type of vegetation we were able to define two new associations, we have been induced to reconsider the syntaxonomical scheme of the hygrophilous woody vegetation of Sicily and to propose a new one.

The environmental context of the Nebrodi Mountains

The Nebrodi chain is placed in the north-eastern part of Sicily (Fig. 1). The upper part is a very extensive mountain area and also rich in forest vegetation (Domina & al. 2018). This richness is a consequence of copious rainfall – also of a snowy nature – and of the heterogeneity of the hydrogeological structure of the area which includes rivers that flow both to Tyrrhenian and the Ionian sides (Giaimi 1994). The general morphology of this area is given by rounded peaks, plateaus and slopes, with peaks often exceeding 1000 m (a.s.l.). The superficial hydrographic network is mainly torrential, referable to the sub dendritic type, in addition there is the head incisions that flow into the Alcantara and Simeto rivers. Of these, the most important are the Favoscuro stream, the Flascio river, the Saracena stream and the Inganno stream, all running approximately North West-South East (Giaimi 1994). The climate of the Nebrodi mountain system is one of the wettest sectors in Sicily, with summer aridity limited to the months of June-August. According to Bagnouuls & Gaussen's classification (1957), the part of the territory below 1200 m (a.s.l.) belongs to the Mesomediterranean type and, above, to the Submediterranean one (Brullo & Grillo 1978). In light of the fact that the system has its maximum elevation in Monte Soro (1847 m a.s.l.) and that a substantial part of the territory lies within the altimetric space between 1200 m and the top of this mountain, the space subject to the sub-Mediterranean climatic type is very extended. On the basis of the data collected in the weather station of Floresta (1275 m a.s.l.) (Fig. 1) – close to the area investigated – the corresponding climatic diagram, according to Walter & Lieth (1960), reveals a dry period of 2-3 months included in summer months (Fig. 2).

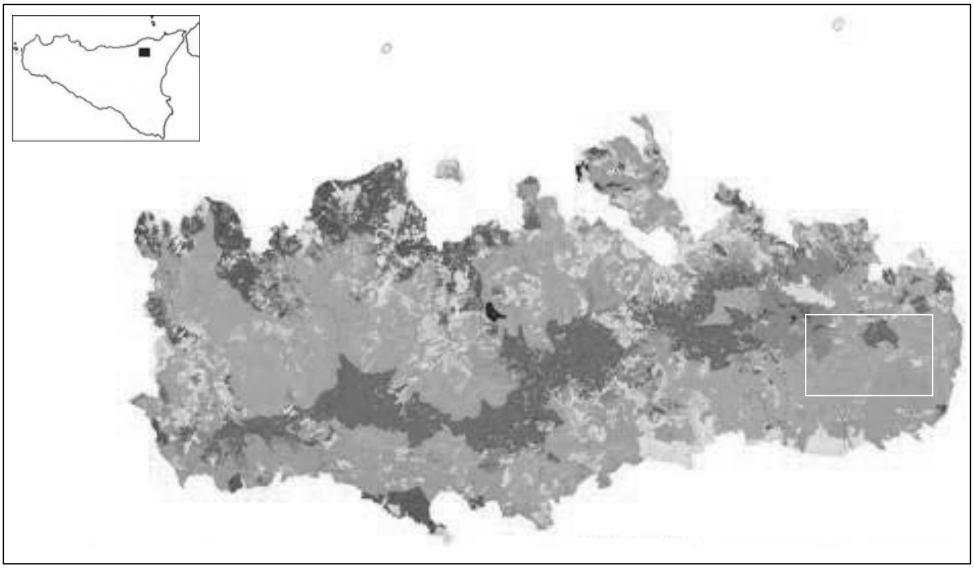


Fig. 1. The territory of the Nebrodi Natural Park in Sicily: evident the diversity of vegetation. In the box on the right, the location of the area investigated (from an unpublished document of the former Laboratory of Systematics, Phytogeography and Plant Ecology of the University of Palermo).

The average annual rainfall recorded in Floresta is over 1300-1400 mm. The precipitations are mainly distributed in the autumn-winter period. Average annual temperatures are comprised between 10-13 °C. The lowest of the whole area are recorded in Floresta where in January the average is -1 °C. In this station, the absolute lowest temperature of -17.4 °C was recorded, while the maximum values were recorded in July, with an average of 19.2 °C and extreme values of 33°-36.5 °C. As observed by Brullo & Grillo (1990), an important factor is represented by snowfall, with one meter of snow falling in an average of 20 days, particularly in January and February. The duration of snow cover is maximum in the higher parts where it can last even for longer periods. According to the bioclimatic classification introduced by Rivas-Martínez (1981, 1982) we are in the Supramediterranean belt, with a temperate Supramediterranean thermotype and Lower sub humid conditions (Bazan & al. 2015). These data justify the presence of extensive mesophilous forest and the presence, in the mountain part, of streams and canals flowing towards the valley, feeding also in summer the main branches of the watercourses that originate from the eastern side of Nebrodi Mountains, with a permanent water flow, although reduced in summer.

The natural vegetation of Nebrodi Mountains has undergone deep transformations over time. The millenary anthropic activities have determined a substantial reduction of the original forest surface and an increase of the aspects of degradation of itself. However, even today, this territory owns an extensive and rich forest heritage of natural and landscape interest (Karadelev & al. 2017), elements that together contribute to enhance the environmental value of the entire Sicilian territory.

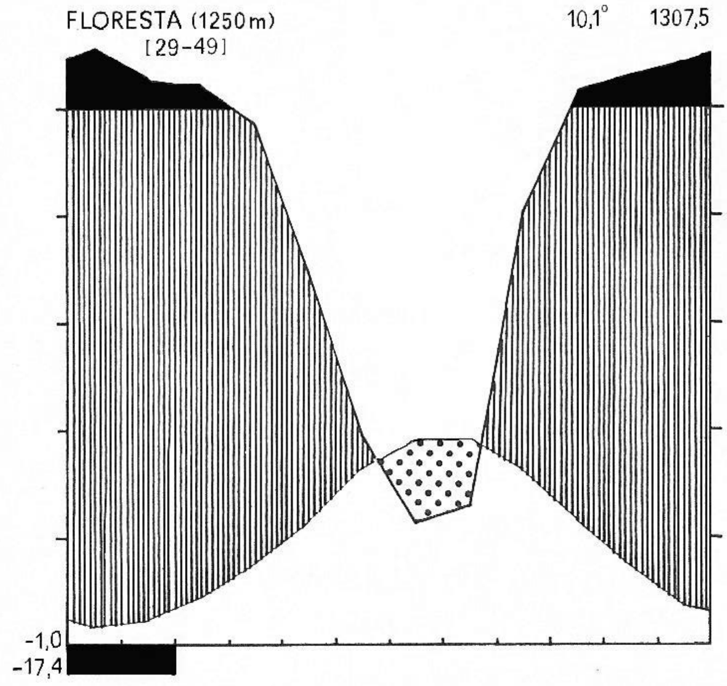


Fig. 2. Floresta weather station (Nebrodi Mountains) (from Brullo & Grillo 1978).

The study area

The investigation area is limited to the eastern part of the Nebrodi system which borders with the Etna area to the east and south-east, and with the Peloritani Mountains to the north-east. It is located almost entirely within the territory of Floresta (Fig. 1), the highest inhabited centre in Sicily (1275 m a.s.l.). Meaningful reliefs in this sector are: Monte Colla (1610 m a.s.l.), Monte Solazzo (1539 m a.s.l.), Monte del Moro (1433 m a.s.l.), Monte di Pietre Bianche (1523 m a.s.l.), Monte Bissalacqua (1424 m a.s.l.), Pizzo Randazzo Vecchio (1420 m a.s.l.), ecc. (see Fig. 3).

Data and Methods

The vegetation examined was that of the small streams in the upper Alcantara river basin, downstream of the northern slopes of Mounts Acquafredda (1447 m a.s.l.), Colla (1611 m a.s.l.), Musarra (1257 m a.s.l.), Pietre Bianche (1523 m a.s.l.) and the southern slopes of Monte Azzarello (1289 m a.s.l.), in the territory of Floresta (Fig. 3), space occupied by deciduous oaks with dominance of *Q. cerris* (*Quercion pubescentis-petraea*) below and thermophilous beech forests (*Geranio versicoloris-Fagion*) upward, but also from widespread coniferous forest systems, in the altitude range 1000-1600 m (a.s.l.). The

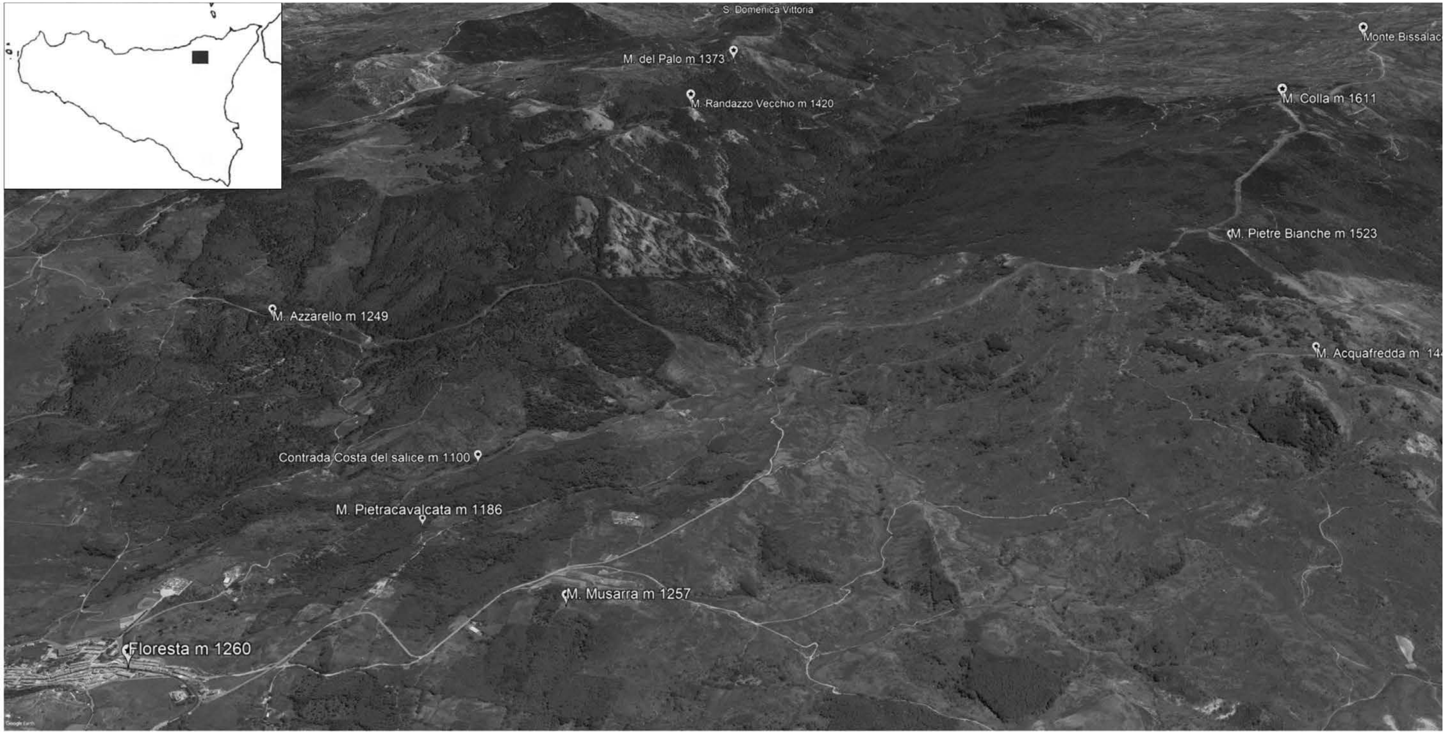


Fig. 3. The studied area of Nebrodi Mountains (N-E Sicily) (prepared by Google Earth Pro).

vegetation survey was carried out in summer, following the phytosociological method of the Zurich-Monpellier school.

The individual surveys have been brought together in two distinct tables, for the forest aspects (Table 1) and for the arborescent aspects (Table 4), respectively. The nomenclature of the plants cited in tables, text and appendix follows the portal to the flora of Italy (http://dryades.units.it/floritaly/index.php), except a few cases. The complete list of the taxa cited in the test and tables is presented in the electronic supplement. Furthermore, both for biological categories and for chorological types, we have followed the nomenclature used by Raimondo & al. (2010).

The phytosociological classification of the vegetation analyzed here, is referred to the syntaxa units recognized by Biondi & al. (2014) which are also followed for the nomenclature of the mentioned syntaxa in the text and in the Electronic Supplementary File (ESF1a). The nomenclature of the plants cited in text, captions, tables, and ESF1b follows Bartolucci & al. (2018), except a few cases. Furthermore, both for biological categories and for chorological types, reference is made to Raimondo & al. (2010). The reunion in six contingents of the numerous chorological types occurring in the phytosociological tables, follows Di Martino & Raimondo (1979). The calculation of the qualitative and quantitative spectra of the biological and chorological categories is based on the same criterion used by the aforementioned authors in their previous study in Sicily (Di Martino & Raimondo 1976).

To compare the studied vegetation and calculate its similarity between associations of the same type in southern Italy and Sicily, in terms of frequency classes of the species, we have used the formula of similarity ratio that for binary data it is the well known formula of Jaccard (Podani 2000) namely the ratio between the intersection and the union of two sets.

Results

On the basis of the floristic comparisons with the syntaxa described by some authors for Southern Italy and Sicily, and also accepted by Biondi & al. (2014) we have defined two new associations: *Alno glutinosae-Salicetum rubentis* and *Euonymo europaei-Salicetum lambertianae*. These two associations are described considering several points of view as follows.

Alno glutinosae-Salicetum rubentis Raimondo, Domina & Di Gristina *ass. nov. hoc loco* (Table 1)
Type: Rel. 5 in Table 1 (geographic coordinates: 37°57’31,03”N/14°54’53,95”E).

This association includes strips of woods on narrow depressions with limited flowing water (Fig. 5d) even during the summer (Fig. 5f). Sometimes, in the flat stretches of the same stream where the riverbed expands, this association is replaced by the *Euonymo-Salicetum lambertianae* the other new association that we describe below.

Characteristic species – Salix ×rubens (Fig. 5c), plant characterizing this association is a nothospecies never mentioned before in phytosociological studies in Sicily and in others Italian and Mediterranean regions. Other characteristics are: *Rhyncochoris elephas* (Fig.

Table 1. Phytosociological table of *Alno-Salicetum rubentis ass. nov.*

Biological form	**Chorological type**	Relevé (n°)	1	2	3	4	5	6	7	8	Frequency
		Altitude (m a.s.l.)	1105	1062	1043	1032	1073	1054	1076	1072	
		Exposure	E	E	E	E	E	SE	NO	SE	
		Slope (°)	10	15	12	20	10	15	10	15	
		Total cover (%)	100	100	100	100	100	100	100	100	
		Trees everage height (m)	22	18	20	18	18	20	15	16	
		Area (m^2)	100	110	100	120	120	110	100	110	
		Species per relevé (n°)									
		Char. and diff. species of association									
P	Europ.	*Salix ×rubens*	1.2	3.3	2.3	2.3	1.2	2.3	2.3	3.4	V
H	NE-Medit.-Mont.	*Rhynchocorys elephas*			+.2	1.2	+.2	1.2	1.2	1.2	IV
G	Stenomedit.	*Euphorbia hirsuta* (loc.)			+	+	+	+	+	1.1	IV
		Char. alliance, order and class									
P	Paleotemp.	*Alnus glutinosa*		2.3	1.2		2.3	1.1	1.2		IV
P	Paleotemp.	*Populus nigra*	2.3	1.1	1.2			1.1			III
P	Paleotemp.	*Solanum dulcamara*			1.1	1.1	1.1	1.1			III
H	Eurasiat.	*Carex pendula*				+		+.2	+.2	+.2	III
P	Paleotemp.	*Populus nigra* var. *italica*	1.2			3.3					II
G	Circumbor.	*Equisetum telmateja*							1.2	1.2	II
G	SE-Europ.	*Symphytum bulbosum*							+.2	1.2	II
P	S-Europ.-Sudsib.	*Fraxinus angustifolia* ssp. *angustifolia*						+		+	II
P	Europ.-Caucas.	*Sambucus nigra*						1.1			I
H	Europ.-Caucas.	*Carex remota*							+.2		I
		Trasgr. of *Salicetea purpureae*									
P	Paleotemp.	*Salix alba*	3.3	1.2	2.3	1.2	2.3	2.3	2.3	2.3	V
P	Eurasiat.	*Salix purpurea* ssp. *lambertiana*	2.3	1.2		2.3	1.2	1.2	1.2	1.2	V
P	Eurasiat.	*Euonymus europaeus*						+		+.2	II
		Trasgr. of *Querco roboris-Fagetea sylvaticae*									
H	Paleotemp.	*Brachypodium sylvaticum* ssp. *sylvaticum*			+.2	+.2	+.2	+	+.2	+.2	IV
G	NE-Medit.-Mont.	*Geranium versicolor*			+	+		+.2	+.2	+	IV
P	Europ.-Caucas.	*Acer pseudoplatanus*				1.1	1.1		1.1		II
H	Paleotemp.	*Lathyrus pratensis* ssp. *pratensis*					+.2	+.2	+.2		II
H	Europ.-Caucas.	*Primula vulgaris* ssp. *vulgaris*						+.2	+.2	+.2	II
P	Europ.-Caucas.	*Acer campestre*				1.1		1.1			II
P	Europ.-Caucas.	*Corylus avellana*			1.1			+			II
H	Eurosib.	*Viola reichenbachiana*						+.2		+.2	II
P	Subatlant.	*Daphne laureola*						1.1			I
P	Eurimedit.	*Hedera helix* ssp. *helix*						1.1			I
H	S-Europ.-Sudsib.	*Anthriscus nemorosa*						+.2			I
H	Endem. Sic.	*Aquilegia sicula*						+.2			I
P	Paleotemp.	*Crataegus monogyna*					+				I
		Other species									
G	Circumbor.	*Equisetum palustre*	1.2	1.2	1.3	1.2	+.2	1.2	+.2	1.2	V
H	Subendem.	*Cirsium creticum* ssp. *triumfettii*	1.2	1.2	1.2		1.2	1.2	1.2	1.2	V
H	Eurasiat.	*Rumex conglomeratus*	+	+		+	+	+	+	+.2	V
H	Eurimedit.	*Mentha longifolia*			1.2	1.2	1.2	1.2	+.2	+.2	IV
H	Paleotemp.	*Juncus inflexus* ssp. *inflexus*	1.2	1.2		+.2	+.2	1.2	+.2		IV
H	Eurasiat.	*Plantago major*			+	+.2	+.2	+.2	+.2	+	IV
H	Circumbor.	*Elymus caninus*		+.2	+.2		+	+.2	+	+	IV
G	Circumbor.	*Juncus articulatus* ssp. *articulates*	1.2	1.2		1.2			1.2	1.2	IV
H	Subcosmop.	*Urtica dioica*			2.3	1.2		1.2	+.2	1.2	IV
P	Paleotemp.	*Rosa canina*			+.2	1.2		1.2	1.2	1.2	IV
H	Endem. Sic.	*Tanacetum vulgare* ssp. *siculum*	1.2	1.2	+.2	+.2		1.2			IV
H	Paleotemp.	*Mentha aquatica* s.l.			+.2	1.2	1.2	1.2	+.2		IV
H	Circumbor.	*Holcus lanatus* ssp. *lanatus*	1.2	1.2		+	+.2	+.2			IV
H	Endem. Sic.	*Arrhenatherum elatius* ssp. *nebrodense*			+	+.2		+.2	+.2	+.2	IV
T	Endem. Sic.	*Medicago lupulina* ssp. *cupaniana*			+	+	+.2	+.2		+.2	IV
H	Eurasiat.	*Epilobium montanum*	+	+				+.2	+.2	+	IV
H	Circumbor.	*Phleum pratense* ssp. *pratense*			+		+	+	+.2	+.2	IV
H	Paleotemp.	*Trifolium repens*			1.2			1.2	+.2	1.2	III
H	Eurimedit.	*Mentha pulegium* ssp. *pulegium*	+.2	+.2		1.2				1.2	III
H	Subtrop.	*Hordeum bulbosum*			+.2	+.2		+.2		+.2	III
G	Circumbor.	*Elymus repens*	+.2			+		+.2	+.2		III
H	Eurasiat.	*Heracleum sphondylium* ssp.			+		+		+	+.2	III

Table 1. continued.

		elegans									
P	Eurimedit.	*Rubus ulmifolius*						1.2	1.2	1.2	II
H	Eurimedit.-Subatl.	*Oenanthe pimpinelloides*	1.2	1.2			+				II
H	Eurosib.	*Juncus conglomeratus*	+.2	+.2						+.2	II
H	Europ.-Caucas.	*Cynosurus cristatus*			+.2		+.2	+.2			II
H	Eurimedit.	*Helosciadium nodiflorum* ssp. *nodiflorum*				+.2	+.2	+.2			II
H	W-Medit.	*Oenanthe globulosa* ssp. *kunzei*						+.2	+.2	+.2	II
H	Endem.	*Taraxacum siculum*						+.2	+.2	+.2	II
H	Eurimedit.	*Dipsacus fullonum*	+	+		+					II
H	W-Medit.	*Cirsium vulgare* ssp. *crinitum*	+	+					+		II
G	Cosmopol.	*Pteridium aquilinum* ssp. *aquilinum*			1.2	1.2					II
H		*Trifolium* sp.			1.2	1.2					II
H	Paleotemp.	*Lolium arundinaceum* ssp. *arundinaceum*				1.2	+.2				II
P		*Rubus* sp.			1.2			+			II
H	N-Eurimedit.	*Ranunculus velutinus*						1.1	+.2		II
T	Stenomedit.	*Calepina irregularis*							+.2	1.2	II
H	Paleotemp.	*Potentilla reptans*	+.2	+.2							II
H	Circumbor.	*Lolium perenne*				+.2		+.2			II
H	Paleotemp.	*Ranunculus repens*					+.2	+.2			II
H	Paleotemp.	*Alliaria petiolata*							+.2	+.2	II
P	Europ.-Caucas.	*Prunus spinosa* ssp. *spinosa*							+.2	+.2	II
T	Subcosmop.	*Torilis arvensis* ssp. *arvensis*			+	+.2					II
H	S-Stenomedit.	*Barbarea bracteosa*							+.2	+	II
G	Stenomedit.	*Dactylorhiza maculata* ssp. *saccifera*					+	+			II
H	Eurasiat.	*Veronica beccabunga* ssp. *beccabunga*						1.2			I
G	Paleotemp.	*Tussilago farfara*				+.2					I
I	Subcosmop.	*Glyceria fluitans*				+.2					I
H	Paleotemp.	*Epilobium hirsutum*					+.2				I
T	S Amer.	*Capsella rubella*						+.2			I
T		*Crepis* sp.						+.2			I
T	Eurimedit.-Subatl.	*Crepis vesicaria*						+.2			I
H	Paleotemp.	*Dactylis glomerata*						+.2			I
H	Eurimedit.	*Galium palustre* ssp. *elongatum*						+.2			I
H	Eurosib.	*Trifolium pratense*						+.2			I
H	Cosmopol.	*Veronica anagallis-aquatica*						+.2			I
T	Eurasiat.	*Sonchus asper*				+					I
H	Stenomedit.	*Carex distachya*					+				I
H	Paleotemp.	*Cichorium intybus*					+				I
Ch	Endem. Sic.	*Euphorbia gasparrinii*					+				I
H	Stenomedit.	*Hypericum perfoliatum*					+				I
P	S-Europ.-Pontico	*Prunus mahaleb*					+				I
H	Eurimedit.	*Arctium minus*						+			I
H	Europ.-Caucas.	*Bellis perennis*						+			I
T	Subcosmop.	*Bromus hordeaceus*						+			I
P		*Ulmus* sp.						+			I

5e), and *Euphorbia hirsuta.*

The first is a rare north-western Mediterranean-mountain element – in Sicily occurring in other different hygrophilous plant communities (Brullo & Grillo 1978; Gianguzzi & al. 2004); the second is quite frequent in our vegetation stands and it is also mentioned, together with *Apium graveolens* and *Alnus glutinosa* in the *Apio graveolentis-Alnetum glutinosae*, association from Corsica, that belongs to the *Alnion glutinosae* (*Alnetalia* and *Alnetea glutinosae*) (see Reymann & al. 2016).

Floristic organization – The association consists basically of four species: *Alnus glutinosa*, *Populus nigra*, *Salix alba* and *S.* ×*rubens* (Figs. 4 a-c and 5a-b). To these, in the tree layer, occasionally is present *Fraxinus angustifolia* subsp. *angustifolia*, *Acer pseudoplatanus*, *A. campestre*; *Salix purpurea* subsp. *lambertiana* is frequent in the shrubby layer in which occurs also *Rosa canina*, *Crataegus monogyna* and, occasionally, *Euonymus europaeus*. The suffruticose and herbaceous layer comprises many species, including *Euphorbia hirsuta, Equisetum palustre*, *E. telmateja*, *Mentha aquatica*, *M. longifolia*, *M. pulegium, Carex pendula*, *C. remota*, *Ranunculus repens*, some grasses (*Holcus lanatus*, *Phleum pratense, Arrhenatherum elatius* subsp. *nebrodense, Elymus caninus, E. repens, Hordeum bulbosum*), *Epilobium hirsutum*, *Heracleum spondylium* subsp. *elegans, J. conglomeratus, J. articulatus* subsp. *articulatus, Trifolium fragiferum, Plantago major, Potentilla reptans, Barbarea bracteosa* (see Table 1).

Biological and biogeographical structure – The examined association consists of species belonging to different biological categories, among which, the hemicryptophytes (55.2% and 58,0%) and the phanerophytes (23.9% and 23.6%) (Table 2, Fig. 6a) play the fundamental role, both qualitatively and quantitatively. The phanerophytes are defining the structure of the vegetation of the proposed association (Table 2, Fig. 6b).

From the biogeographical point of view, the florula is represented by numerous chorological types (chorotypes). The Mediterranean (45.6% and 46.1%) and the boreal chorotypes (33.7% and 37.9%) (Table 3, Fig. 6c) play a considerable role (Table 3, Fig. 6d); the regional endemism are absent.

Table 2. Data of biological spectra of *Alno-Salicetum rubentis.*

Biological forms	florula%	vegetation%
H	55.2	58.0
P	23.9	23.6
G	10.4	12.8
T	8.3	5.0
Ch	1.1	0.3
I	1.1	0.3

Table 3. Data of chorological spectra of *Alno-Salicetum rubentis*.

Chorological contingents	florula %	vegetation %
Mediterranean	45.6	46.1
Boreal	33.7	37.9
Oriental	6.5	6.0
Cosmopolitan	6.5	4.3
Western	5.4	3.9
Meridional	2.3	1.8

Fig. 4. General and particular aspects of *Alno-Salicetum rubentis*: a, b, c, e) plant landscape, structure of forest vegetation and main trees of *Alnus glutinosa*, *Salix ×rubens*, *S. alba* and *Polulus nigra*; d) ancient big tree of *Salix alba*; f) polycormic base of the same ancient big tree of *Salix alba.*

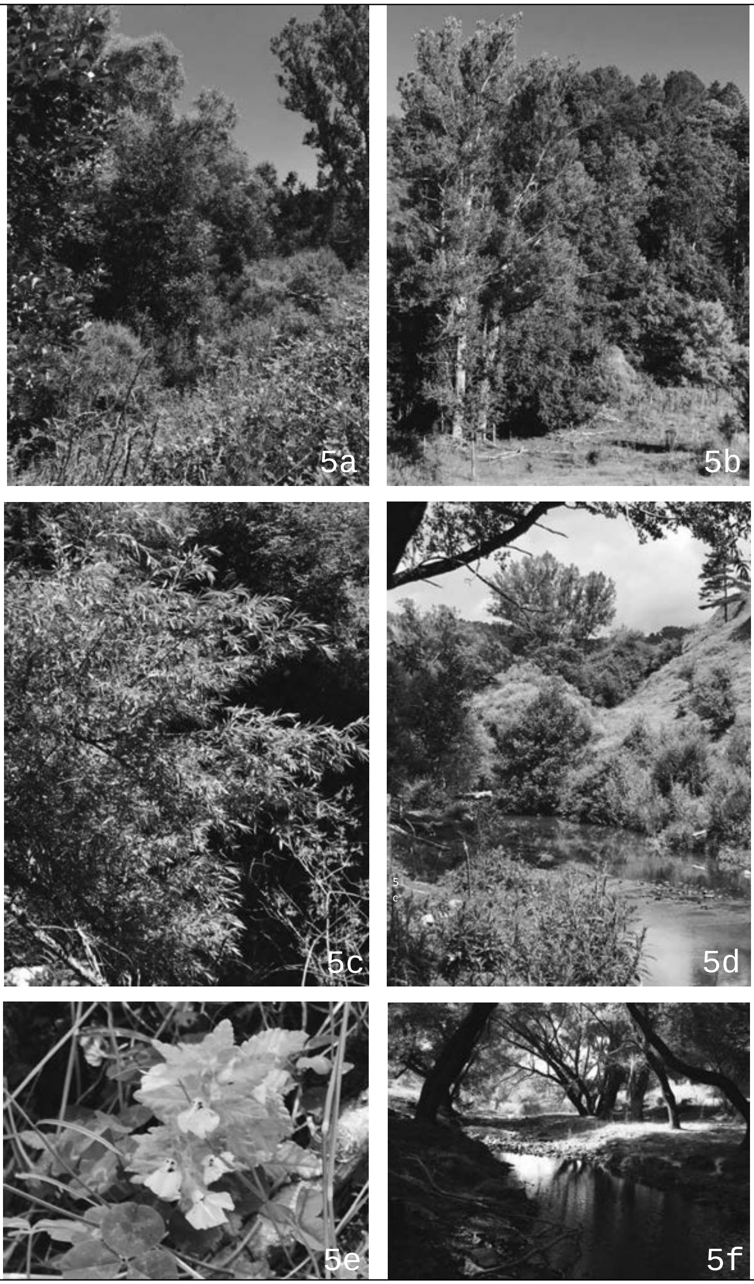
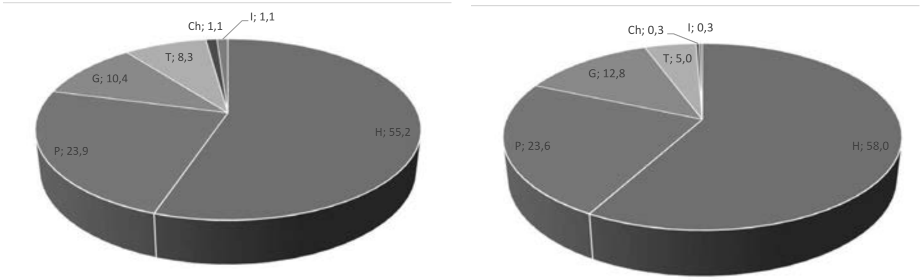
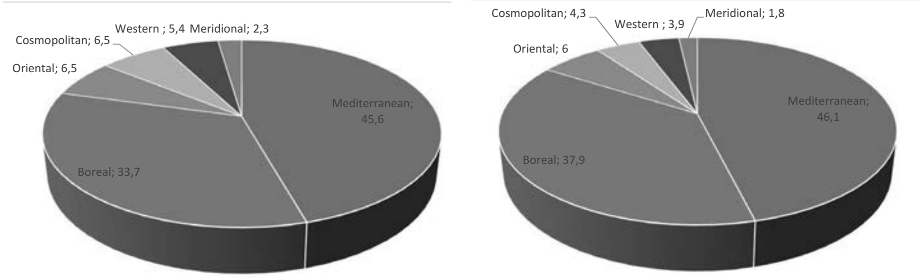


Fig. 5. General and particular aspects of *Alno-Salicetum rubentis*: a) plant landscape and structure of the association; b) in the foreground, on the left, exuberant *Populus nigra* trees; c) stems and leaves of *Salix ×rubens,* characteristic tree species of the association; d) landscape of river vegetation in early summer at easthern slopes of Monte Azzarello; e) flowering plant of *Rhyncochorys elephas,* characteristic erbaceous species of the association; f) landscape of river vegetation in late summer at Piano Grande.



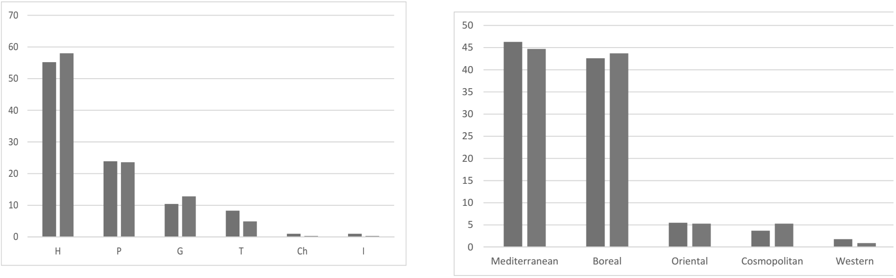
a) Biological qualitative (florula) spectrum of *Alno-Salicetum rubentis.*

b) Biological quantitative (vegetation) spectrum of *Alno-Salicetum rubentis.*



c) Chorological qualitative (florula) spectrum of *Alno-Salicetum rubentis.*

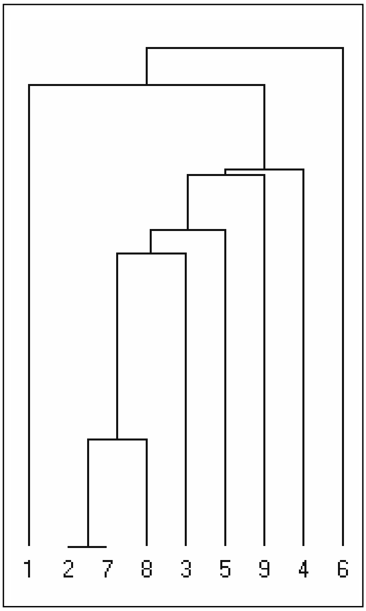
d) Chorological quantitative (vegetation) spectrum of *Alno-Salicetum rubentis.*



e) Comparison between qualitative (blue) and quantitative(orange) biological spectra of the *Alno-Salicetum rubentis*.

f) Comparison between qualitative (blue) and quantitative (orange) chorological spectra of the *Alno-Salicetum rubentis.*

Fig**.** 6. Graphic representation of biological and chorological spectra of *Alno-Salicetum rubentis* (a, b, c, d, e, f).



1 = *Alno glutinosae-Salicetum rubentis* (*ass. nov.)*
2 = *Alnetum glutinoso-cordatae* (from Brullo 2001)
3 = *Alno-Salicetum tyrrhenicae* (from Brullo 2001)
4 = *Hyperico-Salicetum ionicae* (from Brullo 2001)
5 = *Polysticho-Alnetum glutinosae* (from Brullo 2001)
6 = *Euphorbio-Alnetum glutinosae* (from Brullo 2001)
7 = *Alnetum glutinoso-cordatae* (from Brullo & Spampinato 1997)
8 = *Angelico sylvestris-Alnetum glutinosae* (from Brullo & Spampinato 1997)
9 = *Ulmo canescentis-Salicetum pedicellatae* (from Brullo & Spampinato 1990)

Fig. 7. Dendrogram obatined by cluster analysis based on average linkage within merged groups (Podani 2000).

Syntaxonomical position – From Table 1, we can see that the species characteristic of the class *Salici purpureae-Populetea nigrae* are well represented. In particular, the order *Populetalia albae* is represented by *Sambucus nigra, Carex pendula, C. remota, Equisetum telmateia, Hypericum hircinum* subsp. *majus, Solanum dulcamara* and *Symphytum bulbosum.* The high frequency in the tree layer of *Populus nigra* and *Salix alba* (Figs 4d, 4f and 5a-b), respectively characterizing the class and the alliance *Populion albae*, allows us to include this new association in this alliance.

The rich presence of species of *Querco roboris-Fagetea sylvaticae* (= *Carpino-Fagetea sylvaticae*) such as, *Acer pseudoplatanus, A. campestre, Crataegus monogyna, Clematis vitalba, Hedera helix, Daphne laureola, Brachypodium sylvaticum, Lathyrus pratensis, Viola reichenbachiana, Geranium versicolor* and *Sanicula europaea* (Table 1), suggests that it can be considered as a natural transformation of the surrounding climatic vegetation due to the effects of high level of water content in the soil.

Affinities – The *Alno glutinosae-Salicetum rubentis* in Sicily does not relate to other associations. It finds affinity with associations of Calabria, in particular with the *Alnetum glutinoso-cordatae,* the *Alno-Salicetum tyrrhenicae,* the *Hyperico-Salicetum jonicae,* the *Euphorbio corallioides-Alnetum glutinosae* and the *Angelico-Alnetum glutinosae.* In Sicily it has affinity only with the *Ulmo canescentis-Salicetum pedicellatae* from different area.

The dendrogram in Fig. 7 shows the distinction of the new Sicilian association (number 1) from the others in Southern Italy and the association of the same alliance previously described for Sicily (Brullo & Spampinato 1990).

Euonymo europaei-Salicetum lambertianae Raimondo, Domina & Di Gristina *ass. nov. hoc loco* (Table 4).

Type: Rel. 5 in Table 4 (geographic coordinates: 37° 57’38,57”N/14°54’28,24”E).

This association occupies the muddy-silty margins of streams and small flat channels, where water flows slowly on the surface for most of the year. Its physiognomy is due to *Salix purpurea* subsp. *lambertiana* (Figs. 8a-d) and *Euonymus europaeus* (Fig. 8e).

Characteristic species – This association is characterized by few species. They are *Euonymus europaeus*, species of the *Querco-Fagetea* in other environmental and geographical contexts that in this association occurs with considerable frequency and with exuberant plants (Fig. 8e-f), *Salix purpurea* subsp. *lambertiana,* dominant in the arborescent layer and *Euphorbia meuselii*, an endemic shrubs, that also occurring in the south of the Italian peninsula, in mesophilic evergreen oak woods and deciduous oak woods. All the three species can be considered a territorial characteristic or local characteristic species.

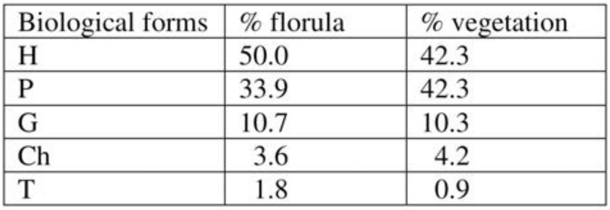
Floristic organization – As can be seen in Table 4, the vegetation investigated is basically constituted by *Salix purpurea* which, as already mentioned, corresponds to a distinct taxon of subspecific level (*S. purpurea* subsp. *lambertiana*). Several other woody, suffruticose and herbaceous species are associated with this willow. In the arborescent layer – besides *Salix purpurea* subsp. *lambertiana* – *Euonymus europaeus* and *Rosa canina* are very frequent. Occasionally *S. alba* and *Alnus glutinosa* are occurring as trasgressive from the *Alno-Salicetum rubentis*. Occasionally among the trees there is a presence of *Malus crescimannoi* and *Pyrus ciancioi*, two endemic trees frequent in the mantle vegetation of the contiguous woods. In the herbaceous layer, *Euphorbia meuselii* as well as *Carex remota,* species indicated as characteristic of the Apennine alleance *Alno-Fraxinion* (Pedrotti & Gafta, 1996). Even some herbaceous species including *Urtica dioica*, *Equisetum palustre*, *Agrostis stolonifera* subsp. *scabriglumis*, *Mentha spicata* and *Elymus repens*, contribute to characterize the florula of this association.

Biological and biogeographical structure – The florula of this association is composed of species belonging to different biological categories among which always the hemicryptophytes (50% and 42.3%) (Table 5a, 9a) and the phanerophytes (33.9% and 42.3%) stand out both qualitatively and quantitatively (Table 5b, Fig. 9b); this last category, as for the previous association, determines the physiognomy of the vegetation of this association. From the biogeographical point of view, numerous chorotypes are represented, belonging to Mediterranean (46.3% and 44.7%) and the boreal chorotype (42.6% and 43.7%) emerge (Table 6a, Fig. 9c). The phytogeographic spectrum comprises numerous geo-elements including the European, Eurasian, paleotemperate and cosmopolitan species. The role of the Mediterranean chorotype (euro and steno) is limited, but in some cases decisive (Table 6b, Fig. 9d); within it the endemic component is well reperesnted (*Malus crescimannoi*, *Pyrus ciancioi*, .*Arrhenatherum elatius* subsp. *nebrodense* and *Euphorbia meuselii*).

Table 4. Phytosociological table of *Euonymo-Salicetum lambertianae.*

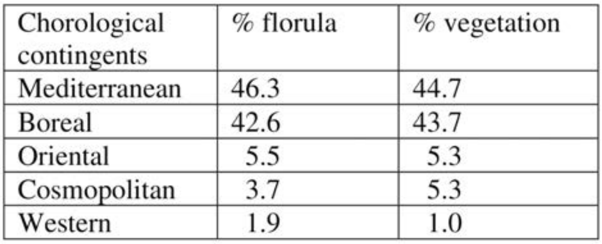
Biological form	**Chorological type**	Relevé (n°)	1	2	3	4	5	6	Frequency
		Altitude (m a.s.l.)	1062	1293	1105	1108	1078	1153	
		Exposure	E	NO	N	NW	E	SE	
		Slope (°)	5	3	3	5	4	3	
		Total cover (%)	95	100	95	100	95	95	
		Woody layer average height (m)	5,0	6,0	5,5	6,0	5,0	5,5	
		Area (m^2)	70	90	80	80	70	90	
		Species per relevé							
		Char. and diff. species of association							
P	Eurasiat.	*Salix purpurea* ssp. *lambertiana*	4.5	5.5	4.5	5.5	4.5	4.5	V
P	Eurasiat.	*Euonymus europaeus* (diff.)	1.1	1.1	1.2		+.2	+.2	V
Ch	Endem.	*Euphorbia meuselii* (diff.)	1.1	+.2		1.1	+.2		IV
		Char. of the alliance, order and class							
P	Paleotemp.	*Salix alba*		1.1			1.1		II
		Trasgr. of *Populion*, *Populetalia* and *Salici purpureae-Populetea nigrae*							
P	Paleotemp.	*Solanum dulcamara*	1.2	1.1	1.1	+			IV
H	NE-Medit.-Mont.	*Rhynchocorys elephas*		+.2	+.2	+.2		+.2	IV
G	Stenomedit.	*Euphorbia hirsuta*	1.1	+			+	1.2	IV
P	Eurasiat.	*Salix caprea*			1.2	1.2		1.2	III
P	Europ.-Caucas.	*Sambucus nigra*				+.2	1.1		II
H	Eurasiat.	*Carex pendula*		+.2		+.2			II
P	Paleotemp.	*Alnus glutinosa*			1.1				I
P	Europ.	*Salix ×rubens*					1.1		I
P	S-Europ.-Sudsib.	*Fraxinus angustifolia*						1.1	I
P	Eurimedit	*Hypericum hircinum* ssp. *majus*				+.2			I
		Trasgr. of *Querco roboris Fagetea sylvaticae*							
P	Europ.-Caucas.	*Acer campestre*	1.1	1.1	1.1		1.1	1.1	V
P	Paleotemp.	*Rosa canina*	1.1	1.2	1.2	1.2		1.2	V
P	Paleotemp.	*Crataegus monogyna*	+	1.1			1.1		III
H	Paleotemp.	*Brachypodium sylvaticum* ssp. *sylvaticum*	+.2		+.2			+.2	III
P	Subatlant.	*Daphne laureola*			+		+.2		II
P	Europ.-Caucas.	*Clematis vitalba*						1.2	I
P	Eurimedit.	*Rubus ulmifolius*						1.2	I
H	Circumbor.	*Prunella vulgaris* ssp. *vulgaris*	1.1						I
H	Circumbor.	*Elymus caninus*	+.2						I
Ch	Eurimedit.	*Ruscus aculeatus*			+.2				I
H	Paleotemp.	*Sanicula europaea*				+.2			I
G	NE-Medit.-Mont.	*Geranium versicolor*				+			I
H	Endem. Sic.	*Aquilegia sicula*					+		I
		Other species							
H	Subcosmop.	*Urtica dioica*	1.2	+.2	1.2	1.2	+.2		V
H	Endem. Sic.	*Arrhenatherum elatius* ssp. *nebrodense*	+.2	+.2	+.2	+.2		+	V
P		*Rubus* sp.	1.2	1.2	1.2		1.2		IV
G	Circumbor.	*Equisetum palustre*	1.2		1.2	1.2			III
H	Euroasiat.	*Mentha spicata*	1.2				1.2	+.2	III
H	Europ.-Caucas.	*Primula vulgaris* ssp. *vulgaris*			+.2	+.2		1.2	III
H	Circumbor.	*Agrostis stolonifera* ssp. *scabriglumis*		+.2		+.2	+.2		III
P	Endem. Sic.	*Malus crescimannoi*				1.1		1.1	II
P		*Pyrus* sp.	1.1					+	II
H	Endem. Sic.	*Tanacetum vulgare* ssp. *siculum*	+.2		+.2				II
H	Eurasiat.	*Plantago major*	+.2					+.2	II
G	Circumbor.	*Elymus repens*			+.2			+.2	II
H	Eurasiat.	*Rumex conglomeratus*	+			+			II
G	Circumbor.	*Equisetum telmateia*				1.2			I
H	Subendem.	*Cirsium creticum* ssp. *triumfettii*						1.2	I
G	Circumbor.	*Juncus articulatus* ssp. *articulatus*						1.2	I
H	Eurimedit.	*Mentha pulegium* ssp. *pulegium*						1.2	I
H	Subcosmop.	*Urtica dioica*						1.2	I
P	Endem. Sic.	*Pyrus ciancioi*			1.1				I
H	Paleotemp.	*Lolium arundinaceum* ssp. *arundinaceum*	+.2						I
H	Paleotemp.	*Ranunculus repens*	+.2						I
H	Eurosib.	*Trifoilum pratense*		+.2					I
T	Paleotemp.	*Persicaria lapathifolia*		+.2					I
H	Eurosib.	*Juncus conglomeratus*					+.2		I
H	Paleotemp.	*Mentha aquatica* s.l.					+.2		I
P	Europ.-Caucas.	*Prunus spinosa* ssp. *spinosa*						+.2	I
H	Paleotemp.	*Juncus inflexus* ssp. *inflexus*						+.2	I
H	Eurasiat.	*Epilobium montanum*						+.2	I
H	Eurimedit.	*Carex distans*						+.2	I
H	Paleotemp.	*Epilobium hirsutum*	+						I
H	Europa-Asia	*Heracleum sphondylium* ssp. *elegans*						+	I

Table 5. Data of biological spectra of *Euonymo-Salicetum lambertianae.*



Biological forms	% florula	% vegetation
H	50.0	42.3
P	33.9	42.3
G	10.7	10.3
Ch	3.6	4.2
T	1.8	0.9

Table 6. Data of chorological spectra of *Euonymo-Salicetum lambertianae.*



Chorological contingents	% florula	% vegetation
Mediterranean	46.3	44.7
Boreal	42.6	43.7
Oriental	5.5	5.3
Cosmopolitan	3.7	5.3
Western	1.9	1.0

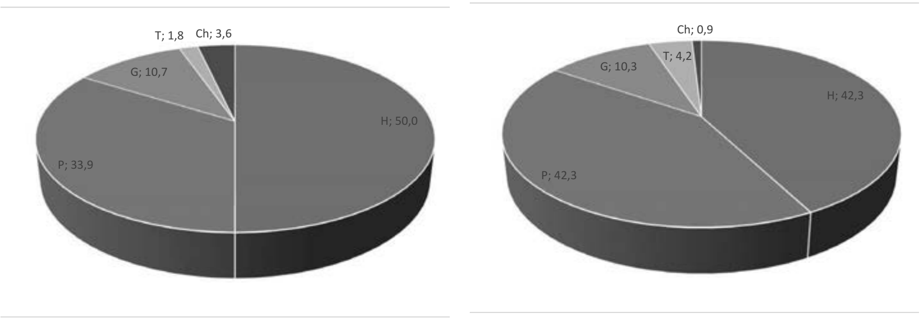
Syntaxonomical position – The *Euonymo europaei-Salicetum lambertianae* is an association referable to the *Salicion albae*, alliance of the order *Salicetalia purpureae*. In the association, the only feature of the alliance present is *Salix alba*. *Salix purpurea* subsp. *lambertiana* physiognomizes this association and it is considered differential species; for this two roles the same taxon contributes to give its name. The described association is spatially and therefore also dynamically correlated to *Alno-Salicetum rubentis*, association of the same class *Salici purpureae-Populetea nigrae*, more evolved and referred to different order and alliance.

In the examined association, *Carex pendula* and *Sambucus nigra* – characteristics of the *Populion* and *Populetalia albae* –are to be considered transgressive. Also *Acer campestre* and *Brachypodium sylvaticum* are transgressive species, but of the climatic communities occurring to the margins of the association and referred to the *Querco roboris-Fagetea sylvaticae* class.

Affinities – The *Euonymo europaei-Salicetum lambertianae* has an affinity with the willow woods of Calabria (Brullo & Spampinato 1997) framed in the alliance *Salicion albae*, where we find the following associations: *Eriantho-Salicetum amplexicaulis*, *Alno-Salicetum jonicae, Salicetum albo-brutiae,* and finally the *Salicetum lambertiano-elaeagni.* The new Sicilian association is relatively similar only with the *Salicetum albo-purpureae* occurring also in south Italy (Calabria).

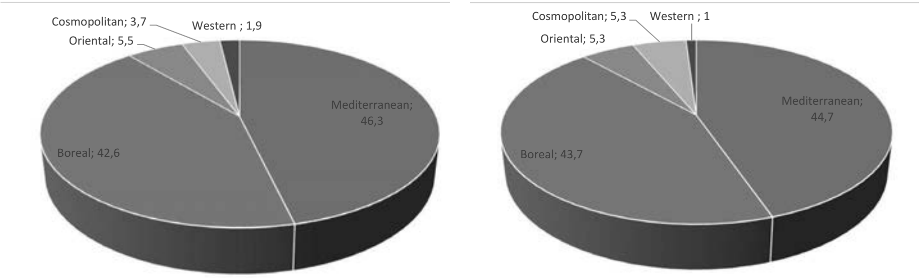
Distances and affinities of the new association with other similar associations described for the southern regions of the Italian Peninsula and Sicily were calculated by processing with Similarity ratio (Podani 2000). From the dendrogram obtained

Fig. 8. General and particular aspects of *Euonymo-Salicetum lambertianae*: a) general plant landscape (northern slopes of Monte Colla); b) linear physiognomic aspect of the association; remarkable is the exclusive dominance of *Salix purpurea* subsp. *lambertianae*; c) structure of the basal layer of the arborescent vegetation; d) basal layer of the arborescent vegetation of the association; e) autumnal arborescent aspect of the association: in the foreground *Salix purpurea* subsp. *lambertiana* with *Euonymus europaeus*; f) vigorous small tree of *Euonymus europaeus* in autumn.



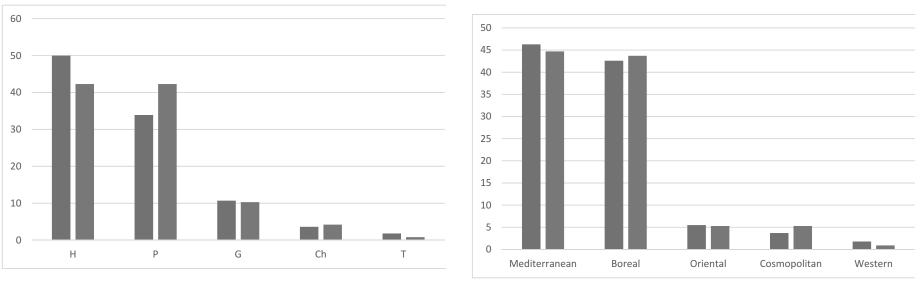
a) Biological qualitative (florula) spectrum of *Euonymo-Salicetum lambertianae.*

b) Biological quantitative (vegetation) spectrum of *Euonymo-Salicetum lambertianae.*



c) Chorological qualitative (florula) spectrum of *Euonymo-Salicetum lambertianae.*

d) Chorological quantitative (vegetation) spectrum of *Euonymo-Salicetum lambertianae.*



e) Comparison between qualitative (blue) and quantitative (orange) biological spectra of the *Euonymo-Salicetum lambertianae*.

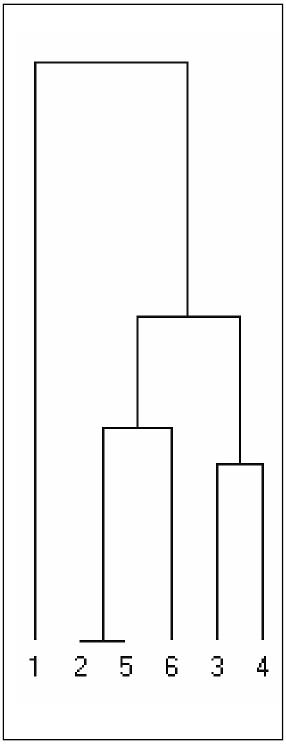
f) Comparison between qualitative (blue) and quantitative (orange) chorological spectra of the *Euonymo-Salicetum lambertianae*.

Fig. 9. Graphic representation of biological and chorological spectra of *Euonymo-Salicetum lambertianae* (a, b, c, d, e, f).

(Fig. 10), the distinction of the new Sicilian association is clear from the other in Southern Italy, and the association of the same alliance previously described for Sicily (Brullo & Spampinato 1990). The peninsular associations mentioned above have a greater affinity between them. As with *Alno glutinosae-Salicetum rubentis*, also in this case the other associations mentioned above have greater affinity with each other.

Discussion and conclusions

In the studies on the vegetation of the waterbodies of Sicily – filed to the most diffused aspects, mainly included in the thermo and meso-Mediterranean phytoclimatic belts – analyses of submontane phytocoenoses (Supramediterranean), actually little diffused in the Island, were missing. The vegetation previously studied had been framed in various units of *Populetalia albae*, *Salicetalia purpureae* and *Nerio-Tamaricetalia,* orders also referring to *Querco roboris-Fagetea sylvaticae, Salicetea purpureae* and *Nerio-Tamaricetea* classes. In light of the new acquisitions, this approach is superseded only as regards the first order placed in two distinct classes: the prodrome of the Italian vegetation (Biondi & al. 2014) refers it to *Salici purpureae-Populetum nigrae*, several other authors to *Alno glutinosae-Populetum albae* (Bournérias & al. 2001; Mucina & al. 2016; Reymann & al. 2016).



1 = *Euonymo europaei-Salicetum lambertianae* (*ass. nov.*)
2 = *Salicetum albo-brutiae* (from Brullo & al. 2001)
3 = *Eriantho-Salicetum amplexicaulis* (from Brullo & al. 2001)
4 = *Alno-Salicetum ionicae* (from Brullo & al. 2001)
5 = *Salicetum lambertiano-elaeagni* (from Brullo & Spampinato 1997)
6 = *Salicetum albo-purpureae* (from Brullo & Spampinato 1990)

Fig. 10. Dendrogram obtained by cluster analysis based on average linkage within merged groups (Podani 2000).

The study presented here, examines unprecedented aspects located in the Nebrodi Mountains, the largest and wettest mountain system in Sicily and, consequently, covered by wide forests. It is not a case that the largest and most important waterways of the island originate from it, including the Alcantara river and some tributaries of the Simeto river.

The phytosociological study of the riparian vegetation of the small watercourses examined – the only ones with a permanent regime, although with large fluctuations in water flow during the year – allowed to highlight the presence of phytocoenoses not yet detected on the Island. These are two related associations: the first one is the real forestry aspect. The two associations have floristic and ecological affinities with recurrent communities in the southern Apennines (Brullo & Spampinato 1997), in particular in Calabria, the extreme region of the Italian peninsula close to Sicily. In this region, similar aspects have been described in Sila (Barbagallo & al. 1990) and Aspromonte (Brullo & Spampinato 1997; Brullo & al. 2001). From a phytosociological point of view, the two associations described here are also linked to some recurring associations in other areas of the same Nebrodi district and other sectors of Sicily (Brullo & Spampinato 1990; Gianguzzi 1999; Gianguzzi & al. 2004). Nevertheless, unlike the associations already known – including the *Salicetum albo-pedicellatae* and the *Saliceto pedicellatae-purpureae* – the associations described are more mesophilic and justify their classification in two distinct classes – respectively *Alno glutinosae-Populetea albae* and *Salicetea purpureae*. In particular, the association *Alno glutinosae-Salicetum rubentis*, framed here in the alliance *Populion albae* (*Populetalia albae*); therefore, the *Euonymo europaei-Salicetum lambertianae* in the alliance *Salicion albae* (*Salicetalia purpureae*).

Also based on the results presented here, we can conclude by offering a new syntaxonomic framework of the riparian vegetation of the waterways of Sicily. It takes into account the higher order units established after the first syntaxonomic gradings received by the various associations at the time of their respective descriptions.

AZONAL VEGETATION (ALLUVIAL FORESTS AND SHRUBS) IN SICILY
SYNTAXONOMIC FRAMEWORK PROPOSED (*)

SALICI PURPUREAE-POPULETEA NIGRAE Rivas Mart. & Cantò ex Rivas Mart. & al. 1991

- *POPULETALIA ALBAE* Br.-Bl. & Tchou 1949
  - *POPULION ALBAE* Br.-Bl. ex Tchou 1949
    - *Roso sempervirentis-Populetum nigrae* Pedrotti & Gafta 1992
    - ***Alno glutinosae-Salicetum rubentis*** Raimondo, Domina & Di Gristina *ass. nov. hoc loco*
  - *PLATANION ORIENTALIS* I. Kárpati & V. Kárpati 1961
    - *Platano- Salicetum pedicellatae* Barbagallo, Brullo & Fagotto 1979
    - *Platano-Salicetum gussonei* Brullo & Spampinato 1990

OSMUNDO-ALNION GLUTINOSAE Dierschke & Rivas-Martínez 1975

Osmundo regalis-Salicetum pedicellatae Brullo & Spampinato 1990

SALICETALIA PURPUREAE Moor 1958

SALICION ALBAE Soó 1951

Salicetum albo-purpureae (I. Kárpati & V. Kárpati 1961) Barbagallo, Brullo & Fagotto 1979

Euonymo europaei-Salicetum lambertianae Raimondo, Domina & Di Gristina *ass. nov. hoc loco*

SALICION PEDICELLATAE Rivas-Martínez & al. 1984

Salicetum albo-pedicellatae Brullo & Spampinato 1990

Ulmo canescentis-Salicetum pedicellatae Brullo & Spampinato 1990

Agropyro panormitani-Salicetum pedicellatae Brullo & Spampinato 1990

NERIO-TAMARICETEA Br.-Bl. & O. Bolòs 1958

NERIO OLEANDRI -VITICETALIA AGNI-CASTI De Foucault, Bensettiti & Paradis 2012

RUBO ULMIFOLII-NERION OLEANDRI O. Bolòs 1985

Sparti-Nerietum oleandri Brullo & Spampinato 1990

TAMARICETALIA Br.-Bl. & O. Bolòs 1958 em. Izco, Fernández-González & A. Molina 1984

TAMARICION AFRICANAE Br.-Bl. & O. Bolòs 1957

Tamaricetum gallicae Br.-Bl. & O. Bolòs 1957

Aggr. a *Tamarix africana* Brullo & Spampinato 1990

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*This scheme is inspired to the syntaxonomic framework proposed for Italian vegetation by Biondi & al. (2014).

From the syntaxonomic framework presented above, in Sicily, the *Salicion albae* alliance is represented by the *Salicetum albo-purpureae* and by the *Euonymo europaei-Salicetum lambertianae,* the new association described here for the Nebrodi Mountains.

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References

Barbagallo, C., Brullo, S., Furnari, F., Longhitano, N. & Signorello, P. 1982: Studio fitosociologico e cartografico della vegetazione (1:25.000) del territorio di Serra S. Bruno (Calabria). – In: C.N.R., s.

AQ/1/227, Coll. Programma Finalizzato “Promozione della Qualità dell’Ambiente”. Roma.

Bazan, G., Marino, P., Guarino, R., Domina, G. & Schicchi, R. 2015: Bioclimatology and vegetation series in Sicily: a geostatistical approach. – Ann. Bot. Fenn. **51:** 1-18. https://doi.org/10.5735/085.052.0202

Biondi, E., Blasi, C., Allegrezza, M., Anzellotti, I., Azzella, M. M., Carli, E., Casavecchia, S., Copiz, R., Del Vico, E., Facioni, L., Galdenzi, D., Gasparri, R., Lasen, C., Pesaresi, S., Poldini, L., Sburlino, G., Taffetani, F., Vagge, I., Zitti, S. & Zivkovic, L. 2014: Plant communities of Italy: The Vegetation Prodrome. – Pl. Biosyst. **148(4):** 728-814. https://doi.org/ 10.1080/11263504.2014.948527

Bournérias, M., Arnal, G. & Bock, C. 2001: Guide des groupements végétaux de la région parisienne. – Paris.

Brullo, S. & Grillo, M. 1978: Ricerche fitosociologiche sui pascoli dei monti Nebrodi (Sicilia settentrionale). – Not. Fitosoc. **13:** 23-61.

— & Spampinato, G. 1990: La vegetazione dei corsi d’acqua della Sicilia. – Boll. Accad. Gioenia **23(336):** 192-251.

— & — 1997: Indagine fitosociologica sulle ripisilve della Calabria (Italia meridionale). – Lazaroa **18:** 105-151.

— & — 1999: Syntaxonomy of higrophilous woods of the *Alno-Quercion roboris*. – Ann. Bot. (Rome) **57:** 133-146.

—, Cirino, E. & Longhitano, N. 1995: Vegetazione della Sicilia: quadro sintassonomico. – Atti Convegni Lincei **115:** 285-305.

—, Scelsi, F. & Spampinato, G. 2001: La vegetazione dell’Aspromonte. – Reggio Calabria.

Di Martino, A. & Raimondo, F. M. 1976: Le infestanti delle colture di frumento della Sicilia occidentale. – Not. Fitosoc. **11:** 45-74.

— & — 1979: Biological and chorological survey of the Sicilian flora. – Webbia **34(1):** 309-335. https://doi.org/10.1080/00837792.1979.10670174

Domina, G., Venturella, G. & Gargano, M. L. 2018: Synthetic cartography for mapping biodiversity in the Mediterranean region: Sicily as a case study. – PhytoKeys **109:** 77-92. https://doi.org/10.3897/phytokeys.109.28297

Giaimi, G. 1994: Il Parco dei Nebrodi. – Palermo.

Gianguzzi, L. 1999: Flora e Vegetazione dei Nebrodi. Itinerari didattici. Regione Siciliana, Assessorato Agricoltura e Foreste. – Palermo.

—, La Mantia, A. & Lo Presti, R. M. 2004: Distribuzione, ecologia e *status* conservativo di *Petagnaea gussonei* (Sprengel) Rauschert (*Apiaceae*). – Naturalista sicil., s 4, **28(1):** 205-242.

Karadelev, M., Rusevska, K., Venturella, G., Torta, L. & Gargano, M. L. 2017: First record of *Capnobotrys dingleyae* (*Metacapnodiaceae*) on *Taxus baccata* for southern Europe. – Pl. Biosyst. 1**51(6):** 941-943. https://doi.org/10.1080/11263504.2017.1289274

Mucina, L., Bültmann, H., Dierßen, K., Theurillat, J-P., Raus, T., Čarni, A, Šumberová, K., Willner, W., Dengler, J., Gavilán Garcìa, R., Chytrý, M., Hájek, M., Di Pietro, R., Iakushenko, D., Pallas, J., Daniëls, F. J. A., Bergmeier, E., Santos Guerra, A., Ermakov, N., Valachovič, M., Schaminée, J. H. J., Lysenko, T., Didukh, Y. P., Pignatti, S, Rodwell, J. S., Capelo, J., Weber, H. E., Solomeshch, A., Dimopoulos, P., Aguiar, C., Hennekens, S. M. & Ticýh, L. 2016: Vegetation of Europe: hierarchical floristic classification system of vascular plant, bryophyte, lichen, and algal communities. – Appl. Veg. Sci. **19 (Suppl. 1):** 3-264. https://doi.org/10.1111/avsc.12257

Pedrotti, F. & Gafta, D. 1996: Ecologia delle foreste ripariali e paludose dell’Italia. – L’Uomo e l’Ambiente (Camerino) **23:** 1-165.

Pignatti, S. 2017: Flora d’Italia, 2^a ed., **2.** – Milano.

Podani, J. 2000: Introduction to the exploration of multivariate biological data. – Leiden.

Raimondo, F. M., Domina, G. & Spadaro, V. 2010: Checklist of the vascular flora of Sicily. – Quad. Bot. Amb. Appl. **21(2010):** 189-252.

—, Schicchi, R. & Bazan, G. 2010: Analisi della vegetazione ripicola dell'alto Alcantara (Nebrodi, Sicilia). – In: Countdown 2010 save biodiversity. Il contributo della scienza della vegetazione, Università degli Studi di Pavia, Dipartimento di Ecologia del Territorio. – Pavia.
Reymann, J., Panajotis, C., Bioret, F., Bacchetta, G., Delage, A., Delbosc, P., Gamisans, J., Gauberville, C., Hugot, L., O'Deye-Guizien, K., Piazza, C. & Pioli, A. 2016: Prodrome des Végétations de Corse. – Doc. Phytosoc. Sér. 3, **4:** 1-176. https://doi.org/ 10.3406/ecmed.2018.2028
Rivas-Martínez, S. 1981: Les étages bioclimatiques de la végétation de la Péninsula Ibérique. – Anales Jard. Bot. Madrid **37(2):** 251-268.
— 1982: Etages bioclimatiques, secteurs chorologiques et series de vegetation de l'Espagne méditerranéenne. – Ecol. Medit. **8(1-2):** 275-288. https://doi.org/10.3406/ecmed.1982.1954
Schicchi, R. 2004: Materiali per una carta tematica delle emergenze floristiche e vegetazionali del parco dei Nebrodi. – Naturalista Sicil., s.4., **28(1):** 39-163.
Walter, H. & Lieth, H. 1960: Klimadiagramm-Weltatlas. – Jena.

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Locality, date and author/s of the reliefs in tables 1 and 4.

Table 1 (*Alno glutinosae-Salicetum rubentis*)
Rel. 1: Contrada Costa del Salice, 20 June 2019, Di Gristina & Raimondo
Rel. 2: Torrentello in Contrada Costa del Salice, 20 June 2019, Di Gristina & Raimondo
Rel. 3: Piano Grande, 20 June 2019, Di Gristina & Raimondo
Rel. 4: Torrente Inganno 24 June 2009, Raimondo
Rel. 5: Piano Grande: 24 June 2009, Raimondo
Rel. 6: Vallone sotto Monte Azzarello 24 June 2009, Raimondo
Rel. 7: Vallone sotto Monte Acquafredda, 27 June 2019, Domina & Raimondo
Rel. 8: Torrente Favoscuro, 27 June 2019, Domina & Raimondo

Table 4 (*Euonymo europaei-Salicetum lambertianae*)
Rel. 1:Torrentello in Contrada Costa del Salice, 20 June 2019, Di Gristina & Raimondo
Rel. 2: Incisione sul versante nord di Monte Colla, 24 June 2009, Raimondo
Rel. 3: Vallone confluente nel Torrente Inganno, 24 June 2009, Raimondo
Rel. 4: Incisione a valle di Monte Bissalacqua, 20 June 2019, Di Gristina & Raimondo
Rel. 5: Incisione a valle di Monte Musarra, 27 June 2019, Domina & Raimondo
Rel. 6: Vallone confluente nel Torrente Favoscuro, 27 June 2019 Domina & Raimondo

Article

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Taxonomic investigation on *Allium hirtovaginum* group (*Amaryllidaceae*) from East Mediterranean area

Abstract

Brullo, S. & Salmeri, C.: Taxonomic investigation on *Allium hirtovaginum* group (*Amaryllidaceae*) from East Mediterranean area. — Fl. Medit. 31 (Special Issue): 169-211. 2021. — ISSN: 1120-4052 printed, 2240-4538 online.

Within taxonomic studies on *Allium* sect. *Codonoprasum* from Mediterranean flora, populations belonging to *A. hirtovaginum* Candargy group were examined. Based on field investigation and herbarium surveyes, this group is represented by very critical and not well known taxa, distributed in the East Mediterranean, showing a marked morphological variability. Currently, the species referable to this group in addition to *A. hirtovaginum* are also *A. pilosum* Sibth. & Sm., *A. aeginiense* Brullo, Giusso & Terrasi and *A. nerimaniae* Koçyiğit & Kaya. Besides, other 13 species are here described as new to science, they are *A. pythagoricum, A. pignattii, A. hippocraticum, A. abanticum, A. velutinum, A. carium, A. papillosum, A. adenanthum, A. smyrnaeum, A. pavonianum, A. denticulatum* and *A. compactatum*. A detailed morphological description together with a careful illustration, as well as remarks on their karyology, phenology, ecology, geographic distribution, and taxonomic relationships are provided for each investigated species. An analytical key regarding all the species attributable to this group was processed too.

Key words: *Allium hirtovaginum*, biogeography, East Mediterranean, karyology, sect. *Codonoprasum*, taxonomy.

Introduction

Allium is one of the largest and complex monocotyledonous genera, distributed mainly in the northern hemisphere, with about 1,200 taxa known so far (Govaerts & al. 2020). Within this genus, it is possible to detect a high rate of endemics, which are continuously described from the Mediterranean and Asian territories, representing the main centres of species diversity together with North America (Fritsch & Friesen 2002). Based on literature data, many species and critical groups fall into the subgen. *Allium* and in particular in the sect. *Codonoprasum* Reichenb., which gathers a large number of taxa distributed mainly in the Euro-Mediterranean and Irano-Turanian territories. In fact, previous cytotaxonomic investigations allowed us to describe a significant number of new species belonging to this section and to re-evaluate several critical or little-known species (Brullo & al. 1993, 1994, 1996a, 1996b, 1996c, 1997a, 1997b, 1999, 2001a, 2001b, 2002, 2003a, 2003b, 2004, 2007, 2008a, 2008b, 2009, 2010, 2012, 2013, 2014, 2017, 2019;

Brullo & Tzanoudakis 1994; Salmeri 1998; Bogdanović & al. 2008, 2009, 2011; Giusso & al. 2015; Salmeri & al. 2016; Özhatay & al. 2018). These studies emphasized that in this section the populations referable to the group of *Allium hirtovaginum* Candargy gravitating in the eastern Mediterranean are of particular interest (Halacsy1904: Hayek 1932; Stearn 1978, 1980; Kollmann 1984; Özhatay 1993; Dimopoulos & al. 2013; Govaerts & al. 2020; Flora of Greece Web 2020). This species, described by Candargy (1897) from the island of Lesbos in the eastern Aegean, similarly to all the other species in this section, is characterized by thin leaves distributed on all or part of the scape, spathe with two persistent valves usually longer than the inflorescence, with a well developed appendage, simple staminal filaments, ovary with inconspicuous nectariferous pores and distinctly trilobed more or less obovoid capsule. However, it differs for some very peculiar morphological traits mainly consisting in leaves with a dense hairy indumentum and stamens exserted from the perigon. These features occur constantly in all populations morphologically similar to *Allium hirtovaginum*, which are widespread in many territories of the Aegean area, mainland Greece and Anatolia. Based on literature (Brullo & al. 2008; Koçyiğit & Kaya 2020), *A. aeginiense* Brullo, Giusso & Terrasi and *A. nerimaniae* Koçyiğit & Kaya also close relationships with *A. hirtovaginum*. Besides according to Brullo & al. (2001a), *A. pilosum* Sibth. & Sm. should also be added to this group. Karyological investigations on *A. hirtovaginum* s.l. were carried out by Tanker & Kurucu (1979), Özhatay (1993) and Karavokyrou & Tzanoudakis (1991), which always reported a diploid chromosome count (2*n* = 16). Extensive field investigations carried out in various localities of Greece, especially in the Aegean islands, as well as in western Anatolia (Turkey) allowed us to discover many *Allium* populations all clearly referable to the *Allium hirtovaginum* group. Morphological and karyological investigations performed on living material emphasized that most of them are well differentiated from the known species of this group and therefore they can be treated as species new to science. In order to highlight the most relevant differences among the various examined populations referable to both the already known species and the new ones, the morphological, karyological, phenological, chorological and ecological characteristics of each are provided, together with the taxonomic relationships, a detailed iconography and a list of all examined herbarium specimens.

Materials and Methods

The morphological study was based on living plants collected in Greece and Turkey, which were then cultivated in the Botanical Garden of Catania. Furthermore, herbarium collections from various botanical museums were examined for taxonomic comparison (B, BM, C, CAT, FI, G, HUJ, ISTE, K, M, OXF, P, UPA, W and WU). Qualitative and quantitative morphological traits were examined under a Zeiss Stemi SV11 Apo stereomicroscope at 6–66× magnification from fresh material (about 10 individuals). In particular the vegetative and reproductive features were chosen according to their diagnostic value to discriminate against the populations under investigation. Herbarium specimens and available literature data were also employed to better define the range of intra-specific variability. Karyological analyses were performed on mitotic plates obtained from root meristematic cells of cultivated bulbs (at least five), pre-treated with 0.3% (w/v) colchicine at room temperature for 3 h, fixed in Farmer's fixative (3:1 v/v, absolute ethanol: glacial acetic acid) for 12 hours, and hydrolyzed with 1N HCl for 7 min at 60°C. Chromosomes were stained using the Feulgen method (Feulgen & Rossenbach 1924). The somatic chromosome number was established and karyotype details were defined from about 10 representative metaphase plates (2 per individual). Metaphase chromosomes were measured using the image analysis systems Zeiss Axiovision 4.8. Karyotyping was performed using Cromolab© 1.1 software (Brullo 2002) for the recognition and ordering of homologues. Chromosome nomenclature and karyotype formulas followed Levan & al. (1964) and Tzanoudakis (1983).

Results

1. ***Allium hirtovaginum*** Candargy, Bull. Soc, Bot. France 44: 142, 1897 – Fig. 1.

Type. Greece, Lesbos, nelle collline presso Moria, 30.5.1992, *S. Brullo & P. Minissale s.n .* (Neotype: CAT, here designated).

Bulb ovoid, 10-15 × 7-10 mm, with outer tunics coriaceous, striated, blackish brown, often suffused with purple, the innermost membranaceous, whitish-yellow. *Stem* erect or erect-ascending, glabrous, 10-32 cm high, usually covered by the leaf sheaths up to 1/2 of total length. *Leaves* 3-4, subequal or shorter than the inflorescence, totally covered by dense hairs, patent, 0.1-0.2 mm long, longer at throat, blade semicylindrical, ribbed, up to 18 cm long. *Inflorescence* expanded, lax, 4-5 cm in diameter, with 20-40 flowers, on pedicels unequal, glabrous, 15-30 mm long. *Spathe* with 2 valves, unilateral, erect, unequal, longer than the inflorescence, hairy at the top and in the appendage, the largest 5-7-nerved, 6-12 cm long, the smallest 5-nerved, 3.5-7 cm long. *Perigon* campanulate, 4.5-5 mm long, with tepals elliptical, 2-2.5 mm wide, purplish-pink, tinged with green, denticulate and apiculate at the apex. *Stamens* usually only the inners exserted from the perigon, with simple filaments unequal, dark purple above and pale lilac below, the outers 2-2,5 mm long, the inners 4-5 mm long, below connate with tepals into an annulus 0.7-0.8 mm high, without interstaminal teeth; anthers yellow, elliptical, rounded at the apex, 1.5 × 1 mm. *Ovary* subglobose, throttled below, green, papillose above, 1.5-1.6 × 1.8-2 mm; style purplish in the middle, 2 mm long. *Capsule* trivalved, broadly obovoid, 3.8-4 × 4-4.2 mm.

Distribution and habitat. This species described by Candargy (1897) from the Island of Lesbos (East Aegean), was later reported for other Aegean islands, mainland Greece, and several localities in south-western and north-western Anatolia (Tanker & Kurucu 1979; Özhatay 1993; Kollmann 1984; Karavokyrou & Tzanoudakis 1991; Dimopoulos & al. 2013; Koçyiğit & Kaya 2020). In this regard, it should be noted that various populations previously attributed to *A. hirtovaginum* s.l. are treated in this study as new species morphologically very distinct from *A. hirtovaginum* s. str. Therefore, on the real occurrence of *A. hirtovaginum* in other Greek and Anatolian territories, further detailed field and herbarium surveys are needed. Particularly based on data provided by Koçyiğit & Kaya (2020), the Istanbul Herbarium (ISTE) preserves a very conspicuous number of Turkish specimens which these authors attributed to *A. hirtovaginum*. According to our field surveys, this species appears to be confined to the island of Lesbos (Fig. 2A), where it grows in phrygana mainly characterized by *Sarcopoterium spinosum* (L.) Spach, *Cistus* sp. pl. and other sclerophyllous scrubs, occurring at low altitude (100-300 m a.s.l.).

Karyology. According to Brullo & al. (2008a, Fig. 3), the investigated population of *A. hirtovaginum* coming from the type locality is characterized by a chromosome number $2n = 2x = 16$: $12m + 2m^{sat} + 2msm^{sat}$ (Fig. 17A). This karyotype is morphologically quite constant in all examined individuals of this species (Fig. 18A).

Phenology. Flowering from late May to early June.

Etymology. The specific epithet refers to the leaves covered by dense hairs.

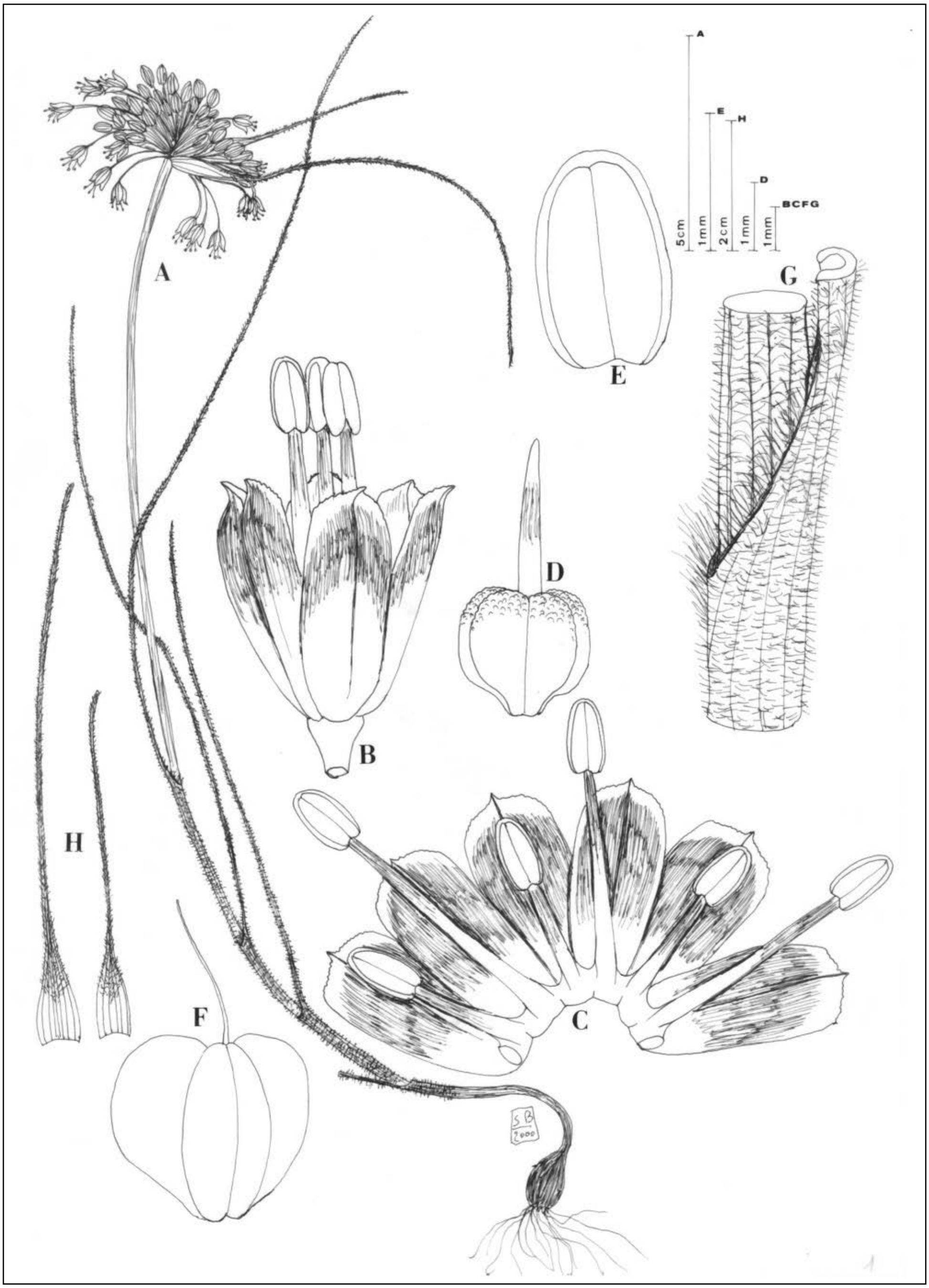

Fig. 1. *Allium hirtovaginum* Candargy: **A.** Habit; **B.** flower; **C.** open perigon and stamens; **D.** ovary; **E.** anther; **F.** Capsule; **G.** indumentum of leaf sheaths; **H.** spathe valves. (Drawing by S. Brullo from living plants of type locality).

Taxonomic notes. Morphologically, *Allium hirtovaginum* shows some relationships with the species belonging to *A. stamineum* Boiss. group, mainly in some floral tracts. Both species are in fact characterized by a campanulate perigon with straight stamen filaments usually long exserted, but completely differ in the leaf indumentum, since in *A. hirtovaginum* has leaves totally covered by dense hairs, while *A. stamineum* always shows hairless leaves. Within the Sect. *Codonoprasum*, the leaf hairiness is a feature occurring also in other species of the eastern Mediterranean, such as *A. ionicum* Brullo & Tzanoudakis from Ionian Islands, *A. rhodopaeum* Velen. from Balkans, *A. archeotrichon* Brullo & al. from Rhodos, *A. makrianum* Brullo & al. from Chios, etc. However, all these species, except *A. pilosum*, differ from *A. hirtovaginum* in having the stamen filaments always included into the perigon. As concerns the typification of this species, extensive investigations carried out in the main European herbaria searching for exsiccata collected by Candargy were unsuccessful. This is supported by Flora of Greece Web (2020) claiming that Candargy's (father and son) herbarium appears to have been lost. Therefore, we consider appropriate to designate a neotype, using the material coming from Moria in the Island of Lesbos, which is the "*locus classicus*" mentioned in the protologue by Candargy (1897).

Additional specimens examined. Greece, Lesbos a Karestepas, 30.5.1992, *S. Brullo & P. Minissale s.n* .(CAT); ibid., esemplare coltivato, 8.6.1993, *S. Brullo s.n.* (CAT).

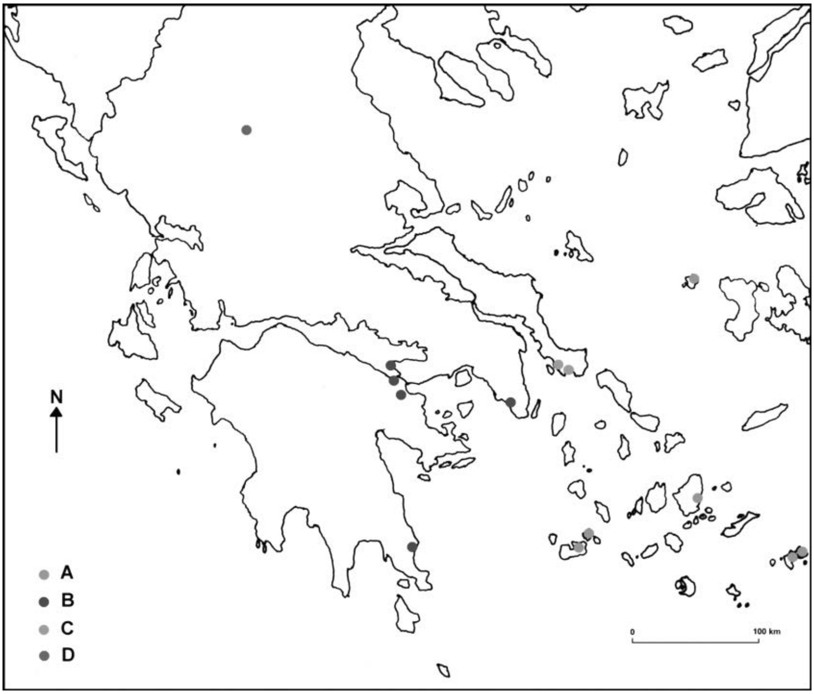

Fig. 2. Geographical distribution of *Allium hirtovaginum* (**A**), *A. smyrnaeum* (**B**), *A. pignattii* (**C**), *A. pythagoricum* (**D**), *A. trichospathum* (**E**), *A. papillosum* (**F**), *A. pavonianum* (**G**), *A. compactatum* (**H**), *A. adenanthum* (**I**), *A. carium* (**J**), *A. denticulatum* (**K**) and *A. hippocraticum* (**L**).

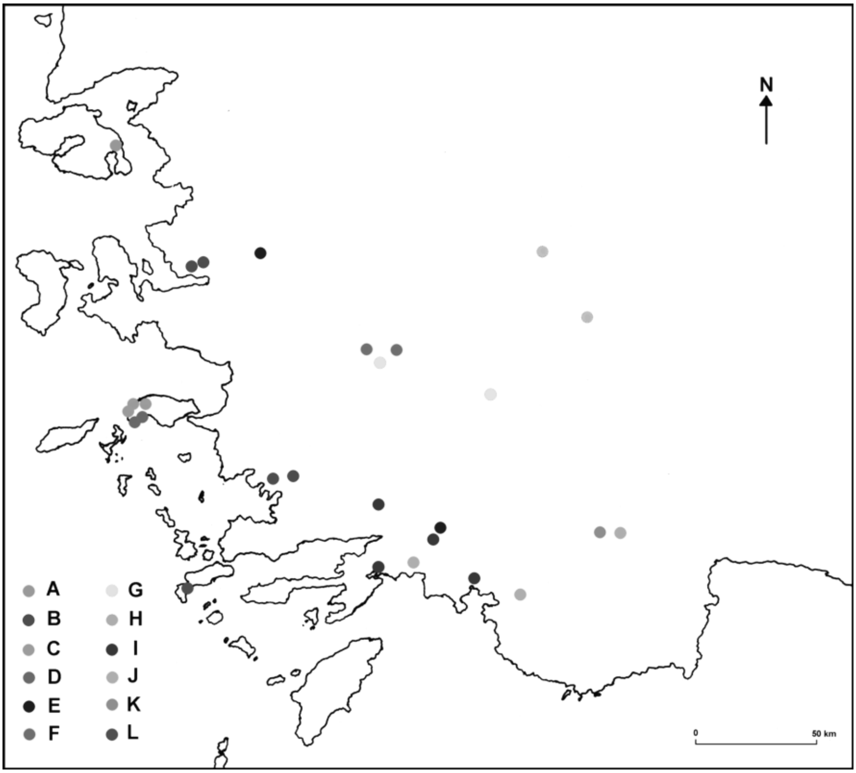

Fig. 3. Geographical distribution of *A. pilosum* (**A**), *A. velutinum* (**B**), *A. abanticum* (**C**) and *A. aegyniense* (**D**).

2. ***Allium pilosum*** Sm. in Sibth. & Sm., Fl. Graec. Prodr. 1(2): 225, 1809

Iconography. Tav. 321 (Sibthorp & Smith 1823); Fig. 3 (Brullo & al. 2001a)

Type. Greece, In insula Cimolo = Kimolo near Milos, Cycladis, s.d., *Sibthorp* (Holo: OXF), designated by Brullo & al. (2001a); Cimolia, *Sibthorp* (Syn: BM 001066444).

Bulb ovoid-subglobose, 6 × 5 mm, with outer tunics coriaceous, purplish-black, often the innermost membranaceous, whitish. *Stem* erect, glabrous, 2.5-20 cm high, usually covered by the leaf sheaths up to 1/2 of total length. *Leaves* 3, subequal or shorter than the inflorescence, totally covered by dense hairs, patent, 0.8-1.2 mm long, blade semicylindrical, ribbed, up to 13 cm long. *Inflorescence* expanded, lax, with 20-30 flowers, on pedicels unequal, glabrous, 5-15 mm long. *Spathe* with 2 valves, divaricate, unequal, subequal or longer than the inflorescence, with hairy appendage, the largest 5-7-nerved, 1-4 cm long, the smallest 3-5-nerved, 1-1.5 cm long. *Perigon* campanulate, 3.5-4(4.5) mm long, with tepals oblong to elliptical, 1.8-2 mm wide, uniformly purplish-lilac, rounded and apiculate at the apex. *Stamens* usually only the inners exserted from the perigon, at the end all exserted, with simple filaments unequal, almost totally purplish-pink, 2-4 mm long, below connate with tepals into an annulus 0.6-0.8 mm high; anthers yellow, elliptical, slightly apiculate at the apex, 1.2-1.3 × 0.5-0.7 mm. *Ovary* subglobose to subglobose-ovoid, green, papillose above, 1.2-1.8 × 1.5-1.7 mm; style purplish below, 1.4 mm long. *Capsule* trivalved, subglobose, 3.2 × 2.8 mm.

Distribution and habitat. This species was described from Kimolos, a small island near Milos in the Cyclades Archipelago (see Sibthorp & Smith 1809, 1823) and later recorded also from other neighboring islands, such as Astypalea (D'Urville 1822), Milos (Halacsy 1904), and Psara (Kollmann 1984). Its occurrence in the aforesaid islands was further confirmed by Brullo & al. (2001a), with the inclusion of Naxos (Fig. 3A). These authors also emphasized that the record from the island of Samos quoted by Rechinger (1943) was probably to be referred to *A. hirtovaginum*. As far as the ecological requirements are concerned, *A. pilosum* occurs on siliceous substrata, as schists, granites and vulcanites, growing mainly in the ephemeral meadows admidst the phryganas.

Karyology. As reported by Brullo & al. (2001a), *Allium pilosum* has a diploid chromosome number with $2n = 2x = 16$: $14m + 2m^{sat}$. The karyotype is regular and uniform, characterized by metacentric pairs, one of which is microsatellited (see Brullo & al. 2001a, Fig. 7A-C).

Phenology. Flowering from May to early June.

Etymology. The specific epithet refers to the hairy leaves.

Taxonomic notes. According to Brullo & al. (2001a), *Allium pilosum* is a species well distinct from the other ones of this group, showing only some relationships with *A. hirtovaginum*, mainly in having leaves and spathe valves hairy, perigon campanulate, and stamens exserted with filament purplish above. Nevertheless, several diacritical features allow the two species to be well differentiated, such as the occurrence in *A. pilosum* of bulbs smaller, stems much shorter, leaves with longer hairs, spathe valves very smaller, pedicels shorter, perigon smaller, uniformly purplish-lilac, anthers smaller, ovary not throttled below and capsule smaller.

Additional specimens examined. See Brullo & al. (2001a).

3. ***Allium aeginiense*** Brullo, Giusso & Terrasi, Candollea 63: 199, 2008

Iconography. Fig. 1 (Brullo & al. 2008).

Type. Greece, Thessaly, Meteore (Kalanbaka) substrati conglomeratici presso il Monastero di Megalo Meteoro, 8.VII. 2004, *Brullo, Bacchetta, Giusso & Guarino, s.n.* (Holo: CAT).

Bulb ovoid, 15-22 × 9-11 mm, with outer tunics feeble fibrous, dark brown, the innermost membranaceous, pale brown. *Stem* erect or erect-ascending, rigid, glabrous, 20-30 cm high, usually covered by the leaf sheaths for 1/3 - 1/2 of total length. *Leaves* 3-4, shorter than the inflorescence, totally covered by dense hairs, appressed to patent, 0.2-1.8 mm long, blade flat, ribbed, up to 18 cm long. *Inflorescence* expanded, lax, 4.5-5 cm in diameter, with 20-40 flowers, on pedicels unequal, glabrous, 15-25 mm long. *Spathe* with 2 valves, divaricate to reflexed, unequal, longer than the inflorescence, densely hairy at least in the appendage, both 7-nerved, the largest 6-12 cm long, the smallest 3.5-7 cm long. *Perigon* campanulate, 5-5.5 mm long, with tepals equal, rectangular, 1.6-2 mm wide, purplish-pink, tinged with purple, midrib purplish-green, smooth and truncate at the apex. *Stamens* all exserted from the perigon, with simple filaments subequal, purplish above and white below, 6-7 mm long, below connate with tepals into an annulus 0.6-0.8 mm high, no interstaminal teeth; anthers yellow, elliptical, rounded at the apex, 1.5-1.6 × 0.8-0.9 mm. *Ovary* ellipsoid, slightly throttled below, green, tuberculate above, 2.1-2.4 × 1.9-2 mm; style white, 0.8-1 mm long. *Capsule* trivalved, subglobose, 3.8-4.2 × 4.2-4.4 mm.

Distribution and habitat. It is a very rare and localized species, currently circumscribed to the top of the rocky pillars occurring in the Meteora area near Kalambaka in Thessaly (central Greece) at about 600-700 m of elevation (Fig. 3D). The substrata are composed by a mixture of sandstone and conglomerate having a lacustrian origin dating back to the Oligo-Miocene. Usually, *A. aeginiense* colonizes the crevices of the bare rock, especially in the flatter stands or anyway slightly sloping, characterized by a very feeble soil accumulation. In these very small places, it grows together with other geophytes and a few small herbaceous species.

Karyology. This species is characterized by a diploid chromosome complement with $2n = 2x = 16$: $14m + 2msm^{sat}$. Its karyotype is regular and uniform in all individuals examined by Brullo & al. (2008a, Fig. 2).

Phenology. Flowering from late June to early July.

Etymology. The specific epithet refers to “Aeginum”, latin name of Kalambaka town.

Taxonomic notes. As already highlighted by Brullo & al. (2008), *Allium aeginiense* shows close relationships with *A. hirtovaginum*, mainly in having leaves and spathe valves hairy, perigon pink-purplish, and stamens exserted with filament purplish above. However, relevant features allow them to be clearly distinguished, since *A. aeginiense* is characterized by larger bulbs with outer tunics fibrous, leaves longer, covered by longer hairs, spathe valves both 7-nerved, tepals rectangular, narrower, smooth and truncate al the apex, stamen filaments subequal and longer, ovary ellipsoid, larger, style shorter and totally white, and capsule subglobose. Besides, it differs for its ecological requirement, being a more mesic species linked to rock crevices, as well as also for its phenology, since it flowers about one month later than *A. hirtovaginum*.

4. *Allium nerimaniae* Koçyiğit & E. Kaya, Phytotaxa 435(1): 17, 2020

Iconography. (Fig. 2, Koçyiğit & Kaya 2020)

Type. Turkey, B9 Van, Gürpinar, around Sapakonak village, elevation 2535 m, 7.9.2013, E. *Kaya 4455* (Holo: ISTE; iso: NGBB, AEF).

Bulb ovoid-subglobose, (1)15-20(25) × 16-23(25) mm, with outer tunics fleeble fibrous, light brown, the innermost papyraceous, yellowish to dirty white. *Stem* erect, rigid, velutinous, (30)50-60(70) cm high, usually covered by the leaf sheaths for 1/2 – 2/3 of total length. *Leaves* 4-5(6), shorter than the inflorescence, totally covered by dense velutinous-scabrous tomentum, blade flat, canaliculate, 8-10 cm long. *Inflorescence* dense, subglobose, 6-6.2 cm in diameter, with more than 100 flowers, on pedicels subequal, pruinose, 30-35 mm long. *Spathe* with 2 valves, divaricate, unequal, longer than the inflorescence, 8-11-nerved, slightly villous at the margins, the largest 8-10 cm long, the smallest 6-7 cm long. *Perigon* globose, with tepals unequal, oblong, truncate at the apex, yellowish-dirty white, striate with purple at the apex, outers 3.5-4 × 1.8-2 mm, with midrib green, inners 4.5-5 × 1-8-2 mm, with midrib dark purplish. *Stamens* all exserted from the perigon, with simple filaments subequal, whitish-yellow, 4.5-5 mm long, below connate with tepals into an annulus 0.5-0.8 mm high; anthers yellow, ovate, rounded at the apex, 0.8-1 × 0.4-0.5 mm. *Ovary* globose-ovoid, slightly throttled below, green, smooth, 1.7-2 × 1.5-1.7 mm; style white, 4.5-5 mm long. *Capsule* trivalved, globose-oblong, 4.5-5 × 4.7-5mm.

Distribution and habitat. Allium nerimaniae is a very rare endemic species, localized in East Turkey with a punctiform distribution. According to Koçyiğit & Kaya (2020, Fig. 3), it is known only from the type locality, where it grows in alpine meadows at 2500-2550 m a,s.l. together with other orophilous geophytes.

Karyology. Unknown.

Phenology. Flowering in July.

Etymology. The species is dedicated to Neriman Özhatay, Turkish botanist, specialist of the genus *Allium.*

Taxonomic notes. For its morphological features *Allium nerimaniae* clearly belongs to the Sect. *Codonoprasum* and can be referred to *A. hirtovaginum* group for the leaves covered by dense hairs and the stamens exserted from the perigon. However, it differs in having scape velutinous, with very appressed and intricate hairiness especially in the outermost leaves, inflorescence dense and subglobose, subequal pedicels, perigon globose with tepals closely appressed and strongly unequal. For such set of characters completely absent in all other populations of the *A. hirtovaginum* group, *A. nerimaniae* can be considered a quite isolated species, showing no direct affinity with any specific taxon. Probably, this must be attributed to its remarkable geographical isolation and its localization in high altitude stands.

5. ***Allium pythagoricum*** Brullo & Salmeri, spec. nova (Fig. 4)

Allio hirtovagino similis, sed bulbo majore, tunicis fibrosis, scapo 1/2-2/3 vaginis foliorum tecto, pilis foliorum longioribus, spathae valvis glabris, perigonio minore, tepalis viridi-brunneis, porpora suffusis, apice rotundatis, staminum filamentibus brevioribus, purpureis basi, annulo longiore, denticulato inter stamina, antheris ovatis, minoribus, ovario subcylindrico, longiore, stylo albo, breviore, capsula subglobosa, minore.

Type. Greece, Isola di Samos, Votsalaka in garighe costiere a Sud di Marathokampos, 20.6.1993, *S. Brullo & P. Minissale 17* (Holo: CAT).

Bulb ovoid, 15-17 × 13-16 mm, with outer tunics fleeble fibrous, dark brown, the innermost fibrous, pale brown. *Stem* erect, glabrous, 18-25 cm high, usually covered by the leaf sheaths for 1/2 - 2/3 of total length. *Leaves* 4-5, subequal to shorter than the inflorescence, totally covered by dense hairs, sub-appressed to patent, 0.2-1 mm long, blade flat, 10-17 cm long, ribbed. *Inflorescence* expanded, lax, 5-6 cm in diameter, with 20-35 flowers, on pedicels unequal, glabrous, 15-30 mm long. *Spathe* with 2 valves, opposite, divaricate, unequal, longer than the inflorescence, glabrous, the largest 7-nerved, 8-16 cm long, the smallest 5-nerved, 3.5-9 cm long. *Perigon* campanulate, 4-4.5 mm long, with tepals equal, elliptical, 2-2.5 mm wide, green-brown, tinged with purple, midrib green, smooth and rounded at the apex. *Stamens* with simple filaments unequal, purplish above and white below, usually only the inners exserted from the perigon, 3-3.5 mm long, the outers shorter, 1.8-2 mm long, below connate with tepals into an annulus 1-1.2 mm high, provided with interstaminal teeth; anthers pale yellow, ovate, rounded at the apex, 1-1.1 × 0.8 mm. *Ovary* subcylindrical, green, papillose above, 2.2-2.5 × 1.8 mm; style white, 1 mm long. *Capsule* trivalved, subglobose, 3-3.5 × 3.8 mm.

Distribution and habitat. The species occurs along coastal places in phryganas characterized by low markedly xerophilous shrubs. It was collected in some stands of the south-western side of Samos, a Greek island in the eastern Aegean, near the Turkish coast (Fig. 2D). This area located South of Marathokampos is represented by a very extensive sandy belt, currently subject to an intense anthropic pressure due to beach tourism, which has largely compromised the natural landscape.

Karyology. The two examined populations of *Allium pythagoricum* coming from Votsalaka and Psili Ammos showed the diploid chromosome complement $2n = 2x = 16$: $10m + 4msm + 2msm^{sat}$ (Fig. 17B). The karyotype structure is rather similar in both populations and is characterized by ten metacentric and six metasubmetacentric chromosomes, two of which microsatellited on the short arms (Fig. 18B).

Phenology. Flowering in the second half of June.

Etymology. Pythagoras, philosopher and mathematician born in Samos ca. 569 BC, is commemorated.

Taxonomic note. Allium pythagoricum is closely related to *A. hirtovaginum* sharing several features, such as leaves totally hairy, inflorescence lax and expanded, perigon campanulate, just the inner stamens exserted, and ovary papillose above. However, many other morphological characters well separate the two species, since *A. hirtovaginum* shows bulbs smaller, with outer tunics coriaceous and inner ones membranaceous, stem covered by the leaf sheaths up to 1/2 of total length, leaf hairs shorter, spatha valves glabrous, perigon longer, purplish-pink, denticulate and apiculate at the apex, stamen filaments longer, purplish above, annulus shorter, without interstaminal teeth, anthers elliptical, longer, ovary subglobose, longer, style shorter, purplish in the middle, capsule broadly obovoid, larger. Besides, it has an earlier flowering and karyotype with only one metasubmetacentric pair and two pairs of chromosomes microsatellited on short arms.

Paratype. Greece, Isola di Samos, Psili Ammos in garighe costiere a Sud di Marathokampos, 20.6.1993, *S. Brullo* & *P. Minissale 26* (CAT).

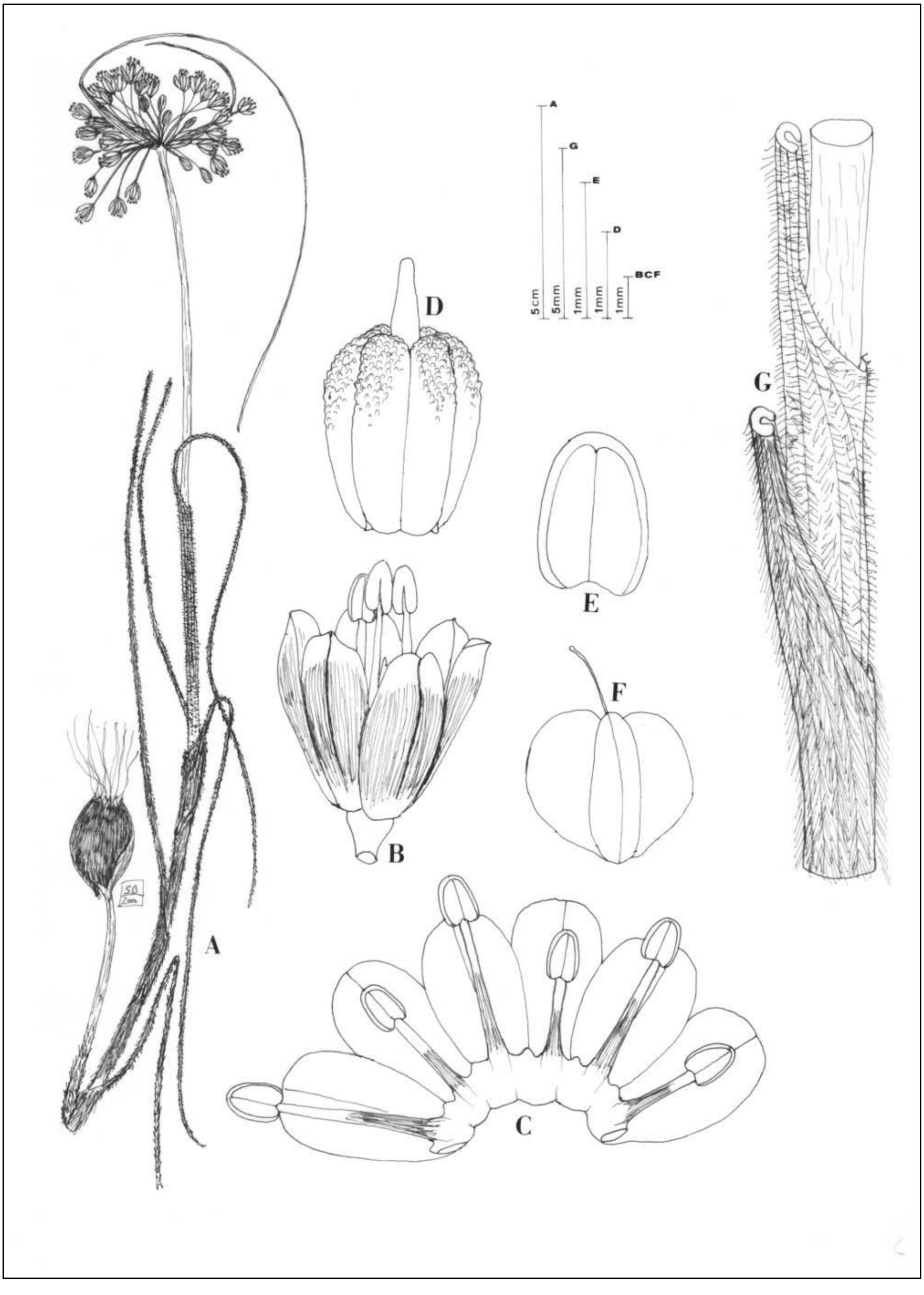

Fig. 4. *Allium pythagoricum* Brullo & Salmeri: **A.** Habit; **B.** flower; **C.** open perigon and stamens; **D.** ovary; **E.** anther; **F.** Capsule; **G.** indumentum of leaf sheaths. (Drawing by S. Brullo from living plants of type locality).

6. ***Allium pignattii*** Brullo & Salmeri, spec. nova (Fig. 5)

Allio pythagorico similis, sed bulbi tunicis interioribus membranaceis, foliis longioribus, pilis longioribus, spathae valvis appendicibus minute ciliatis margine, perigonio cylindrico-campanulato, longiore, uniformiter colorato, tepalis apiculatis apice, staminum filamentibus albis, leviter violaceo suffusis, dentibus interstaminalibus nullis, ovario longiore, capsula subglobosa, minore.

Type. Greece, Isola di Samos, sulle colline nei dintorni di Marathokampos, 5.6.1993, *S. Brullo & P. Minissale 25.* (Holo: CAT).

Bulb ovoid, 12-18 × 8-15 mm, with outer tunics fibrous, brown, the innermost ones membranaceous, pale brown. *Stem* erect, glabrous, 20-38 cm high, usually covered by the leaf sheaths for 1/2 - 2/3 of total length. *Leaves* 4-5, shorter than the inflorescence, totally covered by dense hairs, sub-appressed to patent, 0.6-1 mm long, blade semicylindrical, ribbed, up to 38 cm long. *Inflorescence* expanded, lax, 5-6 cm in diameter, with 25-40 flowers, on pedicels unequal, glabrous, 10-30 mm long. *Spathe* with 2 valves, divaricate to reflexed, unequal, longer than the inflorescence, with appendage finely ciliate at the margin, the largest 7-nerved, 8-18 cm long, the smallest 5-nerved, 4-8 cm long. *Perigon* cylindrical-campanulate, 4.5-5 mm long, with tepals equal, elliptical, 2-2.2 mm wide, uniformly green-brown, midrib green, smooth and apiculate at the apex. *Stamens* with simple filaments, unequal, white slightly tinged with violet, usually only the inners exserted from the perigon, 3-3.5 mm long, the outers shorter, 1.6-1.8 mm long, below connate with tepals into an annulus 0.8-0.9 mm high, without interstaminal teeth; anthers yellow, elliptical, rounded at the apex, 1.1 × 0.7 mm. *Ovary* cylindrical-obovoid, green, papillose above, 3 × 2 mm; style white, 1.6 mm long. *Capsule* trivalved, subglobose, 3.5 × 4 mm.

Distribution and habitat. This species occurs in some localities of the interior of the island of Samos (Fig. 2C), where it grows in grasslands and phryganas at an elevation not exceeding 700 m a.s.l.

Karyology. The examined population of *Allium pignattii,* coming from the type locality, is characterized by a diploid chromosome complement with $2n = 2x = 16$: $10m + 4m^{sat} + 2msm^{sat}$ (Fig. 17C). The karyotype structure is differentiated by 14 metacentric chromosomes, four of which are microsatellited on the short arms and 2 metasubmetacentric microsatellited chromosomes (Fig. 18C).

Phenology. Flowering from late May to early June.

Etymology. The species is named in honour of Sandro Pignatti, eminent Italian botanist.

Taxonomic notes. For its habit and some morphological features, *Allium pignattii* is closely related to *A. pythagoricum*, also occurring in Samos but in coastal stands. However, the two species differ in some significant diacritical characters, mainly regarding bulb tunics, leaves, spathe, perigon, stamens and ovary. In particular, *A. pignattii* shows innermost bulb tunics membranaceous, leaves longer, covered with longer hairs, appendages of the spathe valves finely ciliate at the margin, longer perigon cylindrical-campanulate, uniformly coloured, stamen filaments slightly tinged with lilac, without interstaminal teeth, ovary longer, while *A. pythagoricum* has bulb tunics totally fibrous, leaves clearly shorter with shorter hairs, spathe valves totally glabrous, perigon shorter, campanulate, tinged with purple, stamen filaments purplish above, with interstaminal teeth, ovary shorter. Other differences concern the karyotype, since that one of *A. pignattii* is characterized by 14 metacentric and 2 submetacentric chromosomes, with 4 microsatellited pairs, while *A. pythagoricum* shows 10 metacentric and 6 metasubmetacentric chromosomes, with one microsatellited pair.

Paratypes. Greece, Isola di Samos, Isidoros nella phrygana, 6.6.1993, *S. Brullo & P. Minissale 32* (CAT); Ibid., alla base di monte Kerkis, 6.6.1993, *S. Brullo & P. Minissale 31* (CAT).

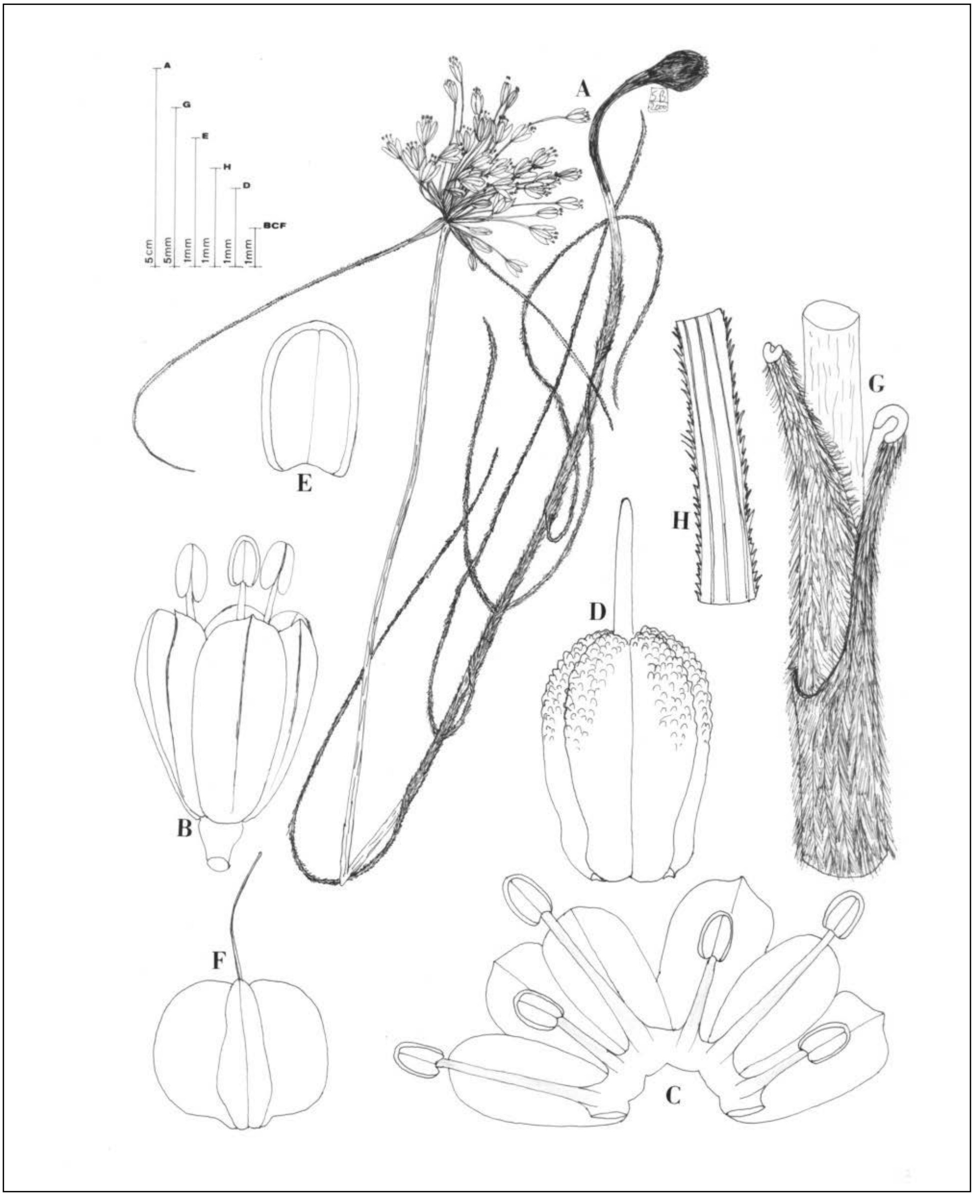

Fig. 5. *Allium pignattii* Brullo & Salmeri: **A.** Habit; **B.** flower; **C.** open perigon and stamens; **D.** ovary; **E.** anther; **F.** Capsule; **G.** indumentum of leaf sheaths; **H.** appendage of the spathe valve. (Drawing by S. Brullo from living plants of type locality).

7. *Allium hippocraticum* Brullo & Salmeri, spec. nova (Fig. 6)

Allio pythagorico similis, sed bulbis ellipsoideis, tunicis esterioribus albo-cinerascentibus, foliis longioribus, inflorescentia longioribus, pilis foliorum brevioribus, spathae valvis appendicibus dense pilosis, perigonio longiore, tepalis atrobrunneo striatis, obtusis apice, staminum filamentibus subaequalibus, longioribus, omnino purpurescentibus, antheris albescentibus, ovario obovoideo, longiore, stylo longiore, capsula globosa-obovoidea, maiore.

Type. Greece, Isola di Kos, nei dintorni di Kefalos, coltivato, 12.7.1994, *S. Brullo & F. Scelsi C30* (Holo: CAT).

Bulb ellipsoid, 13-16 × 9-11 mm, with outer tunics fibrous, greyish-white, the innermost ones membranaceous-fibrous, pale yellow. *Stem* erect, glabrous, 18-25 cm high, usually covered by the leaf sheaths for 1/2 - 2/3 of total length. *Leaves* 4-5, longer than the inflorescence, totally covered by dense hairs, patent, 0.2-0.3 mm long, blade semicylindrical, ribbed, up to 24 cm long. *Inflorescence* expanded, lax, 4-5 cm in diameter, with 25-35 flowers, on pedicels unequal, glabrous, 15-25 mm long. *Spathe* with 2 valves, divaricate, unequal, longer than the inflorescence, with appendage densely hairy, the largest 7-nerved, 10-13 cm long, the smallest 5-nerved, 4.5-6 cm long. *Perigon* campanulate, 5 mm long, with tepals equal, elliptical, 2.2 mm wide, green-brown, striate with dark brown, midrib green, smooth and obtuse at the apex. *Stamens* with simple filaments, subequal, totally purplish, all exserted from the perigon, 4-4.2 mm long, below connate with tepals into an annulus 1-1.2 mm high, provided with interstaminal teeth; anthers whitish, elliptical, slightly apiculate at the apex, 1-1.1 × 0.7-0.8 mm. *Ovary* obovoid, green, slightly papillose above, 2.8-3 × 2 mm; style white, 2.2 mm long. *Capsule* trivalved, globose-obovoid, 4 × 4 mm.

Distribution and habitat. This species was collected in the island of Kos (Dodekanisos archipelago), where it is quite rare (Fig. 2L). A population was surveyed near Kefalos, a small town located in the western of the island, mainly growing in grasslands.

Karyology. The examined population of *Allium hippocraticum* coming from the type locality is characterized by a diploid chromosome complements with $2n = 2x = 16$: 10m + 6msm (Fig. 17D). The karyotype structure is differentiated by 10 metacentric and 6 metasubmetacentric chromosomes; no evident satellites were detected (Fig. 18D).

Phenology. Flowering from late June to early July.

Etymology. Hippocrates, father of medicine born in Kos ca. 460BC, is commemorated.

Taxonomic notes. Allium hippocraticum shows close morphological relations with *A. pythagoricum*, especially for the flowers with tepals green-brown and interstaminal teeth, as well as for the similar karyotype structure, though several diacritic features allow them to be distinguished quite well. In particular, *A. hippocraticum* differs from *A. pythagoricum* in having bulbs ellipsoid, with tunics greyish-white, leaves longer far exceeding the inflorescence, with very shorter hairs, spathe valves with appendages densely hairy, tepals longer, striate with dark brown, obtuse at the apex, stamen filaments subequal and longer, uniformly purplish, anthers whitish, ovary obovoid, longer, style longer, capsule subglobose-ovoid, larger. Converserly, *A. pythagoricum* shows bulbs ovoid, with tunics entirely fibrous, leaves shorter, not exceeding the inflorescence, covered by longer hairs, spathe valves with appendages glabrous, tepals shorter, tinged with purple, rounded at the apex, stamen filaments unequal and shorter, purple above, anthers pale yellow, ovary subcylindrical, shorter, style shorter, capsule subglobose, smaller. The two species also differ in their phenology, since *A. hippocraticum* flowers about one month later.

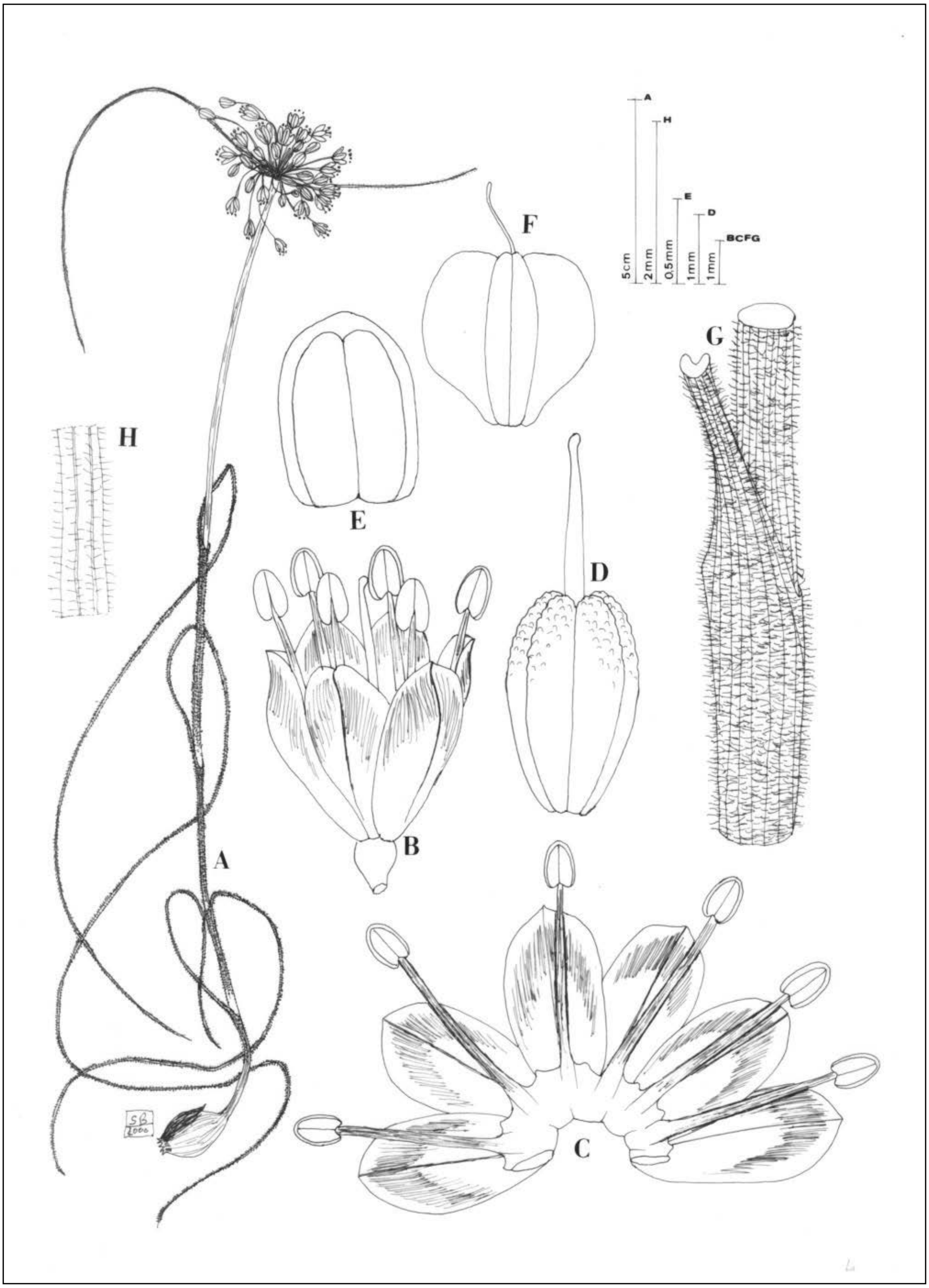

Fig. 6. *Allium hippocraticum* Brullo & Salmeri: **A.** Habit; **B.** flower; **C.** open perigon and stamens; **D.** ovary; **E.** anther; **F.** Capsule; **G.** indumentum of leaf sheaths; **H.** appendage of the spathe valve. (Drawing by S. Brullo from living plants of type locality).

8. ***Allium abanticum*** Brullo & Salmeri, spec. nova (Fig. 7)

Allio pythagorico similis, sed bulbi tunicis interioribus membranaceis, scapo breviore, foliis brevioribus, pilis valde brevioribus, inflorescentia plus compacta, spathae valvis brevioribus, tepalis angustioribus, viridibus, supra brunneo-purpuram striatis, obtusis apice, staminum filamentibus albis, longioribus, antheris brevioribus, ovario ellipsoideo-obovoideo, longiore, capsula obovoidea, maiore.

Type. Greece, Isola di Eubea, presso Marmaris lungo la costa rocciosa scistosa, 5.6.1992, *S. Brullo* & *P. Pavone s.n,* (Holo: CAT).

Bulb ovoid, 10-20 × 6-12 mm, with outer tunics fibrous, greyish-brown, the innermost ones membranaceous, pale brown. *Stem* erect, glabrous, 10-18 cm high, usually covered by the leaf sheaths for 1/2 - 2/3 of total length. *Leaves* 4, shorter than the inflorescence, totally covered by dense hairs, patent, 0.2-0.3 mm long, blade semicylindrical, 4-6 cm long, ribbed. *Inflorescence* expanded, more or less compact, 3-4 cm in diameter, with 15-30 flowers, on pedicels unequal, glabrous, 5-20 mm long. *Spathe* with 2 valves, opposite, erect, unequal, longer than the inflorescence, glabrous, the largest 7-nerved, 3-6 cm long, the smallest 5-nerved, 1.5-4 cm long. *Perigon* campanulate, 4-5 mm long, with tepals equal, elliptical, 1.6-2 mm wide, greenish, above striate with purplish-brown, midrib green, smooth and rounded at the apex. *Stamens* with simple filaments unequal, white, inners exserted from the perigon, 4-4.2 mm long, the outers usually shorter, 2-3.5 mm long, below connate with tepals into an annulus 1-1.2 mm high, provided with interstaminal teeth; anthers pale yellow, ovate, rounded at the apex, 0.7-0.8 × 0.7-0.8 mm. *Ovary* ellipsoid-obovoid, green, papillose above, 3-3.5 × 1.3-1.8 mm; style white, 0.8- 1 mm long. *Capsule* trivalved, obovoid, 4.8 × 3.2 mm.

Distribution and habitat. This species occurs along the low rocky south-western coast of the Euboea island between Marmaris and Karistos (Fig.3C). In these stands it grows in the clearings among the pulvinate dwarf shrubs of phryganas, xerophilous community widespread in this territory.

Karyology. The investigated population coming from Karistos shows a diploid chromosome complement with $2n = 2x = 16$: $12m + 2m^{sat} + 2msm$ (Fig. 17E). Its karyotype is characterized by seven metacentric pairs, one of which satellited on short arms, and 2 meta-submetacentric chromosomes (Fig. 18E).

Phenology. Flowering from late May to early June.

Etymology. The epithet comes from "*Abantes*", ancient tribe that inhabited the island of Euboea.

Taxonomic notes. *Allium abanticum* is well differentiated from the other species of the *A. hirtovaginum* group mainly for its small size (19-20 cm tall) and more compact inflorescence with very reduced spathe valves, features clearly also maintained in cultivated plants. For the glabrous spathe valves, unequal stamen filaments and occurrence of interstaminal teeth, it shows some relationships mainly with *A. pythagoricum*, while based on the type of leaf indumentum and the occurrence of interstaminal teeth it is rather similar to *A. hippocraticum*. Several relevant morphological differences separated it from both species.

Paratype. Greece, Isola di Eubea, litorale roccioso calcareo presso Karistos, 6.6.1992, *S. Brullo* & *P. Pavone s.n.* (CAT).

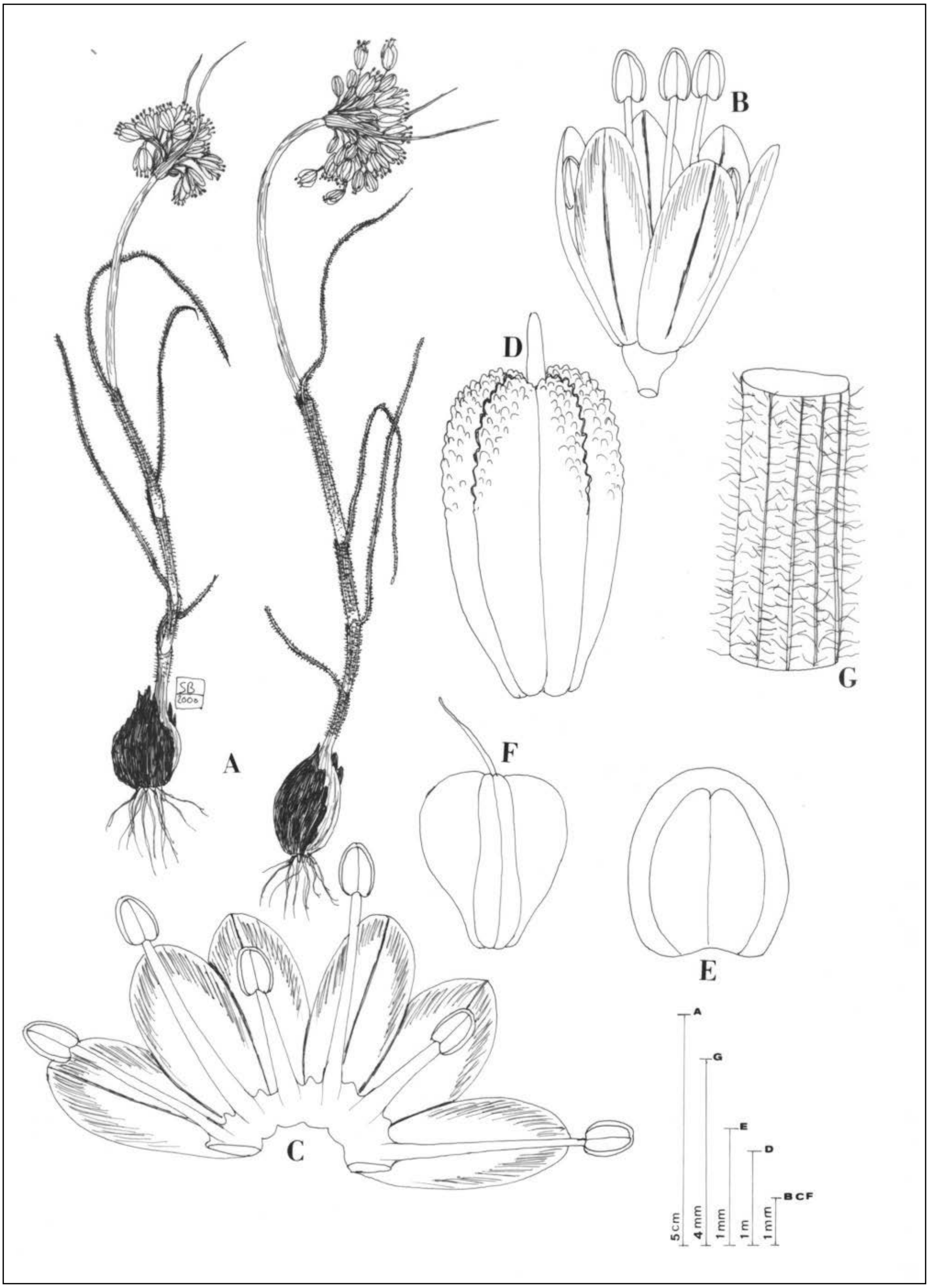

Fig. 7. *Allium abanticum* Brullo & Salmeri: **A.** Habit; **B.** flower; **C.** open perigon and stamens; **D.** ovary; **E.** anther; **F.** Capsule; **G.** indumentum of leaf sheaths. (Drawing by S. Brullo from living plants of type locality).

9. *Allium velutinum* Brullo & Salmeri, spec. nova (Fig. 8)

Allio pythagorico similis, sed bulbis minoribus, tunicis brunneolis, scapo longiore, pilis foliorum velutinis brevioribus, inflorescentia minore, spathae valvis brevioribus, tepalis longioribus, viridi-luteis, obtusis apice, staminum filamentibus subaequalibus, albis, longioribus, antheris luteis, longioribus, ovario ovoideo, laevi, capsula obovoidea, maiore.

Type. Greece, Peloponneso, sulle colline nei dintorni di Monenvasia, 5.6.1992, *S. Brullo & P. Pavone s.n.* (Holo: CAT).

Bulb ovoid, 10-15 × 6-10 mm, with outer tunics fibrous, pale brown, the innermost fibrous, straw-colored. *Stem* erect, glabrous, 30-50 cm high, usually covered by the leaf sheaths for 1/2 - 2/3 of total length. *Leaves* 5-6, shorter than the inflorescence, totally covered by dense velutinous indumentum with hairs patent, 0.05-0.1 mm long, blade flat, canaliculate, 10-18 cm long, ribbed. *Inflorescence* expanded, more or less compact, 2.5-4.5 cm in diameter, with 20-45 flowers, on pedicels unequal, glabrous, 8-25 mm long. *Spathe* with 2 valves, opposite, divaricate, unequal, longer than the inflorescence, glabrous, the largest 6-7-nerved, 7-10 cm long, the smallest 5-nerved, 3-5 cm long. *Perigon* campanulate, 4.5-5 mm long, with tepals equal, elliptical, 2-2.5 mm wide, greenish-yellow, above tinged with purple, midrib green, smooth and rounded at the apex. *Stamens* with simple filaments subequal, white, all exserted from the perigon, 5.5-6.5 mm long, below connate with tepals into an annulus 1-1.3 mm high, provided with short interstaminal teeth; anthers yellow, oblong, rounded at the apex, 1.2-1.3 × 0.8-0.9 mm. *Ovary* ovoid, green, smooth, 2-2.3 × 2; style white, 2-4 mm long. *Capsule* trivalved, obovoid, above tinged with violet, 3.6-3.8 × 4-4.2 mm.

Distribution and habitat. This species was collected in some localities of Peloponnisos and southern Attica, where it shows a fragmentary distribution with small populations (Fig. 3B). It occurs mainly in grasslands and phryganas on limestones.

Karyology. Unknown.

Phenology. Flowering from late May to early June.

Etymology. The epithet refers to the very minute leaf indumentum.

Taxonomic notes. Allium velutinum differs from the other species of the *A. hirtovaginum* group in some quite significant features, such as leaves with very minute and dense hairness, very long stamen filaments, ovary smooth and capsule tinged with violet. For the spathe valves glabrous and the occurrence of interstaminal teeth, it shows some relationships mainly with *A. pythagoricum* and *A. abanticun*, but several relevant morphological differences distinguished it from both species.

Paratypes. Greece, Peloponneso, dintorni di Korynthos nella phrygana, coltivato, 10.6.2003, *S. Brullo & S. Sciandrello s.n,* (CAT); Ibid., Kenkhemeni a Sud di Korinthos, coltivato, 10.6. 2003, *S. Brullo & S. Sciandrello s.n.* (CAT): Ibid., Attica, sito archeologico di Heraion nella peninsula di Perachora (Golfo di Corintho),10.6.2003, coltivato, *S. Brullo & S. Sciandrello s.n.* (CAT); Ibid., Lagonisi a Sud di Atene, lungo la costa rocciosa, 9.6.2003, coltivato, *S. Brullo & S. Sciandrello s.n.* (CAT).

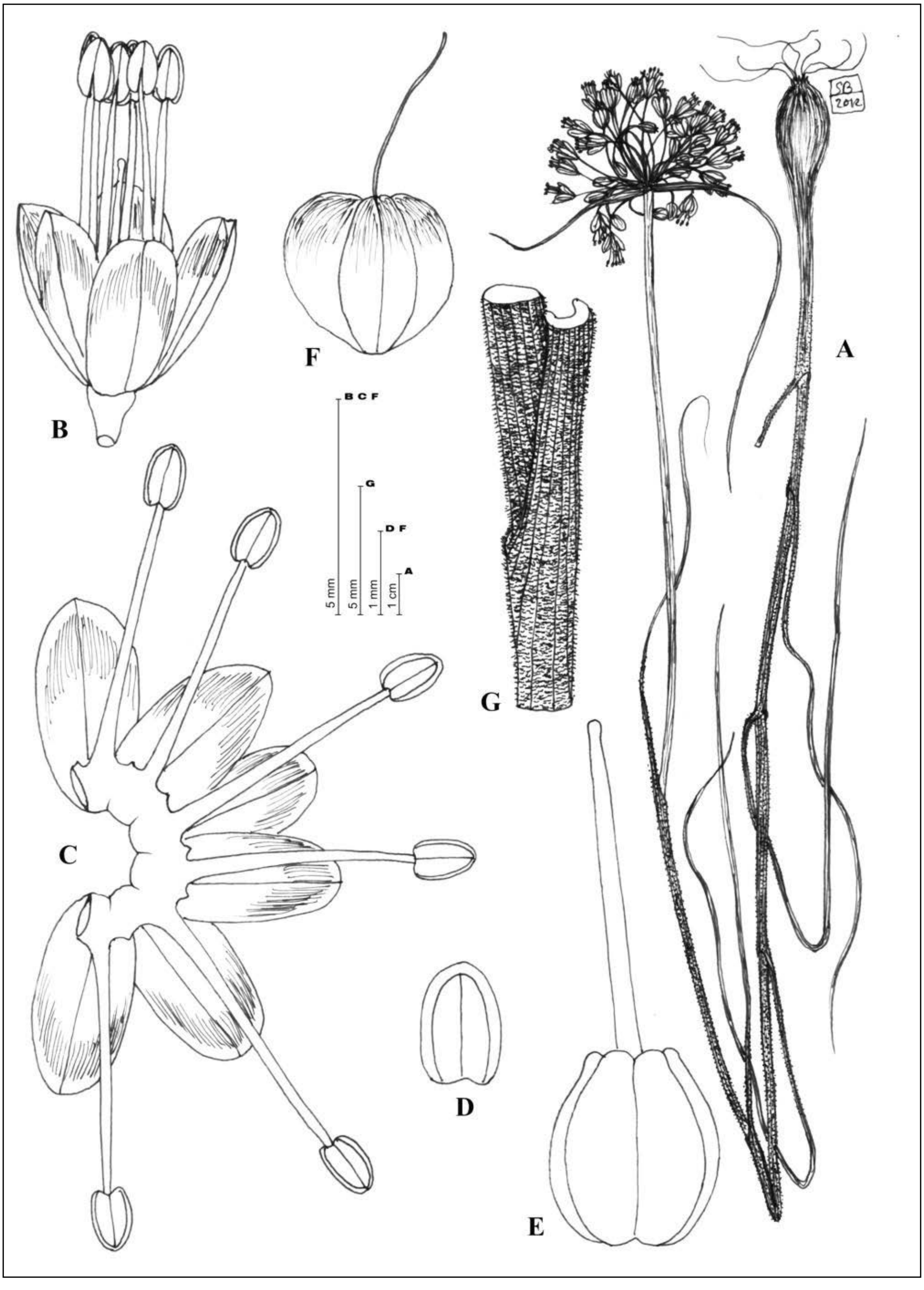

Fig. 8. *Allium velutinum* Brullo & Salmeri: **A.** Habit; **B.** flower; **C.** open perigon and stamens; **D.** ovary; **E.** anther; **F.** Capsule; **G.** indumentum of leaf sheaths. (Drawing by S. Brullo from living plants of type locality).

10. *Allium carium* Brullo & Salmeri, spec. nova (Fig. 9)

Allio abantico similis, sed bulbis ellipsoideis, tunicis exterioribus coriaceis, foliis longioribus, pilis subadpressis, longioribus, inflorescentia laxa, pedicellis longioribus, spathae valvis brevioribus, quam inflorescentia brevioribus vel subaequilongis subaequalibus, tepalis albo-viridibus, supra purpuram striatis, exterioribus latioribus, staminum filamentibus longioribus, omnibus perigonio exsertibus, purpureis supra, sine interstaminalibus dentibus, antheris ellipticis, longioribus, ovario subgloboso, complanato, minore, capsula subglobosa, minore.

Type. Turkey, Anatolia sud-occidentale, dintorni di Koyceğiz a Nord di Fethyie, 21.6.1998, *S. Brullo* & *P. Pavone s.n.* (Holo: CAT).

Bulb ellipsoid, 12-18 × 8-13 mm, with outer tunics coriaceous, brownish, tinged with purple, the inner ones membranaceous, whitish. *Stem* erect, robust, glabrous, 12-18 cm high, usually covered by the leaf sheaths for 1/2 - 2/3 of total length. *Leaves* 4, shorter than the inflorescence, totally covered by dense hairs, subappressed, 0.5-1 mm long, blade flat, canaliculate, up to 10 cm long, ribbed. *Inflorescence* expanded, lax, 4-5 cm in diameter, with 25-35 flowers, on pedicels unequal, glabrous, 15-30 mm long. *Spathe* with 2 valves, opposite, erect, unequal, subequal or shorter than the inflorescence, glabrous, the largest 7-nerved, 2-3 cm long, the smallest 5-nerved, 1.5-2.5 cm long. *Perigon* campanulate, 4.5 mm long, with tepals equal, elliptical, the outers 2.2-2.5 mm wide, the inners 1.7-1.8 mm wide, greenish-white, above striate with purple, midrib green, smooth and rounded at the apex. *Stamens* with simple filaments subequal, all exserted from the perigon, 5.5-6 mm long, white in the lower part and purplish above, below connate with tepals into an annulus 0.9-1 mm high, without interstaminal teeth; anthers yellow, elliptical, rounded at the apex, 1.4 × 0.8 mm. *Ovary* subglobose, flattened, greenish-yellow, slightly papillose above, 1.7 × 2 mm; style white, 4 mm long. *Capsule* trivalved, subglobose, slightly stipitate, 4 × 3.8-4 mm.

Distribution and habitat. Allium carium was found in some localities of south-western Anatolia, as Koyceğiz near Fethyie and Sogut near Korkuteli (Fig. 2J). It is a very rare species growing in the clearings of the maquis.

Karyology. The investigated population coming from the type locality revealed a diploid chromosome complement with $2n = 2x = 16$: $10m + 4m^{sat} + 2msm$ (Fig. 17F). Its karyotype is characterized by seven metacentric pairs, two of which satellited on the short arms (one macrosatellited and the other one microsatellited), and 2 metasubmetacentric chromosomes (Fig. 18F).

Phenology. Flowering from late June to early July.

Etymology. The epithet derives from "Caria", ancient district of south-western Anatolia.

Taxonomic notes. For its small size and leaves shorter than the inflorescence *Allim carium* is morphologically quite similar to *A. abanticum*, but several features allow it to be differentiated from the latter. The most relevant differences are outer tunics coriaceous, leaves longer, covered by hairs subappressed and longer, inflorescence larger with pedicels longer, spathe valves subequal to shorter than inflorescence, tepals greenish-white,wider, stamen filaments longer and all exserted, above purplish, without interstaminal teeth, anthers longer, ovary smaller, subglobose and flattened, capsule smaller. The two species also differ in their phenology, since *A. carium* flowers one month later, and in the karyotype structure as *A.carium* shows an extra macrosatellited chromosome pair.

Paratype. Turkey, Anatolia sud-occidentale, dintorni di Sogut a Ovest di Korkuteli, 21.6.1998, *S. Brullo* & *P. Pavone s.n.* (Holo: CAT).

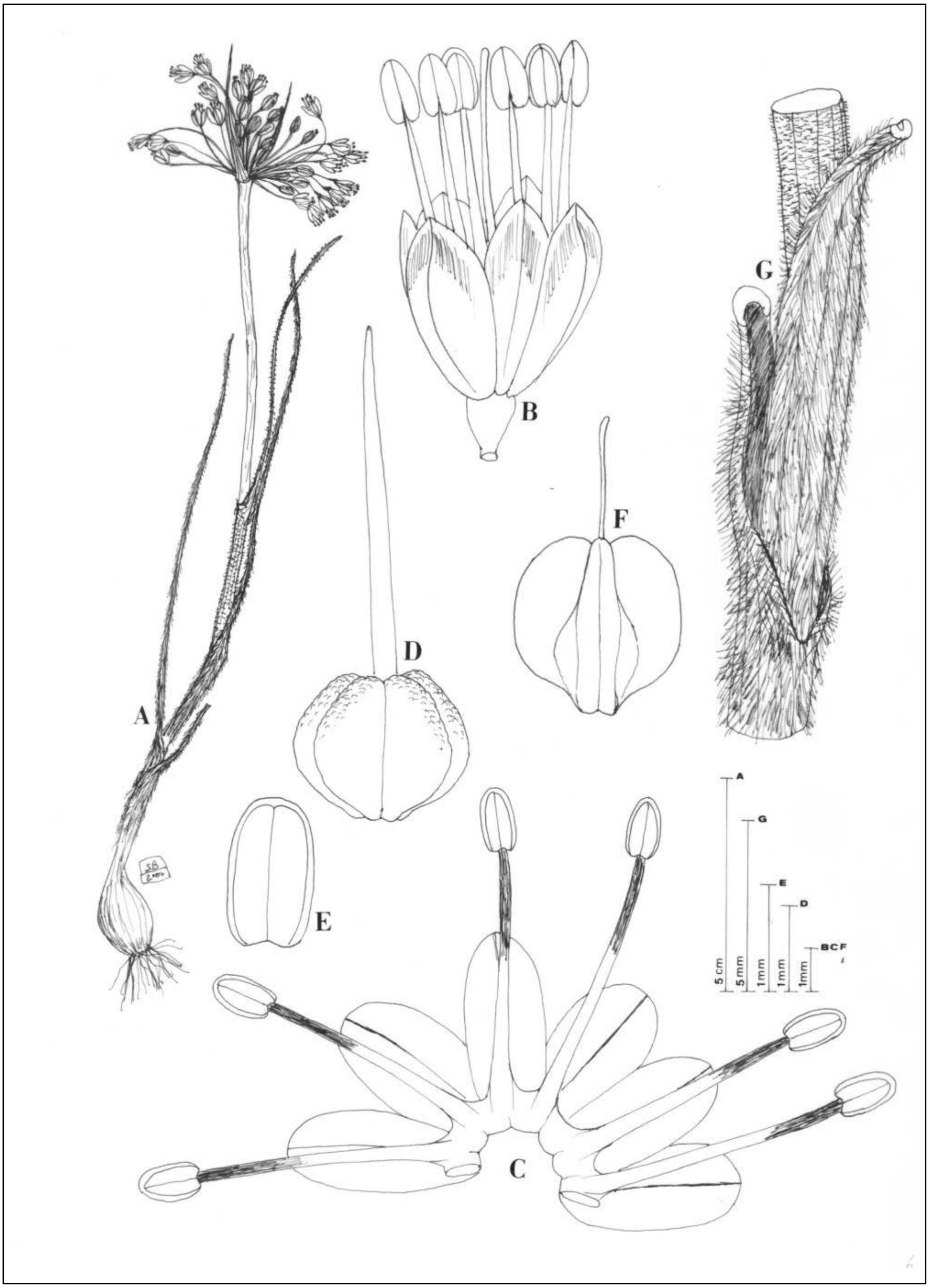

Fig. 9. *Allium carium* Brullo & Salmeri: **A.** Habit; **B.** flower; **C.** open perigon and stamens; **D.** ovary; **E.** anther; **F.** Capsule; **G.** indumentum of leaf sheaths. (Drawing by S. Brullo from living plants of type locality).

11. *Allium papillosum* Brullo & Salmeri, spec. nova (Fig. 10)

Allio cario similis, sed bulbo ovoideo, minore, tunicis exterioribus cinereis, scapo flexuoso, longiore, usque ad 1/2 longitudinem vaginis foliorum tecto, foliis longioribus, pilis patentibus, brevioribus, inflorescentia minore, pedicellis brevioribus, spathae valvis longioribus, quam inflorescentia longioribus, tepalis purpureis, angustoribus, staminum filamentibus brevioribus, antheris luteolis, ovario minore, omnino papilloso, capsula obovoidea.

Type. Turkey, Anatolia sud-occidentale, dintorni di Denizli, 2.7.1987, *S. Brullo*, *P. Pavone* & *P. Signorello s.n.* (Holo: CAT).

Bulb ellipsoid, 10-12 × 6-8 mm, with outer tunics coriaceous, greyish, the innermost ones membranaceous, whitish. *Stem* erect, flexuous, glabrous, 18-28 cm high, usually covered by the leaf sheaths up to 1/2 of total length. *Leaves* 4, shorter than the inflorescence, totally covered by dense hairs, patent, 0.1-0,3 mm long and 0.5-0.8 mm long in the throat, blade flat, canaliculate, up to 15 cm long, ribbed. *Inflorescence* expanded, lax, 4-5 cm in diameter, with 15-25 flowers, on pedicels unequal, glabrous, 12-20 mm long. *Spathe* with 2 valves, erect, opposite, unequal, longer than the inflorescence, glabrous, the largest 7-nerved, 3-7.5 cm long, the smallest 5-nerved, 2.5-3.5 cm long. *Perigon* campanulate, purplish, 4.5 mm long, with tepals equal, elliptical, the outers 2-2.2 mm wide, the inners 1.5-1.6 mm wide, midrib dark purple, smooth and rounded at the apex. *Stamens* with simple filaments subequal, all exserted from the perigon, 5-5.5 mm long, above purplish, below white , below connate with tepals into an annulus 0.7-0.8 mm high, without interstaminal teeth; anthers pale yellow, elliptical, rounded at the apex, 1.3 × 0.8 mm. *Ovary* subglobose, green, entirely papillose, 1.5 × 2 mm; style white, 1-1.2 mm long. *Capsule* trivalved, obovoid, 4 × 4 mm.

Distribution and habitat. Allium papillosum was collected in two stands of south-western Anatolia, such as the hills around Denizli and Kaklik near Nazilli (Fig. 2F). It is a very rare species growing in the clearings of the grasslands.

Karyology: Both investigated populations showed a diploid chromosome complement with $2n = 2x = 16$: $12m + 2m^{sat} + 2msm^{sat}$ (Fig. 17G). Its karyotype is characterized by 14 metacentric chromosomes, one pair provided with macrosatellited on short arms, and 2 metasubmetacentric chromosomes with well developped microsatellites on the short arms (Fig. 18G).

Phenology. Flowering from late June to early July.

Etymology. The epithet refers to ovary entirely covered by papillae.

Taxonomic notes. Allium papillosum shows closest affinity especially with *A. carium*, by sharing bulbs with outer tunic coriaceous, leaves shorter than the inflorescence, spathe valves erect, stamen filaments long exserted from the perigon and purplish above, anthers quite long and lack of interstaminal teeth. However, they differ in numerous morphological traits, since *A. papillosum* is characterized by bulbs ovoid, smaller, with outer tunics greyish, stem longer, flexuous, covered by the leaf sheaths max. 1/2 of total length, leaves longer, with hairs patent and shorter, inflorescence smaller, with shorter pedicels, spathe valves longer, exceeding the inflorescence, tepals purplish, narrower, stamen filaments shorter, anthers pale yellow, ovary smaller, entirely papillose, capsule obovoid. Conversely, *A. carium* is differentiated by a bulb ellipsoid, larger, with outer tunics brown, tinged with purplish, stem much shorter, robust, covered by the leaf sheaths up to 2/3 of total length, leaves shorter, with hairs subappressed and longer, inflorescence larger, with longer pedicels, spathe valves very shorter, not exceeding the inflorescence, tepals greenish-white, wider, stamen filaments longer, anthers yellow, ovary flattened, papillose only at the top, capsule globose.

Paratype. Turkey, Anatolia sud-occidentale, dintorni di Kaklik presso Nazilli, 24.6.1988, *S. Brullo*, *P. Pavone* & *P. Signorello s.n.* (CAT).

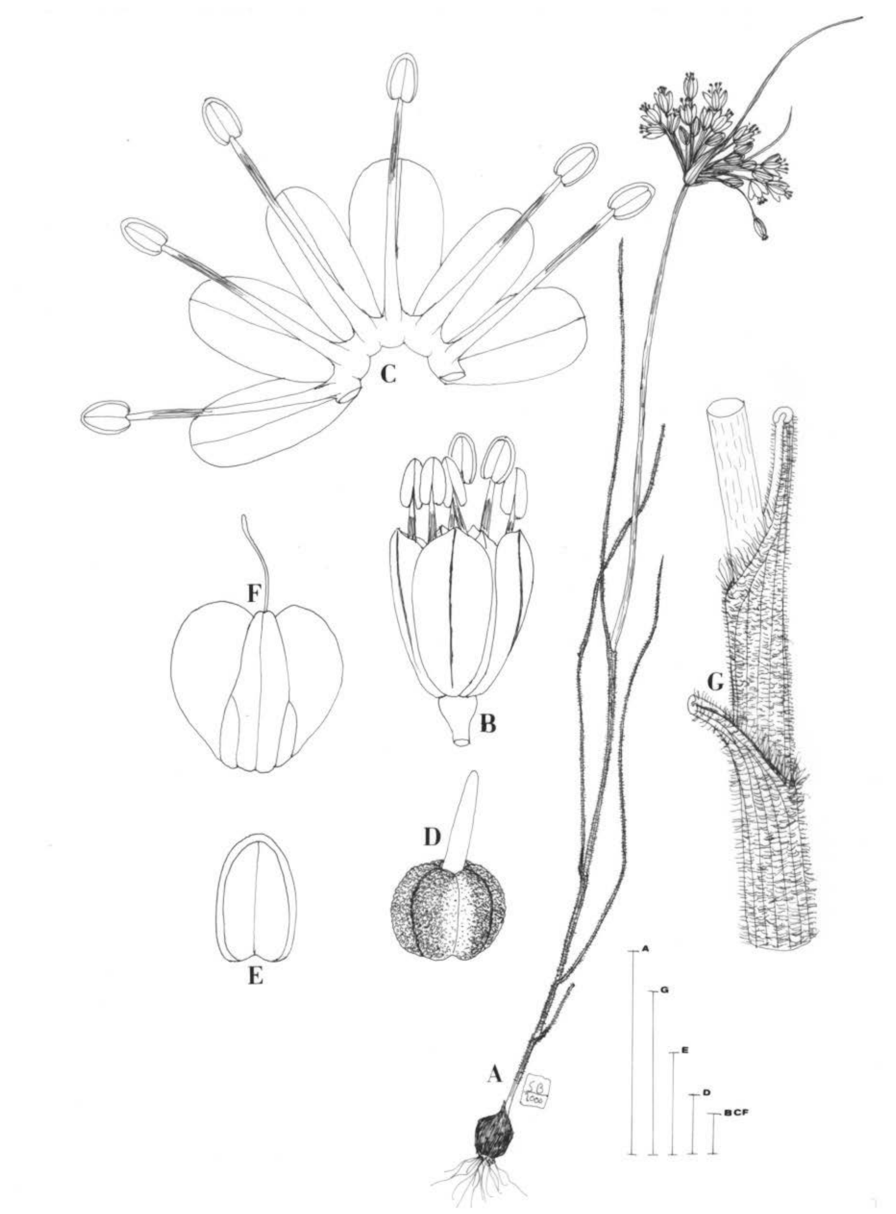

Fig. 10. *Allium papillosum* Brullo & Salmeri: **A.** Habit; **B.** flower; **C.** open perigon and stamens; **D.** ovary; **E.** anther; **F.** Capsule; **G.** indumentum of leaf sheaths. (Drawing by S. Brullo from living plants of type locality).

12. *Allium adenanthum* Brullo & Salmeri, spec. nova (Fig. 11)

Allio hirtovagino similis, sed bulbo ellipsoideo, tunicis exterioribus fibrosis, brunneo-cinereis, scapo flexuoso, longiore, piloso, foliis longioribus, inflorescentia majore, pedicellis longioribus, pilosis, spathae valvis, brevioribus, quam inflorescentia leviter longioribus, tepalis angustoribus, glandulis luteolis conspersis superficiem interiorem, staminum filamentibus omnibus exsertis, ovario majore, subgloboso-ovoideo.

Type. Turkey, Anatolia sud-occidentale, nei pressi di Göcek a Nord di Fethiye, 21.6.1998, *S. Brullo & P. Pavone* s.n. (Holo: CAT).

Bulb ellipsoid, 12-18 × 8-12 mm, with outer tunics fibrous, greyish-brown, the innermost ones membranaceous-fibrous, whitish. *Stem* erect, flexuous, hairy, 16-50 cm high, usually covered by the leaf sheaths for 1/3 - 1/2 of total length. *Leaves* 3-4, shorter than the inflorescence, totally covered by dense hairs, patent, 0.1-0,3 mm long and up to 0.6 mm long in the throat, blade semicylidrical, up to 25 cm long, ribbed. *Inflorescence* expanded, very lax , 6-8 cm in diameter, with 10-25(35) flowers, on pedicels unequal, densely hairy, 10-50 mm long. *Spathe* with 2 valves, unilateral, unequal, slightly longer than the inflorescence (rarely subequal), hairy in the appendages, the largest 6-7-nerved, 2-5 cm long, the smallest 5-nerved, 2.5-4 cm long. *Perigon* campanulate, greenish to purplish-pink. 4-5 mm long, with tepals equal, elliptical, sprinkled with numerous small yellowish glands on the inner surface, the outers 1.8-2 mm wide, the inners 1.5-1.8 mm wide, midrib greenish-purple, smooth and rounded at the apex. *Stamens* with simple filaments subequal, all exserted from the perigon, 4.5-5.5 mm long, above shortly purplish, below white, below connate with tepals into an annulus 0.6-0.8 mm high, without interstaminal teeth; anthers yellow, elliptical, rounded at the apex, 1.4-1.5 × 0.7-0.8 mm. *Ovary* globose-ovoid, green, above and dorsally papillose, 1.7-2 × 2-2.2 mm; style white, 1.5-2.5 mm long. *Capsule* trivalved, obovoid, 4 × 4-4.5 mm.

Distribution and habitat. *Allium adenanthum* was collected in four localities of south-western Anatolia, such as the hills around Göcek near Fethiye, Canalikoy near Mugla, Marmaris and Sandras Dağ (Fig. 2I). In these places it usually grows in the clearings of grasslands and maquis.

Karyology. All investigated populations showed a diploid chromosome complement with $2n = 2x = 16$: $12m + 2m^{sat} + 2msm$ (Fig. 17H). The karyotypes are characterized by more or less metacentric chromosomes, with two pairs actually tending towards the “sms” type (arm ratio around 1.30), one of which always microsatellited on the short arms (Fig. 18H). Differences among populations only regard the evidence of up two extra pairs of microsatellited chromosomes in samples from Sandras Dağ and Mugla.

Phenology. Flowering from June to early July.

Etymology. The epithet refers to the tepals sprinkled with numerous small glands on the inner surface.

Taxonomic notes. Morphologically, *Allium adenanthum* markedly differs from all other species belonging to the group of *A. hirtovaginum* in having stamen filaments densely hairy and tepals with minute glands on the inner surface. Nevertheless, it shows some resemblance mainly to *A. hirtovaginum s.str.* especially in sharing the stem covered by the leaf sheaths up to 1/2 of total length, leaves with minute indumentum, spathe valves unilateral, with appendages hairy, tepals usually purplish-pink and stamen filaments above tinged with purple. Many significant features differentiate effectively the two species. Among these, it is particularly relevant the occurrence in *A. hirtovaginum* of outer bulb tunics coriaceous and dark brown, stem rigid, glabrous, shorter, inflorescence smaller, with pedicels shorter and glabrous, spathe valves longer, tepals eglandular, ovary subglobose.

Paratypes. Turkey, Anatolia sud-occidentale, dintorni di Canalikoy presso Mugla, 20.6.1998, *S. Brullo* & *P. Pavone s.n.* (CAT); Ibid., dintorni di Marmaris, 21.6.1998, *S. Brullo* & *P. Pavone s.n.* (CAT); Ibid. alla base di Sandras Dagi, montagna a Est di Köyceğiz, 2.6.1988, *S. Brullo*, *P. Pavone* & *P. Signorello s.n.* (CAT).

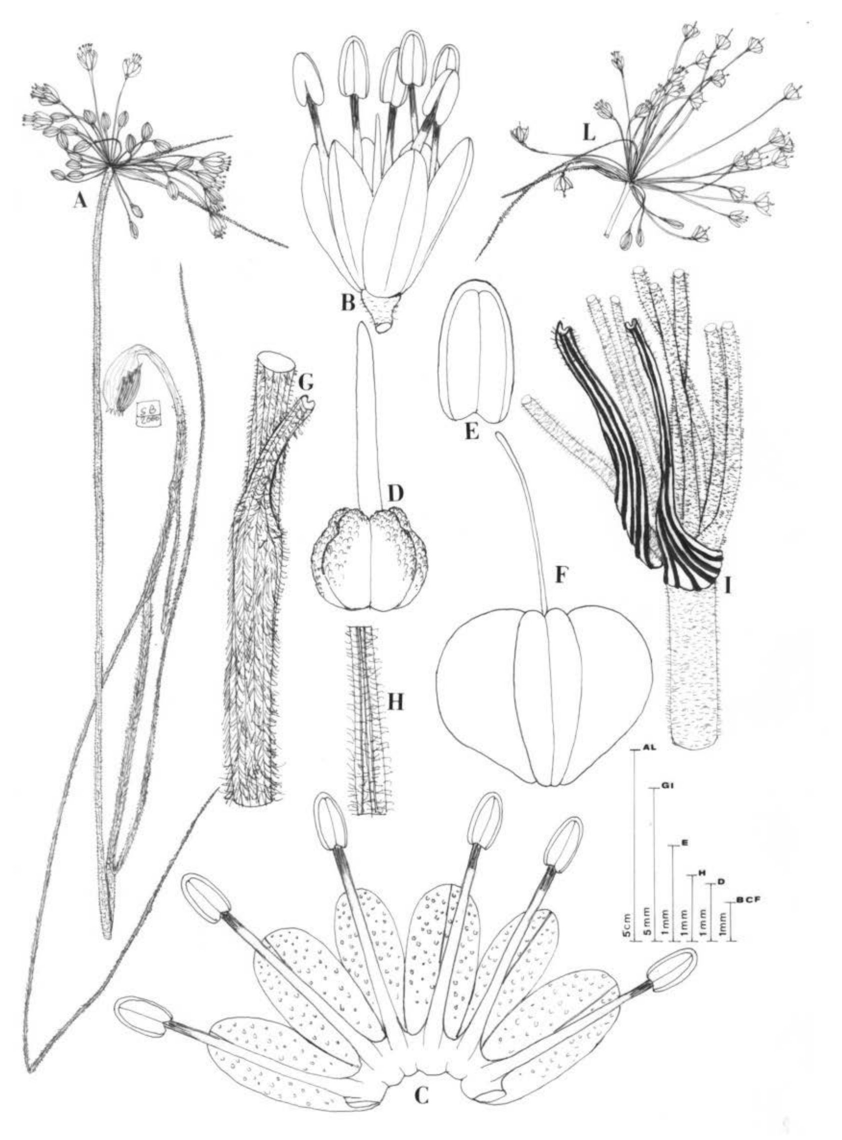

Fig. 11. *Allium adenanthum* Brullo & Salmeri: **A.** Habit; **B.** flower; **C.** open perigon and stamens; **D.** ovary; **E.** anther; **F.** Capsule; **G.** indumentum of leaf sheaths. **H**. appendage of the spathe valve; **I.** base of inflorescence with spate valves and pedicels; **L.** Inflorescence. (Drawing by S. Brullo from living plants of type locality).

13. *Allium smyrnaeum* Brullo & Salmeri, spec. nova (Fig. 12)

Allio hirtovagino similis, sed bulbo majore, tunicis fibrosis, exterioribus brunneis vel brunneo-rubentis, scapo longiore, foliis longioribus, pilis longioribus, inflorescentia fastigiata, compacta, pedicellis longioribus, spathae valvis glabris, tepalis luteo-viridibus, purpuram suffusis, staminum filamentibus omnibus exsertis, albis, annulo dentibus interstaminalibus praedito, antheris luteolis, brevioribus, ovario majore, obovoideo-ellipsoideo, stipitato, supra angulato, capsula majore.

Type. Turkey, Anatolia occidentale, tra Emiralem e Menemer presso Izmir, 19.6.1998, *S. Brullo & P. Pavone s.n.* (Holo: CAT).

Bulb ovoid, 15-22 × 10-16 mm, with outer tunics fibrous, brown to reddish-brown, the innermost ones fibrous, yellowish. *Stem* erect, rigid, glabrous, 20-45 cm high, usually covered by the leaf sheaths up to 1/2 of total length. *Leaves* 3-4, shorter than the inflorescence, totally covered by dense hairs, patent, 0.4-0.6 mm long, blade semicylindrical, up to 20 cm long, ribbed. *Inflorescence* fastigiate, compact, 2-6 cm long and 1.5-4 cm wide, with 20-80 flowers, on pedicels unequal, glabrous, 12-60 mm long. *Spathe* with 2 valves, erect, unilateral, unequal, longer than the inflorescence, glabrous, the largest 7-9-nerved, 6-12 cm long, the smallest 5-7-nerved, 5-7 cm long. *Perigon* campanulate, greenish-yellow, tinged with purplish, 5 mm long, with tepals equal, elliptical, the outers 2-2.5 mm wide, the inners 2 mm wide, midbrib green, smooth and slightly apiculate at the apex. *Stamens* with simple filaments subequal, all exserted from the perigon, 4.5-5.5 mm long, white , below connate with tepals into an annulus 1-1.1 mm high, with interstaminal teeth; anthers pale yellow, elliptical, rounded at the apex, 1 × 0.6 mm. *Ovary* obovoid-ellipsoid, strongly angled at the apex, flattened and dorsally papillose above, green, 3.5-4 × 2 mm; style white, 3-3.5 mm long. *Capsule* trivalved, obovoid, stipitate below, 4.8 × 4.5 mm.

Distribution and habitat. Populations of this species were collected in several stands of western Anatolia, mainly in the Izmir district, such as near Emiralem, Menemer, Selimiye and Labadadaği (Fig. 2B). In this area it showed a very scattered distribution, being especially localized on limestone rocky outcrops and grasslands.

Karyology. The investigated population coming from the type locality shows a diploid chromosome complement with $2n = 2x = 16$: 12m + 4msm (Fig. 17I). The karyotype is characterized by 12 metacentric and 4 metasubmetacentric chromosomes; no evident satellited chromosomes were detected (Fig. 18I).

Phenology. Flowering from late June to early July.

Etymology. The epithet is based on "Smyrna", old name of Izmir, modern Turkish city of western Anatolia.

Taxonomic notes. Allium smyrnaeum is well differentiated from the other species of this group mainly in having inflorescence fastigiate and quite compact, with spathe valves strictly unilateral and almost adherent, whilst in the other ones the inflorescence is generally expanded and loose, with spathe valves opposite and more or less divaricate, or sometimes unilateral but well spaced. Another peculiarity of this species is the ovary strongly angled and flattened at the apex, whereas it is always blunt and rounded in all other species. For the occurrence of spathe valves erect and unilateral, *A. smyrnaeum* shows some relationships with *A. hirtovaginum* s. str., *A. abanticum*, *A. carium*, *A. papillosum* and *A. adenanthum*, from which, however, it differs in several diacritical features.

Paratypes. Turkey, Anatolia occidentale, dintorni di Emiralem presso Izmir, 23.6.1998, *S. Brullo & P. Pavone s.n.* (CAT); Ibid., incolti presso il sito archeologico di Euromus (Selimiye), 20.6.1998, *S. Brullo* & *P. Pavone s.n.* (CAT); Ibid, Labadadaği presso Milas, 20.6.1998, *S. Brullo* & *P. Pavone s.n.* (CAT).

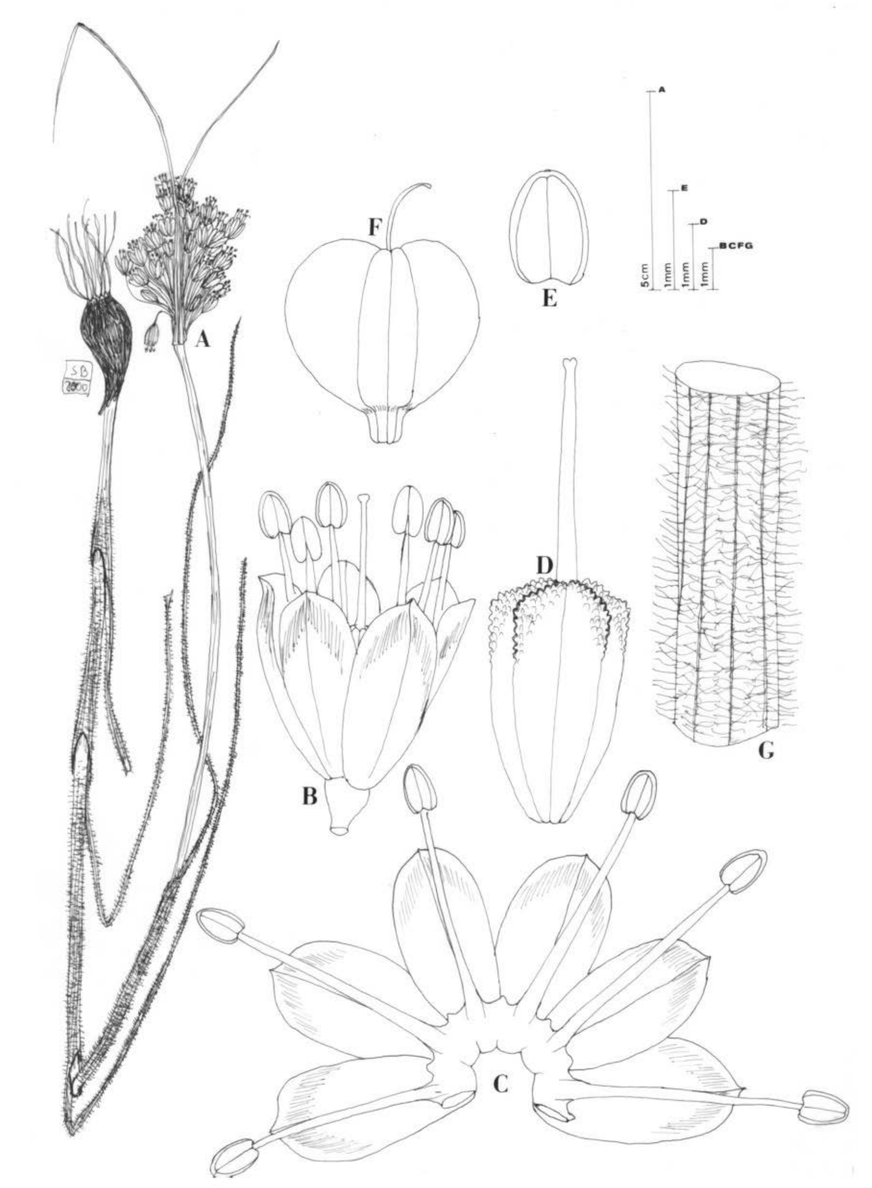

Fig. 12. *Allium smyrnaeum* Brullo & Salmeri: **A.** Habit; **B.** flower; **C.** open perigon and stamens; **D.** ovary; **E.** anther; **F.** Capsule; **G.** indumentum of leaf sheaths. (Drawing by S. Brullo from living plants of type locality).

14. *Allium trichospathum* Brullo & Salmeri, spec. nova (Fig. 13)

Allio hirtovagino similis, sed bulbi tunicis fibrosis, brunneolis, scapo longiore, foliis longioribus, pilis longioribus, subadpressis, inflorescentia majore, cum plures flores, pedicellis plerumque longioribus, spathae valvis oppositis, longioribus, appendicibus longe ciliatis, tepalis luteo-viridibus, brunneum suffusis, staminum filamentibus albis, longioribus, annulo interstaminalibus dentibus praedito, antheris luteolis, brevioribus, ovario majore, obovoideo-ellipsoideo, stipitato, supra leviter angulato, capsula majore.

Type. Turkey, Anatolia occidentale, Manisa Dağ montagna a Nord-Est di Izmir, su depositi sabbiosi, 28.6.1987, *S. Brullo*, *P. Pavone* & *P. Signorello s.n.* (Holo: CAT).

Bulb ovoid, 12-16 × 8-12 mm, with tunics fibrous, pale brown. *Stem* erect, rigid, robust, glabrous, 20-45 cm high, usually covered by the leaf sheaths up to 1/2 of total length. *Leaves* 3-4, shorter than the inflorescence, totally covered by dense hairs, subappressed, 0.5-0,7 mm long, blade semicylindrical, up to 20 cm long, ribbed. *Inflorescence* expanded, lax, 6-7 cm in diameter, with 35-50 flowers, on pedicels unequal, glabrous, 15-45 mm long. *Spathe* with 2 valves, erect, opposite, unequal, longer than the inflorescence, long and densely ciliate in the appendages, the largest 7-nerved, 10-16 cm long, the smallest 5-nerved, 8-12 cm long. *Perigon* campanulate, greenish-yellow, tinged with brown, 5 mm long, with tepals equal, elliptical, 2 mm wide, midrib green, smooth and apiculate at the apex. *Stamens* with simple filaments, white, the outers included, with filaments 1.5-2 mm long, the inners with filaments exserted from the perigon, 3-3.5 mm long , below connate with tepals into an annulus 0.7-0.9 mm high, with interstaminal teeth; anthers pale yellow, elliptical, rounded at the apex, 1.1-1.3 × 0.6-0.8 mm. *Ovary* ovoid-ellipsoid, slightly angled and flattened at the apex, papillose above, green, 3 × 1.8-2 mm; style white, 0.5 mm long. *Capsule* trivalved, obovoid, stipitate below, 5 × 4 mm.

Distribution and habitat. This species was collected in two mountain stands of western Anatolia, on Manisa Dağ and Sandras Dağ (Fig. 2E). In these places it grows exclusively on sandy substrata within grasslands.

Karyology. The two investigated populations coming from Sandras Dağ and Manisa Dağ show a diploid chromosome complement with $2n = 2x = 16$ (Fig. 17J,K). The karyotype is characterized by more or less metacentric, with 2 pairs of metasubmetacentric type (arm ratio exceeding 1.30), one of which satellited on the short arm (Fig. 18J, K). Difference among populations regard the occurrence of macrosatellites in the smallest metacentric pair of samples from Sandras Dağ, which were not detected in the other investigated population.

Phenology. Flowering from late June to early July.

Etymology. The epithet refers to the spathe valves with appendages covered by dense hairs.

Taxonomic notes. *Allium trichospathum* shows a certain similarity with *A. hirtovaginum* s. str. mainly for the habit, leaf indumentum, spathe valves and some flower characters, but markedly differs in having bulb tunics fibrous, stem usually much more developed and robust, leaf hairs longer and appressed, richer inflorescence, with pedicels longer, spathe valves opposite and longer, tepals greenish-yellow, stamen filaments white, occurrence of interstaminal teeth, anthers smaller, ovary much larger, elongated and angulate above, capsule larger. Besides, for its habit and some other features such as the hairiness of leaf and spathe valves, tepal colour and occurrence of interstaminal teeth, this species seems to have some taxonomic relation with *A. rhodopeum* Velen., species distributed in the Balkans (Brullo & al. 1998). This last species, however, is well differentiated from *A. trichospathum* in having the stamens fully included into the perigon, a typical feature of another species group of *Allium* of the Sect. *Codonoprasum*, e.i. *A. paniculatum* L. *s.l.*

Paratype. Turkey, Anatolia sud-occidentale, Sandras Dağ a Est di Mugla, su sabbie scistose, 26.6.1988, *S. Brullo, P. Pavone & P. Signorello s.n.* (CAT).

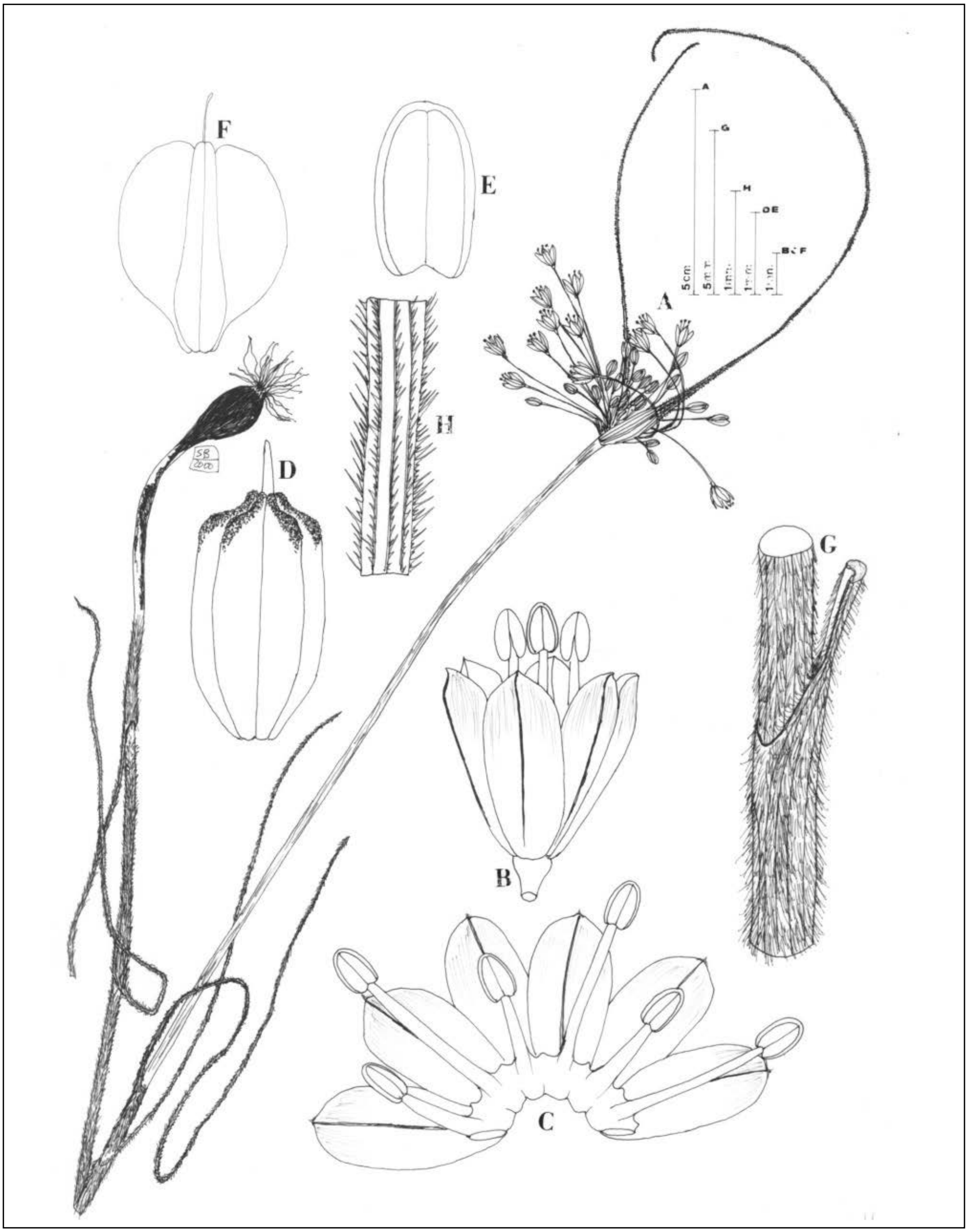

Fig. 13. *Allium trichospathum* Brullo & Salmeri: **A.** Habit; **B.** flower; **C.** open perigon and stamens; **D.** ovary; **E.** anther; **F.** Capsule; **G.** indumentum of leaf sheaths; **H**. appendage of the spathe valve. (Drawing by S. Brullo from living plants of type locality).

15. *Allium pavonianum* Brullo & Salmeri, spec. nova (Fig. 14)

Allio smyrnaeo similis, sed bulbi tunicis exterioribus fibrosis, brunneolis, scapo longiore, foliis pilis foliorum brevioribus, inflorescentia majore, pedicellis plerumque longioribus, spathae valvis oppositis, plerumque longioribus, tepalis brevioribus, brunneum suffusis, rotundatis apice, staminum filamentibus brevioribus, omnino purpureum soffusis, annulo sine interstaminalibus dentibus, ovario minore, non stipitato, supra leviter angulato, capsula minore, subglobosa, complanata.

Type. Turkey, Anatolia occidentale, Beidag presso Nazilli,, 26.6.1987, *S. Brullo*, *P. Pavone* & *P. Signorello s.n.* (Holo: CAT).

Bulb ovoid, 16-20 × 12-15 mm, with outer tunics fibrous, pale brown, the inners membranaceous, whitish. *Stem* erect, rigid, very robust, glabrous, 35-60 cm high, usually covered by the leaf sheaths 1/3-1/2 of total length. *Leaves* 3-4, shorter than the inflorescence, totally covered by dense hairs, patent, 0.1-0.3 mm long, blade semicylindrical, up to 20 cm long, ribbed. *Inflorescence* fastigiate, compact, 3-6 cm long, with 50-100 flowers, on pedicels unequal, glabrous, 10-55 mm long. *Spathe* with 2 valves erect, opposite, unequal, longer than the inflorescence, glabrous, the largest 7-nerved, 6-18 cm long, the smallest 5-nerved, 3-10 cm long. *Perigon* campanulate, greenish-yellow, tinged with brown, 4.3-4.5 mm long, with tepals equal, oblong, 2-2.2 mm wide, midrib green, smooth and rounded at the apex. *Stamens* with simple filaments, completely tinged with purplish, subequal, all exserted from the perigon, 3.7-4 mm long,, below connate with tepals into an annulus 0.5-0.6 mm high, no interstaminal teeth; anthers pale yellow, elliptical, rounded at the apex, 1-1.2 × 0.6-0.7 mm. *Ovary* obovoid-ellipsoid, slightly angled and flattened at the apex, dorsally papillose above, green, 3 × 2 mm; style white, 3 mm long. *Capsule* trivalved, subglobose, flattened, 4 × 3 mm.

Distribution and habitat. This species occurs in some submountain stands near Nazilli in central-western Anatolia (Fig. 2G), where it grows in grasslands and in the clearings of the scrublands.

Karyology. Unknown.

Phenology. Flowering from late June to early July.

Etymology. The species is named in honour of our colleague and friend Pietro Pavone, botanist at Catania University, specialist in the cytotaxonomy of bulbous plants.

Taxonomic notes. Due to its big size, leaf indumentum, inflorescence fastigiate and many-flowered, stamens all exserted from the perigon and ovary well developed, *Allium pavonianum* shows closer relationships mainly with *A. smyrnaeum*, from which it differs in several features regarding mainly the bulb tunics, spathe valves, the flowers and fruit. The most relevant differences are the occurrence in *A. pavonianum* of innermost bulb tunics membranaceous, stem more developed, leaves with shorter hairs, pedicels usually longer, spathe valves opposite, tepals shorter, stamen filaments shorter and tinged with purplish, annulus without interstaminal teeth, ovary shorter, capsule smaller, subglobose and flattened.

Paratype. Turkey, Anatolia occidentale, Kartiz Dag (Nazilli), 26.6.1987, *S. Brullo, P. Pavone & P. Signorello s.n.* (CAT).

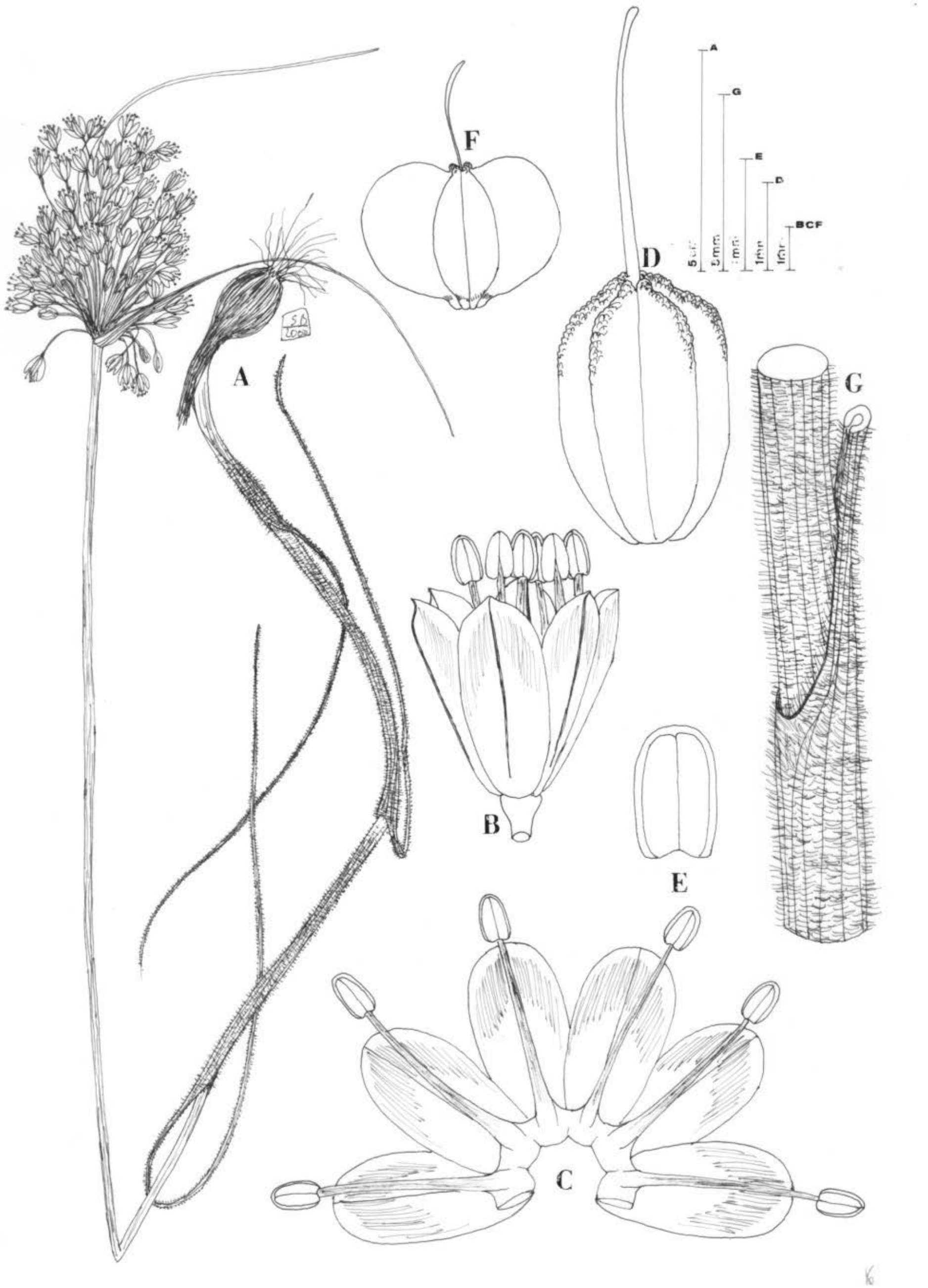

Fig. 14. *Allium pavonianum* Brullo & Salmeri: **A.** Habit; **B.** flower; **C.** open perigon and stamens; **D.** ovary; **E.** anther; **F.** Capsule; **G.** indumentum of leaf sheaths. (Drawing by S. Brullo from living plants of type locality)

16. ***Allium denticulatum*** Brullo & Salmeri, spec. nova (Fig. 15)

Allio papilloso similis, sed bulbo ovoideo, minore, tunicis fibrosis, scapo breviore, 1/2-2/3 longitudinem vaginis foliorum tecto, foliis 3, brevioribus, secum costas minute denticulatis et pilosis, inflorescentia minore, tepalis longioribus, albo-luteis, interioribus latioribus, staminum filamentibus albidis, antheris longioribus, ovario majore, ovoideo, laevi, stylo longiore, capsula subglobosa, majore.

Type. Turkey, Anatolia occidentale, Kizilkadag (Korkuteli), 21.6.1998, *S. Brullo & P. Pavone s.n.,* (Holo: CAT).

Bulb ovoid, 6-10 × 5-6 mm, with outer tunics fibrous, greyish, the innermost ones fibrous, whitish. *Stem* erect, flexuous, glabrous, 10-20 cm high, usually covered by the leaf sheaths 1/2-2/3 of total length. *Leaves* 3, subequal to shorter than the inflorescence, totally covered along the ribs by minute teeth and hairs, much less than 1 mm long, blade semicylindrical, canaliculate, up to 10 cm long, ribbed. *Inflorescence* expanded, lax, 2.5-4 cm in diameter, with 10-20 flowers, on pedicels unequal, glabrous, 5-20 mm long. *Spathe* with 2 valves, erect, opposite, unequal, longer than the inflorescence, glabrous, the largest 7-nerved, 2.5-6 cm long, the smallest 5-nerved, 2-3 cm long. *Perigon* campanulate, whitish-yellow, 4,8-5 mm long, with tepals subequal, elliptical, smooth and somewhat obtuse at the apex, the outers 2.2 mm wide, the inners 2 mm wide, midrib green. *Stamens* with simple filaments subequal, all exserted from the perigon, 4.5-5.5 mm long, white, below connate with tepals into an annulus 0.8-0.9 mm high, without interstaminal teeth; anthers pale yellow, elliptical, rounded at the apex, 1.7-1.8 × 0.8 mm. *Ovary* ovoid, greenish-yellow, smooth, 1.8-2 × 2-2.2 mm; style white, 2-3 mm long. *Capsule* trivalved, subglobose, 4.5 × 4.5-4.7 mm.

Distribution and habitat. Allium denticulatum occurs on Kizilkadag mountain near Korkuteli (western Anatolia), where grows in the clearings of the maquis (Fig. 2K). This species appear to be very rare and localized.

Karyology. Unknown.

Phenology. Flowering from late June to early July.

Etymology. The specific epithet refers to the leaves minutely denticulate.

Taxonomic notes. Allium denticulatum differs markedly from the other species of the *A. hirtovaginum* group for the leaf indumentum, since the leaves are not covered with dense and more or less developed hairs, but they are minutely hairy and denticulate along the ribs. For this peculiarity, it seems to have an intermediate taxonomic position between the typical species of *A. hirtovaginum* group, which have hairy leaves, and those of *A. stamineum* group, which are instead tipically hairless (see Brullo & al. 2007). Currently, due to its hairiness, although quite inconspicuous, and lacking further data supporting a different arrangement, we consider more appropriate to include this species in the *A. hirtovaginum* group. Within this group, *A. denticulatum* shows a certain affinity especially with *A. papillosum*, since both share a stem slender and flexuous, spathe valves erect, opposite and few developed, all stamens exserted from the perigon, no interstaminal teeth and ovary quite small. Nevertheless, in addition to the leaf indumentum, *A. denticulatum* is well differentiated in having a smaller size, bulb ovoid and smaller, with tunics fibrous, stem covered by the leaf sheaths up to 2/3 of its length, leaves 3, inflorescence smaller, tepals whitish-yellow, longer, stamen filaments white, anthers longer, ovary smooth, stile longer, capsule subglobose, larger.

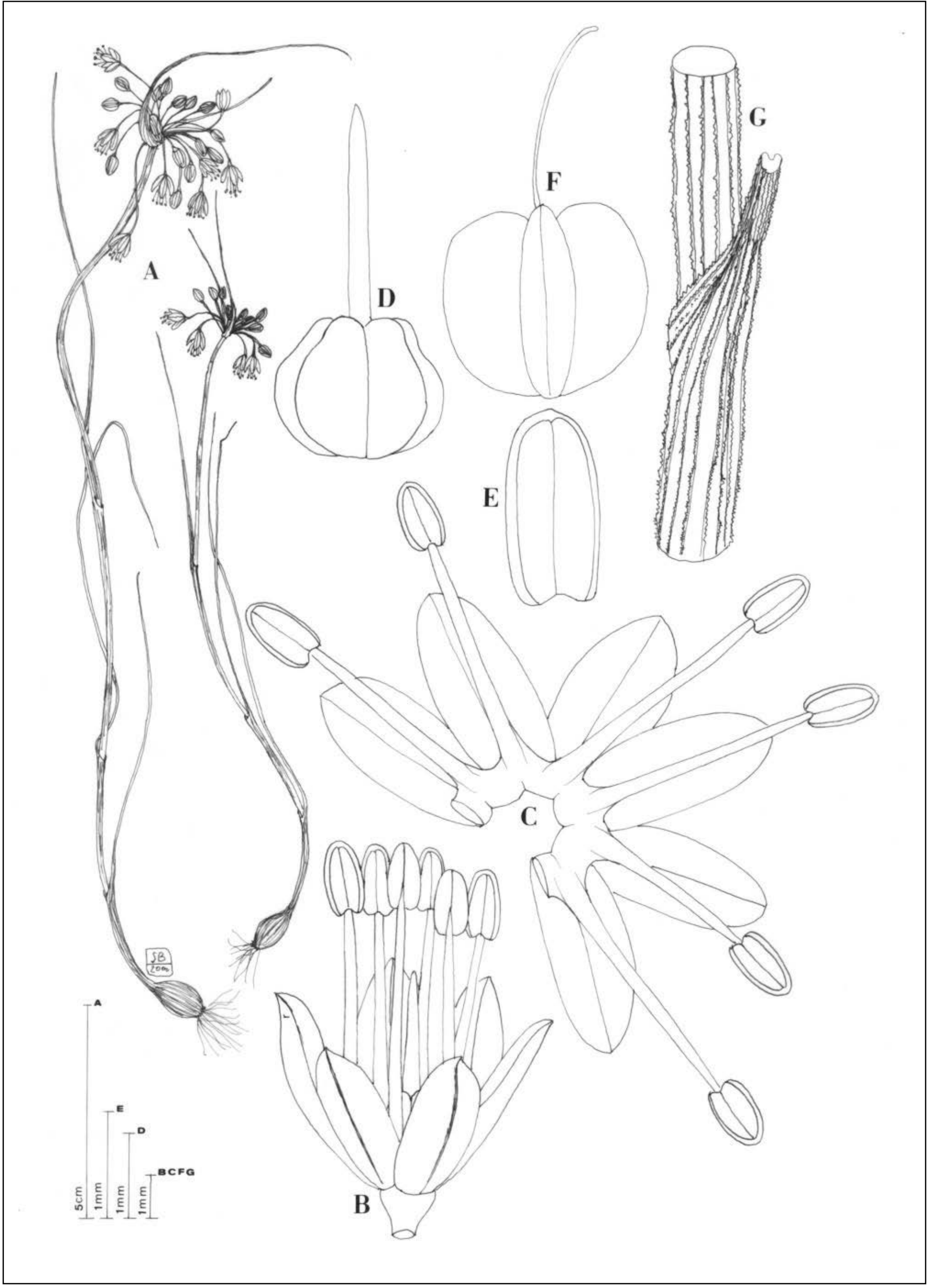

Fig. 15. *Allium denticulatum* Brullo & Salmeri: **A.** Habit; **B.** flower; **C.** open perigon and stamens; **D.** ovary; **E.** anther; **F.** Capsule; **G.** indumentum of leaf sheaths. (Drawing by S. Brullo from living plants of type locality).

17. *Allium compactatum* Brullo & Salmeri, spec. nova (Fig. 16)

Allio denticulato similis, sed bulbis saepe aggregatis, majoribus, scapo robusto, longiore, foliis longioribus, inflorescentia hemispaerica, minore, compactata, spathae valvis longioribus, tepalis longioribus, viriduli-luteis, staminum annulo latiore, interstaminalibus lobulis, antheris brevioribus, luteis, ovario majore, subcylindrico, duabus apicalibus prominentibus gibbis in quoque loculo, capsula obovoidea, minore, colliculata apice.

Type. Turkey, Anatolia occidentale, nello colline presso Civril a Sud di Usak, 27.7.1998, *S. Brullo & P. Pavone s,n,* (Holo: CAT).

Bulbs usually clustered, ovoid, 12-20 × 6-10 mm, with tunics slightly fibrous, the outers greyish, the inners yellowish. *Stem* erect, often curved at the base, robust, glabrous, 20-40 cm high, usually covered by the leaf sheaths 1/2-2/3 of total length. *Leaves* 3, shorter than the inflorescence, totally covered along the ribs by minute teeth and hairs, much less than 1 mm long, blade semicylindrical, canaliculate, up to 13 cm long, ribbed. *Inflorescence* hemispherical, quite compact, 1.5-2.8 cm in diameter, with 10-35 flowers, on pedicels unequal, glabrous, 7-15 mm long. *Spathe* with 2 valves, erect, opposite, unequal, longer than the inflorescence, glabrous, the largest 7-nerved, 6-13 cm long, the smallest 5-nerved, 2.5-9 cm long. *Perigon* campanulate, greenish-yellow, with tepals subequal, elliptical, the outers 5-5.5 × 2.2-2.4 mm, the inners 5.5-5.8 × 1.8-2 mm, midrib green, smooth and somewhat obtuse at the apex. *Stamens* with simple filaments subequal, all exserted from the perigon, 4.5-5 mm long, white, below connate with tepals into an annulus 1.2-1.5 mm high, with interstaminal rounded lobules; anthers yellow, elliptical, rounded at the apex, 1-1.1 × 0.5-0.6 mm. *Ovary* subcylidrical, greenish-yellow, smooth, 2.5-3 × 1.8-2 mm, with 2 apical prominent gibbosities for each loculus; style white, 1.5-3 mm long. *Capsule* trivalved, obovoid, 4 × 4 mm, colliculate at the apex.

Distribution and habitat. Allium compactatum was collected in some localities near Usak, inland of western Anatolia (Fig, 2H). In these stands it is quite rare and sporadic, growing usually in the clearings of the maquis.

Karyology. The investigated populations coming from Civril were diploid with a chromosome complement $2n = 2x = 16$: 10m + 6msm (Fig. 17L). The karyotype is characterized by more or less metacentric chromosomes with 3 metasubmetacentric pairs. No satellited chomosomes were found (Fig. 18L).

Phenology. Flowering from late July to early August.

Etymology. The epithet refers to the inflorescence with very compacted flowers.

Taxonomic notes. Allium denticulatum is well differentiated from the other species of *A. hirtovaginum* group in having the inflorescence hemispherical with quite compacted flowers not expanded and lax or sometimes fastigiate like in all other species. Based on this trait as well as on the occurrence of stamens exserted from the perigon, it shows some relationships with the species belonging to *A. staticiforme* Sm. (Brullo & al. 1995, 2017), which however markedly differ in having mostly hairless leaves, very short spathe valves and much smaller flowers. Among the examined species of the *A. hirtovaginum* group, it seems to have closer affinity only with *A. denticulatum*, since both species share the leaves not densely hairy, but just provided to a minute denticulation mixed with inconspicuous hairs along the ribs. However, the two species show remarkable differences in vegetative and reproductive structures, including the occurrence in *A. denticulatum* of bulbs isolated and smaller, stem slender, flexuous and shorter, inflorescence lax and expanded, larger, spathe valves shorter, tepals shorter, whitish-yellow, annulus larger, without interstaminal lobules, anthers longer, pale yellow, ovary ovoid, smaller, smooth at the apex, capsule subglobose, larger, smooth.

Paratype. Turkey, colline nei dintorni di Usak, 27.7.1998, *S. Brullo* & *P. Pavone s.n.* (CAT).

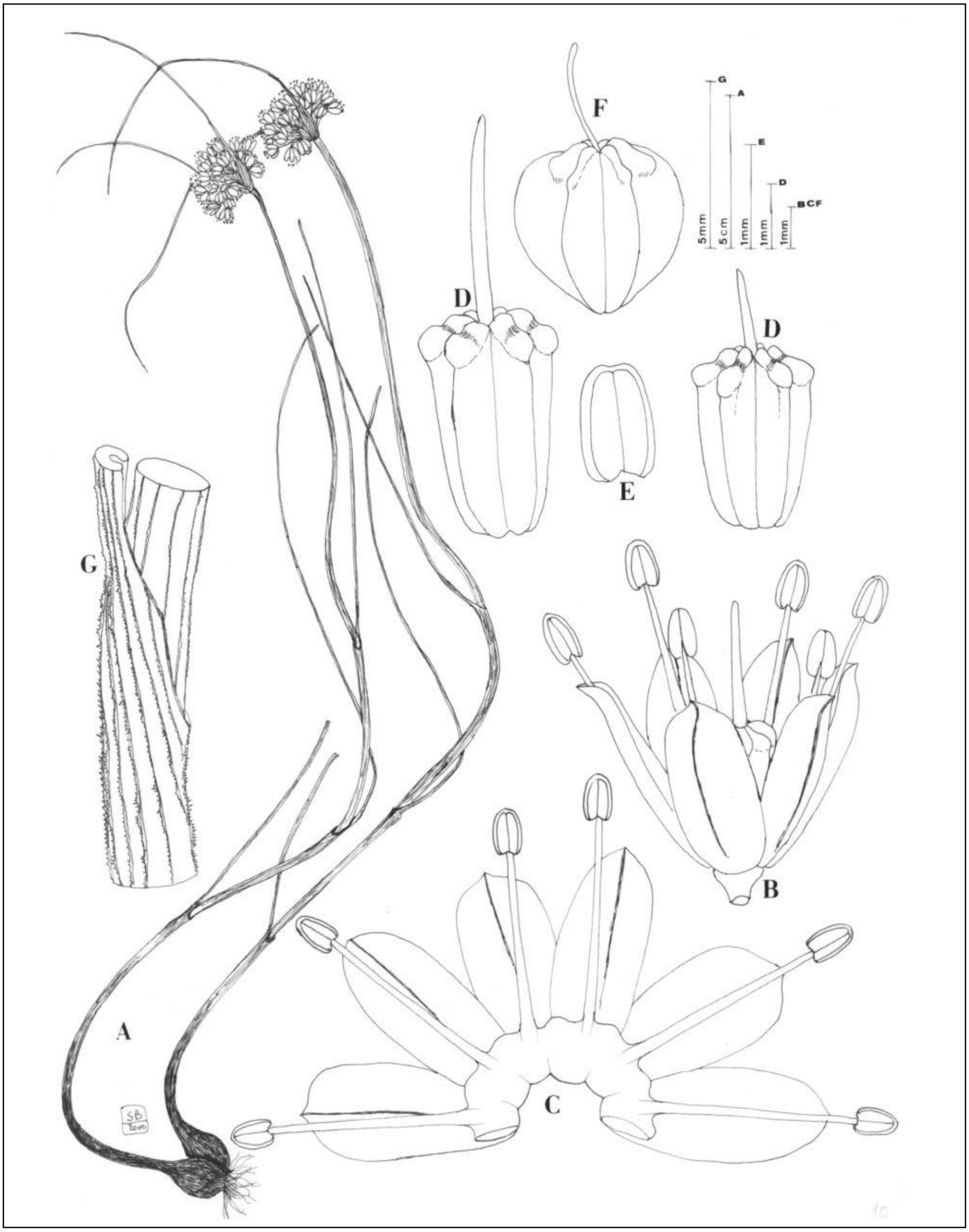

Fig. 16. *Allium compactatum* Brullo & Salmeri: **A.** Habit; **B.** flower; **C.** open perigon and stamens; **D.** ovary; **E.** anther; **F.** Capsule; **G.** indumentum of leaf sheaths. (Drawing by S. Brullo from living plants of type locality).

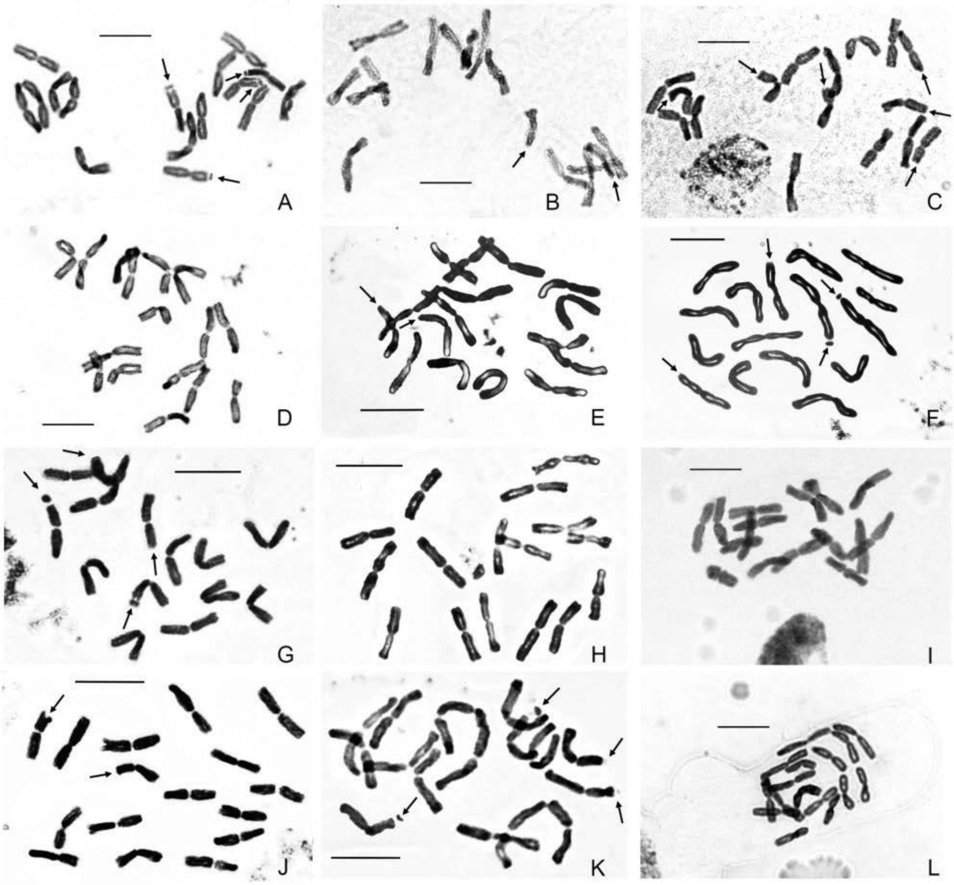

Fig. 17. Mitotic metaphase plates of: **A.** *A. hirtovaginum* (Lesbos, Karestapas); **B.** *A. pythagoricum* (Samos, Psili Amnos); **C.** *A. pignattii* (Samos, Marathokampos); **D.** *A. hippocraticum* (Kos, Kefalos); **E.** *A. abanticum* (Euboea, Karistos); **F.** *A. carium* (Turkey, Fethyie); **G.** *A. papillosum* (Turkey, Denizli); **H.** *A. adenanthum* (Turkey, Gocek); **I.** *A. smyrnaeum* (Turkey, Izmir); **J.** *A. trichosphatum* (Turkey, Manisa Dağ); **K.** *A. trichosphatum* (Turkey, Sandras Dağ); **L.** *A. compactatum* (Turkey, Civril). Bars = 10 µm. Arrows mark satellited chromosomes.

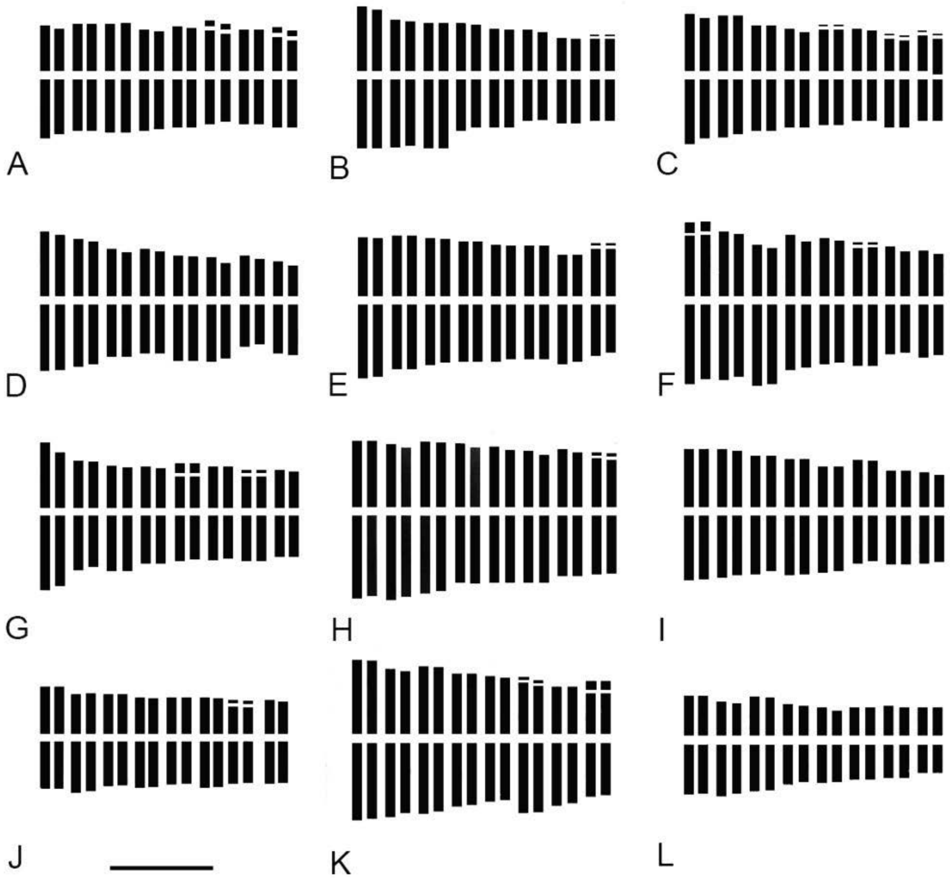

Fig. 18. Karyograms obtained from 10 well spread metaphase plates: **A.** *A. hirtovaginum* (Lesbos, Karestapas); **B.** *A. pythagoricum* (Samos, Psili Amnos); **C.** *A. pignattii* (Samos, Marathokampos); **D.** *A. hippocraticum* (Kos, Kefalos); **E.** *A. abanticum* (Euboea, Karistos); **F.** *A. carium* (Turkey, Fethyie); **G.** *A. papillosum* (Turkey, Denizli); **H.** *A. adenanthum* (Turkey, Gocek); **I.** *A. smyrnaeum* (Turkey, Izmir); **J.** *A. trichosphatum* (Turkey, Manisa Dağ); **K.** *A. trichosphatum* (Turkey, Sandras Dağ); **L.** *A. compactatum* (Turkey, Civril). Bars = 10 μm.).

Key to the investigated *Allium* species belonging to the *A. hirtovaginum* group

1. Stem hairy up to the top **2**
– Stem always hairless **3**
2. Leaves covered by velutinous-scabrous indumentum; inflorescence with more than 100-flowers; pedicels glabrous; spathe valve opposite, glabrous, 8-11-nerved; perigon globose, with tepals unequal, eglandular; stamen filaments entirely white .... ***A. nerimaniae***
– Leaves covered by dense hairy indumentum; inflorescence with 10-35-flowers; pedicels hairy; spathe valves unilateral, with appendages hairy, 5-7-nerved; perigon campanulate, with tepals equal, sprinkled with glands on inner surface; stamen filaments purplish above.. ***A. adenanthum***
3. Leaves denticulate with inconspicuous hairs along the ribs **4**
– Leaves completely covered by dense hairy indumentum **5**
4. Stem 10-20 cm tall; inflorescence expanded and lax; tepals 4.8-5 mm long; anthers 1.7-1.8 mm long; ovary smooth, 1.8-2 mm long .... ***A. denticulatum***
– Stem 20-40 cm tall; inflorescence hemispherical and compacted; tepals 5-5.5 mm long; anthers 1-1.1 mm long; ovary with apical prominent gibbosities, 2.5-3 mm long...***A. compactatum***
5. Spathe valves with appendages hairy **6**
– Spathe valves with appendages glabrous **11**
6. Tepals purplish-pink or purplish-lilac; ovary 1.2-2.4 mm long **7**
– Tepals greenish-brown or greenish-yellow; ovary 2.8-3 mm long **9**
7. Spathe valves subequal or slightly longer than inflorescence; flower pedicels 5-15 mm long; perigon 3.5-4 (4.5) mm long; stamen filaments 2-4 mm long, entirely purple.. ***A. pilosum***
– Spathe valves much longer than the inflorescence; flower pedicels 15-30 mm long; perigon 4.5-5.5 mm long; stamen filaments 4-7 mm long, purplish only above **8**
8. Outer bulb tunic coriaceous; spathe valves unilateral erect; leaves with hairs 0.1-0.2 mm long; perigon 4.5-5 mm long; only inner stamen filaments exserted from perigon, 4-5 mm long; ovary 1.5-1.6 mm long .... ***A. hirtovaginum***
– Outer bulb tunic fibrous; spathe valves opposite, divaricate-reflexed; leaf with hairs 0.2.1.8 mm long; perigon 5-5.5 mm long; stamen filaments all exserted from the perigon, 6-7 mm long; ovary 2.1-2.4 mm long .... ***A. aeginiense***
9. Leaves longer than the inflorescence, with hairs patent, 0.2-0.3 mm long; stamen filaments all exserted from the perigon, 4-4.2 mm long .... ***A. hippocraticum***
– Leaves shorter than the inflorescence, with hairs subappressed 0.5-1 mm long; stamen filaments only the inners exserted from the perigon, 3-3.5 mm long **10**
10. Spathe valves divaricate-reflexed, with appendages hairy at the margin; flower pedicels 10-30 mm long; no interstaminal teeth .... ***A. pignattii***
– Spathe valves erect, with appendages totally hairy; flower pedicels up to 45 mm long; occurrence of interstaminal teeth .... ***A. trichospathum***
11. Stem 10-18 cm tall **12**
– Stem 18-50 cm tall **13**
12. Outer bulb tunics fibrous; leaves with hairs patent, 0.2-0.3 mm long; spathe valves longer than the inflorescence, the largest 3-6 cm long; stamen filaments white, only inners

exserted from the perigon, 4-4.2 long, with interstaminal teeth; ovary 3-3.5 mm long.. ***A. abanticum***
– Outer bulb tunics coriaceous; leaves with hairs subappressed, 0.5-1 mm long; spathe valves subequal or shorter than inflorescence, the largest 2-3 cm long; stamen filaments purplish above, all exserted from the perigon, 5.5-6 long, no interstaminal teeth; ovary 1.7 mm long .... ***A. carium***
13. Inflorescence fastigiate, compact; ovary 3-3.5 mm long **14**
– Inflorescence expanded, lax; ovary 1.5-2.4 mm long **15**
14. Leaf hairs 0.4-0.6 mm long; spathe valves unilateral; perigon 5 mm long; stamen filaments white; annulus with interstaminal teeth; ovary 3.5-4 mm long .... ***A. smyrnaeum***
– Leaf hairs 0.1-0.3 mm long; spathe valves opposite; perigon 4.3-4.5 mm long; stamen filaments purplish; annulus without interstaminal teeth; ovary 3 mm long...***A. pavonianum***
15. Leaves with hairs up to 1mm long; stamen filaments purplish below, only the inner exserted from the perigon, 3-3.5 mm long; ovary subcylindrical .... ***A. pythagoricum***
– Leaves with hairs 0.05-0.3 mm long; stamen filaments entirely white or purplish above, all exserted from the perigon, 5-6.5 mm long; ovary subglobose or ovoid **16**
16. Stem 18-28 cm tall; leaves with hairs 0.05-1 mm long; spathe valves erect; perigon purplish, 4-4.5 mm long; stamen filaments above purplish, 5-5.5mm long, no interstaminal teeth; ovary subglobose, 1.5 mm long, totally papillose .... ***A. papillosum***
– Stem 30-50 cm tall; leaves with hairs 0.1-0.3 mm long; spathe valves divaricate; perigon greenish-yellow, 4.5-5 mm long; stamen filaments white, 5.5-6.5 mm long, with interstaminal teeth; ovary ovoid, 2-2.3 mm long, smooth .... ***A. velutinum***

Conclusion

This study provides a significant contribution to the knowledge of a group of species of the genus *Allium* sect. *Codonoprasum,* distributed in the eastern Mediterranean territories, in particular Greece and Turkey. On the basis of literature data, this section is still little known from a taxonomic point of view, since it includes numerous critical species and groups, requiring in-depth morphological, karyological, anatomical and molecular investigations. This is confirmed by the high number of species newly described or re-evaluated especially in the Mediterranean area, representing one of the richest diversity centres, especially for this section (Kollmann 1985; Karavokyrou & Tzanoudakis 1994; Brullo & al. 1994, 1995, 1996, 1998, 2002, 2007, 2008b, 2010, 2012; Biel & al. 2006; Peruzzi 2007; Tzanoudakis & Kypriotakis 2008; Trigas & al. 2010; Koçyiğit & al. 2010, 2014, 2016; Koçyiğit & Özhatay 2012; Kalpoutzakis et al 2012; Tzanoudakis & Trigas 2015; Özhatay & al. 2018; Galanos & Tzanoudakis 2019; Trigas & Bareka 2020; Cattaneo 2020). In particular, the species here treated all fall into a quite critical and still taxonomically not well known group, whose populations in the past were usually attributed to *Allium hirtovaginum* (see Tanker & Kurucu 1979; Kollmann 1984; Karavokyrou & Tzanoudakis 1991; Özhatay 1993; Koçyiğit & Kaya 2020). Effectively, *A. hirtovaginum* can be recognized as a species complex, differentiated from the rest of the sect. *Codonoprasum*, especially in having leaves entirely covered by a hairy indumentum, spathe valves often with hairy appendages, and flowers with all or at least the inner stamens exserted from the perigon.

As far as karyology is concerned, all the investigated populations have a diploid chromosome number ($2n = 16$), mostly characterized by metacentric chromosomes and 1 up to 3 metasubmetacentric pairs, with a different number of macro- and/or microsatellited chromosomes. Due to the stamens exserted from perigon, they show some relationships with the species belonging to the *A. stamineum* group, which is also spread in the eastern Mediterranean, where it has a really wide distribution. The latter, anyhow, clearly differs from the *A. hirtovaginum* group in having completely glabrous and smooth leaves. Based on literature data and our extended herbarium investigations carried out in several Botanical Museums (B, BM, C, CAT, FI, G, HUJ, ISTE, K, M, OXF, P, UPA, W and WU), it can be hypothesized that further detailed studies on this group, mainly combined with field surveys, will probably lead to the identification of other new taxa for science.

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References

Biel, B., Tan, K. & Tzanoudakis, D. 2006: A new autumn-flowering species of *Allium* (*Liliaceae*) from the island of Sifnos (Cyclades, Greece). – Willdenowia **36:** 367-372. https://doi.org/10.3372/wi.36.36132

Bogdanovič, S., Brullo, C., Brullo, S., Giusso del Galdo, G., Musarella, C. M. & Salmeri, C. 2011a: *Allium achaium* Boiss & Orph. ex Boiss. (*Alliaceae*), a critical species of Greek flora. – Candollea **66(1):** 57-64.

—, Brullo, S., Giusso del Galdo, G. & Salmeri, C. 2009: A new autumn-flowering species of *Allium* (*Alliaceae*) from Croatia. – Folia Geobot. **44:** 83-93. https://doi.org/10.1007/s12224-009-9032-2

—, —, Mitic, B. & Salmeri, C. 2008: A new species of *Allium* (*Alliaceae*) from Dalmatia. – Bot. J. Linn. Soc. **158:** 106-114.

Brullo, C., Brullo, S., Fragman-Sapir, O., Giusso del Galdo, G. & Salmeri, C. 2014: *Allium therinanthum* (*Amaryllidaceae*), a new species from Israel. – Phytotaxa **164(1):** 29-40. https://doi.org/10.11646/phytotaxa.164.1.3

—, —, Giusso del Galdo, G. & Salmeri, C. 2010: *Allium makrianum* (*Alliaceae*), a new autumnal species from Greece. – Phyton (Horn) **49:** 267-278.

—, —, —, — 2017: *Allium nazarenum* (*Amaryllidaceae*), a new species of the section *Codonoprasum* from Israel. – Phytotaxa **327(3):** 237–251. https://doi.org/10.11646/phytotaxa.327.3.3

Brullo, F. 2002: CromoLabc. Version 1.1. – Catania.

Brullo, S., Brullo, C., Cambria, S., Giusso del Galdo, G. & Salmeri, C. 2019: *Allium albanicum* (*Amaryllidaceae*), a new species from Balkans and its relationships with *A. meteoricum* Heldr. & Hausskn. ex Halácsy. – PhytoKeys **119:** 117-136. https://doi.org/10.3897/phytokeys.119.30790

—, Giacalone, G., Pavone, P. & Salmeri, C. 2012: Filogenesi molecolare di *Allium* Sez. *Codonoprasum* (*Alliaceae*). – Pp. 47-48 in: Peccenini, S., Domina, G., Salmeri, C., Flora vascolare d'Italia: studi biosistematici, taxa endemici e loci classici. Comunicazioni. – Firenze.

—, Giusso del Galdo, G., Terrasi, M. C. 2008a: *Allium aeginiense* Brullo, Giusso & Terrasi (*Alliaceae*), a new species from Greece. – Candollea **63:** 197-203.

—, Guglielmo, A., Pavone, P. & Salmeri, C. 2001a: Cytotaxonomical notes on some rare endemic species of *Allium* (*Alliaceae*) from Greece. – Caryologia **54(1):** 37-57.

—, —, — & — 2002: Osservazioni tassonomiche e cariologiche sulle specie del ciclo di *Allium paniculatum* L. in Italia. – Inform. Bot. Ital. **33(2):** 536-542.

—, —, — & — 2003a: Cytotaxonomical remarks on *Allium pallens* and its relationships with *A. convallarioides* (*Alliaceae*). – Bocconea **16(2):** 557-571.

—, —, — & — 2007: Cytotaxonomical consideration on *Allium stamineum* Boiss. group (*Alliaceae*). – Bocconea **21:** 325-343.

—, —, — & — 2008b: Taxonomic study on *Allium dentiferum* Webb & Berthel. (*Alliaceae*) and its taxonomic relations with allied species from the Mediterranean. – Taxon **57:** 243-253.

—, —, —, — & Terrasi, M. C. 2003b: Three new species of *Allium* Sect. *Codonoprasum* from Greece. – Pl. Biosyst. **137(2):** 131-140.

—, —, —, Scelsi, F. & Terrasi, M. C. 1996a: Cytotaxonomic consideration of *Allium fuscum* Waldst. et Kit. (*Liliaceae*), a critical species of European Flora. Folia Geobot. – Phytotax. **31:** 465-472.

—, — & Terrasi, M. C. 1998: Notes on *Allium rhodopeum* (*Alliaceae*), a neglected species from the E Mediterranean area. – Pl. Biosyst. **132(1):** 63-69.

—, Pavone, P. & Salmeri, C. 1993: Three new species of *Allium* (*Alliaceae*) from Cyprus. – Candollea **48:** 279-290.

—, — & — 1995: Considerazioni citotassonomiche sulle specie appartenenti al ciclo di *A. staticiforme* Sm. (*Liliaceae*) del Mediterraneo orientale. – Boll. Soc. Sarda Sci. Nat. **30:** 501-510.

—, — & — 1996b: *Allium daninianum* (*Alliaceae*), a new species from the Middle East. – Willdenowia **26:** 237-244.

—, — & — 1996c: A new species of *Allium* sect. *Codonoprasum* from Sierra Nevada (Spain). – Sendtnera **3:** 95-100.

—, — & — 1997a: *Allium oporinanthum* (Alliaceae), a new species from NW Mediterranean area. – Anal. Jard. Bot. Madrid **55(2):** 297-302.

—, — & — 1997b: *Allium anzalonei*, eine neue Art für die italienische Flora. – Sendtnera **4:** 33-39.

—, — & — 1999: *Allium archeotrichon* (*Alliaceae*), a new species from Rhodos (Dodekannisos, Greece). – Nord. J. Bot. **19(1):** 41-46.

—, — & — 2001b: *Allium brachyspathum* (*Alliaceae*), a new species from the island of Karpathos (S Aegean area, Greece). – Bocconea **13:** 413-417.

—, — & — 2013: *Allium aetnense* (*Amaryllidaceae*), a new species from Sicily. – Pl. Biosyst. **47(3):** 835-843. https://doi.org/10.1080/11263504.2013.832433

—, —, — & Scrugli, A. 1994: Cytotaxonomical notes on *Allium savii* Parl. (*Liliaceae*), a misappreciated Tyrrhenian element. – Candollea **49:** 271-279.

—, —, — & Terrasi. M. C. 2009: *Allium garganicum* (*Alliaceae*), a new species from Apulia (SE Italy). – Pl. Biosyst. **143 (supl. 1):** 78-84. http://dx.doi.org/10.1080/11263500903487765

—, —, — & Venora, G. 2004: Cytotaxonomic investigation on *Allium exaltatum* (*Alliaceae*) from Cyprus. – Caryologia **57(3):** 274-278.

— & Tzanoudakis, D. 1994: *Allium ionicum* (*Liliacee*) a new species from the Ionian islands (W Grecee). – Willdenowia **24:** 53-57.

Candargy, P. C. 1897: Flore de l'île de Lesbos. 1. Espéces nouvelles. – Bull. Soc. Bot. Fr. **44:** 140-144.

Cattaneo, C. 2020: Description of a new species from Symi island, (SE Aegean, Greece): *Allium carlstroemi* sp. nov. (Amaryllidaceae). – Parnassiana Archives **8:**103-111.

Dimopoulos, P., Raus, T., Bergmeier, E., Costantinidis, T., Iatrou, G., Kokkini, S., Strid, A. & Tzanoudakis, D. 2013: Vascular Plants of Greece. An annotated checklist. – Englera **31:** 1-372.

D'Urville, J. S. C. D. 1822: Enumeratio Plantarum. – Paris.

Feulgen, R. & Rossenbach, H. 1924: Mikroscopisch-chemischer Nachweis einer Nucleinsäure vom Typus der Thymonucleinsäure. – Hoppe-Seyler's Z. Physiol. Chem. **135:** 213-248.

Flora of Greece Web 2020: A brief history of botanical exploration in Greece. Available online: http://portal.cybertaxonomy.org/flora-greece/botanicalExploration [Last accessed 08/10/2020).

Fritsch, R. M. & Friesen, N. 2002: Evolution, domestication, and taxonomy. – Pp. 5-30 in: Rabinowitch, H. D. & Currah, L. (eds), *Allium* Crop Science: Recent Advances. Wallinford. https://doi.org/10.1079/9780851995106.0005

Galanos, C. J. & Tzanoudakis, D. 2019: *Allium panormitisi* (*Amaryllidaceae*), a new autumn- flowering species from Symi Island, SE Aegean, Greece. – Bot. Serb. **43(2):** 197-203. https://doi.org/10.2298/BOTSERB1902197G

Giusso del Galdo, G., Brullo, C., Brullo, S. & Salmeri, C. 2015: *Allium kyrenium* (*Amaryllidaceae*), a new species from Cyprus. – Phytotaxa **213(3):** 282-290. http://dx.doi.org/10.11646/phytotaxa.213.3.8

Govaerts, R., Kington, S., Friesen, N., Fritsch, R., Snijman, D. A., Marcucci, R., Silverstone-Sopkin, P. A. & Brullo, S. 2020: World Checklist of *Amaryllidaceae*. – Facilitated by the Royal Botanic Gardens, Kew. http://wcsp.science.kew.org [Last accessed 1/07/2020]

Halacsy, E. von 1904: Conspectus Flora Graecae, **3. –** Lipsiae.

Hayek, A. von 1932: Prodromus Florae Peninsulae balcanicae. – Feddes Repert. **30(3):** 1-228.

Kalpoutzakis, E., Trigas, P. & Constantinidis, T. 2012: *Allium orestis* sp.nov. (*Amaryllidaceae*) from Parnon and Taigetos mountains, south Peloponnisos, Greece. – Nord. J. Bot. **30:** 195-200.

Karavokyrou, E. & Tzanoudakis, D. 1991: The genus *Allium* in Greece: II. A cytotaxonomical study of the E Aegean species. – Bot. Chron. (Patras) **10:** 777-784.

— & — 1994: Two new species of *Allium* sect. *Codonoprasum* Reichenb. from the East Aegean Islands (Greece). – Ann. Mus. Goulandris **9:** 141-146.

Koçyiğit, M. & Kaya, E. 2020: *Allium nerimaniae* (*Amaryllidaceae*), a new species of *A.* sect. *Codonoprasum* from Turkey. – Phytotaxa **435(1):** 16-24. https://doi.org 10.11646/phytotaxa.435.1.2

— & Özhatay, N. 2012: *Allium maraschicum* sp. nov. (*Alliaceae*) from Turkey. – Nord. J. Bot. **30:** 553-559. https://doi.org/10.1111/j.1756-1051.2012.01268.x

—, — & Akalın, E. 2010: *Allium rumelicum*, sect. *Codonoprasum*, a new species from Europaean Turkey. – Phytol. Balcan. **16:** 355-359.

—, — & Kaya, E. 2014: New species and new records for *Allium* (sect. *Codonoprasum*) from Turkey. – Pp. 514-524 in: Kaya, E., Geophytes of Turkey 3. – Yalova: Ataturk Central Horticultural Research Institute [edition no. 96].

—, Yeşil, Y. & Koyuncu, M. 2016: *Allium dumanii* (*A.* sect. *Codonoprasum*, *Amaryllidaceae*), a new species from E Turkey. – Willdenowia **46:** 113-119. https://doi.org/10.3372/wi.46.46109

Kollmann, F. 1984: *Allium* L. – Pp. 98-211 in: Davis, P. H., Flora of Turkey and the East Aegean Islands, **8. –** Edinburgh.

— 1985: The genus *Allium* in Israel. – Rotem **15:** 1-136.

Levan, A. Freda, K. & Sandberg, A.A. 1964: Nomenclature for centromeric position on chromosomes. – Hereditas **52**: 201-220.

Özhatay, N. 1993: *Allium* in Turkey: distribution, diversity, endemism and chromosome number. – Pp. 247-271 in: Demiriz, H. & Özhatay, N. (eds), 5th OPTIMA Meeting. – Istanbul.

—, Koçyiğit, M., Brullo, S. & Salmeri, S. 2018: *Allium istanbulense* (*Amaryllidaceae)*, a new autumnal species of Sect. *Codonoprasum* from Turkey and its taxonomic position among allied species. – Phytotaxa **334(2):** 152-166. https://doi.org/10.11646/phytotaxa.334.2.5.

Peruzzi, L. 2007: *Allium garbarii* Peruzzi (*Alliaceae*), a new species endemic to Calabria (S Italy). – Candollea **62:** 17-25.

Rechinger, K. H. 1943: Flora Aegaea. – Denkschr. - Österr. Akad. Wiss. Math.-Naturwiss. Kl. **105:** 1-927.

Salmeri, C. 1998: *Allium brulloi* (*Alliaceae*), a new species from Astypalea (Aegean islands, Greece). – Willdenowia **28:** 69-75.

—, Brullo, C., Brullo, S., Giusso del Galdo, G. & Moysiyenko, I. I. 2016: What is *Allium paniculatum* L.? Establishing taxonomic and molecular phylogenetic relationships within *A.* sect. *Codonoprasum* Rchb. – J. Syst. Evol. **54(2):** 123-135. https://doi.org/10.1111/jse.12170

Sibthorp, J & Smith, J. E. 1809: Florae Graecae Prodromus, **1**(**2**)**.** – Londini.

— & — 1823: Flora Graeca, **4.** – Londini.

Stearn, W. T. 1978: European species of *Allium* and allied species of *Alliaceae*: A synonymic enumeration. – Ann. Mus. Goulandris **4**: 83-198.

— 1980: *Allium* L. – Pp. 49-69 in: Tutin, T. G., Heywood, V. H., Burges, N. A., Valentine, D. H., Walters, S. M. & Webb, D. A. (eds), Flora Europaea, **5.** – Cambridge.

Tanker, N. & Kurucu, S. 1979: Cytotaxonomical researches on some species of *Allium* naturally growing in Turkey. – J. Fac. Pharm. Ankara **9:** 64-80.

Trigas, P. & Bareka, P. 2020: *Allium stamatiadae*, a new species of *A.* sect. *Codonoprasum* (Amaryllidaceae) from Andros island (aegean Archipelago, Greece). – Phytotaxa **443(3):** 287-294. https://doi.org/10.11646/phytotaxa.443.3.5

—, Iatrou, G. & Tzanoudakis, D. 2010: *Allium apergii* sp. nov. (*Alliaceae*, *A.* sect. *Codonoprasum*) from Evia island, Greece. – J. Biol. Res.-Thessaloniki **14:** 225-229.

Tzanoudakis, D. 1983: Karyotypes of ten taxa of *Allium* section. *Scorodon* from Greece. – Caryologia **36:** 259-284.

— & Kypriotakis, Z. 2008: *Allium brussalisii* (*Alliaceae*), a new species from Greece. – Bot. J. Linn. Soc. **158:** 140-146. https://doi.org/10.1111/j.1095-8339.2008.00853.x

— & Trigas, P. 2015: *Allium occultum*, a new species of *A.* sect. *Codonoprasum* (*Amaryllidaceae*) from Skiros Island (W Aegean, Greece). – Phytotaxa **202(2):** 135-142. https://doi.org/10.11646/phytotaxa.202.2.5

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Article

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The genus *Iris* as a critical taxon in establishing an integrated approach to Italian plant biodiversity

Abstract

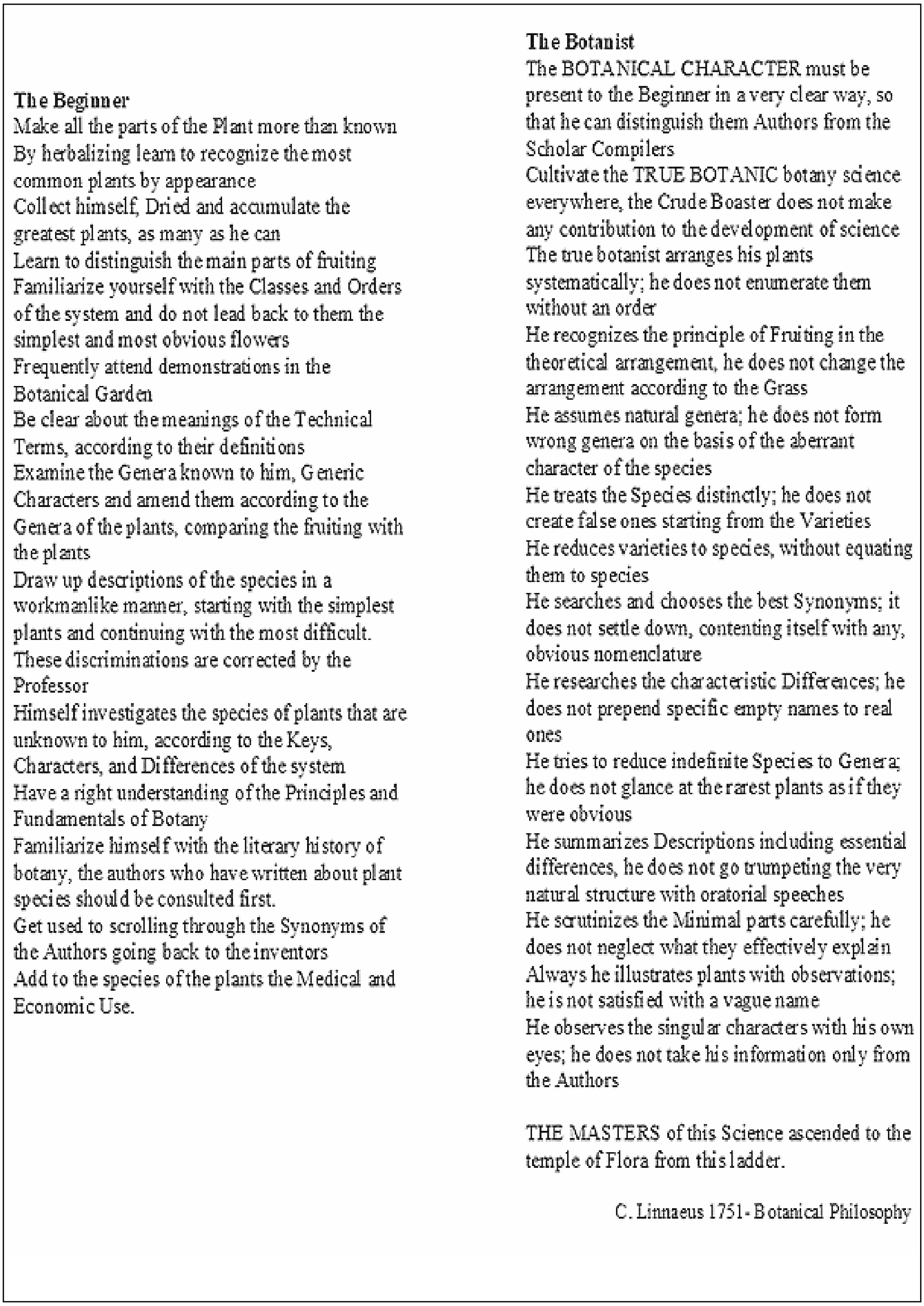
Colasante, M., Fadda, A., Rudall, P. J. & Tarquini, F.: The genus *Iris* as a critical taxon in establishing an integrated approach to Italian plant biodiversity. — Fl. Medit. 31 (Special Issue): 213-239. 2021. — ISSN: 1120-4052 printed, 2240-4538 online.

Accurate updating of systematic information for protection and preservation of plant biodiversity can encounter many problems, both in floristics and in the context of other appropriate and useful technologies. We highlight ongoing studies on the complex genus *Iris* Tourn. ex L. in Italy as a case-study to stimulate researchers into providing new data for the understanding and conservation of natural biodiversity. *Iris* is species-rich, with 300 species and many hybrids, allowing a wide range of suitable techniques and methods, including experimental crosses. We provide examples in which dissemination of hasty, conflicting, misleading or erroneous information through the literature and inaccurate websites can be filtered and validated. Careful initial identification of the taxa and a synergistic biosystematic investigation can help to improve effective quantification and qualification of biodiversity among experts and nature lovers.

Key words: hybrids, phylogeny, plant identification, species investigation, threatened species.

Introduction

To protect and preserve plant biodiversity, it is necessary to improve and update existing systematic information. This basic taxonomic rule is often taken for granted as a central duty (Linnaeus 1751, Fig. 1). Flora texts can provide much information on plant biodiversity (Colasante & al. 2002). With respect to the Italian flora, Pignatti's Flora d'Italia (2017) provides an improved organization; for some critical genera such the genus *Iris* Tourn. ex L., it supplies polytomous diagnostic keys. Such information is essential as a starting point for investigation; it encompasses observation, identification through analytical keys (and their validity), recognition of hybrids as "spies" of active speciation through hybridization, separation between species and hybrids and investigation of their naturalization to better update current data on the qualification and quantification of biodiversity (Colasante & Vosa 1987, 1994, 1995; Colasante & Sauer 1993; Arnold 1997; Colasante & al. 2003; Colasante & Trombini 2003a, 2003b; Colasante 2003a, 2003b, 2004a).



The Beginner

Make all the parts of the Plant more than known

By herbalizing learn to recognize the most common plants by appearance

Collect himself, Dried and accumulate the greatest plants, as many as he can

Learn to distinguish the main parts of fruiting

Familiarize yourself with the Classes and Orders of the system and do not lead back to them the simplest and most obvious flowers

Frequently attend demonstrations in the Botanical Garden

Be clear about the meanings of the Technical Terms, according to their definitions

Examine the Genera known to him, Generic Characters and amend them according to the Genera of the plants, comparing the fruiting with the plants

Draw up descriptions of the species in a workmanlike manner, starting with the simplest plants and continuing with the most difficult. These discriminations are corrected by the Professor

Himself investigates the species of plants that are unknown to him, according to the Keys, Characters, and Differences of the system

Have a right understanding of the Principles and Fundamentals of Botany

Familiarize himself with the literary history of botany, the authors who have written about plant species should be consulted first.

Get used to scrolling through the Synonyms of the Authors going back to the inventors

Add to the species of the plants the Medical and Economic Use.

The Botanist

The BOTANICAL CHARACTER must be present to the Beginner in a very clear way, so that he can distinguish them Authors from the Scholar Compilers

Cultivate the TRUE BOTANIC botany science everywhere, the Crude Boaster does not make any contribution to the development of science

The true botanist arranges his plants systematically; he does not enumerate them without an order

He recognizes the principle of Fruiting in the theoretical arrangement, he does not change the arrangement according to the Grass

He assumes natural genera; he does not form wrong genera on the basis of the aberrant character of the species

He treats the Species distinctly; he does not create false ones starting from the Varieties

He reduces varieties to species, without equating them to species

He searches and chooses the best Synonyms; it does not settle down, contenting itself with any, obvious nomenclature

He researches the characteristic Differences; he does not prepend specific empty names to real ones

He tries to reduce indefinite Species to Genera; he does not glance at the rarest plants as if they were obvious

He summarizes Descriptions including essential differences, he does not go trumpeting the very natural structure with oratorial speeches

He scrutinizes the Minimal parts carefully; he does not neglect what they effectively explain

Always he illustrates plants with observations; he is not satisfied with a vague name

He observes the singular characters with his own eyes; he does not take his information only from the Authors

THE MASTERS of this Science ascended to the temple of Flora from this ladder.

C. Linnaeus 1751- Botanical Philosophy

Fig. 1. The approach for beginners and botanists to study plants by C. Linnaeus (Botanical Philosophy 1751).

In the context of biodiversity investigations of *Iris* in Italy, we elaborate and correlate a range of appropriate datasets, including chemotaxonomy and cytotaxonomy. We report some new data of particular importance, such as the macro-and micromorphology of *I. statellae* Tod., which was previously little-investigated. We also highlight the conservation *in* ed *ex-situ* of *Iris revoluta* Colas. (Medagli & al. 2014), which has a restricted area distribution, and across-breeding experiment currently underway in Sardinia between individuals of two different populations. These types of synergistic investigations are fundamental to laying the basis for knowledge of the genus *Iris*, in which there is considerable variability of characters both within and between species and populations. Over 300 species of *Iris* are currently reported, all more or less complicated by the numerous natural and artificial hybrids (at least 17000 known, Fig. 7), such as that obtained in our cross-breeding experiment. Since ancient times, irises have been attractive to people for various purposes, including commercial, artistic, symbolic and landscaping (Fusi & al. 1977; Parrini 2006; Fang & al. 2008; Signorini & al. 2009; Tarquini & Colasante 2009a). With their amazing beauty, irises involve humans as either unsuspecting or knowledge able pollinators that contribute to the conservation and expansion of their gene-pool. Moreover, deliberately dispersing their reproductive organs (both vegetative and sexual) has often led to their naturalization after cultivation. This synanthropy has existed for millennia, as graphically reported in world literature and art in China, India, Iran, Mesopotamia, Israel, Turkey, Egypt, Europe and America.

Materials and Methods

For many years, *Iris* populations have been analyzed in the field, distinguishing species with or without hybrids (e. g. in Italian Abruzzo, Apulia, Sardinia, Sicily) and more than 8000 herbarium samples, mainly from Europe and China (Colasante 1983, 1986a; Colasante & Vosa 1986, 1987; Colasante & Sauer 1986, 1988; Colasante & Mathew 1987). Classical investigation techniques have been applied case by case, according to the material, using both macro-and micromorphology (Ross 1892; Dykes 1913; Rodionenko 1961 [ed. 1987]; Wu & Cutler 1985; Köhlein 1987; Blackmore & Barnes 1981), chemotaxonomy (Wynne & Henderson 1973; Cerfon 1981; Williams & al. 1997, 2000 (reprint 2001), karyology and cytogenetics (Bini Maleci 1976; Bini Maleci & Maugini 1981; Brullo & al. 1997; Colasante & Vosa 1981, 1994; Simonet 1932, 1947, 1951; Mitra 1956; Randolph 1957; Randolph & Mitra 1959; Ricci 1958, 1966; Rodionenko 1962; Ricci & Colasante 1974; Ponsaerts 1978). In this paper, we supply some results to highlight the biodiversity of the genus *Iris*, both quantitatively and qualitatively, while focusing on the Italian flora (Table 1).

For some populations, we collected live samples with underground organs (rhizomes, bulbs or stolons, etc.) for the conservation of germplasm in the Botanical Gardens of Rome, providing them with identification labels. We also prepared herbarium samples according to traditional dehydration methods. Both *in-situ* populations and material collected for long-term preservation provided the basis for macro-and micromorphological investigations, the latter focusing on pollen grains, karyotypes and chemotaxonomic analyses using current techniques (Colasante, & al. 1989; Williams & al. 1997, 2000 (reprint 2001); Colasante 2017a). For pollen grain observations, we used a Scanning Electron Microscope (SEM) after dehydration in a critical-point drier (Lynch & Webster 1975; Colasante & al. 1989) and a water-glycerin hanging-drop method for observations made under the light microscope.

Table 1. Material under investigation.

Species	**(rigin**	**Figure**
Species grown in cultivation:		
I. tuberosa (L.) Mill.	Marino, Rome	Fig. 2
I. xiphium L.	Gaeta, Latium	Fig. 2
I. lactea Pall.	Monogeneric Giardino dell'Iris, Florence	
I. triflora Balb.	Botanic Garden and Herbarium, Turin	
I. ensata Thunb.	Monogeneric Giardino dell'Iris, Florence	
I. pseudacorus L.	Riserva Naturale Valle dell'Aniene, Rome; Botanic Garden, Rome	Fig. 2
I. tectorum Maxim.	Botanic Garden, Rome	Fig. 2
I. pseudopumila Tineo	Sannicandro Garganico e Gravine di Laterza, Apulia; Piano Battaglia, Madonie, Sicily	Fig. 4
I. pallida Lam.	Impruneta, Chianti, Tuscany; monogeneric Giardino dell'Iris, Florence, Tuscany; Via Nomentana and Via delle Vigne Nuove, Rome	Fig. 15
I. cengialti Ambrosi A. Kern.	Monte Cengialto, Rovereto	
I. cengialti ssp. *illyrica* (Tomm.)	Poldini and Colasante: Monte Nanos, Slovenia	
Species of natural hybrid origin:		
I. bicapitata Colas.	Gargano	Fig. 4
I. lutescens Lam.	Civitavecchia, Torre d'Orlando; Canino, Viterbo, Latium; Monte Calvi, Monte Pescali, Tuscany	Fig .4
I. marsica I. Ricci & Colas.	Monte Pagano, Val di Rose, more than 10 other populations in National Park of Abruzzo, Latium, Molise	Figs 3, 5
I. relicta Colas.	Monte delle Fate, Latium	Fig. 5
I. sabina N. Terracc.	Monte Gennaro-Zappi, Latium Lazio	Figs 3, 5
I. revoluta Colas.	Scoglio Mojuso, Taranto, Apulia	
I. setina Colas.	Sezze and Monte Pilorci, Latium	Fig. 3
I. sicula Tod.	Monte Busambra and Botanical Garden of Catania, Sicily, Sinis Peninsula and the middle Tirso River valley, Sardinia	Fig. 2
Hybrids of dubious origin and / or escaped from cultivation:		
Iris × sambucina L.	Ponte di Nona and Tor Tre Teste, Rome	
I. × germanica L.	several sites in Latium, Abruzzo, Veneto, Sardinia	Fig. 3
I. × albicans Lange	Vibo Valentia, Calabria; some small populations in Nomentana street, Rome; several populations in Sardinia still under investigation	Fig. 3
I.× florentina L.	Monogeneric Giardino dell'Iris, Florence; Botanical Garden of Perugia; some populations in Latium and Tuscany	Fig. 3

In Sardinia, ongoing population-level studies on *Iris* commenced in 2015 with the subgenus *Iris* section *Iris*. For each site, edaphic parameters, geographic coordinates and samples were collected for further study. Some of these samples were donated to the Botanical Garden of Rome and used for a cross-breeding program carried out in Sardinia using a direct crossing method commonly used by *Iris* hybridizers (Sani & Goretti Specht 1960). To facilitate hybridization, we selected irises with similar macromorphological and phenological characteristics; one of these grows on Carloforte Island (south-western Sardinia) for the female line, and the other in the Sinis Peninsula (central-western coast) for the male line. Pollen from the latter was placed on the lower lip of the stigma of the former to facilitate experimental crossing.

Results

Biodiversity

Biodiversity is generally high, with greater or lesser frequency for the observed species (Colasante 1994, 1995a, b, 2003a, 2004a, 2008, 2013, 2014, 2017a; Colasante & Rudall 2000; Colasante & Pacini 2006; Goldblatt 2000, 2008; Colasante & al. 2004; Lamote & al. 2002; Tarquini & al. 2021a, b), but less so in the beardless irises than in the bearded irises that bear multicellular hairs on the external tepals (Genus *Iris* subgenus *Iris* section *Iris*: Mathew 1981).

Anthesis

Anthesis can occur in winter, spring or summer, according to the different species. In section *Iris*, anthesis occurs mainly in early or late spring, commonly with ephemeral flowers (Colasante & Sauer 1993, Colasante 2004b, 2013, 2014, 2017b).

Habitat

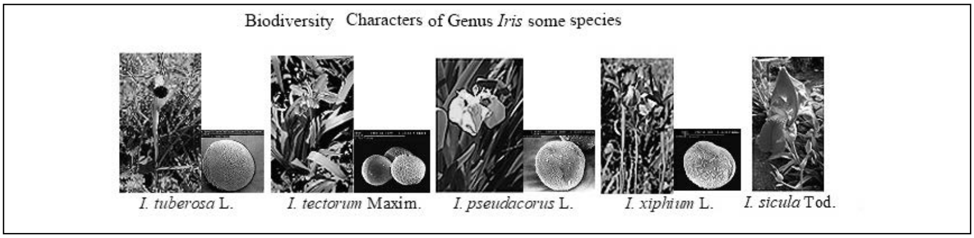
Collectively, habitats are very variable, represented by shallow lakes and marshes (*I. pseudacorus* L., Fig. 2), dry margins of streams and lakes (*I. lactea* Pall.), meadows and olive groves (*I. tuberosa* (L.) Mill., Fig. 2), various substrates – including roofs – in Japan (*I. tectorum* Maxim., Fig. 2), rocky drained places variable in altitudes according to species, from sea level up to over 1000 meters (e.g. *I. bicapitata* Colas., *I. lutescens* Lam., *I. setina* Colas., *I. sabina* N. Terracc., *I. relicta* Colas., *I. marsica* I.Ricci & Colas.), rocky and dry places in Sicily and Sardinia (*I. sicula* Tod. Fig. 2) and marine islets (*I. revoluta* Colas., Fig. 8).

Identification, Characters and Polymorphism

Species identification is complex (Fig. 3) due to high variability of characters observed at all levels: macro-and micromorphological, cytogenetic (Colasante & Vosa 1981, 1995; Colasante & Pacini 2006; Colasante & al. 2003, Colasante & Trombini 2003a, b, 2005a), anatomical (Ross 1892; Rudall, 1994), histological, chemical, chemotaxonomic, biomolecular (Colasante & De Dominicis 1989; Wilson 2011). Pollen grains analyzed by SEM and light microscope (such as the experimental ones of *I.* sp. from Sardinia: Fig. 6) gave good results. Pollen grains show a wide range of patterns in sexine organization and ornamentation, and provide important information for variability as well as for hybrid study and their origin and phylogeny (Arnold & al. 1991; Colasante 1998a; Colasante & Rudall 2000–2001).

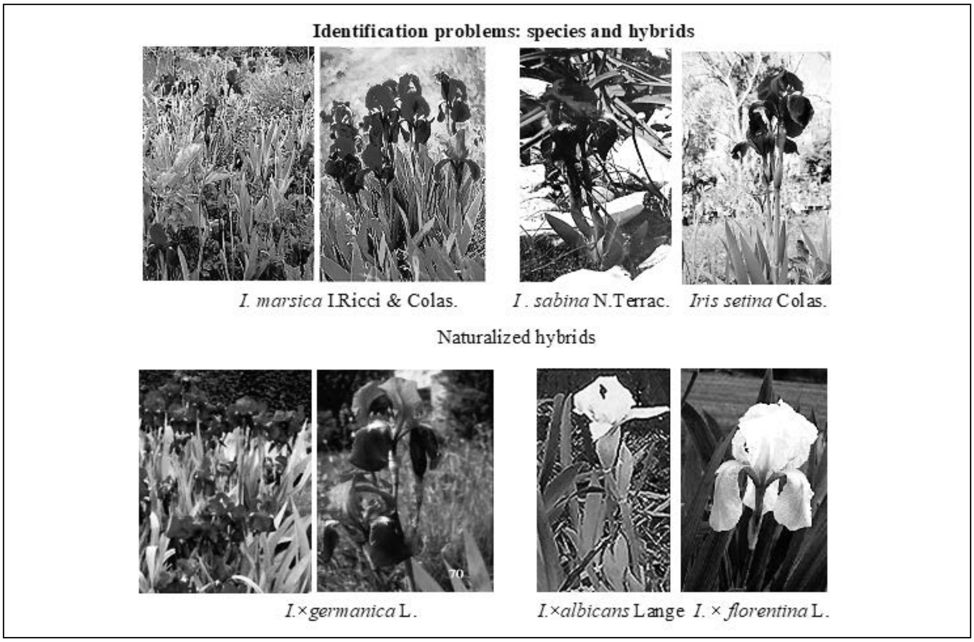
Populations of *I. tuberosa* (L.) Mill. (Fig. 2) in Italy show inter- and intrapopulation flower and leaf polymorphisms (Tarquini & al. 2021), as do irises of subgenus *Iris* section *Iris* such as *I. pseudopumila* Tineo (Colasante & Ricci 1979; Colasante 2008; Fig. 4), *I. lutescens* Lam. (Colasante 1986b, 2014; Fig. 4), *I. bicapitata* Colas. (Colasante 1989; Colasante & Trombini 2005a, b; Fig. 4), *I. marsica* I. Ricci & Colas. (Colasante & Ricci 1977; Fig. 3), *I. pallida* Lam. subsp. *pallida* and subsp. *cengialti* (Ambrosi ex A. Kern) Foster (Colasante 2014).

Leaf shape varies at the interspecific level in the traditional subgenera and sections (Ross 1892; Wu & Cutler 1985), but it is quite similar at the interspecific level within the same section (Colasante 1992), except in hybrids. Modified leaves such as bracts are often diagnostic characters at the species level. Flowering stem height is very variable, providing little species diagnostic significance.



I. tuberosa L. *I. tectorum* Maxim. *I. pseudacorus* L. *I. xiphium* L. *I. sicula* Tod.

Fig. 2. Biodiversity in the genus *Iris* Tourn. ex L.: species and pollen grain ornamentation.



I. marsica I.Ricci & Colas. *I. sabina* N.Terrac. *Iris setina* Colas.

I.×germanica L. *I.×albicans* Lange *I. × florentina* L.

Fig. 3. Identification and problems: species and hybrids. Interspecific variability hinders the real biodiversity in the genus *Iris* Tourn. ex L. subg. *Iris* sect. *Iris* (Mathew 1981).

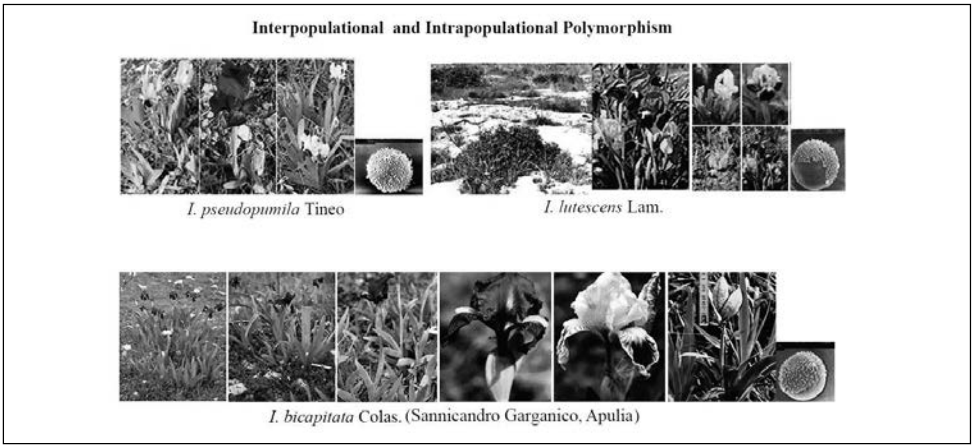


Fig. 4. Inter-and intra- populational polymorphism in the wild populations of *Iris pseudopumila* Tineo in Sicily and Apulia, *I. lutescens* Lam. in Latium, and *I. bicapitata* Colas. in Apulia. For each species Pollen grains in SEM are shown on the right.

Polyploidy, species, natural and experimental hybrids

Polyploidy is frequent in subgenus *Iris* section *Iris*; we analyzed karyotypes to identify the presence of some auto- or allopolyploids and their probable origin (Colasante & Rudall 2000–2001; 2013, 2014, 2017a) and consequent phylogenetic correlations (Colasante 1988; Colasante 2000a, 2000b, 2003a, 2003b, 2004b; Colasante & al. 2003; Goldblatt 2000, 2008; Tarquini & Colasante 2009b). Furthermore, we compared the habits of the species, their pollen morphology (Fig.15), karyotype idiograms of some species at $2n = 40$, with the pair of chromosomes indicative of their diversity (Fig. 5).

Among the bearded irises analyzed, some clearly show natural hybrid origin and good fertility (e.g. *I. bicapitata*) whereas others show lower fertility, albeit caught in the process of stabilization and tendency to introgression with at least one of the progenitors (Colasante 2003a, b; Colasante & Trombini 2003a, 2003b; Colasante & al. 2003). Irises collected in Sardinia used for cross-breeding experiments often produce fewer capsules in nature. Upon initial examination, both sets of taxa appear to be of possible hybrid origin. A high rate of sterility became evident, which is also suggested by the presence of numerous malformed and/or abortive pollen grains (Fig. 6). However, a certain degree of fertility was preserved, as confirmed by experiments reported here. A 5.5 cm capsule containing 16 slightly pear-shaped seeds was obtained (Fig. 6). All seeds were healthy and viable and sprouted in the first year in common-garden substrate. The seedlings produced the first flowers in the second year, with one or two flowers at the stem tip. The specimens born from this crossing are still juvenile because maturity is typically reached from 3 to 5 years of age. The general morphology is largely preserved in the hybrids, but the height is smaller (21.5 cm) than that of the parents measured for three years (54.9 ± 7.5 cm and 56.5 ± 3.5), as we expected given the young age of the seedlings (Simonet 1951, 1955, 1962; Werkmeister 1981; Arnold & al 1991; Hodges & al. 1996; Colasante 2004; Bianconi & al. 2006; Tarquini & Colasante 2009b, 2010a;).

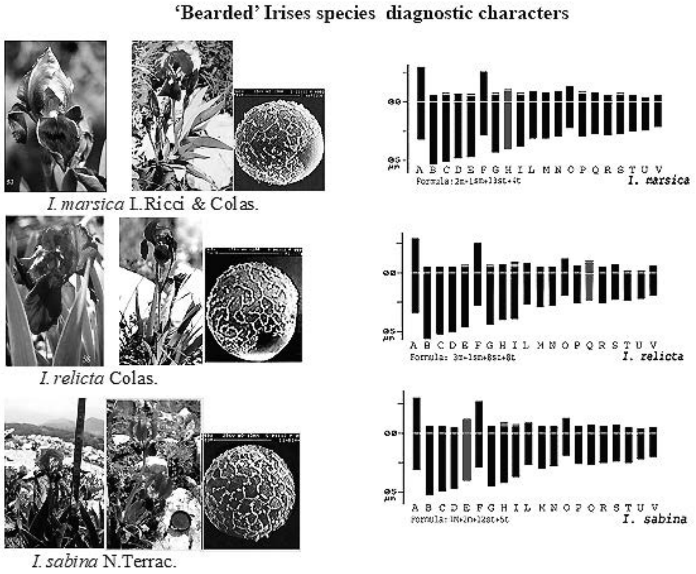


Fig. 5. Species, SEM pollen grain ornamentation and chromosome idiograms of three Italian species with 2*n* = 40 chromosomes. The chromosome pair identifying each species is outlined in red.

Fig. 6. Iris experimental hybridization: plants and LM pollen grains of the taxa undergoingcross-breeding experiments in Sardinia. (a) Female parent *I. sp.* from Carloforte Island and its capsule; (b) male parent *I. sp.* from the Sinis Peninsula; (c) one of the F1 hybrids obtained.

Molecular and Taxonomic problems

Future studies will require a more targeted phylogenetic approach to help resolve the existing classification of *Iris*. Currently the traditional subgenera and sections (e.g. Mathew 1981) are seriously undermined by the well-supported plastid phylogenies of Wilson (2011) and Wilson & al. (2016), so that the current data appear questionable (see also Colasante & De Dominicis 1989; Reeves & al. 2000; Rycheva & al. 2011).

Chemotaxonomic investigations can provide useful specific taxonomic and nomenclatural markers. Some compounds are common to several species, others are present in only a single species, such as apigenin 7,4'-dimethyl ether-6-*C*-glucoside 2"-O-rhamnoside in *I. pallida.* This technique can offer very detailed information and allow separation even between species and hybrids (Williams & al. 1997, 2000–2001). From the taxonomic viewpoint, the relatively low knowledge of *I. sicula* Tod. (1858) (Fig. 2) was evaluated in relation to the other taxa considered similar, such as *I.* × *mesopotamica* Dykes (1913), *I.* × *germanica* L. (1753) (Fig. 3), *I.*× *trojana* A. Kern. ex Stapf. (1887) and *I.* × *cypriana* Foster & Baker (1888).

Many of these taxonomic problems remain the subjects of ongoing studies, one of which concerns the inaccurate identification of *I. sicula* and its erroneous attribution to either *I. pallida* or *I.* × *germanica* according to different authors (see Discussion).

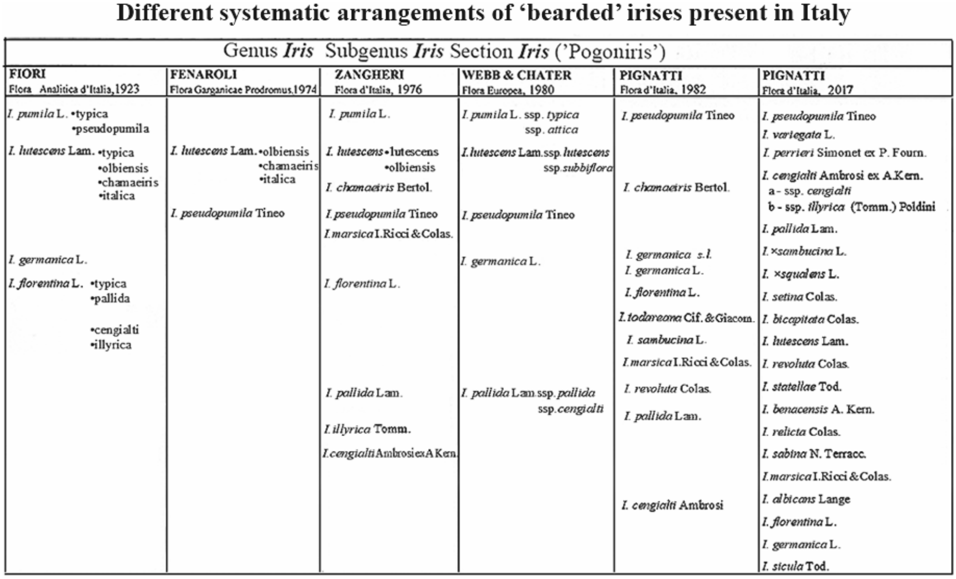
Dissemination of scientific data

Screening of scientific data (e. g. from populations, Herbaria, Botanical Gardens, scientific literature, Flora accounts and dedicated websites) highlights much incorrect or misleading information due to the inaccurate, superficial or erroneous interpretations of the initial sources, as happened for *I. mesopotamica* (see Discussion). Actually, all this affects the exact knowledge and dissemination of real biodiversity. Even the exchange of labels between Herbaria and Botanical Gardens can lead to incorrect attribution. This type of confusion in identification has unfortunately resulted inconsiderable proliferation of species (Parlatore 1858; Terracciano 1899; Lynch 1904; Dykes 1913; Fiori 1923–1929; Lawrence 1953; Werkmeister 1967; Zodda 1967; Fenaroli 1974; Zangheri 1976; Haslam & al. 1977; Warburton 1978; Pignatti 1982, 2017; Innes 1985; Festi 1986; Bianco 1991; Waddick & Zhao 1992; Terpenin & al. 1996; British Iris Society 1997; Poldini 2001; Poldini & al. 2002; Pries 2006; Conti & al. 2005a, 2005b, 2007; Giardina & al. 2007; Camoletto 2008; Camoletto & al. 2009; Arrigoni 2010; Giardina 2010; Mathew 1981; Minà & Palumbo 2011; Mitić & al. 2013).

In the Botanical Garden of Rome (Figs. 11, 12, 13), some *Iris* species have been collected from their *locus classicus* to form systematic *ex-situ* collections placed more or less according to their preferred habitat in systematic-ecological plant beds, with the goal to safeguard the conservation of their genic pool (Figs. 7, 11-13). About thirty years ago, the Italian Iris Society of Florence donated rhizomes of experimental hybrids of subgenus and section *Iris* in a twinning initiative with the monogeneric Garden of Iris (Fig. 14), which hosts hybrids for an international iris competition that has been held every year for more than fifty years (Maugini 1992; Bianconi & al. 2006). This initiative also involves many other iris societies worldwide. Other institutions have also been involved in developing the iris collection, such as San Galliano in the Marche, the Rea Botanic Garden in Trana, Turin, and the University of Perugia. After years of rhizome exchange, there are currently beautiful collections of iris varieties in the Iris Garden of Florence and in the Orto Botanico di Roma, mainly of bearded irises used in the spring for educational exhibitions and cultural seminars for universities, institutes, schools and tourists.

Furthermore, as evidence of their progress over the years, some individual Italian hybridizers have donated experimental hybrids, including Augusto Bianco (Piedmont), Tiziano Dotto (Veneto), Amedeo Fadda (Sardinia) and Giovanni Edoardo Nogaro (Lombardy). Thus, the *Iris* germplasm bank has expanded considerably through the last fifty years in Italy (Table 2) and is now very rich in species, subspecies, hybrids and varieties (Fig. 7).

Table 2. Systematic arrangements of bearded irises present in Italy in six Flora texts.



Different systematic arrangements of 'bearded' irises present in Italy

Genus *Iris* Subgenus *Iris* Section *Iris* ('Pogoniris')					
FIORI Flora Analitica d'Italia, 1923	**FENAROLI** Flora Garganicae Prodromus, 1974	**ZANGHERI** Flora d'Italia, 1976	**WEBB & CHATER** Flora Europea, 1980	**PIGNATTI** Flora d'Italia, 1982	**PIGNATTI** Flora d'Italia, 2017
I. pumila L. •typica •pseudopumila *I. lutescens* Lam. •typica •olbiensis •chamaeiris •italica *I. germanica* L. *I. florentina* L. •typica •pallida •cengialti •illyrica	*I. lutescens* Lam. •olbiensis •chamaeiris •italica *I. pseudopumila* Tineo	*I. pumila* L. *I. lutescens* •lutescens •olbiensis *I. chamaeiris* Bertol. *I. pseudopumila* Tineo *I. marsica* I.Ricci & Colas. *I. florentina* L. *I. pallida* Lam. *I. illyrica* Tomm. *I. cengialti* Ambrosi ex A Kern.	*I. pumila* L. ssp. *typica* ssp. *attica* *I. lutescens* Lam. ssp. *lutescens* ssp. *subbiflora* *I. pseudopumila* Tineo *I. germanica* L. *I. pallida* Lam ssp. *pallida* ssp. *cengialti*	*I. pseudopumila* Tineo *I. chamaeiris* Bertol. *I. germanica s.l.* *I. germanica* L. *I. florentina* L. *I. todareana* Cif. & Giacom. *I. sambucina* L. *I. marsica* I.Ricci & Colas. *I. revoluta* Colas. *I. pallida* Lam. *I. cengialti* Ambrosi	*I. pseudopumila* Tineo *I. variegata* L. *I. perrieri* Simonet ex P. Fourn. *I. cengialti* Ambrosi ex A.Kern. a - ssp. *cengialti* b - ssp. *illyrica* (Tomm.) Poldini *I. pallida* Lam. *I. ×sambucina* L. *I. ×squalens* L. *I. setina* Colas. *I. bicapitata* Colas. *I. lutescens* Lam. *I. revoluta* Colas. *I. statellae* Tod. *I. benacensis* A. Kern. *I. relicta* Colas. *I. sabina* N. Terracc. *I. marsica* I.Ricci & Colas. *I. albicans* Lange *I. florentina* L. *I. germanica* L. *I. sicula* Tod.

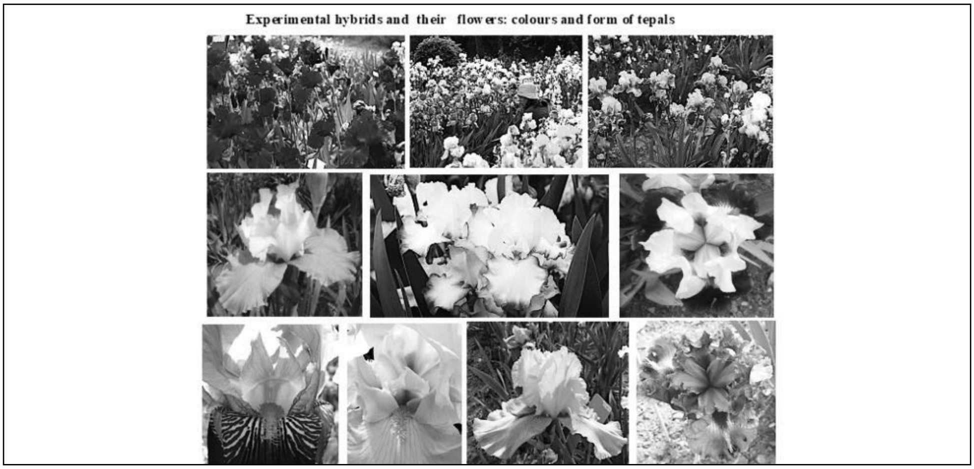


Fig. 7. Iris cultivars: colors and forms in several modern artificial hybrids highlighting the variability increased by cross-breeding activities.

Distribution

Generally, the distribution of the species does not correspond to the real one due to misidentification of the iris in question which is then erroneously represented also in maps. New researches were carried out in the field, in herbaria and Flora texts to reduce the misinformation about identifications. For the Italian subgen. sect. *Iris* a process of updating of the map Region by Region is in progress (Colasante 1987, 2014; Colasante & Altamura 1986, 1988; Colasante & Mathew 1987 – Fig. 10). Remaining problems need to be solved species by species for the taxonomic reasons outlined above, including abundant initial misidentifications. For Sardinia, investigations are underway with the aim of confirming and updating the information necessary for proper identification and consistency of the iris populations. The first results confirm the presence of *Iris foetidissima* L., *I. pseudacorus* L., *I. planifolia* (Mill.) Fiori & Paoletti, *I.* × *germanica*, *I.* × *albicans* Lange and *I. sicula*, the latter erroneously synonymized with *I. pallida* Lam. subsp. *pallida* (Colasante 2017a). Therefore, some stations reported for *I. pallida* subsp. *pallida* (Arrigoni, 2010) host *I. sicula,* whereas *I. pallida* itself appears confined to gardens and crops. Other irises of subgenus *Iris* section *Iris* remain in need of further investigation (Fadda & al. 2021).

Discussion

A primary goal of biosystematic research in plants is to create natural classifications, which are often complicated by convergence and hybridization (Arnold 1997; Arnold & al. 1991; Cruzan & Arnold 1993, 1994; Hodges & al. 1996; Colasante 1998a, 2000c, 2003b, 2004a, 2004b; Colasante & Pacini 2006; Colasante & Trombini 2006a, 2006b; Colasante & Tarquini 2006; Colasante & Mathew 2008). A systematic approach for irises has highlighted the problem of their high level of biodiversity, influenced strongly by speciation through allopolyploidy (Colasante 1988, 1992, 1996a), hybridization, cultivar naturalization and their distribution by man. Even today we can readily find highly critical areas of research to be highlighted and discussed, demonstrating the need for synergy in scientific data to facilitate more precise identification of species, hybrids and garden varieties.

The high level of biodiversity in the results could result partly from an easy environmental-ecological adaptation of taxa and their genetic richness. The relatively short life or ephemeral nature of many iris flowers can represent a barrier to hybridization, though it can occasionally facilitate it (Colasante & Rudall 2000-2001). However, flowering times are variable throughout groups of species of the same subgenus and section, and contemporary flowering can occur even in the same section, due to different causes. Climatic variation, natural and anthropogenic barriers and habitat destruction can all lead to hybridization by anticipating or postponing the flowering period (Fig. 15) and preventing genetic erosion (Colasante & Sauer 1993).

Identification, Characters and Polymorphism

The initial approach to understanding an iris species or taxon requires observation of a wide range of possible characters (Linnaeus 1751, Figs. 1, 15). If the taxon shows intermediate characters or variability in the same population, morphology alone is rarely sufficient to immediately identify a new species or subspecies and further investigation is needed (Colasante & Vosa 1987; Colasante 1992, 1997, 1998a, 1998b; 2004b, Colasante & Trombini 2005a; Colasante & Mathew 2008). A fundamental prerequisite in providing new reliable information on plant biodiversity involves the comparison of different information concerning the origin of the taxon, observation of the population in the *locus classicus*, variability, hybrids and their probable ancestors, related species and the existence of naturalized cultivars. A single character can lead to misleading results that can negatively affect perceived nomenclature, taxonomy and species distribution.

In a highly specialized genus such as *Iris*, exhibiting rich population polymorphism, it is relatively easy to find misidentified taxa, even sometimes confusing ancestors with descendants. Even the leaves can show variability in the different subgenera and sections of the genus (Ross 1892; Wu & Cutler 1985), though leaf anatomical characters in hybrids can indicate their origin and progenitors (Colasante 2004b). In the flowers, morphometric studies show that the length of the perigonium tube is fairly indicative of species, but not always so in natural and experimental hybrids because it can have a variable length range between those of progenitor species or even coincide with one of them. Such polymorphism is therefore not readily informative for taxon separation (Colasante 1995a, b; Colasante 1998a). Other characters can also vary, such as the stem length, which is influenced by plant age, edaphic conditions and altitudinal position. Variation in stem height has been used for classification purposes (Lawrence 1953) but is misleading because it is rarely constant in nature, often varying in the same population and sometimes in the same individual in different years (e. g. *I. pseudopumila*, *I. lutescens*, *I. bicapitata*; Fig. 4). Flowering stem length in the subgenus *Iris* section *Iris* can be considered only for hybrid varieties. Hence, polymorphism is common within and between species and populations in terms of shape, flower colour and distribution. Polymorphism greatly misleads correct identification of species and leads to their proliferation (e. g. *I. lutescens* and *I. chamaeiris* Bertol.). Over-estimation of species numbers and under-estimation of their polymorphism together create many taxonomic synonyms. In other irises, errors of identification can result from superficial choice of diagnostic characters (e. g. *I. benacensis* A. Kern. ex Stapf. and *I. aphylla* L.: Colasante & Mathew 2008, Colasante 2014, 2017a)

Polyploidy and Hybridization

Polyploidy is frequent in natural populations, often with bimodal karyotypes, either as auto- or allopolyploidy; both are used by the progenitor species of natural hybrids to stabilize or defend themselves from environmental stresses. Allopolyploid evolutionary processes against extinction are evident in the crossing between *I. pseudopumila* and *I. reichenbachii* Heuff. to get to *I. sicula,* perhaps following a genome-doubling event (Colasante & al., 2003a; Tarquini & Colasante 2009b; Colasante 2017a). One possible accidental outcome of allopolyploidy could be to help preserve the gene pool from erosion. Allopolyploidy is also useful for experimentally obtaining new hybrids and varieties via new crosses (Foster 1889; Mahan 2007). This latter approach can be achieved taking into account the cognitive background and degree of observation of the researcher and hybridizer, and also the conditions of the specimens, age and size of the plant, timing of anthesis and their sexual and vegetative reproduction, presence of polymorphism, hybridization even in nature, as ascertained by the cytogenetic studies reported here (Figs. 4, 5). In the new experimental hybrid between Sardinian taxa, the progenitors show some common characteristics in anthesis time, macromorphology and phenology, and strengthen the supposition to have at least one common ancestor (all ongoing studies and yet to be fully demonstrated). This result suggests a probable introgressive cross that reinforces the “dominant” progenitor characters.

Molecular and Taxonomic characters

To date, no single biomolecular technique is sufficient to detect ‘bearded’ iris hybrids and separate them from their progenitors, whether species or hybrids (Colasante & De Dominicis 1989; Colasante 2000d; Colasante & Vosa 2000; Reeves & al. 2000; Lamote & al. 2002; Wilson 2011; Raycheva 2011), though in future a combination of next-generation sequencing will help solve many remaining problems.

In our studies, a chemotaxonomic compound (Luteolin di-C-glycoside) strongly characterizes *I. reichenbachii* and is absent from the other species of the same section examined by us (Williams & al. 1997, 2000–2001; Harborne & Williams 2001). Similarly, *I. pallida* is strongly characterized by apigenin 7,4’-dimethyl ether-6-*C*-glucoside 2”-O-rhamnoside. This technique offers detailed information that allows separation between species and hybrids and positively supports cytotaxonomic data of autopolyploidy and allopolyploidy.

Threatened, rare and/or endangered species, Botanical Gardens and Conservation

Many irises of subgenus *Iris* section *Iris* require protection, some of them urgently. Among possible extinct species, *I. statellae* Tod. was known for Sicily in the last century but has not been found during approximately the past 40 years This species shows partially semitectate pollen grains (Fig. 8), and an allopolyploid karyotype with 2*n* = 40. Moreover,

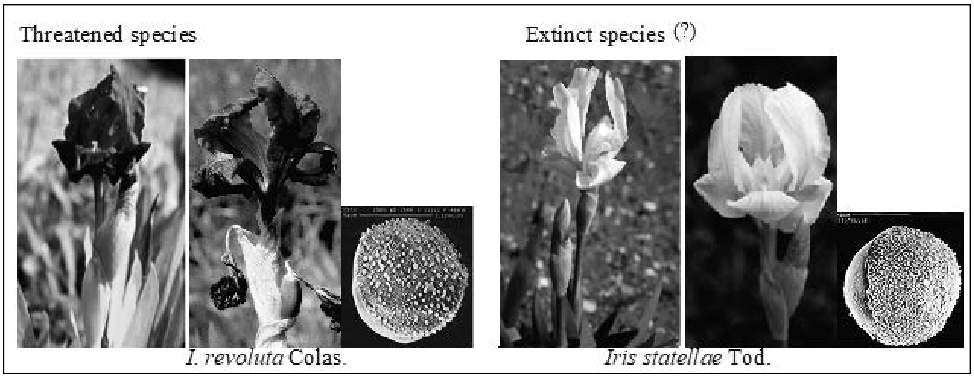


Fig. 8. Conservation: plants and (on right) SEM pollen grains of the Italian threatened species of *I. revoluta* Colas., which is subject to protection measures, and *I. statellae* Tod. (showing pollen grain ornamentation and chromosome number 2*n* = 40), which is presumed extinct.

I. revoluta Colas. (Fig. 8), with a very limited distribution, has been subjected to *ex-situ* and *in-situ* conservation to reduce its threatened range of extinction (Accogli & al. 2008; Medagli & al. 2014). Species and any subspecies to be considered more or less threatened by range or genetic impoverishment include *I.* × *albicans* Lange, *I. benacensis* A. Kern., *I. bicapitata* Colas., *I. cengialti* Ambrosi, *I. foetidissima* L., *I.* × *germanica* L., *I. graminea* L., and its variety 'pseudocyperus' Schur., *I. juncea* Poir., *I. lutescens* Lam., *I. marsica* I.Ricci& Colas., *I. pallida* Lam., *I. perrieri* Simonet ex N. Service, *I. planifolia* (Mill.) Fiori and Paoletti, *I. pseudacorus* L., *I. pseudopumila*Tineo, *I. relicta* Colas., *I. sabina* N.Terracc., *I.* × *sambucina* L., *I. setina* Colas., *I. sibirica* L., *I. sicula* Tod., *I. sintenisii* Janka, *I.* × *squalens* L., *I. tuberosa* (L.) Mill., *I. unguicularis* Poir., *I. variegata* L. and *I. xiphium* L. (Colasante & Rudall 2000). *Iris sicula* must be placed in the species protection list also for Italy; in Malta it is already protected by law (Schedule III and VI of legal notice LN311 / 2006), as well as in Israel where it is reported as *I. mesopotamica* and included in the IUCN Red List (Sapir & al. 2016, IUCN).

Systematic problems

There are examples of both species- and genus proliferation in *Iris* classification. For genera, we highlight the case of a monospecific taxon that still causes debate on its attribution to either the genus *Iris* (*I. tuberosa*) or *Hermodactylus* (L.) Mill. (Tillie & al. 2000–2001). Some botanists underestimate the difference in the arrangement of the ovary due to the complete or incomplete margin of the septa (Colasante 2014). However, plastid data strongly indicate that *Hermodactylus* belongs within the genus *Iris* (Wilson 2011).

With regard to species proliferation, we identify several demonstrable examples of inaccurate and erroneous synonymization:

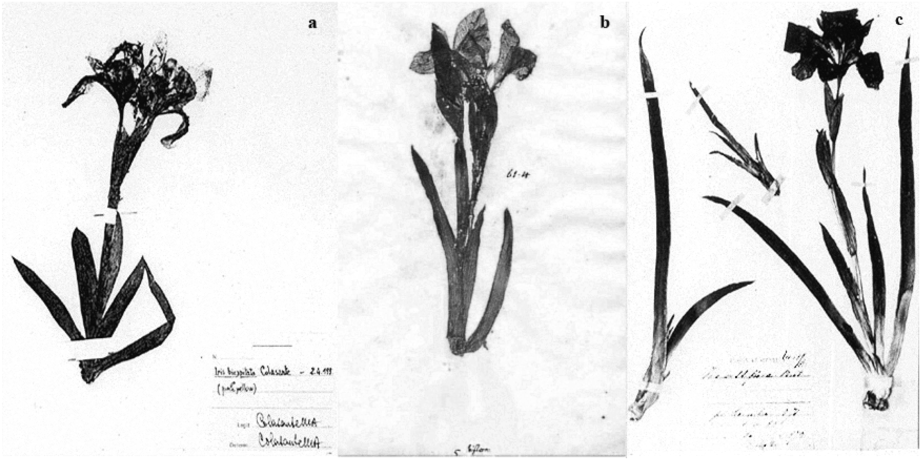


Fig. 9. Type specimens of (a) *I. bicapitata* Colas., (b) *I. biflora* L. and (c) *I. biflora sensu* Petagna.

(1) *Iris biflora* L. (1753, Fig. 9b) was so named due to its anthesis observed twice a year as written in the accompanying note. The establishment of a new species with the same binomial (*I. biflora sensu* Petagna, 1787, Fig. 9c) was a misinterpretation by Petagna, who, misled by the presence of two flowers at the flowering stem apex, misunderstood the first author's note about the combination given to this taxon. In fact, *I. biflora sensu* Petagna (1787) from Apulia, is a new species and has now been assigned the binomial *I. bicapitata* Colas. (Colasante, 1996b; Figs. 4, 9a). Despite this clarification, subsequent studies were carried out on *I. biflora* L. with a proposal to reject this new name (Boltenkov & Crespo, 2019).

(2) Another example concerns *I. mesopotamica* Dykes (1913), which many botanists synonymized with *I.* × *germanica* L., but recent studies (Colasante 2017a) have shown is actually synonymous with *I. sicula* Tod., so the *I. mesopotamica* binomial should be rejected.

(3) *Iris sicula* described by Todaro in 1858, at $2n = 48$, was erroneously synonymized by some authors with *I. pallida* Lam., at $2n = 24$ (Tutin & al. 1980; Arrigoni 2010) and by others with *I.* × *germanica* L., at $2n = 44$ in many Flora texts, floristic lists, reports and websites (Norris 2012; Nowick 2015; WCSP 2019). This suggestion would lead also to synonymizing *I. pallida* Lam. with *I.* × *germanica* L., the latter often confused also with *I. marsica* ($2n = 40$), which is completely unacceptable for all of the cytogenetic, morphological and chemotaxonomical characters that distinguish these taxa. Our results also show that in *I.* × *germanica* L., other taxa and in particular *I.* × *trojana* and *I.* × *cypriana* show a similar problematic situation that prevents genuine understanding. All this reasoning leads us to separate *I.* × *trojana* and *I.* × *cypriana* from *I. sicula*.

(4) A critical situation occurs for *I. perrieri* Simonet ex P. Fourn. (1935) in Piedmont, misidentified and considered incorrectly as a taxonomic synonym of *I. aphylla* L. (1753) in reports, Herbaria, floristic lists and Flora texts (Rotti 1992; Colasante & Mathew 2008; Colasante 2017a), as well as for beardless irises such as *I. lactea* Pall. (1776), *I. triflora* Balbis (1804–1806) and *I. ensata* Thunb. (1794) that show numerous taxonomic and nomenclatural synonyms (Colasante 2009). The perpetuation of unreliable information in texts and websites continues to mask the real biodiversity among these irises and highlights how much criticality still may exist within this genus.

Distribution data and synergy

The erroneous or limited knowledge of the distribution of individual taxa, as well as the proliferation and/or lack of separation of the species, is spread chaotically through mass dissemination and websites, Herbaria, Botanical Gardens and Floras. In sympatric populations of species and related natural hybrids, morphological characters alone often do not allow us to confidently distinguish species from hybrids, especially if the hybrids assumed many characters of the dominant progenitor. Any morphological asymmetry can be increased by introgressive hybridization (e. g. sympatric populations as in Sannicandro Garganico, Apulia, where *I. bicapitata* is present with *I. pseudopumila* as one of its ancestors: Williams & al. 2000 - 2001). Therefore, for a "botanist", under-estimating the "minimum parts" (Linnaeus 1751, Fig. 1) is one of the major impediments to correct identification of the sample (individual, population, species, hybrid, variety). The distribution should be summarized at the end of the studies (Fig. 10), after reviewing synergistically data available from other sources (Fig. 15), including morphology and field-based morphometrics as a first step. Only synergistic surveys can lead to real biodiversity data allowing us to make well-informed decision when prioritizing species for protection (Simonet 1951, 1955, 1962; Werkmeister 1981; Arnold & al 1991; Hodges & al. 1996; Colasante 2004; Bianconi & al. 2006; Tarquini & Colasante 2009b, 2010a).

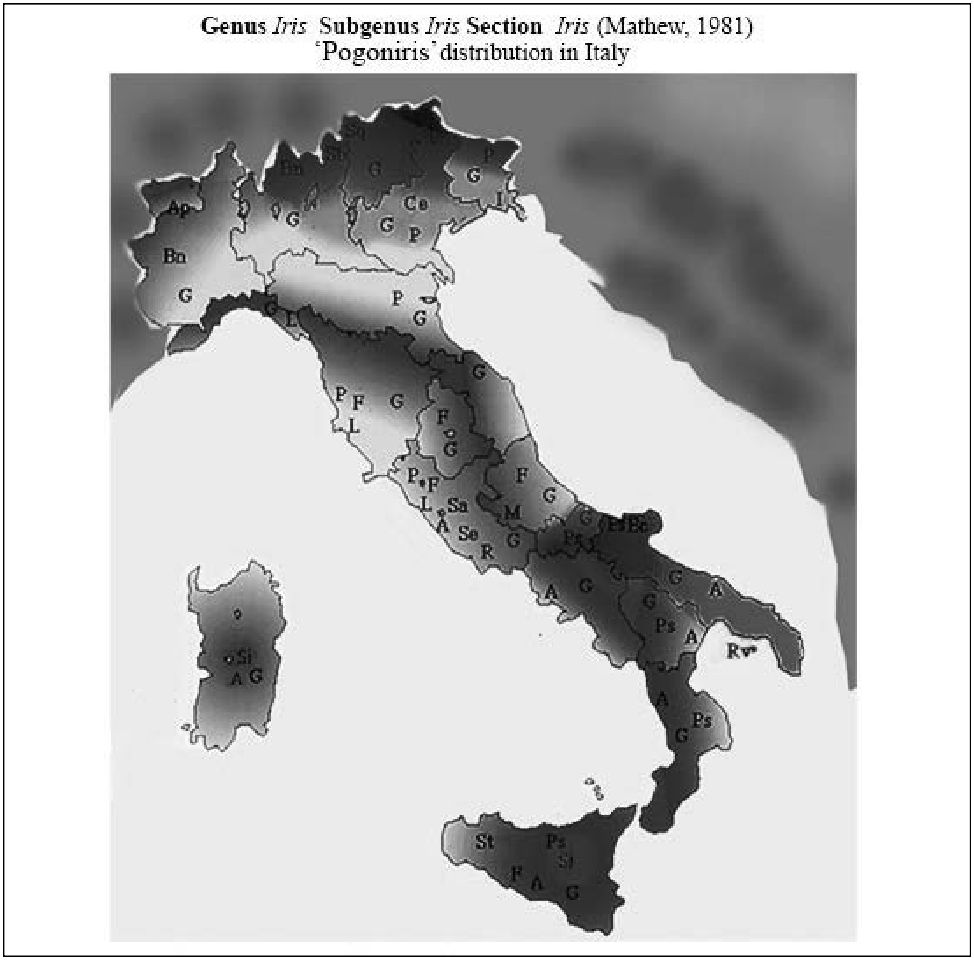


Fig. 10. Updated distribution map of Genus *Iris* Tourn. ex L. subgenus *Iris* section *Iris* (Mathew, 1981). **A** – **I.* × *albicans* Lange , **Bc** – *I. bicapitata* Colas., **Ce** – *I. pallida* subsp. *cengialti* (Ambrosi ex A. Kern.) Foster, **F** – **I.* × *florentina* L., **G** – **I.* × *germanica* L., **I** – *I. pallida* subsp. *illyrica* (Tomm. ex Vis.) K. Richt., Be – *I. benacensis* A. Kern., L – *I. lutescens* Lam., M – *I. marsica* Ricci & Colas., **P** – **I. pallida* Lam., **Pe** – *I. perrieri* Simonet ex N. Service, **Ps** – *I. pseudopumila* Tineo, **R** – *I. relicta* Colas., **Rv** – *I. revoluta* Colas., **Sa** – *I. sabina* N. Terracc., **Sb** – *I.* × *sambucina* L., **Se** – *I. setina* Colas., **Si** – *I. sicula* Tod., **Sq** – *I.*× *squalens* L., **St** – *I. statellae* Tod.
*: cultivated and naturalized in many places of Italy.

Data Dissemination

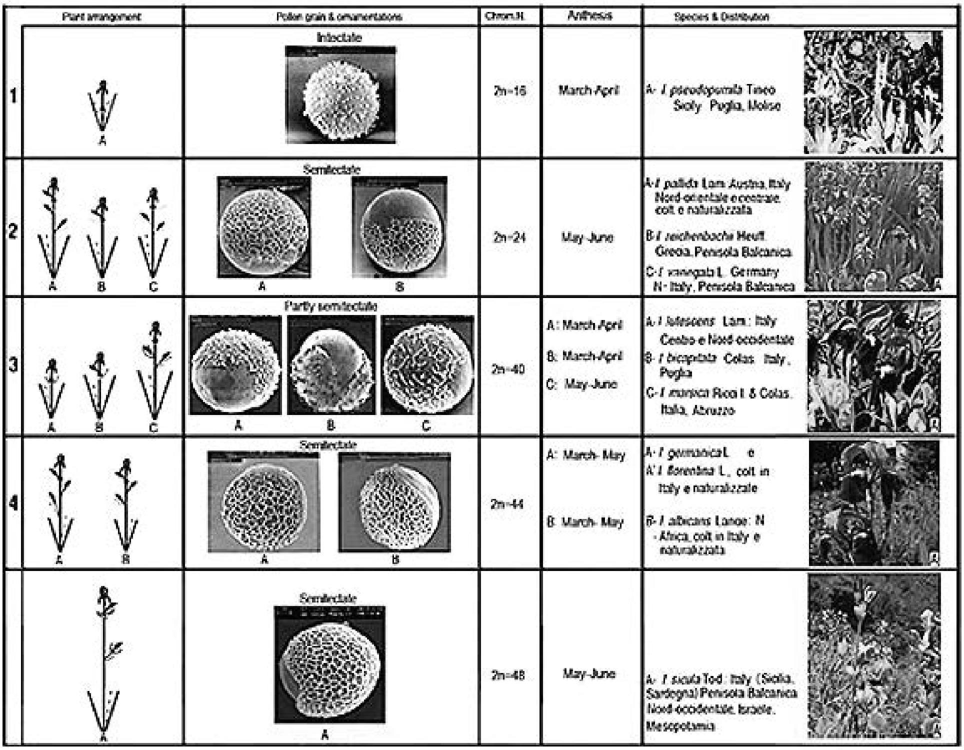
Botanical gardens (Figs. 11-12-13-14) play an important role in this topic (Maunder 2001; Tarquini & Colasante 2010b; Cibrian-Jaramillo & al. 2013); for example, in the dissemination of scientific news, in/ex-situ protection and conservation activities and germplasm collections (Toselli & Bressan 2006; Mounce & al. 2017).

Fig. 11. Rome Botanical Garden: view from above.

Fig. 12. Rome Botanical Garden: Palm path.

Fig. 13. Iris varieties in cultivation.

Fig. 14. The *Iris* monogeneric Garden in Florence at the 53rd *Iris* annual International Competition (2009).



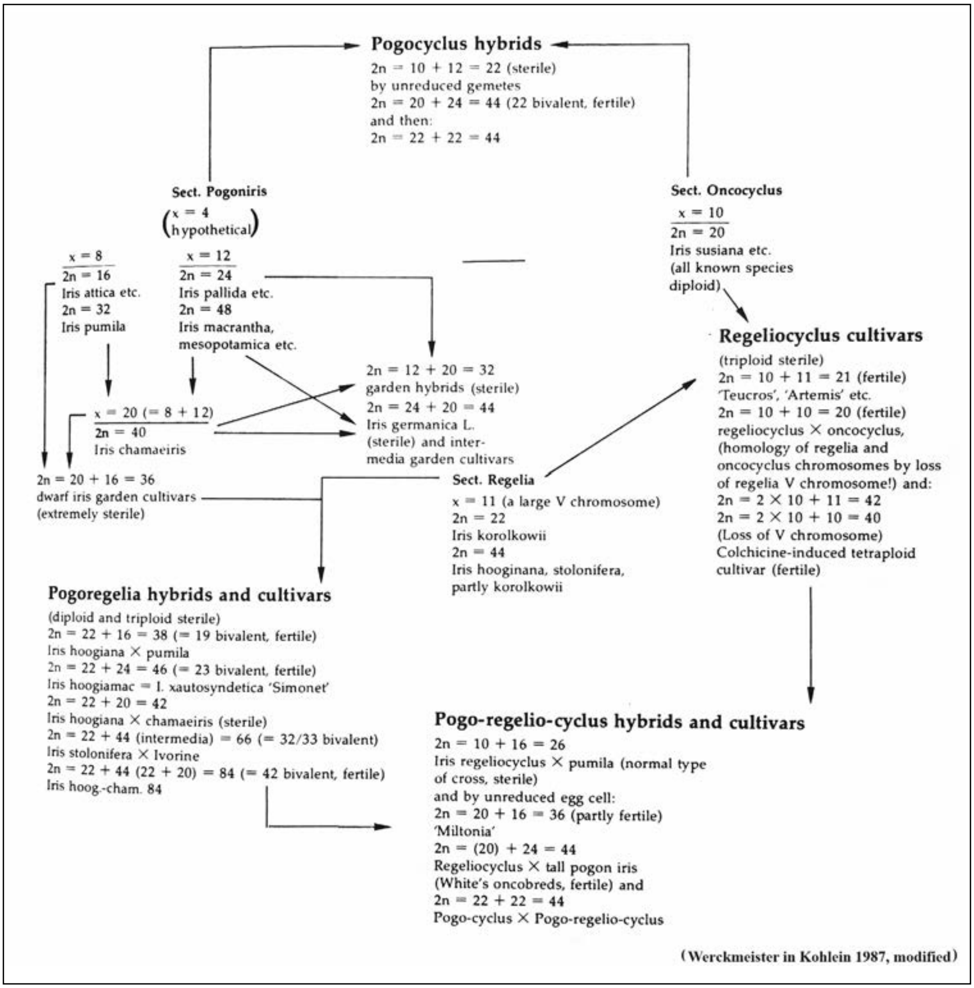
	Plant arrangement	Pollen grain & ornamentations	Chrom.N.	Anthesis	Species & Distribution
1	A	Intectate	2n=16	March-April	A- *I. pseudopumila* Tineo Sicily, Puglia, Molise
2	A B C	Semitectate A B	2n=24	May-June	A- *I. pallida* Lam. Austria, Italy Nord-orientale e centrale, colt. e naturalizzata B- *I. reichenbachii* Heuff. Grecia, Penisola Balcanica C- *I. variegata* L. Germany N- Italy, Penisola Balcanica
3	A B C	Partly semitectate A B C	2n=40	A: March-April B: March-April C: May-June	A- *I. lutescens* Lam.: Italy Centro e Nord-occidentale B- *I. bicapitata* Colas. Italy, Puglia C- *I. marsica* Ricci I. & Colas. Italia, Abruzzo
4	A B	Semitectate A B	2n=44	A: March- May B: March- May	A- *I. germanica* L. e A' *I. florentina* L., colt. in Italy e naturalizzate B- *I. albicans* Lange: N-Africa, colt. in Italy e naturalizzata
	A	Semitectate A	2n=48	May-June	A- *I. sicula* Tod.: Italy (Sicilia, Sardegna) Penisola Balcanica Nord-occidentale, Israele, Mesopotamia

Fig. 15. Genus *Iris* Tourn. ex L., subgenus *Iris,* section *Iris* (*sensu* Mathew 1981): comparative scheme using an integrated-synergistic approach concerning plant arrangement, pollen-grain ornamentation, chromosome number, and anthesis.

Precise dissemination of accurate synergistic data (Fig. 15) is an essential requirement for any serious botanist and germplasm collections (Toselli & Bressan 2006; Mounce & al. 2017).

It is also very important to point out the accurate dissemination of data on the polyploidy of the Tall

Bearded Iris(TBI), often classified according to the height of the flower stem (Lawrence, 1953). A common problem is the widespread misconception that these hybrids are all tetraploid and related to *Iris* × *germanica.* The binomial *Iris* × *germanica* L. is used widely by gardeners and in the horticultural market but it includes several hybrids and cultivars, different from the species described by Linnaeus; this leads to great confusion even in the specialist literature (Norris 2012; Nowick 2015; Tsukatani & al. 2002) and on dedicated websites (WCP 2019). The iris hybrids diagram shown in Fig.16 demonstrates how far these views are from reality about the real identity of *Iris* × *germanica* L.; this scheme is useful to clarify ideas not only to researchers but also to experimental hybridizers and iris lovers (Werckmeister in Kohlein 1981; Colasante 2004b, 2014; Fig.16).



(Werckmeister in Kohlein 1987, modified)

Fig. 16. Diagram of some iris hybrids.

Conclusion

Our synergistic approach will not only avoid superficial conclusions to taxonomic problems and subsequent incorrect dissemination of information but will also emphasize the separation of genuinely distinct taxa. It will help to discourage taxon proliferation and allow the recognition of taxonomic and nomenclatural synonyms, especially regarding highly critical taxa such as the genus *Iris* (notably in *I. lactea* Pall., *I. ensata* Thunb., *Iris sicula* Tod., *I. lutescens* Lam., *I. marsica* I. Ricci & Colas., *Iris* × *germanica* L. and *I. pallida* Lam.).

Despite our long-term and ongoing studies, this approach is still not universally applied, even to Italian irises, though it remains essential for the conservation and protection of biodiversity (IUCN). We invite experts to adopt adequate measures of investigation across vascular plants, according to the Strategic Plan for the protection of biodiversity, 2011–2020, which remains in force today.

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References

Accogli, R., Nutricati, E., Famà, L., Medagli, O., Manno, D., De Bellis, L., Marchiori, S. & Colasante, M. 2008: *Iris revoluta* Colas., natural hybrid origin species: characterization and preservation problems. – Pl. Biosyst. **142(1):** 162-165.

Arnold, M. L. 1997: Natural Hybridization and Evolution. – Oxford.

—, Buckner, C. M. & Robinson, J. J. 1991: Pollen-mediated introgression and hybrid speciation in Louisiana irises. – Proc. Natl. Acad. Sci. USA. **88(4):** 1398-1402.

Arrigoni, V. 2010: *Iridaceae*. – Pp. 453-458 in: Flora dell'Isola di Sardegna, **5.** – Sassari.

Bianco, P. 1991: Le Iris in Puglia. – Boll. Soc. Ital. Iris. **30:** 54-65.

Bianconi, A., Colasante, M. & Trombini, E. 2006: "Bearded Irises" of the Giardino dell'Iris, Società Italiana dell'Iris, Florence: experimental hybridizations". – Pp. 53-59 in: 2°Simp. Inter. dell'Iris "Hybrids and Irises". Firenze, 5-7 maggio. Atti. –Firenze.

Bini Maleci, L. 1976: Investigations on the karyotype of 40 chromosome dwarf bearded irises (third contribution). – Caryologia **29(2):** 203-216.

— & Maugini, E. 1981: *Iris pseudopumila* Tineo e *Iris attica* Boiss. &Heldr.: two very similar karyotypes. – Boll. Soc. Broteriana **52:** 921.

Blackmore, S. & Barnes, S. H. 1991: Pollen and spores patterns of diversification. – Oxford.

Boltenkov, E. V.& Crespo, M. B. 2019: Proposal to reject the name *Iris biflora* (*Iridaceae*). – Taxon **68(5):** 1118-1119.

British Iris Society 1997: A Guide to Species Irises: their Identification and Cultivation. – Cambridge & New York.

Brullo, S., Guglielmo, A., Pavone, P. & Terrasi, M. C. 1997: Mediterrean chromosome number report: 7-898. – In: Kamari, G., Felber, F. & Garbari, F. (eds), – Fl. Medit. **7:** 272-273.

Camoletto, R. 2008: Fogli botanici le famiglie della flora italiana. – Torino.

—, Quaranta, L. & Verza Ballesio, P. 2009: Le iris tra botanica e storia. – Torino.

Cerfon, P. 1981: La chimie de l'Iris Barbu. – Rev. Trim. Soc. Franc. Iris Pl. Bulb. **61:** 2-9.

Colasante, M. 1983: Genus *Iris* L.: reconstructed specimen lists of some Italian Herbaria. – Ann. Bot. **41:** 37-65.

— 1986a: Indagine su campioni di Iris conservati in Erbari come fonte d'informazione. – Boll. Soc. Ital. Iris: 67-71.

— 1986b: Genus *Iris* L. subgenus *Iris* section *Iris*: osservazioni tassonomiche in *Iris* a 2*n* = 40 cromosomi. – Giorn. Bot. Ital. **120** (1-2), Suppl. **2**: 74.

— 1987: Genus *Iris* L. subgenus *Iris* section *Iris*: le iris barbate e la loro distribuzione. – Boll. Soc. Ital. dell'Iris **26:** 46-52.

— 1988: Ibridi anfidiploidi di Iris barbatespontanee a 2 n = 40 presenti in Italia. – Giorn. Bot. Ital. **122**(1), Suppl. **1**: 52.

— 1989: On the three misunderstood wild bearded Irises: *I. bicapitata* nom. nov., *I. relicta* nom.nov., *I. setina* sp. nov. – Giorn. Bot. Ital. **123**(1): 2, Suppl. **1**: 112.

— 1992: Considérations sur les espèces «critiques» d'irisbarbusitaliens et individualization de quelques espèces. – Rev. Iris Bulbeuses. Soc. Franc. Iris Pl. Bulb. **107:** 3-8.

— 1994: Reports on Italian *Iris* species. – Bull. Amer. Iris Society **292:** 82-87.

— 1995a: Iris species & hybrids and polymorphism (photographic collectionin CD of 88 from iris slides of the author). – Roma.

— 1995b: Iris species of Southern Europe. Special Reports. – Proc. Intl. Freq. Cont. Symp.: 23-45. – Missouri.

— 1996a: Relationship between the architecture of pollen grain and some chromosomal data as information for out lining possible evolutionary trends in bearded Irises. – Reprod. Biol. Intern. Confer. R.B.G. Kew, Abstract 31 – London.

— 1996b: Taxonomic note on some Italian Bearded Irises: *Iris relicta* Colas. *nom. nov.* and *Iris bicapitata* Colas. *sp. nov.* – Fl. Medit. **6:** 213-217.

— 1997: Iris, the rainbow flowers (educational-scientific collection of 15 posters in English and Italian on structure, life form, some species, natural and experimental hybrids of Irises). – Roma.

— 1998a: Ancestors and natural hybrids of bearded Irises present in Italy. – Monocots II, Abstract 64–Sydney.

— 1998b: L'architettura dello strato esterno del granulo pollinico nelle Iris barbate. – Boll. Soc. Ital. Iris **37:** 52-56.

— 2000a: Allocyclic segments as a help in phylogeny and evolution of bearded irises present in Italy. – Chromosome Res. **9(1):**107.

— 2000b: Irises and their taxonomy. – Taxonomy today International Conference. – Reading.

— 2000c: Systematics of Iris: species & hybrids. – Proc. Iris Int. Symposium New Zealand Iris Society. 20-37.

— 2000d: Iris, colors and pigments (interactive CD in English and Italian). – Rome.

— 2002: In: Checklist of vascular plants of N Morocco with identification keys **2:** 883-885. – Madrid.

— 2003a: Sulla diversità e sistematica del genere *Iris* L. – Inform. Bot. Ital. **35(1):**198-207.

— 2003b: Natural hybrids of *Iris* L. (Iridaceae) and their importance in evolution and systematics. – Monocots III International Conference. Abstract 17. – Ontario.

— 2004a: Approcci biosistematici nella valutazione della criticità tassonomica degli ibridi naturali di Iris. – Inform. Bot. Ital. **36(2):**476-480.

— 2004b: Investigating Irises. – Species Iris Group of North America, American Iris Society Foundation 1-67. – Molalla.

— 2006: Sinonimi e iris: un punto di vista. – Boll. Soc. Ital. Iris **44:** 67-70.

— 2008: Variabilità di *I. pseudopumila* Tineo.Boll. – Soc. Ital. Iris **46:** 47-51.

— 2009: Quale Iris? Autori e compilatori a confronto. – In: Camoletto, R., Verza Ballesio, P. & Quaranta, L. (eds), Le Iris tra botanica e storia. – Museo Regionale di Storia Naturale. Torino.

— 2013: Iridacee presenti in Italia. – In: Contributi alla ricerca floristica in Italia. – Gruppo per la Floristica. Soc. Bot. Ital. **27.**

— 2014: Le Iridaceae presenti in Italia / Iridaceae present in Italy. Tavole di Anne Eldredge Maury, MATTM. – Open access ed. (2018).

— 2017a: Biodiversity and distribution of *Iridaceae* in Italy. – The New York Botanical GardenBronx **118:** 86-99. – New York U.S.A. http://dx.doi.org/10.21135/893275341.013

— 2017b: Fam. *Iridaceae*. – Pp. 277-319 in: Pignatti, S., Flora d'Italia, 2° ed, **1. –** Milano.

— & Altamura, L. 1986: Distribuzione delle Iris spontanee e naturalizzate nel Lazio. – Ann. Bot. **43.** Suppl. Studi sul Territ. **2:** 69-80.

— & – 1988: Distribuzione delle iris spontanee e naturalizzate in Umbria e Abruzzo-Molise. Note aggiuntive per il Lazio. – Ann. Bot. **44** Suppl. Studi sul Territ. **4:** 125-135.

— & De Dominicis, R. I. 1989: Dati cariologici e geni ribosomali in tre specie di Iris barbate italiane. – Giorn. Bot. Ital. **123**(1, 2) Suppl. **1:** 114.

— & Mathew, B. 1987: Analysis of European Irises based on specimens in the Kew Herbarium (K) including some comments about critica ltaxonomic groups. – Ann. Bot. **45:** 217-238.

— & – 2008: Species of natural hybrid origin and misinformation in the Irises: to reappraisal of the presence of *I. aphylla* L. in Italy. – Pl. Biosyst. **142(1):** 172-178.

— & Pacini, E. 2006: Proceedings of an Int. Symp: "Hybrids and Iris". – Suppl. Boll. Soc. Ital. dell'Iris. – Firenze.

— & Ricci, I. 1977: *Iris germanica* L. e *Iris marsica* Ricci e Colasante: sulla separazione delle due specie. – Ann. Bot. **34:**1-9.

— & — 1979: *Iris pseudopumila* Tin.: confronto citotassonomico tra esemplari provenienti da due diverse località italiane. – Ann. Bot. **37(3):** 261-271.

— & Rudall, P. J. (eds) 2000 (repr. 2001): Irises and Iridaceae: biodiversity & systematics. - Proceedings of the Iridaceae International Conference, Rome, 1998. – Ann. Bot.**2:** 9-209.

— & Sauer, W. 1986: Annotated list of Iris Herbarium from the following European Herbaria: Geneve (G), Zurich (Z, ZT), Graz (GZU) and Vienna (WU, W) including additional data from the Herbaria of Insbruck (IB), Klagenfurt (KL) and Berlin (B). – Ann. Bot. **43:** 53-79.

— & — 1988: Iris specimens investigation and revised lists of some German Herbaria: Tubingen (TUB), Munich (M) and Sauer (Sa). – Ann. Bot. **46:** 35-57.

— & — 1993: The genus *Iris* L. in Latium (Central Italy): general remarks on the morphological and kariological differentiation, as well as on the ecological adaptation and flowering periods. – Linzerbiol. Beitr. **25**(2)**:** 1189-1204.

— & Tarquini, F. 2006: Preliminary data on percentage between species and natural and naturalized *Iris* hybrid taxa present in Italy. – Boll. Soc. Ital. Iris **44:** 60-68.

— & Trombini, E. 2003a: L'ibridazione naturale nelle Iris. – 98° Congresso SBI. Catania, 24-26 settembre 2003. Riassunti: 91.

— & — 2003b: Natural hybrids of Iris and their systematics. – 4th Biennial Conf. of The Systematics Association. Trinity College, Dublin. Booklet of the Proceedings. 61.

— & – 2005a: Considerazioni sulla variabilità di *Iris bicapitata* Colas. – Boll. Soc. Ital. dell'Iris **42-43:** 43-47.

— & – 2005b: Indagine biosistematica su taxa critici del genere *Iris* (Iridaceae) e caratterizzazione di taxa utilizzati dall'uomo a scopo curativo ed alimentare. – Inform. Bot. Ital. **37:** 53-57.

— & Vosa, C. G. 1981: The cytotaxonomic relationship between *Iris palaestina* Boiss. and *Iris alata* Poir. – Caryologia **34(2):** 207-212.

— & – 1986: Iris specimens investigation and check list from Oxford Fielding-Druce Herbarium (OXF). – Ann. Bot. **43:** 81-100.

— &— 1987: The genus *Iris* L.: a short synthesis of its taxonomic problems. – Ann. Bot. **45:** 217-238.

— & — 1994: *Iris pseudopumila* Tineo: some interesting karyological data. – Conf. Booklet Chromosome Conf. IV. 61.

— & – 1995: A new cytotaxonomic approach to the problem of the natural hybrids in the Italian bearded Irises. – Giorn. Bot. Ital. **129(2):** 39.

— & – 2000 (rist. 2001): Iris: allocyclic segments as chromosome markers? – Ann. Bot. **1(2):** 127-134.

—, Difford, M. & Vosa, C. G. 1989: Scanning electronic microscopy of some critical bearded Irises pollen: preliminary observations. – Webbia **43(2):** 339-350.

—, Jury, S. L. & Trombini, E. 2004: An outline of the subgenus *Xiphium* (Mill.) Spach and its species & hybrids. – Species Group Bulletin B.I.S. Autumn. 7-14.

—, Trombini, E. & Possidente, A. 2003: Importance of polyploidy in *Iris* evolution. – Proc. of Polyploidy Int. Conf. Linn. Soc. & Royal Botanic Gardens, Kew, **20.**

Cibrian-Jaramillo, A., Hird, A., Oleas, N., Ma, H., Meerow, A. W., Francisco-Ortega, J. & Griffith, M. P. 2013: What is the conservation value of a plant in a botanic garden? Using indicators to improve management of *ex situ* collections. – Bot. Rev. **79(4):** 559-577.

Conti, F., Abbate, G., Alessandrini, A. & Blasi, C. 2005a: An annotated Check list of the Italian vascular flora. – Roma.

—, Angiolini, C., Bernardo, L., Costalonga, S., Di Pietro, R., Fascetti, S., Giardina, G., Giovi, E., Gubellini, E., Lattanzi, E., Lavezzo, P., Peccenini, S., Salerno, G., Scoppola, A., Tinti, D. & Turrisi, R. E. 2005b: Elenco delle piante raccolte durante l'escursione del gruppo di floristica della Società Botanica Italiana, Basilicata (3-6 giugno 2003). – Inform. Bot. Ital. **36(2).**

—, Alessandrini, A., Bacchetta, G., Banfi, E., Barberis, G., Bartolucci, F., Bernardo, L., Bonaquisti, s., Bouvet, D., Bovio, M., Brusa, G., Del Guacchio, E., Foggi, B., Frattini, S., Galasso, G., Gallo, L., Gangale, C., Gottschlich, G., Grunanger, P., Gubellini, L., Iiriti, G., Lucarini, D., Marchetti., D., Moraldo, B., Peruzzi, L., Poldini, L., Prosser, F., Raffaelli, M., Santangelo, A., Scassellati, E., Scortagagna, S., Selvi, F., Soldano, A., Tinti, D., Ubaldi, D., Uzunov, D. & Vidali, M. 2007: Integrazioni alla check list della flora vascolare italiana. – Nat. Vicentina 1**0(2006):** 5-74.

Cruzan, M. B.& Arnold, M. L. 1993: Ecological and genetic association in an *Iris* hybrid zone. – Evolution **47:** 432-445.

— & — 1994: Assortative mating and natural selection in an Iris hybrid zone. – Evolution **48(6):** 1946-1958.

Dykes, W. R. 1913: The genus *Iris*. – Cambridge University Press. Cambridge (reprinted in 1974 by Dover. New York).

Fadda, A., Tarquini, F. & Colasante, M. 2021: Iris barbate della Sardegna: dati preliminari relativi ad identificazione e distribuzione. – Boll. Soc. Ital. Iris **48:** 41-48.

Fang, R., Houghton, P. J.& Hyland, P. J. 2008: Cytotoxic effects of compounds from *Iris tectorum* on human cancer cell lines. – J. Ethnopharmacol. **118(2):** 257-63.

Fenaroli, L. 1974: *Florae Garganicae Prodromus*. Pars IV. – Webbia **29:** 214-215.

Festi, F. 1986: La flora del Cengio Alto. Museo e Territorio n. 1. – Rovereto.

Fiori, A. 1923-1929: Nuova Flora Analitica d'Italia. – Firenze.

Foster, M. 1889: On irises. – J. Roy. Hort. Soc. **11:** 131-149.

Fusi, P. & Bosetto, Fusi M. 1977: La Chimica degli ironi, principali costituenti dell'olio essenziale dei rizomi d'Iris. – Fitoterapia **2:** 51-59.

Giardina, G. 2010: Piante rare della Sicilia: testi e immagini di 500 entità endemiche e rare dell'isola e dei territori limitrofi. – Palermo.

—, Raimondo, F. M. & Spadaro, V. 2007: A catalogue of plants growing in Sicily. – Bocconea **20:** 5-582.

Goldblatt, P. 2000 (rist. 2001): Phylogeny and classification of the Iridaceae and the relationships of *Iris*. Irises and Iridaceae: biodiversity & systematics. – Proc. Iridaceae Int. Conf. (Rome, Italy, 1998). – Ann. Bot. **1**, n. 2.

— 2008: The Iris family. Natural history and classification. – London.

Harborne, J. B.& Williams, C. A. 2001: The phytochemical richness of the Iridaceae and its systematic significance. – Ann. Bot. **1, 2:** 43-50.

Haslam, S. M., Sell, P. D. &Wolseley, P. A. 1977: A flora of the Maltese Islands. – Malta.

Hodges, S. A., Burke, J. M. & Arnold, M. L. 1996: Natural formation of iris hybrids: experimental evidence on the establishment of hybrid zones. – Evolution **50:** 2504-2509.

Innes, C. 1985: The world of *Iridaceae*. – Ashington.

Köhlein, F. 1987: Iris. (Engl. trans.). – London.

Lamote, V., Roldan-ruiz, I., Coart, E., Loose, M. D. & Bockstaelee, V. 2002: A study of genetic variation in *Iris pseudacorus* populations using amplified fragment length polymorphisms (AFLPs) – Aquatic Bot. **73(1):** 19-31.

Linnaeus, C. 1751: Philosophia Botanica. – Stockholm.

Lawrence, G. H. M. 1953: A reclassification of the genus *Iris*. – Gent. Herb. **8(4):** 346-371.

Lynch, R. I. 1904: The book of the Iris. 133-134. – London & New York.

Lynch, S .P.& Webster, G. L. 1975: A new technique of preparing pollen for scanning electronic microspopy. – Grana **15:** 127-136.

Mahan, C. E. 2007: Classic irises and the men and women who created them. – Malabar Florida.

Mathew, B. 1981: The Iris. – New York.

Maunder, M., Higgens, S., & Culham, A. 2001: The effectiveness of botanic garden collections in supporting plant conservation: a European case study. – Biodiv. & Conserv. **10(3):** 383-401.

Maugini, E. 1992: Il Giardino dell'Iris di Firenze e il suo Concorso Internazionale nell'ambito della Società Italiana dell'Iris. – Atti Convegno "I Giardini dei Semplici e gli Orti Botanici della Toscana". – Siena,7-8 maggio pp. 141-155.

— & Bini Maleci, L. 1973: Indagine cariologica su alcune Iris barbate nane a 40 cromosomi (*Iris chamaeiris* Bertol. *s.l.*). – Caryologia **26(1):**133-155.

— &— 1982: Le specie nane di Iris in Toscana e il loro problema tassonomico. – Webbia**35:** 145-186.

— & Maleci, L. 1974: Further investigations of the karyotype of several 40 chromosomes dwarf bearded Irises (*I. chamaeiris* Bertol. *s.l.*). – Caryologia **27(1):** 117-127.

Medagli, P., Accogli, R. & Wagensommer, R. P. 2014: Schede per una Lista Rossa della Flora vascolare e crittogamica Italiana: *Iris revoluta* Colas. – Inform. Bot. Ital. **46(1):** 121-123.

Mounce, R., Smith, P. & Brockington, S. 2017: *Ex situ* conservation of plant diversity in the world's botanic gardens. – Nature Pl. **3**: 795-802. https://doi.org/10.1038/s41477-017-0019-3

Minà Palumbo, F. 2011: Iconografia della storia naturale delle Madonie. – In: Mazzola, P. & Raimondo, F. M. (eds), **2:** 26, 286-299; **3:** 58-59, 64-65, 100-101, 116-117, 122-123. – Palermo.

Mitić, B., Halbritter, H., Šoštarić, R., & Nikolić, T. 2013: Pollen morphology of the genus *Iris* L. (*Iridaceae*) from Croatia and surrounding area: taxonomic and phylogenetic implications. – Pl. Syst. Evol. **299(1):** 271-288.

Mitra, J. 1956: Karyotype analysis of bearded Iris. – Bot. Gaz. **117:** 265-293.

Nowick, E. 2015: Historical common names of great plains plants, with scientific names index. – Zea e-Books, Book 28, http://digitalcommons.unl.edu/zeabook/28, 221-222.

Parlatore, F. 1858: Iridaceae. Pp. 209-319 in: Flora Italiana, **3.** – Firenze.

Parrini, S. 2006: L'iris e la sua essenza. – Boll. Soc. Ital. Iris **44:** 62-63.

Petagna, V. 1787: *Institutiones Botanicae*. 87. – Napoli.

Pignatti, S. 1982: *Iridaceae*. – Pp. 411-430 in: Flora d'Italia, **3.** – Bologna.

— 2017: *Iridaceae*. – Pp. 411-430 in: Flora d'Italia, 2° ed, **1.** – Milano.

Poldini, L. 2001: *Iris cengialti* Ambrosi ex A. Kern. subsp. *illyrica* (Asch. &Graebn.) [Poldini, *comb. nova*, in Stud. Geobot.]**21:** 8.

—, Oriolo, G.& Vidali, M. 2002: La flora vascolare del Friuli Venezia Giulia. Indice sinonimico. – Udine.

Ponsaerts, E. 1978: Le genetique des Iris. – Rev. Trim. Soc. Francaise Iris Pl. Bulb. **49-50:** 18-20.

Randolph, L. F.1957: Cytogenetics of Median bearded Irises. – Bull. Amer. Iris Soc. **145:** 1-8.

— & Mitra, J. 1959: Iris chromosome numbers. – Bull. Am. Iris Soc. **152:** 2-6.

Reeves, G., Goldblatt, P., Rudall, P. & Chase, M. W. 2000 (rist. 2001): Molecular systematics of *Iridaceae*: a combined analysis of four plastid DNA sequence matrices. - Intern. Conference Iridaceae and Iris: biodiversity & systematics". – Ann. Bot. **1(2):** 29-43.

Ricci, I. 1958: Su un'*Iris* raccolta a M. Trevi (M. Lepini) e *Iris suavolens* Terracciano N. – Ann. Bot. **24(1):** 1-7.

— 1966: Distribuzione geografica e cariologia di *Iris xiphium* L. Segnalazione di una nuova stazione in Italia. – Ann. Bot. **28(3):** 667-674.

— & Colasante, M. 1974: *Iris marsica* n. sp. – Ann. Bot. **32:** 217-235.

Rodionenko, G. I. 1961: The genus *Iris* L. – Acc. Scien.Moscow (in Russian, reprint in English from The British Iris Society).

— 1962: An outline of a new and evolutionary botanical classification of Irises. – The Iris Year Book, 103-119.

Ross, H. 1892: Anatomia comparata delle foglie delle Iridee. – Malpighia **6:** 90-116; 179-205.

Rotti, G. 1992: Notizie sull'areale Valsesiano di *Iris aphylla* L. – Boll. Mus. Reg. Sci. Nat. Torino **10:** 281-288.

Rudall, P. 1994: Anatomy and systematics of Iridaceae. – Bot. J. Linn. Soc. **114(1):** 1-21.

Rycheva, T.,Toyanov, K. & Denev, I. 2011: Genetic diversity and molecular taxonomy study of three genera from *Iridaceae* family in the Bulgarian Flora based on ISSR markers. – Biotechnol. & Biotechnol. Eq. **25(3):** 1-2305.

Sani, G. L. & Specht, F. 1960: Iris. – Bologna.

Schembri, P. J. & Sultana, J. 1989: Red data book for the Maltese Islands. Department of Information – Valletta.

Signorini, M. A., Pacini, E. & Colasante, M. 2009: Natura ed arte: le Iris nella pittura. – Boll. Soc. Ital. Iris **47:** 77-106.

Simonet, M.1932: Recherches cytologiques et genitique chez les Iris. – Bull. Biol. France Belgique **66:** 225-444.

— 1947: Les Iris et leur comportement aux points de vues y stématique, génetique, cytologique, géographique et chimique. – Arch. J. Klaus Stift. **273(4)**: 307-325.

— 1951: Sur la meiose de quelques hybrids d'Iris III. Hybrides entre Pogon iris nains et Pogoniris grands. – C. R. Acad. Sci. Paris 1236-1238.

— 1955: Nouveaux hybrids d'Iris Pogoniris etude descrive d'hybrides Pogoniris nains. – Ann. Sci. Nat. Bot. **11:** 503-528.

— 1962: Quelque shybrides amphidiploides entre espèces de Section ou sous-section differentes dans le genre Iris. – Rev. Cyt. et Biol. Vèg. **25(3-4):** 303-308.

Tarquini, F. & Colasante, M. 2009a: *Iris japonica* Thunb, nota per le sue proprietà curative, conquista l'Occidente con Iris affini e ibridi. – Boll. Soc. Ital. dell'Iris **47:** 55-63.

— & — 2009b: *Iris reichenbachii* Heuff.: la specie ed alcuni suoi ibridi naturali, sperimentali e varietà. – Boll. Soc. Ital. dell'Iris **47:** 65-76.

— & — 2010a: The experimental hybridization, as an important information source about the phylogenesis and the evolution of the genus *Iris* L. Early Events in Monocot Evolution. – Royal Botanic Gardens, Kew and the Linnean Society of London. Abstract.

— & — 2010b: Monogeneric botanic gardens as an import and the source against genetic erosion. – IV Global Botanic Gardens Congress. Botanic Gardens Conservation International & the National Botanic Gardens of Ireland. Dublin, 13-18 June 2010.

—, Nardella, D. & Colasante, M. 2021a: Caratterizzazione di *Iris foetidissima* L. e sue varietà. – Boll. Soc. Ital. dell'Iris **48:** 52-55.

—, — & — 2021b: Caratterizzazione di *Iris tuberosa* L. – Boll. Soc. Ital. dell'Iris **48:** 56-59.

Terpenin, K., Nardi, E. & Garbari, F. 1996: Author and type of the name *Iris cengialtii* (*Iridaceae*). – Giorn. Bot. Ital. **130:** 575-578.

Terracciano, A. 1899: Intorno ad alcune specie d'Iridi che crescono naturalmente nel Mezzogiorno d'Italia. – Atti R. Ist. Incor. 1, 5. Napoli.

Tillie, N., Chase, M. W.& Hall, T. 2000 (rist. 2001): Molecular studies in the genus *Iris* L.: a preliminary study. – Ann. Bot. **1(2):** 105-112.

Todaro, A. 1858: Nuovi generi e nuove specie di piante. – Palermo.

Toselli, E. & Bressan, E. 2006: *I. illyrica* Tomm.: some aspects of biology, ecology and integrated experiences of conservation *in situ* and *ex situ*. – Atti 2° Simp. Intern.dell'Iris "Hybrids& Iris". T.A.F. – Soc. Ital. dell'Iris. 94. – Firenze.

Tsukatani, N., Aii, J., Miyabe, Y., Shimizu, K., Adachi, T. &Yabuya, T. 2002: Identification of somatic hybrids between *Iris ensata* Thunb. and *I. germanica* L. by designing specie-specific primers of ITS region of nuclear DNA. The Japan Mendel Society. – Cytologia **67(4):** 361-366.

Tutin, T. G., Heywood, V. H., Burges, N. A., Valentine, D. H., Walters, S. M. & Webb, D. A. 1980 (2nd Ed. 1993): Iris. Pp. 86-102 in: Flora Europaea, **5.** – Cambridge.

Waddick, W. & Zhao, Y. 1992: Iris of China. – Portland.

Warburton, B. 1978: The world of Irises. – Wichita.

Werckmeister, P. 1967: Catalogus Iridis. Jahrbuch 1967. 2. – Leonberg (Stuttgard).

— 1981: Iris hybridization. – Pp. 275-327 in: Köhlein F. (ed.) 1981, II Ed. English version1987: Iris. – Stuttgard.

Williams, C. A., Harborne, J. B. & Colasante, M.1997: Flavonoid and xanthone patterns in bearded Irises species and pathway of chemical evolution in the genus. – Biochem. Syst. Ecol. **25(4):** 309-325.

—, — & — 2000 (rist. 2001): The pathway of chemical evolution in bearded Iris species based on flavonoid and xanthone patterns. – Intern. Conference "Iridaceae and Iris: biodiversity & systematics". – Ann. Bot. **1(2):**51-58.

Wilson, C. A. 2016: Subgeneric classification in *Iris* reexamined using chloroplast sequence data. – Taxon **60(1):** 27-35.

—, Padiernos, J. & Sapir, Y. 2011: The royal irises (*Iris* subg. *Iris* sect. *Oncocyclus*): Plastid and low-copy nuclear data contribute to an understanding of their phylogenetic relationships. – Taxon **65(1):** 35-46.

Wu, Q. I. & Cutler, D. F. 1985: Taxonomic, evolutionary and ecological implication of the leaf anatomy of rhizomatous *Iris* species. – Bot. J. Linn. Soc. **90:** 253-303.

Wynne, J. & Henderson, N. C. 1973: Anthocyanin pigments in the flower of tall bearded Irises. – Bull. A.I.S. **209:**37-41.

Zangheri, P. 1976: Iridaceae. – Pp. 875-884 in: Flora italiana, **1.** – Padova.

Zodda, G. 1967: Compendio della Flora Teramana. – Arch. Bot. Biogeogr. Ital. **43:** 35-101, 115-156.

List of Selected Websites Visited

https://wcsp.science.kew.org
http://www.theplantlist.org/tpl/record/kew
https://www.actaplantarum.org/
https://www.floraitaliae.actaplantarum.org
http://dryades.units.it/floritaly
https://www.irises.org
https://irissocietynsw.org.au/
http://italic.units.it
http://www.biologia.unipi.it
http://www.britishirissociety.org.uk
http://www.euroiris.org

http://www.iris-bulbeuses.org
http://www.iris-cayeux.com
http://www.irisfirenze.it
http://www.cdn-iris.ca
http://www.irises.org.au
http://www.nziris.org.nz
http://www.luirig.altervista.org/flora.htm
http://www.signa.org
http://www.hips-roots.com
https://www.iucnredlist.org
https://www.historiciris.org
http://irisenligne.blogspot.com
https://flora.org.il
http://elianto.fisica.unimi.it
http://www.maltawildplants.com
https://www.flora-of-cyprus.eu

Note: Actually, many web-sites on irises, but not all providing scientific data and many shows dubious information and even inaccurate (sometimes personally commented out), but according to the purpose of clarifying of this paper only sites of scientific public domain were carefully checked and, in particular, for the update nomenclature, WCSP, Kew (2019), which, if accepted also by these authors, have been followed.

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Fabrizio Martini

Contribution to the knowledge of the genus *Alchemilla* L. (*Rosaceae*) in the Italian Alps: Carnic, Julian Alps and Pre-Alps

Abstract

Martini, F.: Contribution to the knowledge of the genus *Alchemilla* L. (*Rosaceae*) in the Italian Alps: Carnic, Julian Alps and Pre-Alps. — Fl. Medit. 31 (Special Issue): 241-255. 2021. — ISSN: 1120-4052 printed, 2240-4538 online.

This paper aims at improving the knowledge of the genus *Alchemilla* in the flora of Friulian Alps (North-Eastern Italy). During 15 years of field observations 33 species were verified, while the sites of *A. coriacea* represent an unconfirmed historical bibliographic data. *Alchemilla carniolica, A. filicaulis, A. glomerulans, A. hirtipes, A. propinqua, A. venosula* and *A. versipila* occurred in a single population, whereas *A. monticola, A. flabellata, A. connivens* and *A. xanthochlora* were the most common, having more than 40 records on average. The most frequent geoelements were the orophytes, in particular S-European (12 species), the endemic ones, in particular alpics (8) and finally of the Eurosiberian elements (6). The distribution of the genus in the Friulian Alps, reveals that the maximum presence occurs in the western Main Carnic Chain.

Key words: Vascular flora, distribution, species richness, Carnic, Julian Alps and Pre-Alps, Friuli-Venezia Giulia, Italy.

Introduction

The knowledge about the genus *Alchemilla* in Italy and in particular in the Alpine regions had considerable progress in the last decades, especially due to the activity of floristic cartography, which stimulated the study of some critical genres, including *Alchemilla* (Fröhner & al. 2012; Bovio & Festi 2014; Festi & al. 2015). In this light, the publication of the fundamental monograph of Fröhner (1990), integrated in 2007 by the cartographic work of Kurtto & al., was an important incentive for a modern approach to the study of this genus.

The recognition of the species of *Alchemilla* is always a very difficult task due the complexity of forms and lack of description of the diacritic framework of some species. This makes the majority of literature data unsuitable for phytogeographic purposes, when they are not checked by a taxon specialist. Experience showed that up to 90% of the collections specimens are erroneously determined (Fröhner & al. 2012) and, as consequence, the deriving bibliographic citations are also erroneous. For these reasons, all the records given here, except for explicit warning, are based on samples reviewed by S. E. Fröhner (Dresden, D), excellent connoisseur of the genus, and deposited at the Friulian Museum of Natural History of Udine (MFU). Recently, Festi (2017 and 2019) published a monography of the genus that, up to date, is the most complete and exhaustive work in Italy.

In the last years, Friuli Venezia Giulia has been subdivided in quadrants following the project for the floristic mapping of Central Europe (Ehrendorfer & Hamann 1965), and aiming at drafting a new chorological atlas. This project aims at updating the floristic knowledge based on the previous atlas carried out at the base area level (Poldini & al. 2002) by adopting the methods applied to the neighbouring regions (northern Italy, Carinthia and Slovenia).

Materials and methods

This study is mainly based on recent herbarium specimens (2001-2018); in addition, few specimens of local historical herbariums were also considered (TSB, MFU, W). Special attention has been paid to the areas of the region where a higher number of species was expected, in particular in the Main Carnic Chain.

The study will present a commented catalogue of the taxa occurring in the area, referring to the treatises of Festi (1998, 2017 and 2019) for the description and examination of the general diacritical characters. The annotations in the text focused on species details concerning mainly ecological and distributive aspects. For species documented by more than one finding, the altitudinal range has been deduced by herbarium specimens. A selection of specimens is reported in the "*Specimina selecta*" with location, altitude, basic area/quadrant, date of collection; where not otherwise indicated, the specimens were collected by F. Martini, reviewed by S. E. Fröhner and deposited in MFU. The findings appear ordered along the arch: Carnic Prealps (PC), Carnic Alps (AC), Julian Alps (AG) and Julian Prealps (PG). Synonymy has been omitted to avoid a burden of dubious utility.

Systematic prospect

The taxonomy followed what proposed by Fröhner (1990), however, it is to be considered provisional due to the occurrence of some *incertae sedis* taxa.

Sect. *Alchemilla*

- *A. xanthochlora* Rothm.
- *A. micans* Buser
- *A. tirolensis* Buser
- *A. crinita* Buser
- *A. lineata* Buser
- *A. venosula* Buser
- *A. straminea* Buser
- *A. glabra* Neygenf.

A. obtusa Buser
A. reniformis Buser
A. impexa Buser
A. effusa Buser

Sect. *Coriaceae* S. E. Fröhner
[*A. coriacea* Buser]
A. connivens Buser
A. versipila Buser
A. glomerulans Buser
A. undulata Buser

Sect. *Calycinae* Buser em. S. E. Fröhner
A. fissa Günth. & Schumm.

Sect. *Decumbentes* S. E. Fröhner
A. decumbens Buser
A. hirtipes Buser

Sect. *Ultravulgares* S. E. Fröhner
A. subcrenata Buser

Sect. *Plicatae* S. E. Fröhner
A. strigosula Buser
A. propinqua H. Lindb. ex Juz.
A. monticola Opiz
A. filicaulis Buser
A. exigua Buser
A. colorata Buser
A. glaucescens Wallr.

Sect. *Flabellatae* S. E. Fröhner
A. fallax Buser
A. carniolica (Paulin) Fritsch
A. acutata Buser
A. flabellata Buser

Sect. *Alpinae* Buser ex Camus em. S. E. Fröhner
Ser. *Hoppeanae* Buser ex Rothmaler
A. leptoclada Buser
A. alpinula S. E. Fröhner

Commented inventory in alphabetical order

A. acutata Buser

Observations. Observed only in the Main Carnic Chain between M. Crostis and Paularo (1500-2050 m) (*Rhododendro-Vaccinion*, *Adenostylion*, *Nardion*).

Specimina selecta. AC: Panoramica delle Vette, fra M. Neval e Cas. Chiadinis, m 2000, 9443/1, 16.7.2008; vers. SE del Cimon di Crasulina, m 2000, 9443/2, 29.8.2008; cresta fra i M. Dimon e Paularo, m 1970 (9444/1), 10.9.2008.

A. alpinula S. E. Fröhner

Observations. According to current knowledge, it has to be considered an endemic species of the mountain-alpine belts of the South-eastern Alps between Garda Lake and Julian Alps. In the Friulian Alps it is currently known only for their eastern part (Julian Alps and one site in the Carnic Alps), where it grows on rocks, scree slopes of small grain size and dry, stony or discontinuous grasslands, preferably on calcareous soils (Fröhner 2012) between (1300) 1400 and 2200 m (*Potentillion caulescentis*, *Thlaspion rotundifolii*, *Seslerion variae*). The specific epithet intends to emphasize the small size of the plant within the section *Alpinae*.

Specimina selecta. AC: Salita da Sella Poludnig al M. Poludnig, m 1835, 9446/1, 6.8.2014. AG: M. Canin, vers. E di Sella Grubia, m 2050, 9646/2, 17.8.2009; Julische Alpen: Kanaltal: Luschariberg Gipfel, 9547/1, Ronniger, rev. S.E. Fröhner, W; M. Santo di Lussari, vers. NE, lungo la strada, m 1770, 9547/1, 13.7.2010. PG: Salita da P.so di Tanamea a F.lla Kriš, m 1440, 9746/1, 18.8.2012; Bacino superiore del Torr. Bruschie sotto Forca di Campidello, m 1300, 9645/3, 26.6.2015.

A. carniolica (Paulin) Fritsch

Observations. Indicated at Sella Mangart (Fröhner 1990) on the border between Italy and Slovenia (Julian Alps).

A. colorata Buser

Observations. Widespread throughout the Friulian Alps between (770) 1300-1900 m, this South-European orophyte grows on stony, moderately dry to little damp, carbonate or sometimes slightly acid soils of alpine grasslands and dwarf shrub communities (*Seslerion variae*, *Rhododendro-Vaccinion*).

Specimina selecta. PC: Cansiglio: tra caserma Candaglia e Ciol dei Scios, m1280, 9940/2, 3.7.2020, leg. C. Argenti, det. F. Festi, Hb Argenti; AC: Da Cas. M. dei Buoi a Cima Omblalet (Forni Avoltri), m 1715, 9342/4, 21.7.2015; Forni di Sotto: Punta del Mezzodì presso Cas. Chiampiuz, m 1690, 9642/1, 17.7.2015; Sponda sin. del Torr. Fella a SE di Ugovizza, m 770, 9446/4, 1.7.2009, leg. M. Strain, det. S.E.Fröhner; PG: Gran Monte: nei pressi del Rif. Monteaperta, m 1500, 9746/1, 18.8.2012.

A. connivens Buser

Observations. It has been observed along the entire alpine region of the study area from the mountain to the alpine belt between (950) 1200-2300 m. It is a species with a wide ecological range, growing in tall forb communities (*Adenostylion*), grasslands (*Polygono-Trisetion*, *Cynosurion*, *Poion alpinae*, *Nardion*, *Seslerion variae*), wetlands (*Calthion palustris*) and dwarf shrub communities (*Rhododendro-Vaccinion*).

Specimina selecta. PC: Lungo il sentiero da Cas. Pradut (Claut) a M. Resettum, m 1695, 9742/3, 25.7.2015; AC: Alta V. Fleons, passo Sesis, m 2260, 25.7.2013; Vers. SW della Creta d'Aip, sopra la V. d'Aip, 1800, 16.8.2013; AG: Conca di Fusine, poco sopra il bivio fra i sent. per Rif. Zacchi e Biv. Nogara, m 950, 9548/1, 2.6.2011; PG: Vers N del M. Matajur, presso Casere Tu v Dolini, m 1435, 9747/3, 14.8.2008.

[***A. coriacea*** Buser]

Observations. AC: there is a historical datum not confirmed by Gortani (1981) for the Mount Varmost.

A. crinita Buser

Observations. It grows in the mountain to alpine belts between (600) 1000-2000 m and prefers fresh to moist or even moderately dry, base-rich soils of calcareous grasslands (*Seslerion variae*) and sometimes in communities of tall forbs (*Adenostylion*, *Rumicion alpini*).

Specimina selecta. AC: M. Tinisa, prati di Cas. Tintina, m 1500, 9542/3, 31.8.2009; Vers. W di Quota Pascoli presso il laghetto Pera (F. Avoltri), m 1950, 9342/4, 8.8.2014; V. Plecia, sella Plecia, m 1616, 9446/2, 16.7.2011. AG: Fusine in V. Romana, piana fra l'Alpe Tamer e l'Alpe del Lago, m 1000, 9547/2, 25.7.2008.

A. decumbens Buser

Observations. Endemic species of the Alps, it is diffused in the high-mountain-alpine belts between 1500 and 2100 m, where it prefers small-grass coenoses on long snow-covered soils, grasslands, meadows, peat bogs, edges of streams, much more rarely megaforb communities. These records confirmed the citation of Gortani (1981) for Paularo and Coglians mounts, excluding this taxon from the group of chorological doubts as noted in Poldini & al. (2001).

Specimina selecta. PC: Claut, sentiero da Cas. Pradut a M. Resettum, m 1595, 9741/1, 25.7.2015. AC: M. Arvenis, m 1860, 9543/2, 27.6.2002. AG: M. Canin, vers. E di Sella Grubia, m 2050, 9646/2, 17.8.2009.

A. effusa Buser

Observations. S-European orophyte, so far observed only in the western Carnic Alps between 1500 and 2200 m on fresh and wet soils by surface trapelation, from ± basic to weakly acid soils. It frequents vegetation of springs, banks of streams, shrubs and communities of tall forbs.

Specimina selecta. AC: M. Tinisa, fra Le Forcelle e il M. Bruttopasso, m 1840, 9542/3, 31.8.2009; Vers. N M. della Piana (Sappada), m 1970, 9442/1, 12.7.2028, C. e S. Argenti, rev. F.Festi, Hb Argenti; Pramollo, verso Cas. Auernig e For, m 1550, 9445/2, 14.8.2008, M. Crasnich, rev. S.E. Fröhner; Fra i monti Zoncolan e Tamai, m 1740, 1.8.2009, 9543/2.

A. exigua Buser

Observations. It is an endemic species of the Alps, growing from the (lower) mountain to the alpine belt, from (650) 950 to 2000 m. It prefers moderately dry to fresh, humic, often eutrophic, base-rich soils in meadows (*Poion alpinae*, *Nardion*, *Polygono-Trisetion*), grasslands (*Mesobromion*, *Seslerion variae*), clearings and megaphorb communities (*Adenostylion*).

Small specimens of other species have been often erroneously attributed to *A. exigua*, although this taxon, in spite of the specific epithet, may reach the size of related species. The main discriminating characters of *A. exigua* are the presence of thin flower pedicels and stems, the leaves teeth mostly finely pectinate and the small flowers, usually carried in pseudoumbels, briefly pedicellated, with a very slender hypanthium. (Fröhner & al. 2012).

Specimina selecta. PC: V. Zemola (Erto), salita da Stalle Mola a Cas. Bedin di Sopra, m 1520, 9640/3, 17.7.2013; M. Lovinzola, presso la cava, m 1635, 9643/2, 22.8.2008. AC: Vers. W di Quota Pascoli presso il laghetto Pera (F. Avoltri), m 1950, 9342/4, 8.8.2014; Salita da Sella Poludnig al M. Poludnig, m 1445, 9446/1, 6.8.2014. AG: Fusine in V. Romana, piana fra l'Alpe Tamer e l'Alpe del Lago, m 1000, 9547/2, 25.7.2008. PG: M. Glava (Matajur), vers. SW, sent. 736, m 1390, 9743/3, 23.6.2012.

A. fallax Buser

Observations. It grows from the (lower) mountain to the alpine belt between (600) 1000-2000 m on wet and humid soils by surface trapelation, euthrophic, base-rich soils in coenoses of *Adenostylion*, *Piceion excelsae*, *Erico-Pinion*, *Rhododendro-Vaccinion* and *Seslerion variae*.

Specimina selecta. PC: M. Costa Paladin, vers. N a SW di Cas. Fors, m 1540, 9642/4, 31.8.2013. AC: Fra Cas. Fleons Bassa e Cas. Creta Verde (F. Avoltri), m 1924, 9342/4, 8.8.2014; Salita da loc. Cristo di Forca (Amaro) al M. Amariana, m 1500, 9644/1, 24.6.2015. PG: M. Plauris, fra M.ga Confin e Jof di Ungarina, m 1530, 9645/3, 7.7.2011; Colovrat, presso Biv. Zanuso, m 600, 9847/2, 25.6.2011.

A. filicaulis Buser

Observations. For this Eurosibirian-North American species, only one site on the North-western border of the region is known so far. The most important characters useful to distinguish *A. filicaulis* are represented by the red colouration of the basal stipules (shared with *A. tenuis* Buser and *A. rubristipula* Buser, both absent in Friuli) and by the flowers mostly in pseudoumbels, with elongated pedicels and slender hypanthium.

Specimina selecta. AC: Lasen in Martini (2019) per l'alta V. di Sesis nelle vicinanze del Rif. Calvi, m 2160, 9342/3, 11.7.2015, leg. Lasen, rev. S.E. Fröhner, Hb Lasen).

A. fissa Günther & Schummel

Observations. It can be observed mainly on acid substrates between 1300 and 2300 m, usually in grasslands with long snow cover persistence, scree slopes of fine grain, meadows and grasslands (*Nardion*, *Poion alpinae*) and tall forb communities (*Adenostylion*). For distinctive characters with respect to *A. fallax* and *A. venosula*, see Fröhner & al. (2012).

Specimina selecta. PC: M. Lovinzola, nei pressi della cava di marmo, m 1625, 9643/2, 22.8.2008. AC: M. Zoncolan, nei dintorni di M.ga Pozof, m 1600, 9443/4, 31.7.2008. AG: Conca di Fusine, loc. Alpe Vecchia, m 1300, 25.7.2008; Sotto F.lla Infrababa Grande, m 2000, 10.8.2001.

A. flabellata Buser

Observations. From the mountain to the alpine belt, between (750) 1000-2300 m, on moderately dry to moderately moist soils, rocky or superficial, rich to poor in bases and at times weakly acid, in lean grasslands, *Elyna* communities, dwarf shrubs and pine forests (*Seslerion variae*, *Oxytropido-Elynion*, *Rhododendro-Vaccinion*, *Erico-Pinion*). For the distinctive characters with respect to *A. glaucescens* see the notes to the latter.

Specimina selecta. PC: M. Lovinzola, nei pressi della cava, m 1625, 9643/2, 22.8.2008. AC: Vers. S. M. Chiadenis, verso Passo dei Cacciatori, m 2200, 9342/3, 25.7.2013; Lunze, a N di Illegio, m 900, 9544/4, 2.6.2013. AG: M. Mangart, Forc. Mangart, m 2263, 9547/4. PG: M. Plauris, fra M.ga Confin e Jof di Ungarina, m 1450, 9645/3, 7.7.2011; Vetta del M. Matajur, m 1640, 9747/3, 14.8.2008.

A. glabra Neygenf.

Observations. This eurosiberian species grows in the mountain-alpine belts between (950) 1300-2000 m, on humid to wet areas by surface trapelation, silty, euthrophic, base-rich soils in a different type of coenoses: grasslands (*Seslerion variae*, *Nardion*, *Polygono-Trisetion*, *Poion alpinae*), wet meadows (*Cynosurion*), peat bogs, banks of brooks (*Caricion davallianae*, *Calthion palustris*), tall forbs communities (*Adenostylion*) and dwarf shrubs (*Rhododendro-Vaccinion*). Indicated by Poldini & al. (2001) as a chorological doubt, it was later confirmed. The finding on the Cimon di Crasulina also gives credit to the record of Zirnich in Mezzena (1986) for some neighbouring groups of the Carnic Alps (Pal Piccolo, M. Coglians), while the collection on M. Lussari by the same author makes plausible those of Mainardis & Simonetti (1991) from the Julian Pre-Alps (M. Cuarnan, M. Chiampon). Nonetheless, it should be pointed out that the difficult distinction with respect to *A.versipila* makes uncertain the bibliographical records not supported by revised samples.

Specimina selecta. PC: Forni di Sotto: Punta del Mezzodì presso Cas. Chiampiuz, m 1690, 9642/1, 17.7.2015. AC: M. Tinisa, prati di Cas. Tintina, m 1500, 9542/3, 31.8.2009; Sappada: Col di Caneva, m 1890, 25.7.2000, leg. C. Lasen, rev. S.E. Fröhner, Hb Lasen; Vers. SE del Cimon di Crasulina, m 2000 9443/2, 29.8.2008; M. Osternig, sotto Sella Bistrizza, m 1650, 9446/2, 16.7.2011. AG: Conca di Fusine, poco sopra il bivio fra i sent. per Rif. Zacchi e Biv. Nogara, m 950, 9548/1, 25.7.2008; M. Santo di Lussari, lungo la strada che porta verso Cima del Cacciatore, poco fuori l'abitato, m 1750, 9547/1, 13.8.2010. PG: M. Glava (Matajur), vers. SW, sent. 736, m 1405, 9747/3, 23.6.2012.

A. glaucescens Wallr.

Observations. *A. glaucescens*, like *A. glabra*, is also an Eurosiberian species; it prefers moderately humid, mesotrophic, base-rich soils in lean grasslands on carbonate or silicate substrate between (600) 1000-2300 m in lean grasslands (*Mesobromion*, *Seslerion variae*, *Nardion*, *Polygono-Trisetion*). Its presence in Friuli was commented by Feoli Chiapella & Poldini (1986) for some specimens reviewed by F. Lippert (München).

Specimina selecta. PC: Vers. S del Col Chiavrais, loc. Fienili Chiavrais (Forni di Sotto), m 600, 9642/1, 1.8.2014. AC: Sent. n. 140 da M.te Piana a Casera Olbe (Sappada), m 2025, 9442/1, leg. C. & S. Argenti, rev. S.E. Fröhner, Hb Argenti; M. Coglians, Forca Monumenz, m 2290, 21.8.2010; Sponda sin.del Torr. Fella a SE di Ugovizza, m 770, 9446/4, 1.7.2009, leg. M. Strain. AG: Altopiano del Montasio, m 1550, 9546/4, 5.8.2009, leg. A. Danelutto.

A. glomerulans Buser

Observations. *A. glomerulans* populates the subalpine-alpine belts with a preference for eutrophic to mesotrophic soils in snowbeds, peat bogs, vegetation of springs, banks of streams and brooks, alpine shrubs, forest fringes. So far the only finding is in the Carnic Alps and thus extends the eastern limit of the species, previously fixed on the Venetian Alps (Festi 2017; Argenti & al. 2019).

Specimina selecta. AC: Pic Chiadin, vers. S (Forni Avoltri), m 2290, 9443/1, 21.8.2010.

A. hirtipes Buser

Observations. It is an alpic endemic species, whose closest sites in the Italian Alps are located in Alto Adige / Südtirol (Festi 2017). It is present from the mountain to subalpine belt in coenoses referable to *Polygono-Trisetion* and *Nardion*, *Molinion*, *Filipendulo-Petasition*. According to Fröhner (1990), the fairly falcate profile of the lamina teeth represents a more important distinctive character than the abrupt interruption of the hairiness usually towards the half of the stem (from which the specific epithet). Locally it is known only for the following site.

Specimina selecta. AC: M. Zoncolan, dintorni di M.ga Pozof, m 1580, 9443/4, 31.7.2008.

A. impexa Buser

Observations. According to Fröhner & al. (2012), it is an element of the mountain-subalpine belts, widespread throughout the Alps, which grows on humid areas by surface trapelation, silty, base-rich, humic and eutrophicized soils in peat bogs, grasslands, tall forb communities and fine-grained screes, whose broad phytocoenotic spectrum may include *Caricion davallianae*, *Calthion palustris Polygono-Trisetion*, *Poion alpinae*, *Adenostylion* and *Thlaspion rotundifolii.* The absence of previous records from our region is likely due to both the knowledge still insufficient, and perhaps the possible confusion with *A. effusa* (see Fröhner 1990), since *A. impexa* is reported in the Carinthian Alps (Hartl & al. 1992).

Specimina selecta. PC: Punta del Mezzodì (Forni di Sotto) presso Cas. Chiampiuz, m 1690, 9642/1, 17.7.2015. AC: M. Zoncolan, nei dintorni di M.ga Pozof, m 1580, 9443/4, 31.7.2008; M. Tamai, vers W, m 1930, 9543/2, 1.8.2009.

A. leptoclada Buser

Observations. The species has a range extending from the Jura Massif (France) to the western Alps. The site of M. Matajur is the only one so far established in Friuli. It would be therefore the most eastern site for the species (see Kurtto & al. 2007), since the nearest known localities are those of the Bergamo Alps reported in Fröhner & al. (2012) and in Martini & al. (2012). Moreover, some indications of *A. alpina* s.latiss., such as those of Minio and Crichiutti in Gortani & Gortani (1905-06) by Matajur himself should perhaps be ascribed to this species. In addition, the close affinity with *A. conjuncta*, suggests that historical records of the latter may be referred to *A. leptoclada* (Frohner 1990). *A. leptoclada* prefers cracks in cliffs, scree slopes with small size grains, nutrient poor grasslands on rocky or shallow soils, mainly on carbonate substrates (*Potentillion caulescentis*, *Seslerion variae*). *A. alpinula* and *A. leptoclada* are currently the only representatives of the sect. *Alpinae* in the Friulian Alps.

Specimina selecta. PG: M. Matajur, fra Rif. Pelizzo e loc. Dolina, m 1345, 9747/3, 14 8.2008.

A. lineata Buser

Observations. This species were also recorded by Poldini & al. (2001), included as chorological doubt. It is a south European orophyte, present in the mountain-subalpine belts (1200-1800 m), preferably on mesotrophic, base-rich soils in wet meadows (*Cynosurion*), water-flowing habitats (*Caricion ferrugineae*), coenoses of tall grasses and forest fringes (*Adenostylion*).

Specimina selecta. PC: Vers. N del M. Costa Paladin, a E di Forca del Mugnol, m 1480, 9642/3, 31.8.2013. AC: M. Pieltinis, vallecola sotto M.ga Pieltinis, m 1700, 9542/1, 31.7.2013; Timau, dintorni di Cas. Pramosio, m 1520, 9444/1, 1.7.2008; Alta V. Bartolo, pendici a W del valico con l'Austria a sin. di Sella del Bartolo (Ugovizza), m 1200, 9447/1, 28.7.2012. PG: Vers SW del M. Matajur, m 1355, 9747/3, 14.8.2008.

A. micans Buser

Observations. Eurosiberian species that can be observed from the mountain to the alpine belt at an altitude that ranges between (950) 1300 and 2000 m, on wet areas by surface trapelation, silty, euthrophic, base-rich soils in plant communities such as *Calthion palustris*, *Polygono-Trisetion*, *Cynosurion* and *Adenostylion*.

Specimina selecta. AC: V. Pesarina: Pradibosco, m 1200, 9442/3, 18.7.1972, leg. F. Barbieri, TSB; V. Plecia (Ugovizza), m 1310, 94462, 16.7.2011. AG: Fusine in V. Romana, piana fra l'Alpe Tamer e l'Alpe del Lago, m 1000, 9547/2, 25.7.2008. PG: Salita da P.so di Tanamea a F.lla Kriš (Gran Monte), m 1200, 9746/1, 18.8.2012.

A. monticola Opiz

Observations. This eurosiberian *Alchemilla* is one of the most frequent species in the Friulian Alps. It shows a high variability in the hair-covering, with individuals from totally hairless (often confused with *A. subcrenata*) to densely hairy (confused with *A. glaucescens*) (Fröhner & al. 2012). In the region, it is found from the (low) mountain to the alpine belt between 800 and 2100 m, generally on moderately dry to humid, eutrophic, base-rich soils. It grows in dry grasslands of *Mesobromion* and *Seslerion variae*, relatively wet meadows (*Poion alpinae*, *Polygono-Trisetion*, *Cynosurion*,), banks of brooks (*Calthion palustris*) and forest fringes (*Adenostylion*).

Specimina selecta. PC: Punta del Mezzodì (Forni di Sotto) presso Cas. Chiampiuz, m 1690, 9642/1, 17.5.2015. AC: A SE di Cima Sappada, m 1300, 9442/1, leg. S. & C. Argenti, 16.6.2017, Hb Argenti; M. Dimon, m 1690, 9444/1, 10.9.2008; Nei pressi di Cas. Winkel (Pontebba), m 1480, 9445/2, 25.8.2014; Vers. S M. Capin di Ponente, Sella Cantore, m 1413, 9447/3, 24.8.2011. AG: Alta V. Romana fra la Portella e Sella Ursic lungo il sent. 511, m 1740, 9547/4, 13.8.2015; Sella Somdogna, m 1400, 9546/2, 1.9.2010. PG: V. Uccea, S. Anna di Carnizza, m 1110, 9646/3, 8.7.2011; Vers N del M. Matajur, presso Casere Tu v Dolin, m 1435, 9747/3, 14.8.2008.

A. obtusa Buser

Observations. It is an endemic species of the Alps, with only few known sites. In the western Carnic Alps it occurs in the mountain-alpine belts between 1300 and 2000 m. The species prefers wet to humid, loamy, eutrophic, base-rich soils of springs, rivulets (*Calthion palustris*, *Montio-Cardaminetalia*), bushes and forest fringes (*Adenostylion*). It can be confused with specimens of *A. glabra* with developed hair-covering, but *A. obtusa* is a more slender plant, with light blue-green leaves on the upper surface and mostly rounded teeth and not infrequently in some basal leaves the stipules are fused for 0.5-2 mm at the base (free in *A. glabra*).

Specimina selecta. AC: Cima Avroni (Forni di Sotto), m 1620, 9542/3, 24.8.1974, leg. L. Poldini, TSB.

A. propinqua H. Lindb. ex Juz.

Observations. Species of North-eastern Europe, whose Italian sites, disjointed from the main range, were hitherto known only for Trentino (Festi 2017). That of the Val Rauna (near Tarvisio) would constitute to date the eastern limit of the species on the Italian Alps.

Specimina selecta. AC: V. Rauna (Malborghetto), m 1090, 9446/4, 11.6.2013.

A. reniformis Buser

Observations. South European orophyte, is present in the Alps from the Maritime to Styria, as well as on Jura, Fichtelgebirge, Erzgebirge, Sudetes, Carpathians, North-western Balkan Peninsula, Bulgaria and Northern Apennines (Fröhner 1990, Kurtto & al. 2007). It grows in the mountain and subalpine belts between 1450 and 1900 m, on soils with variable contents in bases, also subacid, from moist to wet, mesotrophic, in grasslands, meadows and communities of tall herbs (*Nardion*, *Polygono-Trisetion*, *Adenostylion*).

Specimina selecta. AC: M. Tinisa, vers. N delle Forcelle, m 1670, 9542/3, 31.8.2009; Col Gentile, presso il laghetto di Cas. Forchia, m 1719, 9542/2, 19.8.2011.

A. straminea Buser

Observations. This south European orophyte can be observed throughout the Friulian Alps on moist to wet, base-rich soils, loamy, from eutrophic to mesotrophic. It prefers the mountain-alpine belts (but locally it can also be observed in the lower mountain belt) between (950) 1300 and 2300 m where it populates bogs and banks of streams (*Caricion ferrugineae*), meadows and grasslands (*Polygono-Trisetion*, *Poion alpinae*, *Nardion*, *Seslerion variae*), forest fringes (*Adenostylion*), dwarf shrubs communities (*Rhododendro-Vaccinion*).

Specimina selecta. PC: M. Borgà, vers. E, m 1800, 9740/1, 9.7.2008; M. Lovinzola, lungo la strada fra Sella Chianzutan e M. Verzegnis, m 1470, 9643/2, 22.8.2008. AC: Panoramica delle vette, sotto M. Neval, m 1950, 9443/1, 16.7.2008; Lanza [Pontebba], m 1870, 9445/1, 21.7.2009, leg. C. Genzo. AG: Greto del Rio del Lago a S di Cave, m 980, 9547/3, 5.8.2015; V. Resia, verso M. Guarda, m 1650, 9646/4, 6.7.2011. PG: Vers, N del M. Matajur, presso Casere Tu v Dolini, m 1435, 9747/3, 14.8.2008.

A. strigosula Buser

Observations. It is a South-West European orophyte that in our region is currently known for the western part of the Friulian Alps. The findings corroborate the historical citations of Gortani & Gortani (1905-06, 1981) from Casadorno (Rigolato) and Casera Talm (M. Talm), located a few kilometres SE of M. Neval (see *Specimina selecta*). It has been observed between 1400 and 2000 m on moderately dry to moist soils, silty, rich in limestone and eutrophic, in grasslands and meadows (*Seslerion variae*, *Polygono-Trisetion*).

This species could be easily confused with the closely related *A. subglobosa*, which has not yet been found in Friuli and which has a dark green colouration, at times suffused with violet, infundibuliform-plicated leaves, strongly wavy at the margin, with deep incisions (25-60%) and globose hypantium, largely rounded at the base, glabrous. *A. subglobosa* is known for Alto Adige / Südtirol (Wilhalm & al. 2006).

Specimina selecta. PC: M. Buscada, sopra la cava di marmo, m 1700, 9640/3, 9.7.2008; M. Lovinzola, lungo la strada fra Sella Chianzutan e M. Verzegnis, m 1470, 9643/2, 22.8.2008. AC: Vers. S del M. Pieltinis, m 1920, 9542/1, 31.7.2013; Strada panoramica delle vette, sotto M. Neval, m 1950, 9443/1, 16.7.2008; M. Dimon, m 1775, 9444/1, 10.9.2008.

A. subcrenata Buser

Observations. Species with eurosiberian distribution, of the mountain-alpine belts, locally observed between 1100 and 2000 m, it grows in wet to humid soils, silty, rich in limestone or in bases, eutrophic. It is found in grasslands and meadows (*Poion alpinae*, *Polygono-Trisetion*), vegetation of springs and in the banks of streams (*Calthion palustris*), shrubs and forest fringes (*Adenostylion*).

Specimina selecta. PC: M. Borgà, vers. E, m 1800, 9.7.2008. AC: M. Tinisa, prati di Cas. Tintina, m 1500, 9542/3, 31.8.2009; Vers. W di Quota Pascoli presso il laghetto Pera (F. Avoltri), m 1950, 9342/4, 8.8.2014; Costa Robbia (Ligosullo), m 1410, 9444/2, 8.8.2008, leg. V. Casolo.

A. tirolensis Buser ex Dalla Torre & Sarnth.

Observations. Orophyte of the Eastern Alps with disjunction on the Swiss Jura (Hügin & al. 2009), has recently been removed from the category of species indicated by Poldini & al. (2001) as chorological doubts.

It frequents the mountain-alpine belts (1100-2000 m) on eutrophic, humid, loamy, bases-rich soils in grasslands and meadows referable to *Poion alpinae*, *Nardion* and *Polygono-Trisetion*.

Specimina selecta. PC: V. Zemola (Erto), salita da Stalle Mola a Cas. Bedin di Sopra, m 1520, 9640/3, 17.7.2013; M. Costa Paladin, vers. N a SW di Cas. Fors, m 1530, 9642/4, 31.8.2013. AC: M. Tamai, vers. W, m 1930, 9543/2, 1.8.2009. AG: Piani del Montasio sotto Cima Gambon, m 1580, 9546/4, 5.7.2011; V. Resia sotto M.ga Coot, m 1100, 9646/4, 6.7.2011.

A. undulata Buser

Observations. Endemic to the Alps and the northern and central Apennines, the species appears on the mountain-alpine belts between (1300) 1600 and 2300 m. It is found on humid to wet, humic and base-rich soils, eutrophic, in different habitats: grasslands and meadows (*Poion alpinae* and *Polygono-Trisetion*, for instance), humid environments (*Calthion palustris*, *Caricion ferrugineae*), forest fringes (*Adenostylion*), communities of tall herbs of alpine huts (*Rumicion alpini*).

Small specimens may be confused with *A. decumbens*, but the latter is recognizable because usually has less developed hair-covering particularly on the leaf page and the basal leaves have fewer teeth and are never stellate.

Specimina selecta. PC: M. Borgà, vers. E, m 1800, 9740/1, 9.7.2008. AC: Alta V. Fleons, passo Sesis, m 2260, 9342/3; Vers. S di Cima Madrizze sopra Cas. Winkel (Pontebba), m 1800, 9445/2, 25.8.2014. AG: M. Canin, vers. E di Sella Grubia, m 2050, 9646/2, 17.8.2009. PG: Bacino superiore del Torr. Bruschie, sotto Forca di Campidello, m 1300, 9645/3, 26.5.2015.

A. venosula Buser

Observations. It is a widespread species in the Alps, from the Bergamasque Alps to the Karavanks, it populates the mountain-alpine belts in wet to humid, silty, seldom weakly acid, mesotrophic, base-rich soils. Currently in the Friulian Alps is known only for the site indicated below. For a comparison of characters among other morphologically related species (*A. connivens*, *A. fallax*, *A. fissa*) see the tables in Fröhner & al. (2012).

Specimina selecta. AC: Sopra il Rif. Chiampizzulon (Rigolato), m 1750, 9442/2, 3.8.2013, leg. C. Lasen, Hb Lasen.

A. versipila Buser

Observations. It is a species diffuse especially on the northern slope of the Alps and on the southern Jura (Fröhner & al. 2012). It grows particularly on calcareous soils in grasslands, scree slopes of small grain size, forest fringes. The collection site lies at a short distance from the border with Carinthia, making it plausible that even the sample of uncertain attribution collected at Mauthner-Alm (Fröhner 1990) may be referred here.

The difficult distinction from *A. glabra* makes the collection and careful review of samples essential (Festi 2017).

Specimina selecta. AC: Timau, dintorni di Cas. Pramosio, m 1520, 9444/1, 1.7.2008.

A. xanthochlora Rothm.

Observations. It is a Central European element, widespread in the Friulian Alps, it is found within the (low) mountain-alpine belts between (900) 1300 and 2300 m of altitude in wet to humid, silty, rich in limestone or in bases eutrophic soils. It is a species that populate meadows and pastures (*Poion alpinae*, *Polygono-Trisetion*, *Cynosurion*, for instance), humid environments (*Calthion palustris*, *Filipendulo-Petasition*) and forest fringes (*Adenostylion*).

Specimina selecta. PC: V. Zemola (Erto), salita da Stalle Mola a Cas. Bedin di Sopra, m 1550, 9640/3, 17.7.2013; Vers. N del M. Costa Paladin, a E di Forca del Mugnol, m 1480, 9642/3, 31.8.2013. AC: Alta V. Fleons, passo Sesis, m 2260, 9342/3, 25.7.2013;

Sopra sella Tamai, m 1850, 9543/2, 1.8.2009; Salita da Sella Poludnig al M. Poludnig, m 1545, 9446/1, 6.8.2014. AG: Conca di Fusine, vers. W della Ponza Grande, m 1280, 9548/1, 25.7.2008; Salita a Sella Mogenza dal Rio del Lago, m 1520, 9647/1, 5.8.2015. PG: M. Glava (Matajur), vers. SW, sent. 736, m 1360, 9747/3, 23.6.2012; Colovrat, sotto M. Nagnoj, lungo la strada, m 1190, 9847/2, 4.10.2014.

Discussion and conclusion

The genus *Alchemilla* in the Friulian Alps is currently encompassing by 33 species, to which is added *A. coriacea* of which exists an unconfirmed historical bibliographic data of Gortani (1981) for M. Varmost (Carnic Alps).

The most represented sections are sect. *Alchemilla* with 12 species and sect. *Plicatae* with 7 species. *Alchemilla carniolica*, *A. filicaulis*, *A. glomerulans*, *A. hirtipes*, *A. propinqua*, *A. venosula* and *A. versipila* occurred in a single population, while *A. monticola*, *A. flabellata*, *A. connivens* and *A. xanthochlora* were the most common species, having more than 40 records on average.

From the chorological point of view, we observe the predominance of the orophytes, in particular South-European (12 species), of the endemic, in particular alpics (8), and finally of the Eurosiberian elements (6).

The distribution of *Alchemilla* species richness in the Friulian Alps (Fig. 1), even if still lacking in some zones, reveals that the maximum number of taxa occurs in the western Main Carnic Chain, where a maximum of 13 species is reached in the quadrants 9444/1 (M. Paularo) and 94443/1 (M. Crostis). Southernmost, similar values are found in the quadrants 9443/4 (M. Zoncolan), 9543/2 (Group M. Arvenis-Tamai) and 9542/3 (M. Tinisa). In the Julian Alps the highest values are found in the quadrants 9546/4 (Jof di Montasio-Jof Fuart groups), 9646/2 and 9646/3 (Group of M. Canin). In the Julian Pre-Alps the maximum value is reached on M. Matajur (9747/3), while on the Carnic Pre-Alps the peak can be observed on the chain M. Duranno-M. Borgà (9640/3, 9740/2). This distribution pattern indicates some gaps to fill, the most meaningful of which concerns the group of the M. Cavallo of Pordenone, that it still appears insufficiently investigated.

However, as Fröhner & al. (2012) pointed out, while along the northern foot of the Alps many species penetrate deeply into the Alpine foreland, descending at very low altitudes, on the southern Alps, in particular in the pre-alpine sectors, this occurs with low frequency. As well as in the mountains of the Lombard Pre-Alps, also in Friuli the limit of southern diffusion of the genus seems to stop in the mountain belt around the 900-1000 m, with descents at lower altitudes in the northern slopes. A further limit to the diffusion of *Alchemilla* in Friuli is linked to the scarce diffusion of siliceous substrata, which favour the formation of humid environments (springs, banks of brooks, marshy areas, humid meadows, alder and willow shrubs, etc.). In fact, humid habitat represent the ecological optimum for many species (e.g *A. acutata*, *A. effusa*, *A. glabra*, *A. micans*, *A. subcrenata*, *A. xanthochlora*, etc.). On the other hand, the large diffusion of carbonate substrates in the pre-alpine area, with their high permeability, represent a limiting factor together with the lowering of the less average altitudes. Species linked to carbonate substrates are considered for example *A. alpinula*, *A. colorata*, *A. crinita*, *A. flabellata* and *A. leptoclada*.

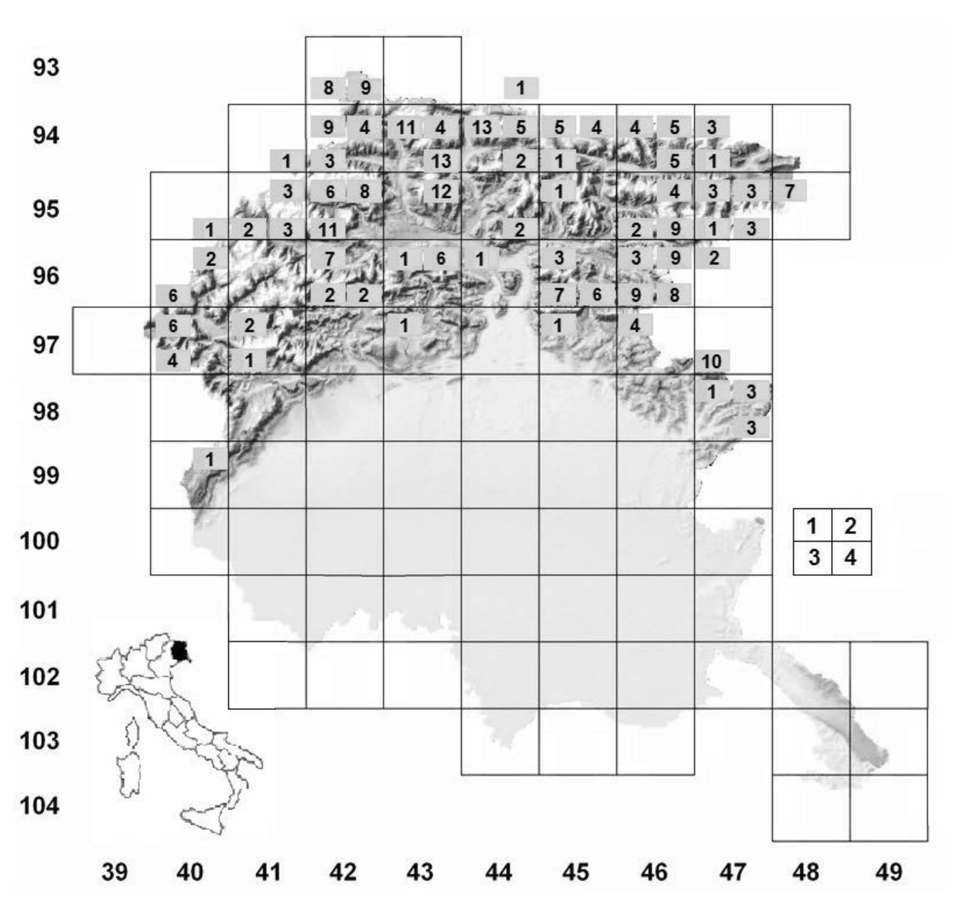

Fig. 1. Distribution of species richness of the genus *Alchemilla* in the Friulian Alps according to the adopted grid.

On the eastern side of the Region (Natisone Valleys) the wide diffusion of the sandstone substrata and the presence of wet ravines, itself favourable to the presence of *Alchemillae*, is contrasted by the relatively modest altitude and the diffusion of woods, whose expansion in recent decades has been greatly facilitated by the abandonment of the management of meadows and pastures.

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References

Argenti, C., Masin, R., Pellegrini, B., Perazza, G., Prosser, F., Scortegagna, S. & Tasinazzo, S. 2019: Flora del Veneto dalle Dolomiti alla laguna veneziana, **1-2.** – Sommacampagna (VR).

Bovio, M. & Festi, F. 2014: Alchemilla L. – Pp. 257-267 in: Bovio, M., Flora vascolare della Valle d'Aosta. – Sarre (AO).

Ehrendorfer, F. & Hamann, U. 1965: Vorschläge zu einer floristischen Kartierung von Mitteleuropa. – Ber. Deutsch. Bot. Ges. **78:** 35-50.

Feoli Chiapella, L. & Poldini, L. 1986: Contributi floristici dal Friuli-Venezia Giulia. – Gortania. Atti Museo Friul. Storia Nat. **7(1985):** 189-222.

Festi, F. 1998: Chiave d'identificazione per le specie italiane del genere *Alchemilla* L. (*Rosaceae*). – Ann. Mus. civ. Rovereto, Sez.: Arch., St., Sc. nat. **14:** 105-174.

— 2017a: *Alchemilla* L. – Pp. 768-799 in: Pignatti, S. (ed.): Flora d'Italia, 2° ed, **2.** – Milano.

— 2017b: *Alchemilla* L. – Pp. 133-179 in: Pignatti, S. (ed.): Flora d'Italia, 2° ed, **2.** – Milano.

—, Lasen, C., Prosser, F. & Argenti, C. 2015: Contributo alla conoscenza del gen. *Alchemilla* L. sulle Alpi Italiane: province di Belluno, Trento e Verona. – Ann. Mus. civ. Rovereto, Sez.: Arch., St., Sc. nat. **30(2014):** 221-289.

Fröhner, S. E. 1990: *Alchemilla* L. – Pp. 13-242 in: Hegi, G. (Begr.): Illustrierte Flora von Mittel-Europa, **4/2 B** – Berlin, Wien.

— 2012: Drei neue Alchemilla-Arten (*Rosaceae*) aus den Alpen von Österreich, Schweiz und Italien. – Carinthia II **202/122:** 53-70.

—, Bona, E., Federici, G. & Martini, F. 2012: Contributo alla conoscenza del gen *Alchemilla* sulle Alpi Italiane: Alpi Retiche Meridionali, Prealpi Lombarde Centrali e Orientali. – Inform. Bot. Ital. **44(1):** 3-73.

Gortani, L. & Gortani, M. 1905-06: Flora friulana con particolare riguardo alla Carnia. – Udine.

Gortani, M., 1981: Supplemento a "Flora Friulana con speciale riguardo alla Carnia". Note postume. – Pubbl. Museo Friulano di Storia Naturale, **29.** – Udine.

Hartl, H., Kniely, G., Leute, G. H., Niklfeld, H. & Perko, M. 1992: Verbreitungsatlas der Farn- und Blütenpflanzen Kärntens. Naturwissenschaftlicher Verein für Kärnten. – Klagenfurt.

Kurtto, A., Fröhner, S. E. & Lampinen, R. 2007: Atlas Florae Europapaeae, **14.** – Helsinki.

Lasen, C. 2019: 101. *Alchemilla filicaulis* Buser (*Rosaceae*). – Pp.35 in: Martini, F. (a cura di), Aggiornamenti alla flora del Friuli Venezia Giulia (Italia nord-orientale). Nuova serie. IV (85-117). – Gortania. Atti Museo Friul. Storia Nat. Botanica, Zoologia, **41(2019).**

Mainardis, G. & Simonetti, G. 1991: Flora delle Prealpi Giulie nord-occidentali tra il fiume Tagliamento ed il gruppo del M. Canin. – Gortania, Atti Museo Friul. Storia Nat. **12(1990):** 31-236.

Martini, F. (ed.), Bona, E., Danieli, S., Fantini, G., Federici, G., Fenaroli, F., Mangili, L., Perico, G., Tagliaferri, F., & Zanotti, E. 2012: Flora vascolare della Lombardia centro-orientrale, **2.** – Trieste.

Mezzena, R. 1986: L'erbario di Carlo Zirnich (Ziri). – Atti Mus. civ. Stor. nat. Trieste **38:** 1-519.

Poldini, L., Oriolo, G. & Vidali, M. 2001: Vascular flora of Friuli Venezia Giulia. An annotated catalogne and synonimic index. – Studia Geobot. **21:** 3-227.

—, — & — 2002: Nuovo Atlante corologico delle piante vascolari nel Friuli Venezia Giulia. – Udine.

Wilhalm, T., Niklfeld, H. & Gutermann, W. 2006: Katalog der Gefäβpflanzen Südtirols. – Veröffentlichungen des Naturmuseums Südtirol, **3.** – Wien/Bozen.

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Forty years of symphenological research in a submontane calcareous beech forest under the influence of climate change

Abstract

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An annual phenological survey was carried out between 1981 and 2020 in a mesic beech forest on limestone (*Hordelymo-Fagetum lathyretosum*) in Germany. Symphenological groups of species were defined according to concurrent flowering times. Using these groups, the vegetation period was subdivided into 9 phenophases, which are a refinement of the flowering waves introduced by Sandro Pignatti for European beech forests. For the three spring phases 2, 3 and 5 the starting time was analysed for a period of 40 years. Despite obvious fluctuations from year to year, the phases tended to start earlier, often in all phases in a synchronous manner. The extension of the vegetation period by 10-11 days is a striking sign of climate change. Finally, 60 years of cooperation and joint experiences of Sandro Pignatti and Hartmut Dierschke are briefly commented on.

Key words: biomonitoring, long-term data, phenophases, plant phenology, symphenological groups, Germany.

Introduction

Starting with Lausi & Pignatti (1973), the first extensive results of symphenological studies were published for beech forest communities, collected by an European observation network (see also Marcello & Pignatti 1965; Pignatti 1972). Already in 1962, during the International Symposium on the Syntaxonomy of Beech Forests in Stolzenau, Pignatti suggested to analyze phenological observations in an European framework. He himself was influenced by A. Marcello from Venice, who carried out plant phenological research and thus provided the basis for Pignatti's work (Marcello 1954). Thus, soon after a call for international cooperation was started. Including the work of vegetation scientists from 14 countries, 1963 datasets were gathered for 204 plots from southern Sweden over central Europe to northwest Italy and eastern Catalonia, as well as south-east Europe. Results were collected in Trieste and electronically analysed using the local computer center. Many forest plots (33) belonged to the beech forest community *Melico-Fagetum.*

The datasets included observations for more than 500 species, 67 of which occurred in more than 10 plots (see also Lausi & Pignatti 1973). The symphenological investigations were concentrated on flowering waves, as well as on periodicity of beech leaves, each very complex and across large latitudinal and altitudinal gradients. This laid the foundations for a scientific branch dealing with annual vegetation rhythms: symphenology (Marcello 1953a; Dierschke 1994).

In contrast to the study of Lausi & Pignatti (1973), I (HD) followed a geographically narrow attempt for a phenological survey since the 1970s, starting with the observation of single stands in the surroundings of Göttingen (Germany). Since 1981, the efforts were concentrated on a single large forest area hosting a mesophilous beech forest stand over limestone. Here, rule-based phenological sequences were identified and generalized. Concerning their concurrent start of flowering, several symphenological species groups were distinguished, used for defining 9 phenophases (Dierschke 1982). The period since 1981 covers times of starting and increasing climate changes, which had an impact on temporal shifts of the phenophases (Dierschke 2000; Heinrichs & al. 2018; Dierschke & Becker 2020). This work summarizes methods and results.

Symphenological groups and phenophases of deciduous forests

The general course of flowering in the herb layer of species-rich beech forests is known since a while (see e.g. Ellenberg 1939). A large-scale summary was first published by Lausi & Pignatti (1973), a recent update was given by Leuschner & Ellenberg (2017). Lausi & Pignatti (1973) recognized several flowering waves of concurrently flowering species. Dierschke used these waves for refining symphenological species groups (species with concurrent flowering; Dierschke 1983, 1994, 1995) and specified them for deciduous forests of central Europe (Dierschke 1982, 1989a).

A short overview of the phenophases and relevant indicators are given in Table 1. The names of the phases are combinations of a woody and a herb species. While the *Corylus-Leucojum*-phase (1) is not easily separable because of the few flowering species, the *Acer-Anemone*-phase (2) starts with a well-recognizable flowering wave of light-depending early spring bloomers (start of spring; Fig. 1 and 2), reaching a flowering maximum in the *Prunus-Ranunculus auricomus*-phase (3) (Fig. 3) and coming to an end when completely unfolded leaves of the trees lead to shady conditions (phase 4). During the *Sorbus-Galium odoratum*-phase (5) a transition towards full shade in the herb layer takes place, where the flowering of *Allium ursinum* can be prominent (Fig. 4). In early summer (phase 6), a new wave of flowering starts in constant shade, but with a constantly decreasing number of flowering plants. Almost all spring geophytes have disappeared, and summer plants now dominate the fragmentary herb layer. In late summer, the *Hedera-Solidago*-phase (9) brings only a few newly flowering species. Following vegetative changes like autumnal colours and defoliation of woody species, the last two phases, autumn (10) and winter (11) can be separated.

Start and duration of phenophases shift with weather changes, especially due to the course of temperatures from late winter to early spring. Thus, start and duration of the phases are different from year to year, and make sensitive indicators for changes in weather and climate. In particular, the spring phases 1-5 shift parallel to continuously rising annual temperatures, and can be used as climate indicators (Dierschke 2000).

Fig. 1. Phenological research area: ca. 145 years old beech forest. *Acer platanoides-Anemone* phenophase (11.04.2011).

Fig. 2. Part of the phenological permanent plot in phenophase 2. *Anemone nemorosa* and *A. ranunculoides* in flower, big leaves of *Allium ursinum*.

Fig. 3. *Prunus-Ranunculus auricomus* phenophase. Herb layer with flowers of *Anemone nemorosa*, *Euphorbia amygdaloides* and *Lathyrus vernus* (20.04.2011).

Survey area and methodology

In 1980 within a species-rich, 145-150 years old beech forest east of Göttingen, a larger permanent plot was installed for phenological investigations (Fig. 1).

It is located at the coordinates N 51° 32'/ E 10° 03' near the edge of a limestone plateau, at about 420m, under suboceanic to submontane climate conditions (mean annual temperature 7.4° C, sum of precipitation 709 mm; see also Heinrichs & al. 2018; Dierschke & Becker 2020).

The forest can be identified as *Hordelymo-Fagetum lathyretosum* following Dierschke (1989b) as part of the former *Melico-Fagetum* (see also Leuschner & Ellenberg 2017).

For a better recognition of the indicator species in the dense herb layer, tags with labels were placed (Fig. 2). To integrate as many species as possible, beside the inner part of the forest a light forest edge along a path was also surveyed.

Since 1981, phenological surveys were carried out continuously.

A specific key was developed for woody species, herbs and grasses, defining 11 stages of vegetative and generative development (Dierschke 1972, 1989c, 1994).

For every day of the survey, vegetative and generative stages of all species were

Fig. 4. *Sorbus-Galium odoratum* phenopase with flowering aspect of *Allium ursinum* (9.05.2011).

noted, once a week in the first years, after more variable periods later on. Species were assigned to symphenological groups according to their start of flowering (Table 1). Phenological phases were defined in days of the year. The results comprise observations for the years 1981-2020 for the three characteristic phases of spring (2, 3 and 5). Fig. 5 shows the starting time of these three phases, compared to the mean values of all 40 years.

The plot was produced using R version 4.03 (R Core Team 2020). A Kruskal-Wallace test using groups of five and ten years was performed using the R package ‘pgirmess’ (Giraudoux 2018).

Some basic statistical values for the period of 40 years are shown in Table 2.

Table 1. Spring and summer phenophases of species-rich deciduous forests and their flowering herbaceous species in the research area

1 *Corylus avellana-Leucojum vernum*-Phase

Hepatica nobilis, *Leucojum vernum*

2 *Acer platanoides-Anemone nemorosa*-Phase

Anemone nemorosa, *A. ranunculoides*, *Asarum europaeum*, *Corydalis cava*, *Mercurialis perennis*, *Primula elatior, Pulmonaria obscura*

3 *Prunus avium-Ranunculus auricomus*-Phase

Euphorbia amygdaloides, *Lathyrus vernus*, *Oxalis acetosella*, *Ranunculus auricomus* agg., *Viola reichenbachiana*

4 *Fagus sylvatica-Galeobdolon luteum*-Phase

Alliaria petiolata, *Cardamine bulbifera*, *Carex sylvatica*, *Galeobdolon luteum*, *Ranunculus lanuginosus*, *Stellaria holostea*

5 *Sorbus aucuparia-Galium odoratum*-Phase

Allium ursinum, *Arum maculatum*, *Galium odoratum*, *Geranium robertianum*, *Polygonatum multiflorum*, *P. verticillatum*, *Veronica montana*, *Vicia sepium*

6 *Cornus sanguinea-Melica uniflora*-Phase

Aconitum vulparia, *Geum urbanum*, *Impatiens parviflora*, *Melica uniflora*, *Phyteuma spicatum*, *Sanicula europaea*

7 *Ligustrum vulgare-Stachys sylvatica*-Phase

Aegopodium podagraria, *Hordelymus europaeus*, *Lilium martagon*, *Stachys sylvatica*

8 *Clematis vitalba-Galium sylvaticum*-Phase

Brachypodium sylvaticum, *Campanula trachelium*, *Circaea lutetiana*, *Dactylis polygama*, *Galium sylvaticum*, *Hypericum hirsutum*

9 *Hedera helix-Solidago virgaurea*-Phase

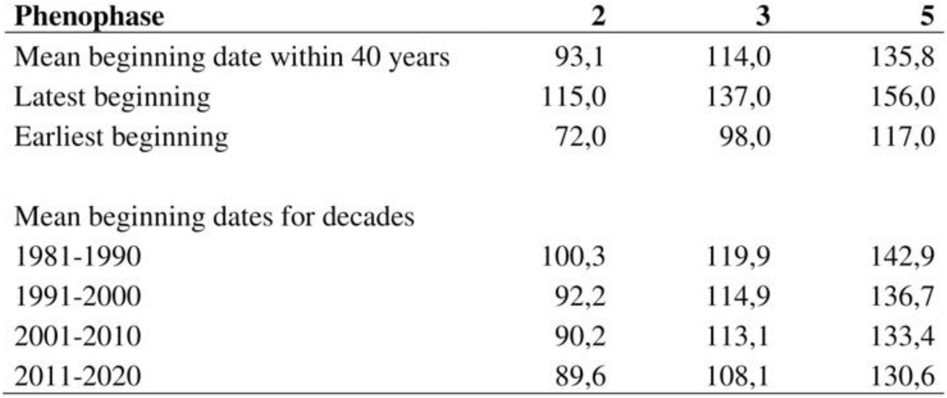
Without new flowering plants in the research area

Results

The start of the phenological phases of spring (2, 3 and 5) depends, beside internal vegetation rhythms, on the weather of the previous months, especially on temperatures. Figure 5 shows striking changes from year to year. A precise analysis shows a continuously earlier start for all phases compared to the 40-year mean. In Table 2, some critical statistical values are presented. Comparing the ten-year means of the first two decades for the *Acer platanoides-Anemone*-phase (2), an advance of 8 days can be observed. In later decades, the advance is less striking. In total, an earlier start of 11 days (from 9th April to 30th March) can be recognized for the period 1981-2020, which is similar to that of the *Prunus avium-Ranunculus auricomus*-phase (3), (9 days earlier, 26th to 17th April), and the *Sorbus aucuparia-Galium odoratum*-phase (5) (11 days, 22nd to 11th May). The amplitude of the variance in starting dates is highest in phase 2 with 43 days, as a result of cold temperature setbacks in some years (12th March to 24th April). In phases 3 and 5, the amplitude is 39 days (7th April to 16th May, and 26th April to 4th June). Shifts of the starting dates of the three phases usually happen simultaneously, i.e. the beginning of phase 2 is crucial for the start of the following spring phases. Some shifts to a later start of phases 3 and 5 are due to earlier cold air events in that year.

Even more striking is the comparison of the starting dates of each phase within the decades when the number of later or earlier starts are considered. From 1981 to 1990, late starting dates dominate (phases 2 and 3 in seven years, phase 5 in eight years), along with harsh winters with long-lasting snow covers. This was the case especially for the years 1983/84 and 1986/87. The latest start of phase 2 was in 1984 (24th April). In recent years, late starting dates were rare, with the exception of 2006. Already in the period 1991-2000, 4 to 5 years had an earlier start of phase 2, while in 2001-2010, 6 earlier years were recorded, and in the last decade 7-8 earlier years. Because the changes of the starting day from year to year were strong, there was no statistically significant trend for 5- and 10-year periods.

Table 2. Some dates of the beginning of phenophase 2, 3 and 5.



Phenophase	2	3	5
Mean beginning date within 40 years	93,1	114,0	135,8
Latest beginning	115,0	137,0	156,0
Earliest beginning	72,0	98,0	117,0
Mean beginning dates for decades			
1981-1990	100,3	119,9	142,9
1991-2000	92,2	114,9	136,7
2001-2010	90,2	113,1	133,4
2011-2020	89,6	108,1	130,6

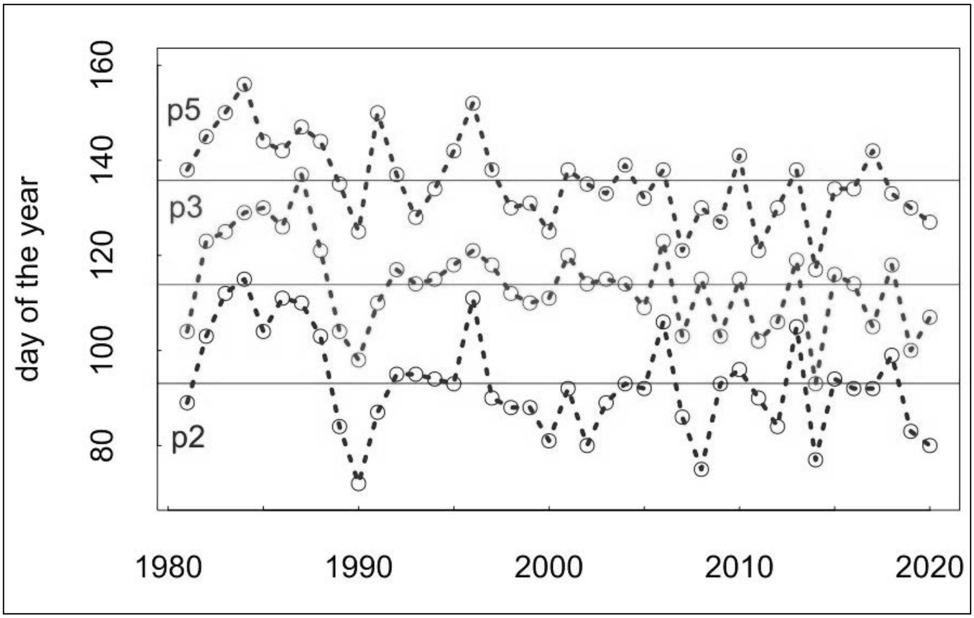


Fig. 5. Beginning of the phenophases p2, p3 and p5 and mean values 1981-2020.

Discussion

Symphenological species groups

In plant communities, species groups with common behaviour can be distinguished, such as the sociological species groups used in syntaxonomy (Dierschke 1994). Often used are also ecological species groups as indicators for stand conditions (for forests: Leuschner & Ellenberg 2017). Chronological changes in vegetation development can be characterized and detected by symphenological species groups, which aggregate species with nearly similar phenology (Dierschke 1994). Both vegetative and generative developments are used as criteria. Vegetative criteria are e.g. leaves turning green in spring, full leaf development in the canopies, as well as autumn colouring and defoliation at the end of the vegetation period. A characteristic sign of vegetation development is the concurrent flowering of herb species, as shown in the present study. Its analysis shows, especially in species-rich forests, a typical, annually-repeating sequence of phenophases (Dierschke 1982). Within each phase, the species usually reach their full flower development, while their whole flowering period may extend also into the following phases, so that the sum of flowering species is higher in each phase.

When these phases are generally known, symphenological species groups can be compiled over large areas as well. Altogether, it became obvious that they keep stable across large spatial and long time-scales, being well suitable to separate certain phenophases (Dierschke 1982, 1994). It is interesting that phenophases initially observed in forests do also occur in open habitats, especially in several grassland communities (Dierschke & Briemle 2002). So, for central Europe 1577 plant species of low to middle altitudes, corresponding to the beginning of their flowering time, were assigned to nine phenophases which were first identified in forests (Dierschke 1995). For deciduous forests, 340 species applied in this context. In the herb layer, 7 species start flowering in phase 1, 33 in phase 2, 22 in phase 3, 20 in phase 4, 46 in phase 5, 37 in phase 6, 26 in phase 7, 38 in phase 8, and 4 in phase 9. In summary, in spring (phases 1-5) the forests host 95 newly flowering species, in early summer (phases 6-7) 63, in high summer 38, and in early autumn only four. Altogether, nature offers an extensive inventory for phenological characterization and separation of different time periods, whereas in every forest stand only a small proportion occurs (table 1). The flowering order of phenological groups is rather constant across large areas and altitudes (Leuschner & Ellenberg 2017), so that even landscapes with a diverse vegetation mosaic can be classified by seasons according to the order of geophenophases (Dierschke 2015).

Flowering waves and phenophases

The rhythmic phenological changes in the course of the year are very obvious and long-known for species-rich deciduous forests; already Ellenberg (1939) roughly separated three main flowering phases in northwestern Germany. His phenological spectrum contains a phase of 9 spring green species, and 2 phases of early and late flowering summer green species, with 21 and 13 species respectively. In addition, there is a group of 14 winter green species most of which flower in spring. This corresponds approximately with the three flowering waves described by Pignatti (1972) and Lausi & Pignatti (1973) for the European beech forests: a heliophilous wave in April/May, followed by a first and a second wave of shade tolerant species in June and July. Our own finely separated phases (Table 1) can be assigned accordingly. The first heliophilous phase by Lausi & Pignatti (1973), during which trees are still bare, corresponds to our phases 1-4. Phase 5 is a transition to early summer, the forest ground being shady, but many species could benefit from the previous availability of light. This applies to the spring geophytes of our study area; *Allium ursinum, Arum maculatum, Polygonatum multiflorum* and *P. verticillatum*. *Allium ursinum* belongs to the first species sprouting in spring, developing leaves and flower buds in phases 3-4.

During flowering, its leaves begin to wilt already, parallel to those of several other spring geophytes (see also Heinrichs & al. 2018). So we consider this first phase with shade of the canopy (5) as the end of spring. Generally, the beginning of the phases is often influenced by the start of the second phase (Fig. 5). The second shade-tolerant flowering wave of Lausi und Pignatti (1973) is almost congruent with our phases 6-7, which are mostly dominated by flowering hemicryptophytes. Phase 8 makes the long summer phase, only vaguely separable in Lausi & Pignatti (1973) and also in our studies. Already Dierschke (1982, 1994) described such flowering waves for the *Melico*-F*agetum*, where in spring (phase 1-5) 22 species were flowering, in early summer (6-7) further 9 species, and in high summer only 4 species.

Phenophases, biomonitoring und climate change

The dependency of annual periodicity of plant development from weather conditions was recognized already in earlier times. According to Schnelle (1955), Karl von Linné (Linnaeus) can be considered as the founder of systematic phenological observations and of phenology itself as a discipline. Starting in the mid of the 18th century, he established a phenological observation network in Sweden (for the historical development of plant phenology see Schnelle 1955, Dierschke 1994). In Germany, observation networks were established, maintained and analysed by the German weather service (*Deutscher Wetterdienst*, e. g. Kolbe & Kaiser-Weiss 2015). Plants can be used as bioindicators for the sum of weather events, also for displaying climate changes over longer time. For German observers, form-sheets with species lists are provided, on which the development of certain stages like leaf unfolding, start of flowering, full flowering etc. are noted. Data analysis for certain times and/or areas can deliver starting dates for phenological phases (Schnelle 1955). Such events are visualised for many contributing regions of the continent in the data viewer of the pan-European phenology database (http://www.pep725.eu/), where also updated publications can be downloaded.

The approach followed by Dierschke uses symphenological species groups for this kind of climate monitoring. Not every species has the same reaction in each year, so that several synchronously flowering species can give more robust results for monitoring weather and climate changes (Dierschke 2000). However, this approach is less innovative than originally thought, as according to Schnelle (1955), already Marcello (1953a-b) proposed the use of species groups in Italy in the 1940s and perhaps even introduced the term symphenology. Obviously influenced by Marcello, Lausi & Pignatti (1973) recognized symphenological species groups, analysing their start of flowering over large areas of Europe in a pioneer attempt of a large-scale symphenological monitoring. Wilmanns (in Dierschke 1972) had called upon an international symphenological observation network for standard plant communities already in 1970. Unfortunately, this approach was not followed, and up to now nothing comparable was installed. Observation plots do not necessarily have to be far from settlements, and can be even installed in botanical gardens. Dierschke (2016) showed that starting times of phenological groups in the Old Botanical Garden in Göttingen and in his own private garden are similar to those of a permanent plot in a distant forest, although they start earlier due to lower altitude and sheltered urban conditions.

The complex influences on periodic vegetation rhythms are not fully understood yet: as a basis for phenological phenomena and their deviations, Leuschner & Ellenberg (2017) mention the temperatures of soil and soil water, day length and genotypes, beside the course and the sum of air temperatures. After 40 years of phenological observations in our survey area, the spring phases 2-5 started 10-11 days earlier.

The start of the *Acer platanoides-Anemone nemorosa*-phase (phase 2) was often decisive for the later course (Fig. 5). Decadal means (Table 2) started earlier in the first years (even 8 days between the first and the second decade for phase 2). Since 1989, a period of mild winters and an early beginning of the vegetation period begun (Dierschke 2000). So the earliest beginning of phase 2 from 1981-2020 was on March, 12th 1990, with correspondingly early starts of the following phases. Later, the trend of continuous warming proceeded (Schönwiese 2020), but the tendency to earlier phenophases became weaker, perhaps because the length of days limits this development. Also, drought damage in the previous vegetation period might have played a role.

Further studies used the phenological data from our research area (already Dierschke 2000). According to Heinrichs & al. (2018), between 1981-1990 and 2008-2017 the growing season for *Allium ursinum* was extended from 51.5 to 57.2 days in this area. Further data and interpretations can be found in Dierschke (2016), and in Dierschke & Becker (2020).

In their meta-study Menzel & al. (2006) analysed large datasets of phenological observations from all over Europe. For the period 1971-2000, earlier leaf unfolding and flowering of 2.5 days per decade applied, which suits to our observations until 2020. According to Menzel & al. (2006), most phases are correlated with mean temperatures of the last and the previous months. The results indicate changes in spring and summer phenology across the continent. Similar results were published by Kolbe & Kaiser-Weiss (2015), who analysed the period 1951-2012 for Germany. In spring and summer, clear correlations apply for the beginning of certain phases and air temperatures, including those from the previous months. Especially since 1981, earlier beginnings of the phases were visible. Ge & al. (2014) compared phenological observations from China, Japan and Switzerland, showing very similar trends across the three areas. The latter example shows, that effects are indeed global. Recent developments for phenological observations use automatic visual interpretation of either repeated camera monitoring or remote sensing with satellite data (Nijland & al. 2016; Bórnez & al. 2020; Misra & al. 2020). Such approaches are promising for delivering continuous large-scale measures, but need maintenance, calibration and ground validation by trained experts. Symphenological groups could be used also in this context.

Personal notes of H. Dierschke

I know Sandro Pignatti since 60 years; initially we were affiliated as colleagues, later as friends. As a young student, in spring 1961 I worked for Reinhold Tüxen at the Federal Institute for Vegetation Mapping (*Bundesanstalt für Vegetationskartierung*) in Stolzenau. Just at this time a Symposium of the International Association for Vegetation Science (IAVS) about “anthropogenic vegetation” took place. More than 100 participants from 14 countries came together, from Italy L. Fenaroli, S. Gentile, V. Giacomini, E. Marchese-Poli and E. & S. Pignatti. That is where I met Erika and Sandro for the first time. Sandro impressed with a presentation on “*Polyploidie-Verhältnisse der anthropogenen Pflanzengesellschaften und Vegetationsserien*“ (Pignatti 1966). Many further common conferences of the IAVS followed until 1969 in Stolzenau, then until 1981 in Rinteln and later in other places like Corrientes (1983), Bailleul (1985, 1994), Uppsala (1989), Warsaw (1990), Eger (1991), Shanghai (1992), Santa Cruz de Tenerife (1993), Nagano (2000), and Naples (2003), were Sandro repeatedly attracted attention by innovative ideas and activities. All his contributions in Stolzenau and Rinteln were published (Pignatti 1966, 1968 a/b, 1972, 1978, 1980, 1981; Pignatti & Pignatti 1966, 1982; Christofolini & al. 1970; Pignatti & al. 1977; Lausi & al. 1979). Several times he was a session president of the meetings, and in 1969 he gave the laudatory speech for Reinhold Tüxen’s 70th birthday. In 1988 he was the organizer of the 31. IAVS symposium in Frascati about “Spontaneous vegetation in settlements” with participants from 18 countries (Ubrizsy Savoia 1989). – We spent together several long IAVS excursions, such as those in Japan (1974, 1984 and 2000), Argentina (1983), Southwestern Australia (1990), Eastern China (1992), etc. I also have a good memory of the well-organized excursions by Franco Pedrotti and his staff in central Italy in 1982, when we walked longer sections of the ways through the Apennines side by side.

As a successor of Heinz Ellenberg, Sandro Pignatti was president of the IAVS between 1986 and 1994. At the same time I was secretary general, and we worked together in a productive and friendly way. In 1991, Sandro was one of the initiators of a new international cooperation of vegetation scientists, the “European Vegetation Surveys” (EVS). He organized, led and inspired small and later larger meetings of geobotanists in the Orto Botanico in Rome for many years. I was part of this from the beginning in 1992 to 2009. Also in this case, short to several day long excursions in the wider surrounding were special events. My last meeting with Sandro was in Rinteln in 2012, when he was honored with the Reinhold-Tüxen-prize. After sixty years of friendship, I am happy to dedicate this article about the phenology of beech forests to him.

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References

Bórnez, K., Descals, A., Verger, A. & Peñuelas, J. 2020: Land surface phenology from VEGETATION and PROBA-V data. Assessment over deciduous forests. – Int. J. Appl. Earth Obs. Geoinf. **84:** 101974 online.

Christofolini, G., Lausi, D. & Pignatti, S. 1970: Über statistische Eigenschaften der Charakterarten und deren Verwendung zur Aufstellung einer empirischen Systematik der Pflanzengesellschaften. – Pp. 8-25 in: Tüxen, R. (ed.): Gesellschaftsmorphologie (Strukturforschung). – Den Haag.

Dierschke, H. 1972: Zur Aufnahme und Darstellung phänologischer Erscheinungen in Pflanzengesellschaften. – Pp. 291-311 in: Tüxen, R. (ed.): Grundfragen und Methoden in der Pflanzensoziologie. – Den Haag.

— 1982: Pflanzensoziologische und ökologische Untersuchungen in Wäldern Süd-Niedersachsens. I. Phänologischer Jahresrhythmus sommergrüner Wälder. – Tuexenia **2:** 172-194.

— 1983: Symphänologische Artengruppen sommergrüner Laubwälder und verwandter Gesellschaften Mitteleuropas. – Verhandl. Ges. Ökologie **11:** 71-87.

— 1989a: Kleinräumige Vegetationsstruktur und phänologischer Rhythmus eines Kalkbuchenwaldes. – Verhandl. Ges. Ökologie **17:** 131-143.

— 1989b: Artenreiche Buchenwald-Gesellschaften Nordwest-Deutschlands. – Ber. Reinhold-Tüxen-Ges. **1:** 107-147.

— 1989c: Symphänologischer Aufnahme- und Bestimmungsschlüssel für Blütenpflanzen und ihre Gesellschaften in Mitteleuropa. – Tuexenia **9:** 477-484.

— 1994: Pflanzensoziologie. Grundlagen und Methoden. – Stuttgart.

— 1995: Phänologische und symphänologische Artengruppen von Blütenpflanzen Mitteleuropas. – Tuexenia **15:** 523-560.

— 2000: Phenological phases and phenological species groups of mesic beech forests and their suitability for climatical monitoring. – Phytocoenologia **30:** 469-476.

— 2005: Laurophyllisation – auch eine Erscheinung im nördlichen Mitteleuropa? Zur aktuellen Ausbreitung von *Hedera helix* in sommergrünen Laubwäldern. – Ber. Reinhold-Tüxen-Ges. **17:** 151-168.

— 2015: Jahreszeitliche physiognomische Veränderungen einer Landschaft unter botanischem Blickwinkel, dargestellt für die Muschelkalkgebiete in der Umgebung von Göttingen. Teil 1: Analytische Landschaftsphänologie. – Tuexenia **35:** 285-308.

— 2016: Phytophänologisches Biomonitoring – Geobotanische Forschungen zum Klimawandel vor der Haustür. – Florist. Rundbriefe **50:** 127-148.

— & Becker, T. 2020: 37 Jahre Dauerflächenuntersuchungen in einem Kalkbuchenwald – eine Zeitreihe 1980-2001-2016. – Tuexenia **40:** 71-100.

— & Briemle, G. 2002: Kulturgrasland. Wiesen, Weiden und verwandte Staudenfluren. – Stuttgart.

Ellenberg, H. 1939: Über Zusammensetzung, Standort und Stoffproduktion bodenfeuchter Eichen- und Buchen-Mischwaldgesellschaften Nordwestdeutschlands. – Mitt. Florist.-soziol. Arbeitsgem. Niedersachsen **5:** 1-135.

Ge, Q., Wang, H., Zheng, J., Rutishauser, T. & Dai, J. 2014: A 170 year spring phenology index of plants in eastern China. – J. Geophys. Res. Biogeosci. **119:** 301–311.

Giraudoux, P., Antonietti, J.-P., Beale, C., Pleydell, D. & Treglia, M. 2018: Package ‘pgirmess’ – Spatial Analysis and Data Mining for Field Ecologists.

Heinrichs, S., Dierschke, H., Kompa, T. & Schmidt, W. 2018: Effect of phenology, nutrient availability and windthrow on flowering of *Allium ursinum* – results from long-term monitoring and experiments. – Tuexenia **38:** 111-134.

Kolbe, C. & Kaiser-Weiss, A. K. 2015: Pflanzenreaktionen in Bezug zum Klimawandel in Deutschland – eine statistische Analyse phänologischer Daten. – Phänologie-Journal Deutscher Wetterdienst **44:** 1-4.

Lausi, D. & Pignatti, S. 1973: Die Phänologie der europäischen Buchenwälder auf pflanzensoziologischer Grundlage. – Phytocoenologia **1:** 1-63.

—, — & Poldini, L. 1979: Statistische Untersuchungen über die Wiederbewaldung auf dem Triester Karst. – Pp. 445-457 in: Tüxen, R. & Sommer, W.-H. (eds): Gesellschaftsentwicklung (Syndynamik). – Vaduz.

Leuschner, C. & Ellenberg, H. 2017: Ecology of Central European Forests. Vegetation Ecology of Central Europe Vol I. – Cham.

Marcello, A. 1953a: Il concetto di interazione in sinfenologia. – Atti Ist. Veneto di Scienze, Lettre ed Arti, **111** (after Schnelle 1955).

— 1953b: Nuovi criteri per osservazioni fitofenologiche. – N. G. Bot. Ital. n.s. **42:** 534-556.

— 1954: De la méthode en symphénologie. – Ricerca Sci. **25:** 1431-1442.

— & Pignatti, S. 1965: Prime notizie di una Rete Fenologica Internazionale nelle Faggete europee per l´anno 1963. – N. G. Bot. Ital. n.s. **72:** 582-586.

Menzel, A., Sparks, T. H., Estrella, N., Koch, E., Aasas, A., Alm-Kübler, K., Bissolli, P., Braslavská, O., Briede, A., Chmielewski, F. M., Crepinsek, Z., Curnel, Y., Dahl, A., Defila, C., Donnelly, A., Filella, Y., Jatczak, K., Måge, F., Mestre, A., Nordli, Ø., Peñuelas, J., Pirinen, P., Remišova, V., Scheifinger, H., Striz, M., Susnik, A., van Vliet, A. J. H., Wielgolaski, F-E., Zach, S. & Zust, A. 2006: European phenological response to climate change matches the warming pattern. – Global Change Biol. **12:** 1969-1976.

Misra, G., Cawkwell, F. & Wingler, A. 2020: Status of Phenological Research Using Sentinel-2 Data: A Review. – Remote Sens. **12(7):** 2760. https://doi.org/10.3390/rs12172760

Nijland, W., Bolton, D., Coops, N. & Stenhouse, G. B. 2016: Imaging phenology - scaling from camera plots to landscapes. – Remote Sens. Environ. **177:** 13-20. https://doi.org/10.1016/j.rse.2016.02.018

Pignatti, E. & Pignatti, S. 1966: Anthropogene Meeresalgen-Gesellschaften an der Adriatischen Küste. – Pp. 1-7 in: Tüxen, R. (ed.): Anthropogene Vegetation. – Den Haag.

— & — 1982: Josias Braun-Blanquet (1884–1980). – Pp. 7-9 in: Dierschke, H. (ed.): Struktur und Dynamik von Wäldern. – Vaduz.

Pignatti, S. 1966: Polyploidie-Verhältnisse der anthropogenen Pflanzengesellschaften und Vegetationsserien. – Pp. 108-120 in: Tüxen, R. (ed.): Anthropogene Vegetation. – Den Haag.

— 1968a: Die Verwertung der sogenannten Gesamtarten für die floristische Systematik. – Pp. 71-77 in: Tüxen, R. (ed): Pflanzensoziologische Systematik. – Den Haag.

— 1968b: Die Inflation der höheren pflanzensoziologischen Einheiten. – Pp. 85-97 in: Tüxen, R. (ed.): Pflanzensoziologische Systematik. – Den Haag.

— 1972: Vorläufiger Bericht über die Phänologie europäischer Buchenwälder. – Pp. 227-345 in: van der Maarel, E. & Tüxen, R. (eds): Grundfragen und Methoden in der Pflanzensoziologie. – Den Haag.

— 1978: Zur Methodik der Aufnahme von Gesellschaftskomplexen. – Pp. 27-41 in: Tüxen, R. (ed.): Assoziationskomplexe (Sigmeten). – Vaduz.

— 1980: Epharmonische Beziehungen zwischen struktureller und funktioneller Ordnung in der Vegetation. – Pp. 385-398 in: Wilmanns, O. & Tüxen, R. (eds): Epharmonie. – Vaduz.

— 1981: Die Syntaxonomie einiger Endemiten-reicher Vegetationstypen im Mittelmeergebiet. – Pp. 403-425 in: Dierschke, H. (ed.): Syntaxonomie. – Vaduz.

—, Avanzini, A. & Nimis, P. 1977: Die klimatisch bedingte Dornpolster-Vegetation der Gebirge Süditaliens, Siziliens und Sardiniens. – Pp. 373-390 in: Dierschke, H. (ed.): Vegetation und Klima. – Vaduz.

R Core Team 2020: R: A language and environment for statistical computing. – R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Schnelle, F. 1955: Pflanzen-Phänologie. – Leipzig.

Schönwiese, C. 2020: Klimawandel kompakt. Ein globales Problem wissenschaftlich erklärt. 3. Aufl. – Stuttgart.

Ubrizsy Savoia, A. (ed.) 1989: Spontaneous vegetation in settlements. – Braun-Blanquetia **3:** 1-443.

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The taxonomic interpretation of Mediterranean oaks of *Quercus* sect. *Quercus* (*Fagaceae*): uncertainties and diverging concepts

Abstract

Grossoni, P., Bruschi, P., Bussotti, F., Pollastrini, M. & Selvi, F.: The taxonomic interpretation of Mediterranean oaks of *Quercus* sect. *Quercus* (*Fagaceae*): uncertainties and diverging concepts. — Fl. Medit. 31 (Special Issue): 271-278. 2021. — ISSN: 1120-4052 printed, 2240-4538 online.

The high degree of polymorphism found in the genus *Quercus* is certainly the main cause of the divergent taxonomic treatments that have often generated more uncertainties, if not confusion, than clarity. However, in recent years, also thanks to the use of molecular investigation techniques, several doubts have now been overcome. In this paper we summarized the main literature on the topic and provide a synthetic evaluation of the systematic position of the Italian taxa belonging to the so-called "*Quercus pubescens* group" ("downy oaks").

Key words: *Quercus pubescens* complex, downy oaks, Mediterranean Basin.

Introduction

Oaks (*Quercus* L., *Fagaceae* Dumort.) are widely distributed in the Northern hemisphere playing important roles in providing forest products (timber, fuel wood, cork, mushrooms, extracts and derivatives, etc.), in conservation of biodiversity, protection of landscape and all related ecosystem services. In Italy, oak forests occupy about 2,873,000 ha, corresponding to 29.4% of the entire national forest area (Corona & al. 2004). The genus *Quercus* includes a large number of species. Camus (1936-39) quoted about 800 taxa, while Krüssmann (1986) reported about 450 species. The most recent taxonomic revisions tend to reduce the number of species by putting more emphasis on similar characters and adopting a wider species concept, so that currently between 300 and 350 species are recognized. Denk & al. (2017) provide a list of 858 names among species, synonyms, subspecies, hybrids, and dubious species.

The classification of oak species is under debate since centuries. Recently Denk & Grimm (2010) and Denk & al. (2017) revised the past classifications (Ørsted 1871; Schwarz 1936-39; Camus 1936-39; Nixon 1993) and proposed a new one based on a phylogenetic and molecular approach. According to this recent classification, *Quercus* is subdivided into two subgenera, *Q.* subg. *Quercus* and *Q.* subg. *Cerris*, both including several sections. Oak species have very different general habit (trees to shrubs), phenology (evergreen, deciduous, semi-deciduous), and ecological requirements (from tropical to boreal and Mediterranean). Several species display strong polymorphism and a remarkable ability to form hybrids, making their taxonomic limits, and the species concept itself, quite elusive.

As early as in 1911, Antonino Borzì had deemed that the genus *Quercus* did provide "[...] the perfect negation of the concept of species [...]", followed by the statement "[...] it is an immense chaos [...]". Still in the last quarter of the last century, Burger (1975) stressed the difficulty of applying the biological species concept in *Quercus*, due to relatively frequent gene exchanges between different species. A few years later, referring to the "ability" of *Q. alba* L. and *Q. stellata* Wangenh. to form hybrids with other 11 species of the eastern United States, Whittemore & Schaal (1991) confirmed that oak species are easily interfertile due to weak and incomplete interspecific reproductive barriers. On the other hand, the lack of sharp morphological delimitations, together with low interspecific genetic differentiation, have often been interpreted as the consequence of natural hybridisation in *Quercus* (Bruschi & al. 2000; Salvini & al. 2009). Incorporation of heterospecific alleles, through hybridization and regression, would yield reduced interspecific distances compared to values expected for taxa that had been fully isolated genetically subsequent to speciation. Similar considerations can be found in Le Hardÿ de Beaulieu & Lamant (2010), who published an illustrated world monograph of *Quercus*, that can be considered evolved from the work of Aimée Camus (1936-1939). Based on data collected across the genus in different continents, these two authors also stressed the difficulty of applying the biological species concept to oaks. In fact, several complexes of sympatric "species" exist in which taxa are capable of frequent gene exchange, thus reducing their morphological divergence. According to Le Hardÿ de Beaulieu & Lamant (2010) it would be more correct to use the term "multispecies" when referring to these complexes.

Gene flow and hybridization have certainly played an important role also in the evolutionary history of oaks of the Mediterranean Basin. This region is considered a hotspot of plant biodiversity (Médail & Quézel 1999), resulting from its biogeographic history and natural heterogeneity of habitats and environmental conditions. Events like migration, micro-evolution, isolation in glacial refugia, range disjunctions and others have favoured the formation of many endemic species but also local phenotypic variation in populations sometimes classified as distinct entities or taxa. Moreover, the strong and long impact of human activities on habitats, landscape and vegetation, especially forest fragmentation, has contributed to promote hybridization and introgression between taxa in many plant groups (Médail & al. 2019).

In 1997 some of us (Bussotti & Grossoni 1997) published a comparative analysis of the differences between several classifications of taxa of *Quercus* described from the Mediterranean region (Camus 1936-1939; Greuter & al. 1986; Krüssmann 1986; Nixon 1993; Pignatti 1982; Schwarz 1964, 1993). They found that these classifications had several nomenclatural and taxonomic discrepancies, the use of names and synonyms being inconsistent and based on contrasting species concepts. This resulted in doubts, uncertainties and contradictory conclusions. That analysis was subsequently repulished in the journal Forêt Méditerranéenne (Bussotti & Grossoni 1998). It pointed out that the greatest perplexities and uncertainties concerned the groups "*Q. pubescens* - *Q. petraea*" and "*Q. faginea* - *Q. lusitanica*", in which a high genetic diversity is associated with the tendency to differentiate numerous local phenotypes along almost continuous morphological gradients, without any clear correlation with ecological or geographical factors, thus making it very difficult to separate well-defined taxa.

The present contribution aims at revisiting the past and current classifications of the species belonging to *Q.* subg. *Quercus* in Italy, with special reference to the group *Q. pubescens* – *Q. petraea* group and related entities of the so-called "downy oaks".

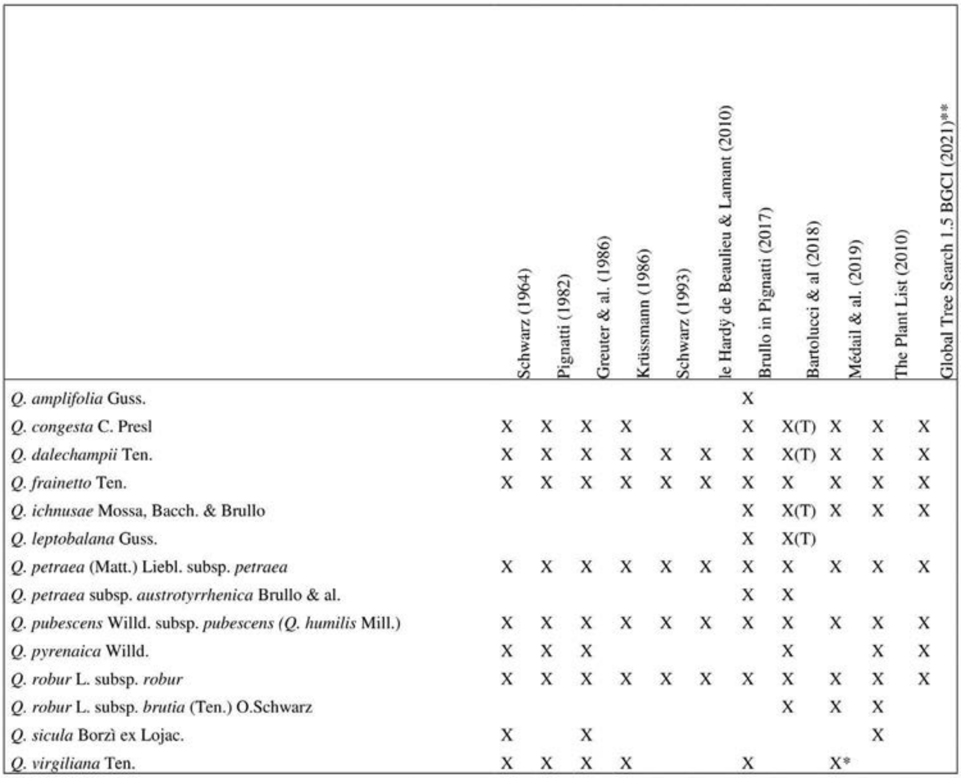
Taxa of *Quercus* sect. *Quercus* in Italy

Among the species currently placed in *Quercus* sect. *Quercus, Q. robur* was the only one described by Linnaeus (1753). Fiori (1923-1925) still used this name for the whole complex, albeit dividing it into numerous infraspecific taxa, many of which are currently obsolete. Subsequently, Di Tella (1930) and Merendi (1930) distinguished the English oak ("*Q. pedunculata* Ehrh.") from the sessile oak, in which they included both "*Q. sessilis* Ehrh." and "*Q. lanuginosa* Lam.". All these entities were placed by Fiori (1930) in *Q. robur* and were generically called referred to as "*querce roveri*".

More recent classifications are summarized in Table 1, which shows a persistent variability in the number of species, as well as the presence of numerous doubtful species. The unequivocally recognized species are *Q. robur* L., *Q. petraea* (Matt.) Liebl., *Q. pubescens* Willd. and *Q. frainetto* Ten., while *Q. pyrenaica* Willd., already considered as rare and present only in the Val di Susa (Piemonte) in the first edition of *Flora d'Italia* (Pignatti 1982), was excluded from the native Italian flora in the second edition (Brullo 2017) and by Brullo & al. (1999) and Brullo (2017), whereas Bartolucci & al. (2018) still include *Q. pyrenaica* in their list of the Italian native flora. These authors subdivided each *Q. petraea* and *Q. robur* into two subspecies, while Brullo (2017) considered *Q. brutia* Ten., omitted from Table 1, as a "phantom species".

Recently, Bussotti (2020) summarised a synoptic table with the main morphological characters of the three principal species of the «*robur-petraea-pubescens*» complex; among them, *Q. robur* presents the lowest identification difficulty, due to the uniqueness and stability of the characters that consistently separate it from all other species. On the other hand, the distinction between *Q. pubescens* and *Q. petraea* is often uncertain due to the lack of stable and reliable morphological characters concerning twigs (shape, size, presence/absence of pubescence), leaves (size, shape, pubescence) and fruits (cupule of the acorns). Indeed, most of these characters show a continuous series of intermediate states connecting one species to the other and are often widely variable even within the same population or geographic area.

Table 1. List of native taxa in *Quercus* subgen. *Quercus* accepted and quoted for Italy in relevant recent literature and web sources.



	Schwarz (1964)	Pignatti (1982)	Greuter & al. (1986)	Krüssmann (1986)	Schwarz (1993)	le Hardÿ de Beaulieu & Lamant (2010)	Brullo in Pignatti (2017)	Bartolucci & al (2018)	Médail & al. (2019)	The Plant List (2010)	Global Tree Search 1.5 BGCI (2021)**
Q. amplifolia Guss.							X				
Q. congesta C. Presl	X	X	X	X			X	X(T)	X	X	X
Q. dalechampii Ten.	X	X	X	X	X	X	X	X(T)	X	X	X
Q. frainetto Ten.	X	X	X	X	X	X	X	X	X	X	X
Q. ichnusae Mossa, Bacch. & Brullo							X	X(T)	X	X	X
Q. leptobalana Guss.							X	X(T)			
Q. petraea (Matt.) Liebl. subsp. *petraea*	X	X	X	X	X	X	X	X	X	X	X
Q. petraea subsp. *austrotyrrhenica* Brullo & al.							X	X			
Q. pubescens Willd. subsp. *pubescens (Q. humilis* Mill.)	X	X	X	X	X	X	X	X	X	X	X
Q. pyrenaica Willd.	X	X	X					X		X	X
Q. robur L. subsp. *robur*	X	X	X	X	X	X	X	X	X	X	X
Q. robur L. subsp. *brutia* (Ten.) O.Schwarz								X	X	X	
Q. sicula Borzì ex Lojac.	X		X							X	
Q. virgiliana Ten.	X	X	X	X			X		X*		

* treated as "*Q. pubescens* subsp. *virgiliana*", without authorship of that combination.

(T): as taxonomically doubtful

** = https://tools.bgci.org/global_tree_search.php

The downy oaks

Quercus pubescens is a very polymorphic species, and its circumscription includes a swarm of closely related entities, that are currently still considered as independent taxa in some recent accounts of the Italian flora, as reported in Table 1.

Considering the species within *Q. pubescens* "lato sensu", compared to those recognized by Brullo (2017), the list by Bartolucci & al. (2018) does not include *Q. virgiliana* (Ten.) Ten., nor *Q. amplifolia* Guss., while *Q. ichnusae* Mossa & al. and *Q. leptobalana* Guss. are included. Schwarz (1993) also reported *Q. sicula* Borzì ex Lojac., although, at the time, it had already been qualified as a "mistake" by Antonino Borzì (Brullo & al. 1999). There is also an inconsistency in the spelling of one epithet: "leptobalana" in Bartolucci & al. (2018) and "leptobalanos" in Brullo & al. (1999) and Brullo (2017), a discrepancy which has its roots in the 19th century and, evidently, persists to date (both names are attributed to Guss. 1844)., whereas *Q. pubescens* has been definitively accepted instead *Q. humilis* Mill. (*Q. humilis* is now accepted as synonymous only for *Q. pubescens* subsp. *pubescens*).

The entities related to the "downy oak" complex were identified and determined for the first time in Sicily, Sardinia or southern Calabria; according to Brullo & al. (1999) and Brullo (2017) the Italian range of *Q. pubescens* is limited to the peninsular and continental regions, it being replaced in the large islands and in some areas of the southern peninsula by other species of the same complex, *Quercus virgiliana* and *Q. dalechampii* Ten.; these have also been reported in various countries of south-eastern Europe and the Balkans. However, there is much uncertainty as to the correctness of these reports, due to the often contradictory descriptions of the corresponding entities (Di Pietro & al. 2012) and an overly subjective approach to recognition and classification. Arrigoni (2018), due to the lack of reproductive isolation, does not recognize *Q. virgiliana* and considers it as a synonymy of *Q. pubescens*, together with all the other putative species of the group (*Q. congesta* C. Presl, *Q. amplifolia*, *Q. ichnusae*, and *Q. leptobalana*)

A first morphometric approach to discriminate *Q. pubescens* from other species of the same group in Sicily was attempted by Di Noto & al. (1995), without conclusive results. Based on the study of 20 *Q. pubescens* populations randomly sampled in central and southern Italy, Bruschi & Grossoni (2004) observed a high morphological and molecular variability (with populations from Sicily, Sardinia and Calabria showing a higher average diversity than the others). While morphological characters (those related to the acorn cap) allowed these authors to identify five different groups, no differences were detected at molecular level. The same conclusions were drawn by Franjić & al. (2006) in a molecular study on *Q. pubescens* populations of Southern Croatia: "*This study confirms a high variability of* Q. pubescens *populations, but differences were not so big to confirm the opinion of existence of several species in this area*". Di Pietro & al. (2016) found that all morphological characters analysed in 24 Apulian populations exhibited continuous variation, so that none of them could be used as a character to discriminate between populations; they concluded that it "is unlikely that more than one species belonging to the *Quercus pubescens* complex occurs in the Apulia region". Di Pietro & al. (2020a, b, c) expanded this approach by comparing morphological and genetic aspects of seven taxa of the *Q. pubescens* group (*Quercus pubescens, Q. amplifolia, Q. congesta, Q. dalechampii, Q. ichnusae, Q. leptobalanos, Q. virgiliana*) in southern Italy and the islands (Sicily and Sardinia), concluding that "*In light of the results obtained, the taxonomic classification for the pubescent white oaks currently reported in the major Italian floras and checklists for the study area was not confirmed by molecular analyses*".

Hybridisation within *Quercus* sect. *Quercus* appears to be extensive (Rushton 1993), and recorded hybrids between *Q. petraea* and *Q. robur* (Bacilieri & al. 1995) and between *Q. petraea* and *Q. pubescens* (Salvini & al. 2009) are common and widespread.

The results of a parentage analysis carried out through microsatellite markers on a mixed *Q. petraea* – *Q. pubescens* population (Salvini & al. 2009) showed an asymmetrical gene flow with a predominant component in the direction *Q. petraea* versus *Q. pubescens*. These results also showed that intermediate individuals are pollen-receptive towards both species and their high pollen viability provides potential for fostering high rates of introgression.

Conclusions

The accurate morphological and genetic analyses, carried out by the various research groups mentioned in this article, allow us to exclude that the multitude of botanical names associated with the *Q. pubescens* group is mirroring effective differentiation into well-defined species, thus supporting the conclusions of Wellstein & Spada (2015): "*While some schools in southern Europe still emphasize the distinctness and the species status of many taxa described during the earliest botanical surveys, the current trend is toward rejecting many names and considering them as synonyms*".

Polymorphism is frequent in oak species. Corti (1959), for example, mentioned 175 infra-specific taxa under *Quercus ilex*, that is considered a non-controversial species. *Q. ilex* is characterised by a set of well-defined and generally accepted characters, whereas the characterization of the "white oaks" is more subtle and their evaluation can be affected by a certain degree of subjectivity.

In the absence of selective reproductive barriers, hybridization can generate phenotypes with appreciable morphological and ecological diversity, even with extreme forms that can sometimes be quite distinctive. However, these phenotypes are usually distributed along continuous morphological gradients, and have no or little geographic or ecological distinctness, being often overlapping and mixed in the same locality or forest areas.

However, a taxonomic simplification does not imply a simplification at the genetic and ecological level. The deciduous oak forests of southern Italy are a large reserve of genetic variability that is an important asset for the adaptation of European forests to climate change. Southern provenances of deciduous oaks are good candidates to restore the Central European forests affected by drought in a context of "assisted migration" (Bussotti & al. 2015).

References

Arrigoni, P. V. 2018: Flora Analitica della Toscana, **4.** – Firenze.

Bacilieri, R., Ducousso, A. & Kremer, A. 1995: Genetic, morphological and phenological di differentiation between *Quercus petraea* (Matt.) Liebl. and *Quercus robur* L. in a mixed stand of northwest of France. – Silvae Genetica **44:** 1-10.

Bartolucci, F., Peruzzi, L., Galasso, G., Albano, A., Alessandrini, A., Ardenghi, N. M. G., Astuti, G., Bacchetta, G., Ballelli, S., Banfi, E., Barberis, G., Bernardo, L., Bouvet, D., Bovio, M., Cecchi, L., Di Pietro, R., Domina, G., Fascetti, S., Fenu, G., Festi, F., Foggi, B., Gallo, L., Gottschlich, G., Gubellini, L., Iamonico, D., Iberite, M., Jiménez-Mejías, P., Lattanzi, E., Marchetti, D., Martinetto, E., Masin, R. R., Medagli, P., Passalacqua, N. G., Peccenini, S., Pennesi, R., Pierini, B., Poldini, L., Prosser, F., Raimondo, F. M., Roma-Marzio, F., Rosati, L., Santangelo, A., Scoppola, A., Scortegagna, S., Selvaggi, A., Selvi, F., Soldano, A., Stinca, A., Wagensommer, R. P., Wilhalm, T. & Conti, F. 2018: An updated checklist of the vascular flora native to Italy. – Pl. Biosyst. **152:** 179-303. https://doi.org/10.1080/11263504.2017.1419996

Borzì, A. 1911: Le querce della flora italiana. Rassegna descrittiva. – Boll. Reale Orto Bot. Giard. Colon. Palermo **10:** 41-66.

Brullo, S. 2017: *Quercus* L. - Quercia. – Pp. 686-697 in: Pignatti, S., Guarino, R. & La Rosa, M. (eds), Flora d'Italia, Ed. 2, &. Flora Digitale, **1.** – Milano.

—, Guarino, R., Siracusa, G. 1999: Revisione tassonomica delle querce caducifoglie della Sicilia. — Webbia **54:** 1-72.

Bruschi, P. & Grossoni, P. 2004: Variabilità morfologica e molecolare in *Quercus pubescens* (Willd.) dell'Italia centro-meridionale – Inform. Bot. Ital. **36:** 529-531.

—, Vendramin, G. G., Bussotti, F. & Grossoni, P. 2000: Morphological and molecular differentation between *Quercus petraea* (Matt.) Liebl. and *Quercus pubescens* Willd. (Fagaceae) in northern and central Italy. – Ann. Bot. **85:** 325-333.

—, —, — & — 2003: Morphological and molecular diversity among Italian populations of *Quercus petraea (Fagaceae).* – Ann. Bot. **91:** 707-716.

Burger, W.C. 1975: The specie concept in *Quercus*. – Taxon **24:** 45-50.

Bussotti, F. 2020: *Quercus* L. – Pp. 200-265 in: Grossoni, P., Bruschi, P., Bussotti, F., Pollastrini, M. & Selvi, F.: Trattato di botanica forestale, **2.** Le angiosperme. – Milano.

— & Grossoni, P. 1997: Querce europee e mediterranee: problemi tassonomici. – Italia Forest. Mont. **52:** 240-260.

— & — 1998: Des problèmes dans la classification des chênes. Taxonomie en Europe et région méditerranéenne. – Forêt Médit. **19:** 267-278.

—, Pollastrini, M., Holland, V. & Brüggemann, W. 2015: Functional traits and adaptive capacity of European forests to climate change. – Environm. Exper. Bot. **111:** 91-113. https://doi.org/10.1016/j.envexpbot.2014.11.006

Camus, A. 1936-1939: Les chênes: monographie du genre *Quercus*, **1**, **2.** – Paris.

Corona, P., Macrì, A. & Marchetti, M. 2004: Boschi e foreste in Italia secondo le più recenti fonti informative. – Italia Forest. Mont. **2:** 119-136.

Corti, R. 1959: Ricerche sul ciclo riproduttivo di specie del gen. *Quercus* della flora italiana. IV. Osservazioni sulla embriologia e sul ciclo riproduttivo di *Quercus ilex*. – Ann. Accad. Ital. Sci. Forest. **8:** 19-42.

Denk, T. & Grimm, G. W. 2010: The oaks of western eurasia: traditional classifications and evidence from two nuclear markers. – Taxon **59:** 351-366.

—, —, Manos, P. S., Deng, M. & Hipp, A. L. 2017: An updated infrageneric classification of the oaks: review of previous taxonomic schemes and synthesis of evolutionary patterns. – Pp. 13-38 in: Gil-Pelegrin, E., Peguero-Pina, J. J. & Sancho-Knapik, D.: Oaks, physiological ecology. Exploring the functional diversity of genus *Quercus* L. – Tree Physiol. **7**. – Cham.

Di Noto, G., Grossoni, P. & Bussotti, F. 1995: Variabilità morfologica di piante del genere *Quercus* (*Fagaceae*) nel territorio delle Madonie: confronto fra exsiccata dell'Herbarium Panormitanum e campioni raccolti in natura. – Inform. Bot. Ital. **27:** 303-304.

Di Pietro, R., Viscosi, V., Peruzzi, L. & Fortini, P. 2012: A review of the application of the name *Quercus dalechampii*. – Taxon **61:** 1311-1316.

—, Di Marzio, P., Medagli, P., Misano, G., Silletti, G., Wagensommer, R. & Fortini, P. 2016: Evidence from multivariate morphometric study of the *Quercus pubescens* complex in southeast Italy. – Bot. Serbica **40:** 83-100.

—, Conte, A. L., Di Marzio, P., Gianguzzi, L., Spampinato, G., Caldarella, O. & Fortini, P. 2020a: A multivariate morphometric analysis of diagnostic traits in southern Italy and Sicily pubescent oaks. – Folia Geobot. **55:** 163-183. https://doi.org/10.1007/s12224-020-09378-0

—, —, —, P., Fortini, P., Farris, E., Gianguzzi, L., Müller, M., Rosati, L., Spampinato, G. & Gailing, O. 2020b: Does the genetic diversity among pubescent white oaks in southern Italy, Sicily and Sardinia islands support the current taxonomic classification? – Eur. J. Forest Res. **140:** 355-371. https://doi.org/10.1007/s10342-020-01334-z.

—, Di Marzio, P., Antonecchia, G., Conte, A. L. & Fortini, P. 2020c: Preliminary characterization of the *Quercus pubescens* complex in southern Italy using molecular markers. – Acta Bot. Croat. **79:** 15-25.

Di Tella, G. 1930: La farnia. – L'Alpe **17:** 351-356.

Enescu, C. M., Curtu, A. L & Șofletea, N. 2013: Is *Quercus virgiliana* a distinct morphological and genetic entity among European white oaks? – Turk. J. Agric. Forest. **37:** 632-641.

Grossoni, P. & Bruschi, P. 2014: A proposito delle querce. – Pp: 223-236 in: Cianfaglione, K. (ed.): L'importanza degli alberi e del bosco. – Trento.

Fineschi, S. & Vendramin, G. G. 2004: La diversità cloroplastica delle querce italiane: evidenze di una maggiore ricchezza genetica nelle popolazioni meridionali e insulari. – Forest@ **1:** 82-87.

Fiori, A. 1923-25: *Quercus* L. – Pp. 361-367 in: Fiori, A.: Nuova flora analitica d'Italia, **1.** – Firenze.

— 1930: Le querce roveri. – Alpe **17:** 348-350.

Greuter, W., Burdet, H. M. & Long, G. 1986: Med-Checklist. A critical inventory of vascular plants of the circum-mediterranean countries. 3. *Dicotyledones (Convolvulaceae-Labiatae).* – Berlin.

Le Hardÿ de Beaulieu, A. & Lamant, T. 2010: Guide illustré des chênes, **1-2.** – Geer.

Krüssmann, G. 1986: Manual of cultivated broadleaved trees and shrubs, **2.** – London.

Linné, C. 1753: Species plantarum. – Stockholm.

Médail, F. & Quézel, P. 1999: Biodiversity hotspots in the Mediterranean basin: setting global conservation priorities. – Conserv. Biol. **13:** 1510-1513.

—, Monnet, A.-C., Pavon, D., Nikolic, T., Dimopoulos, P., Bacchetta, G., Arroyo, J., Barina, Z., Albassatneh, M. C., Domina, G., Fady, B., Matevski, V., Mifsud, S. & Leriche, A.: 2019: What is a tree in the Mediterranean basin hotspot? A critical analysis. – Forest Ecosyst. **6**: 17. https://doi.org/10.1186/s40663-019-0170-6.

Merendi, A. 1930: La rovere. – Alpe **17:** 357-364.

Nixon, K. C. 1993: Infrageneric classification of *Quercus* (*Fagaceae*) and typification of sectional names. – Ann. Sci. Forest. **50:** 25s–34s.

Ørsted, A. S. 1871: Bidrag til kundskab om egefamilien i nutid og fortid. – Kongl. Danske Vidensk. Selsk. Skr. Naturvidensk. Math. Afd. **5(9):** 331–538.

Pignatti, S. 1982: *Quercus* L. – Pp. 113-120 in: Flora d'Italia, **1.** – Bologna.

Rushton, B. S. 1993: Natural hybridization within the genus *Quercus*. – Ann. Sci. Forest. **50:** 73s–91s.

Salvini, D., Bruschi, P., Fineschi, S., Grossoni, P., Kjær, E. & Vendramin, G. G. 2009: Natural hybridisation between *Quercus petraea* (Matt.) Liebl. and *Quercus pubescens* Willd. within an Italian stand as revealed by microsatellite fingerprinting. – Pl. Biol. **11:** 758-765.

Schwarz, O. 1936–39: Monographie der Eichen Europas und des Mittelmeergebietes. – Repert. Spec. Nov. Regni Veg., Sonderbeih. **D:** 1-400. – Berlin.

— 1964: *Quercus* L. – In: Tutin, T. G., Heywood, V. H., Burges, N. A., Valentine, D. H., Walters, S. M., & Webb, D. A. (eds), Flora europaea, **1.** – Cambridge.

— 1993: *Quercus* L. – In: Tutin, T. G., Burges, N. A., Chater, A. O., Edmondson, J. R., Heywood, V. H. & Moore, D. M (eds), Flora europaea, ed. 2., **1.** – Cambridge.

Wellstein, C. & Spada, F. 2015: The status of *Quercus pubescens* Willd. in Europe. – Pp. 153-163 in: Box, E. O. & Fujiwara, K. (eds), Warm-temperate deciduous forests around the northern hemisphere. – Geobot. Stud. – Cham.

Whittemore, A. T. & Schaal, B. A. 1991: Interspecific gene flow in sympatric oaks. – Proc. Natl. Acad. Sci. U.S.A. **88:** 2540-2544.

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Article

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Reproductive phenology in relation to fire and substrate in coastal Heath near Lancelin, Western Australia

Abstract

Barrett, S. & Ladd, P. G.: Reproductive phenology in relation to fire and substrate in coastal Heath near Lancelin, Western Australia. — Fl. Medit. 31 (Special Issue): 279-296. 2021. — ISSN: 1120-4052 printed, 2240-4538 online.

Plant reproductive phenology has evolved to enable species to persist within the constraints of the environmental conditions in which they grow. Climate is an important control over phenology but other environmental factors such a disturbance will also influence when reproduction can occur. Quantitative reproductive phenology – flowering and fruiting, were examined in heath (kwongan) and coastal scrub near Lancelin, Western Australia. Two questions were addressed - how is reproductive phenology affected by time since fire and do communities on different substrates under the same climate have different reproductive timing? In five sites with a range of fire histories differences were observed in both within-year reproductive patterns and total reproductive performance. The most prolific flowering occurred early in the season and preceded the time when the majority of species were flowering. Reproductive activity was more seasonally constrained in the most recently burnt site compared with more protracted flowering at the sites several years after fire. Flowering and fruiting were greatest at the longest unburnt site, more than 6 years post-fire. Life history characteristics and juvenile period of species were important influences on reproductive output, with annuals the main contributors to reproduction soon after fire while woody plants took longer to resume or begin reproduction. A comparison of reproductive phenology on a range of substrates showed the coastal dune scrub vegetation to have more protracted reproductive activity than coastal heathland vegetation. Differences of reproductive timing and intensity in heathland vegetation on different substrate types were not marked. Sites on different substrates but with similar fire histories appeared to be more strongly influenced by time since fire than by substrate.

Key words: flowering, fruiting, reproductive phenology.

Introduction

The reproductive phenology of species is one of the key components of community function, being integral to continuation of the species and having ramifications beyond any one particular species if pollinators, seed/fruit dispersers and propagule predators are involved (e.g. Rafferty & Nabity 2017). Phenology in a general sense is under climatic control. Temperature and water availability are particularly important cues (Segrestin & al. 2018) while day length is also influential for many species at high latitudes and altitudes (Li & al. 2016). In tropical areas seasonality is important and phylogenetic relationships seem to be strongly correlated with time of flowering within seasons (Wright & Calderon 1995). Within Mediterranean climate regions flowering may also be strongly seasonal but phylogenetic constraints are less apparent (Petanidou & al. 1995), although in some important South African Cape groups (*Restionaceae*) evolution of flowering time is related to phylogeny (Linder 2020). While most Mediterranean climate regions are strongly seasonal it is usually water not temperature that is the main environmental factor influencing community function (Dunn & al. 1976). Overlaid on this climatic skeleton is the influence of frequent fire to which phenological patterns of some species have also developed (Pignatti & al. 2002; Pyke 2017)

Both the timing and intensity of plant reproduction after fire are significant in terms of fire management and species conservation in heathland ecosystems. Fire may influence plant reproduction in a range of ways eg. fire-stimulated flowering (Gill & Ingwersen 1976; Gill & Groves 1981; Lamont & Downes 2011; Lamont & al. 2019), more profuse flowering in the early post-fire years (Gill & Groves 1981; Pyke 1983), synchronised flowering and seed production for populations within a species and escape from predation through predator satiation (O'Dowd & Gill 1984). More successful pollination may also be an outcome as fire has been found to increase pollinator diversity in a number of systems such as central European forests (Bogusch & al. 2015) and abundance of pollinators in Mediterranean pine forests (Lazerina & al. 2017). However, a high frequency of fire may be inimical to reproduction due to depleted soil resources (Carbone & Aguilar 2017). The establishment of seed banks is influenced by juvenile period and the time required to first set seed after fire (Benson 1985; van der Moezel & al. 1987; Muir 1987; Wills 1989). Species composition may also be affected by time since fire; species richness is often greatest in the early post-fire years (Pate & al. 1985; Bell & Koch 1980) particularly in Australian heaths.

Studies of reproductive phenology in heath or shrubland vegetation have focussed mainly on seasonal variation in flowering and have been either descriptive in nature or have detailed only the number of species flowering each month (eg. Specht & al. 1981; Milewski & Davidge 1981; Bell & Stephens 1984). While flowering of certain species is abundant after fire, giving the impression of communities highly attuned to episodic disturbance, it has not been well documented just how important this is in terms of whole community reproductive effort over time. There have been few quantitative studies of reproductive phenology or changes in reproductive intensity in relation to fire on a community basis (e.g. McFarland 1990; Petanidou & al. 1995).

The effects of substrate on community flowering patterns in heath and shrublands have been investigated by Wills (1989), McFarland (1990) and Pierce & Cowling (1984). Substrate influences both the nutrient availability and water retention capability of the soil. Substrate has been proposed as a major determinant of phenophases in mediterranean-type ecosystems through an interplay of water availability and nutrient cycling (Specht & al. 1983). Heathlands in Australia occur on a number of different substrate types. Casual observation suggests that flowering phenology varies in relation to soil type but there have been no detailed studies examining communities on different substrates.

The aims of this study were to quantify flowering and fruiting cycles in coastal heath in south western Australia. Both the timing and intensity of flowering and fruiting were examined in relation to fire and substrate in order to determine the relative influence of these factors on reproductive phenology.

Methods

This study was undertaken near Lancelin Western Australia (31°01'S, 115°20'E). The climate is strongly mediterranean (annual rainfall 627 mm) most of which falls in winter. Temperatures range from an average maximum of 30°C in summer; 19°C in winter and average minimums of 16 - 18°C in summer; 10°C in winter (Fig. 1). The study sites were located on two sections of a chronosequence of late quaternary near-coastal sand dunes (Turner & al. 2018).

Five sites were chosen for sampling in coastal heathland in Nilgen Nature Reserve, 6 km north east of Lancelin (approximately 30°57' 48.00" S 115°21' 05.00 E). These sites were located on deep acid sands in close proximity to each other and were representative of a range of fire histories. Time since last fire was 1, 2.5, 5, 6 and greater than 6 years corresponding to sites 1 (1990), 2 (1988), 3 (1986), 4 (1985), and 5 (pre-1985). Heath on sandy substrates in this area of Australia is referred to as kwongan – basically sand heath (Beard & Pate 1984). An additional five sites were located on a range of substrate types, site 6 (long unburnt, > 8 years) on skeletal soils of a limestone ridge (7 km north east of Lancelin), sites 7 (burnt 1991) and 8 (long unburnt, > 8 years) on deep calcareous sands and sites 9 and 10 (both long unburnt, > 8 years) on unconsolidated coastal sand-dunes (about 4 km south of Lancelin, Table 1). At each site three randomly selected 3 m × 3 m plots were established. During monthly visits to each site from March 1991 to February 1992 quadrats were investigated for species flowering and fruiting. 'Intensity' was estimated by means of a logarithmic scoring system (McFarland 1990) (1 = one flower or fruit per quadrat, 2 = a few flowers or fruits per quadrat, 3 = flowers or fruits common in quadrat, 4 = profuse flowering or fruiting in quadrat).

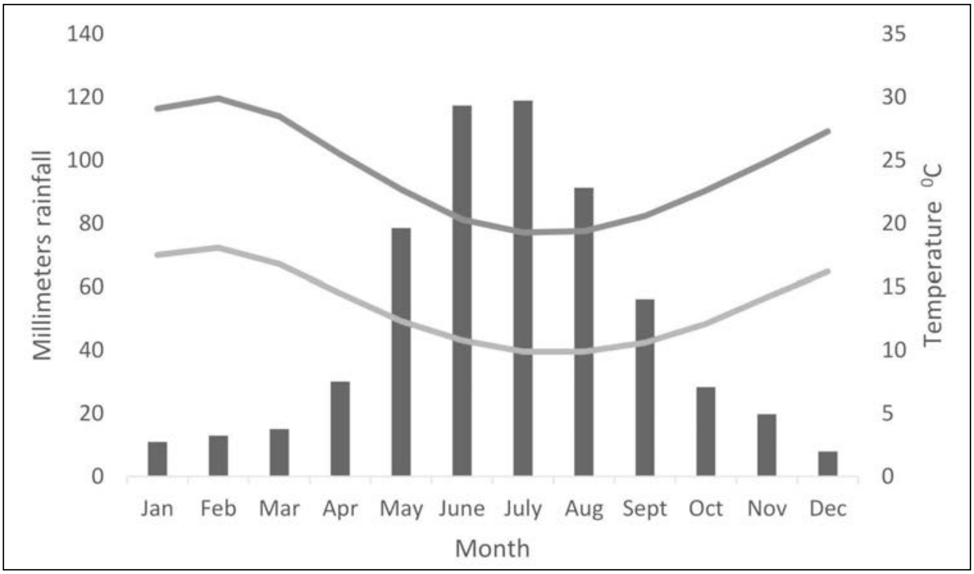

Fig. 1. Annual rainfall and temperature for the Lancelin weather station that is close to the study sites – orange line is maximum mean temperature and the grey line minimum mean temperature.

Table 1. Site characteristics.

Site	1	2	3	4	5	6	7	8	9	10
Vegetation structure	Low open heathland	Low heathland	Heathland	Heathland	Heathland	Low heathland	Open heathland	Shrubland	Shrubland	Heathland
Dominant species	*Hibbertia hypericoides, Hypocalymma xanthopetalum*	*Acacia lasiocarpa, Jacksonia stricta*	*Jacksonia stricta, Hibbertia hypericoides*	*Banksia sessilis, Hakea trifurcata*	*Banksia leptophylla, Bankia sessilis*	*Banksia sessilis, Hibbertia hypericoides*	*Melaleuca systena, Phyllanthus calycina*	*Melaleuca systena, Acacia lasiocarpa*	*Myoporum insulare, Scaevola crassifolia*	*Myoporum insulare. Olearia axillaris*
Post-fire age	1 year	2.5 years	5 years	6 years	Long unburnt	5 years	1 year	2 years	Long unburnt	Long unburnt
Geomorphic unit	Spearwood						Quindalup			
Soil type	Deep yellow siliceous sand with A horizon extending beyond 1m					Limestone caprock over brown sand	Grey sandy A1 horizon over white sand		White sand with no horizon	
pH	6.7	6.3	6.4	6.7	6.5	6.3	8.4	8.0	8.7	8.7

Inflorescences or infructescences such as those of *Banksia* and *Stackhousia* species were counted as single flowers or fruits. Species noted to be flowering from casual observation within 50 m of each site were also recorded. However, this excluded individuals flowering near disturbed areas such as trails or firebreaks.

Total annual flowering and fruiting scores for each site were analysed by means of a oneway analysis of variance (SPSS Inc. 1986). The data were analysed in two groups: (i) fire history: sites 1-5; (ii) substrate: sites 5, 6, 8-10.

Results

Flowering and fruiting data were obtained for 198 species. Data on the intensity of flowering and fruiting were obtained for 162 species which occurred within site quadrats. Sites on the Quindalup sands, particularly sites 9 and 10 on a near-coastal dune were much less species rich than those on the older Spearwood sands (Table 2).

Time Since Fire

The number of species which did not flower was highest in the more recently burnt sites. Therophytes dominated flowering in the first year with a sudden upsurge of flowering following

Table 2. Lifeform composition of the study sites.

Lifeform\Site	1	2	3	4	5	6	7	8	9	10
Therophyte	23	1	1	4	0	7	19	7	5	3
Geophyte	1	4	7	5	1	4	3	3	0	0
Hemicryptophyte	4	8	9	7	5	9	3	8	4	1
Chamaephyte	6	10	5	5	10	5	6	10	1	4
Phanerophyte	4	29	20	23	14	26	0	6	6	4
Other	0	1	1	2	1	1	0	1	0	0
Total no. of species	39	55	46	50	36	58	38	43	25	22

fire but decreased dramatically to a generally constant low level in the following years. In contrast, phanerophyte flowering increased from a very low level at one year post fire to account for almost half the species flowering on the long unburnt site (Fig. 2a). Species richness rose in the initial post-fire period reaching a maximum at 2.5 years post-fire (site 2/1988).

Flowering intensity showed a different pattern from number of species flowering (Fig. 2b). On the long unburnt sites flowering intensity peaked before the majority of species flowered. The most recently burnt site (site 1, 1990) had the lowest while site 5 (pre 1985) had the highest total flowering intensities for the year. On site 5 most species flowered in October (mid spring) but flowering intensity was highest in late winter and early spring (August, September). The site burnt in 1985 (5 years before) had more species flowering in September and October but similarly, greatest intensity in August and September.

The pattern of fruiting intensity and number of species in fruit was more closely similar than was the case for flowering (Fig. 3a, b). In addition, the fruiting pattern generally showed a similar pattern to flowering but occurred a month later. All except the most recently burnt site showed peaks of intensity and number of species fruiting in November; this site showed a peak in October. Fruiting intensity was most evenly spread and was highest in the longest unburnt site 5.

A one-way analysis of variance failed to show a significant effect (*P* > 0.05) across sites with different fire histories for total annual flowering or fruiting scores in sites 1 - 5.

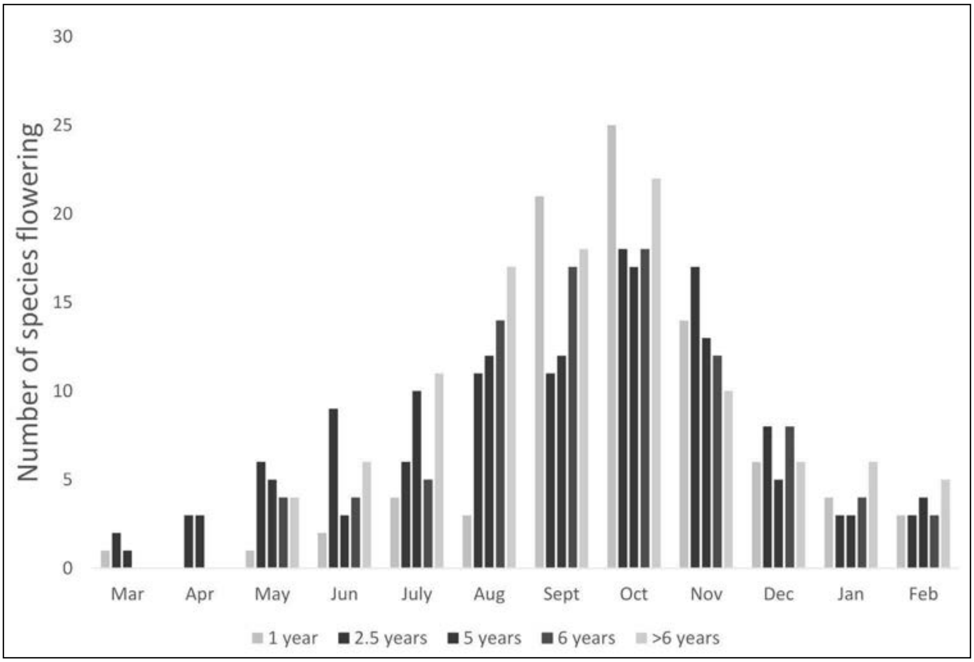

Fig. 2a. Number of species flowering per month at the sites (1 - 5) used in the "time since fire" study.

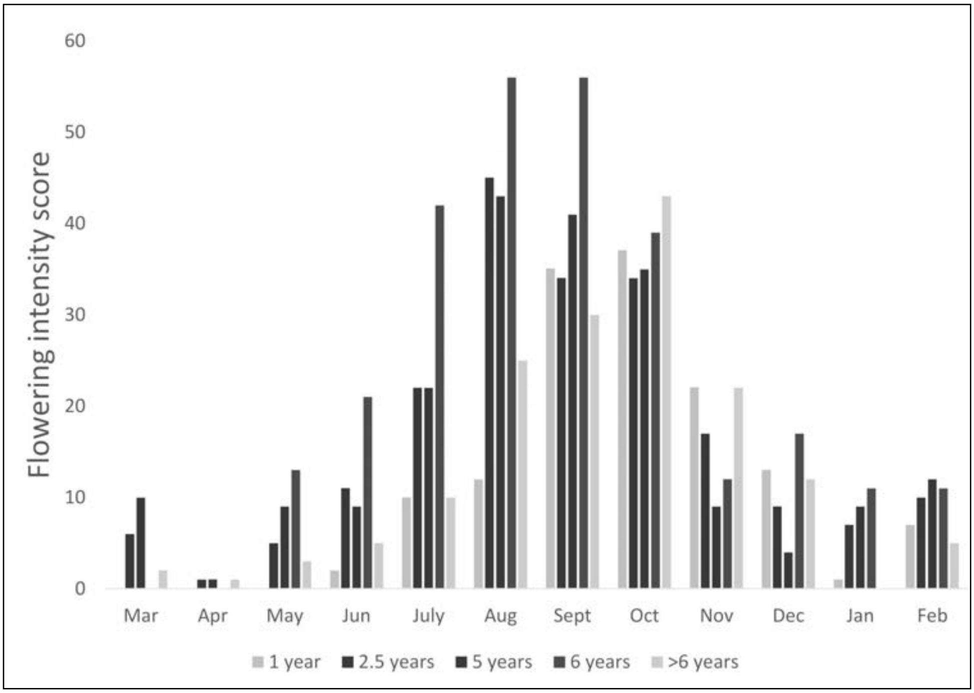

Fig. 2b. Flowering intensity at the sites (1 - 5) used in the "time since fire" study.

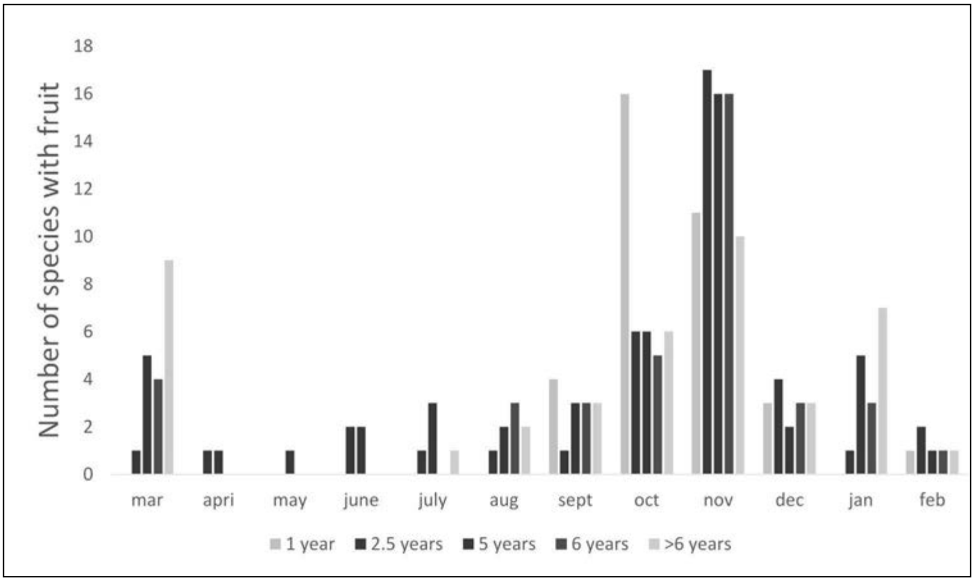

Fig. 3a. Number of species in fruit in each month at the sites (1 - 5) used in the "time since fire" study.

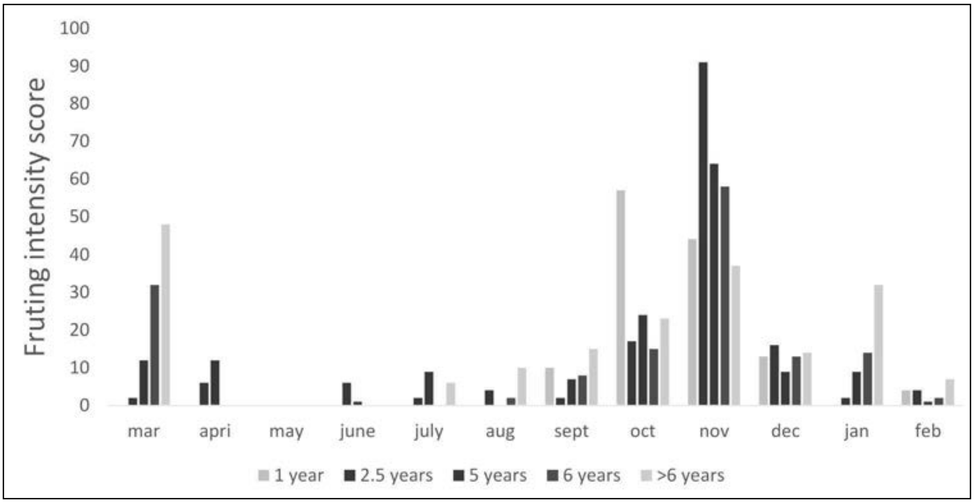

Fig. 3b. Fruiting intensity at the sites (1 - 5) used in the "time since fire" study.

Substrate

Species richness in the coastal dune sites was considerably lower than that of the other sites contrasting markedly with the species-rich site 6 on skeletal limestone soil. Thus, there were a smaller number of species that flowered at these dune sites (Table 2). Flowering intensity on the deep sand Spearwood site (Site 5) was much higher and earlier than on the geologically more recent Quindalup sands (Sites 9 and 10). Although the number of species flowering and flowering intensity in the coastal dune sites was low, flowering was relatively high in late winter and into mid spring (Fig. 4a, b). Total annual flowering intensity scores were highest in sites 6 and 8 and lowest in the coastal dune sites.

Total species with fruit was highest in November (Fig. 5a) for the shallow soil limestone site (site 6), a month later than the maximum flowering and for the heath on Quindalup sand (site 8) and the foredune site (site 10). Total fruiting intensity scores followed a similar pattern to that of flowering intensity (Fig. 5b). The foredune sites (sites 9 and 10) had few species fruiting and low intensity due to low species richness and was generally absent or very low in winter compared to the other sites but carried on into the summer and autumn.

Site 5 in the Nature Reserve sites was included with sites 6, 8, 9, 10 in a one way analysis of variance which showed it was statistically valid to test for differences in number of species flowering between sites ($p<0.05$). However, Tukey's multiple range test showed that the only significant differences were between site 5 in the Nature Reserve and sites 9, 10 (the coastal dune sites). The analysis of variance for number of species fruiting also showed it was statistically valid to test for differences between sites ($p<0.05$). However multiple range tests showed no two pairs of sites to be significantly different.

Comparing sites on different substrates with similar fire history shows that the flowering and fruiting patterns of site 1 on brown siliceous sands of the Spearwood System and site 7 on calcareous sands of the Quindalup System, both recently burnt, show marked similarities.

At both sites there was a similar upsurge of flowering in spring driven particularly by the many annuals flowering in the first year after fire (Fig. 6a, b). As with the other sites, number of species fruiting and fruiting intensity peaked a month later (Fig. 7a, b).

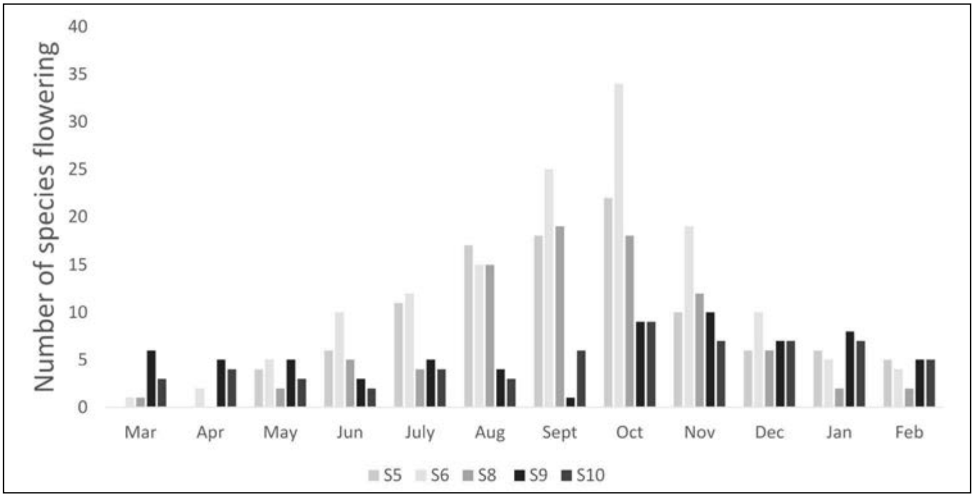

Fig. 4a. Number of species flowering per month at the sites (5, 6, 8 - 10) used in the substrate study.

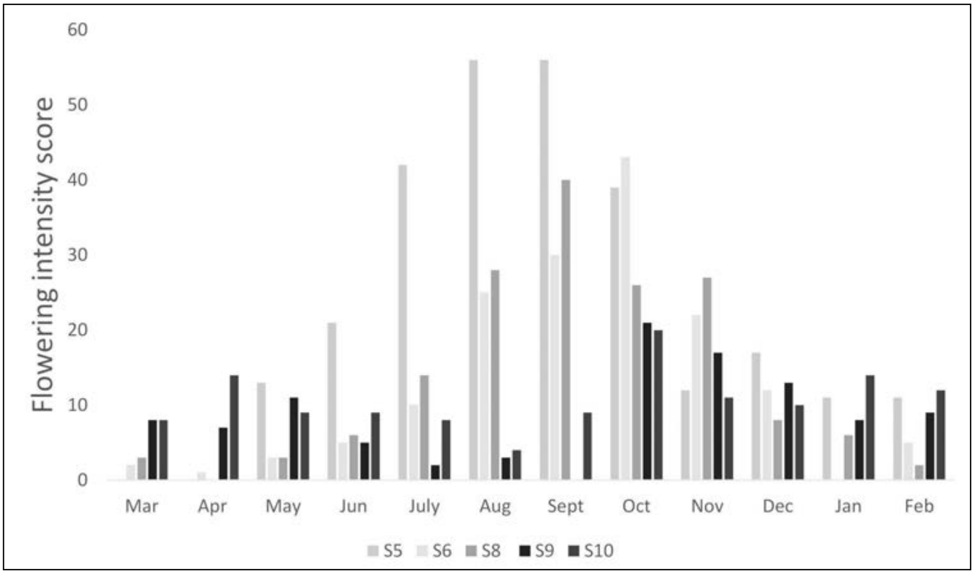

Fig. 4b. Flowering intensity per month at the sites (5, 6, 8 - 10) used in the substrate study.

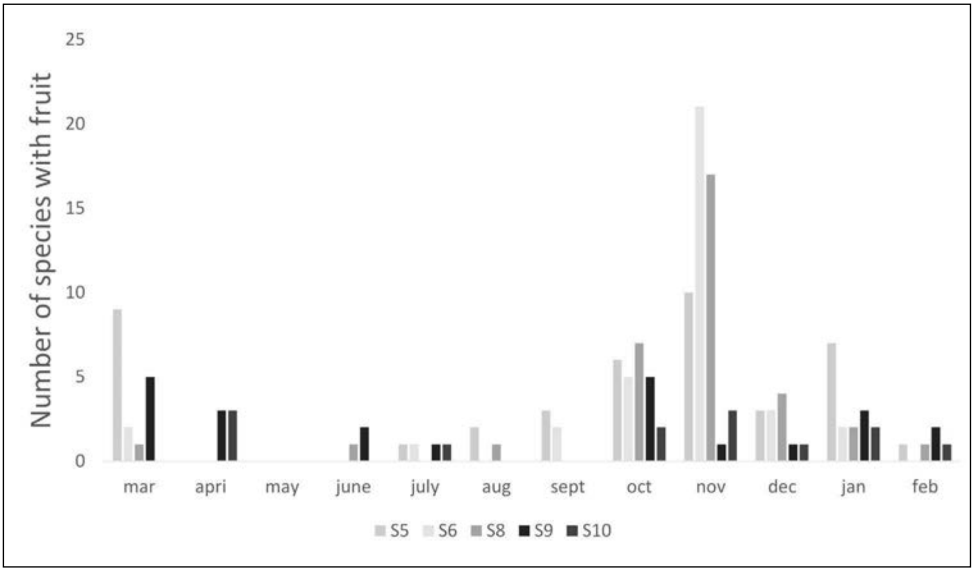

Fig. 5a. Number of species fruiting at the sites (5,6, 8 - 10) used in the substrate study.

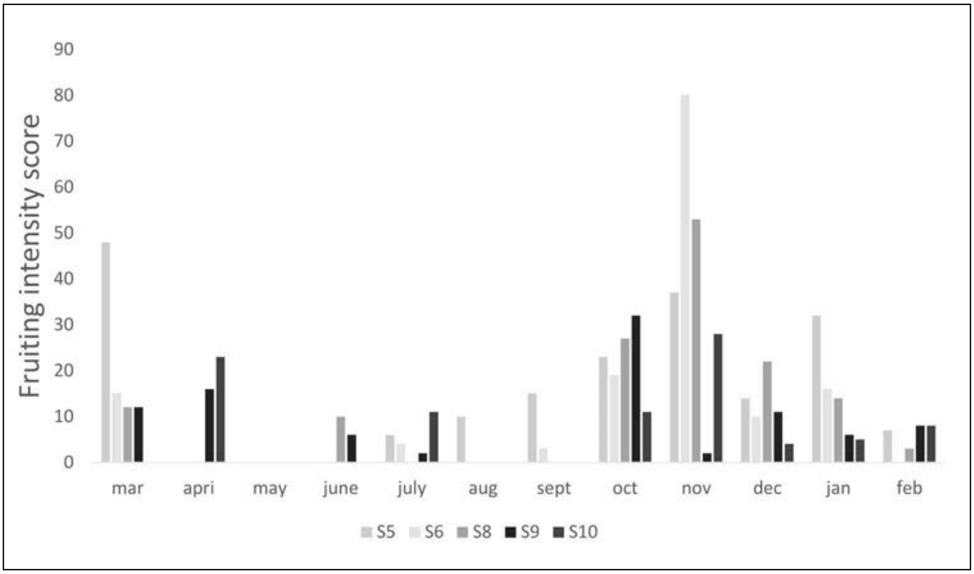

Fig. 5b. Fruiting intensity at the sites (5,6, 8 - 10) used in the substrate study.

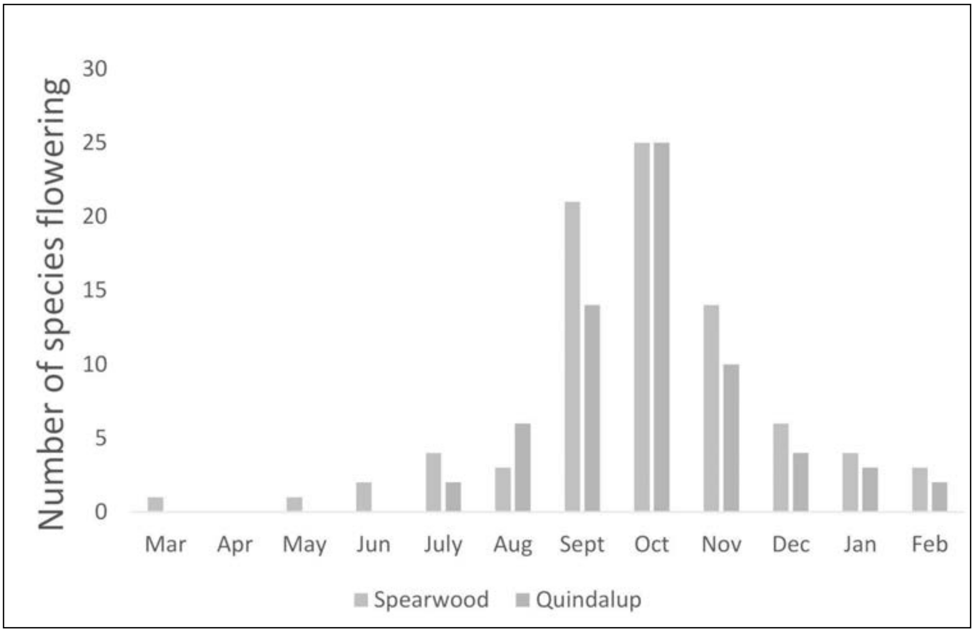

Fig. 6a. Number of species flowering per month at the sites 1 and 7 – both one year after fire.

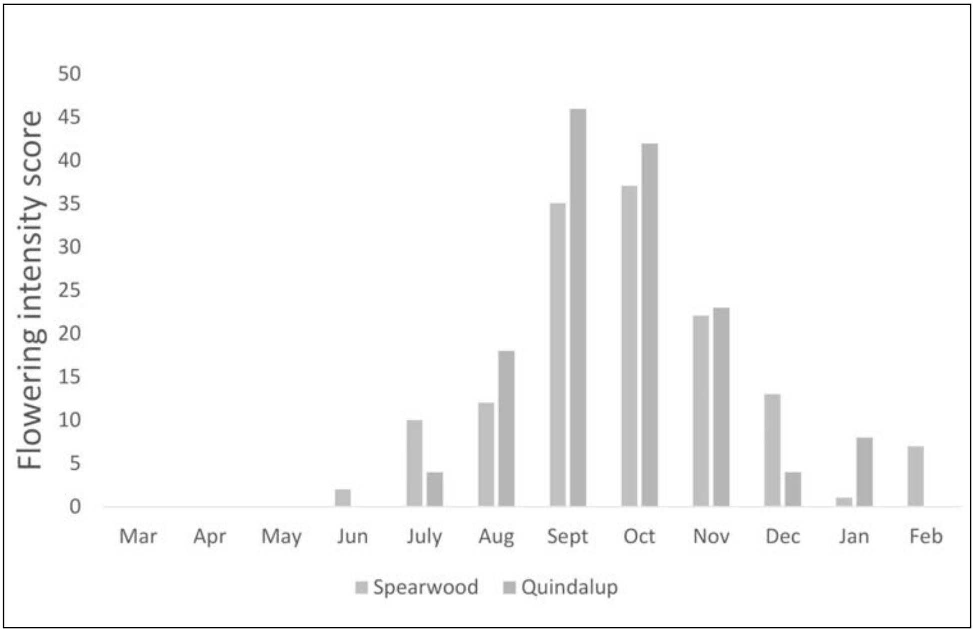

Fig. 6b. Flowering intensity per month at the sites 1 and 7 – both one year after fire.

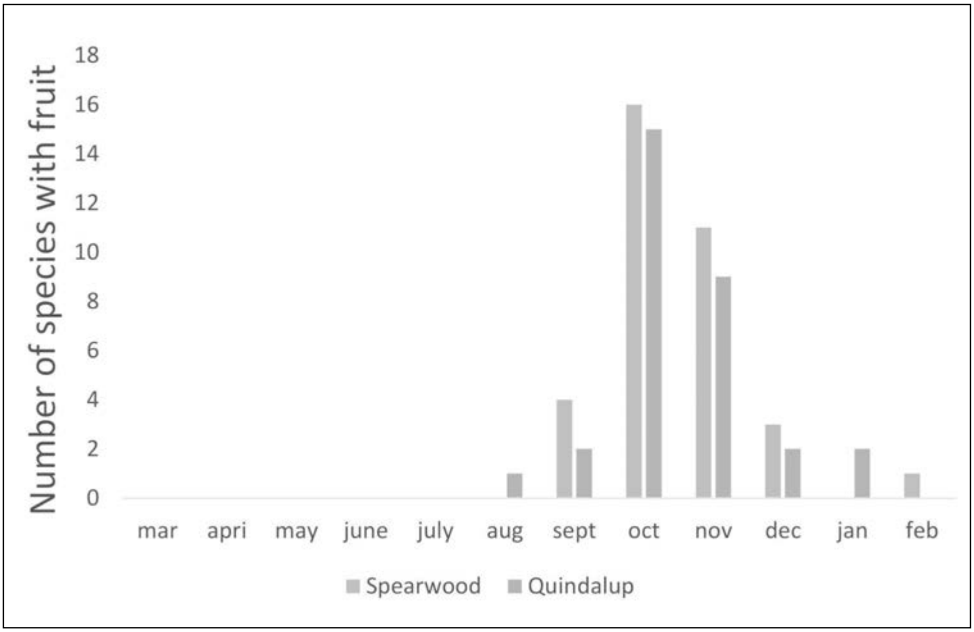

Fig. 7a. Number of species fruiting per month at the sites 1 and 7 – both one year after fire.

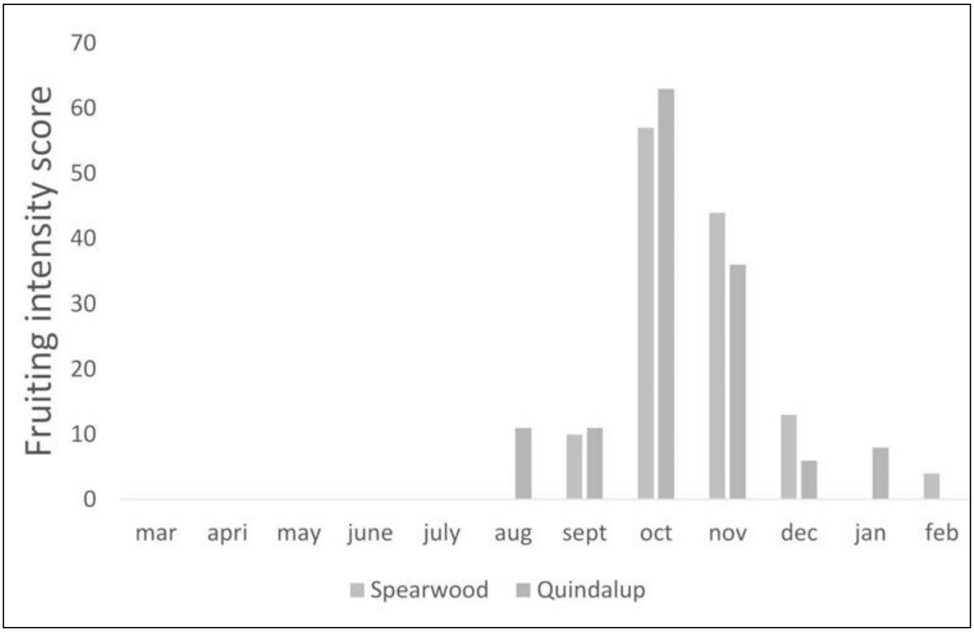

Fig. 7b. Fruiting intensity per month at the sites 1 and 7 – both one year after fire.

Discussion

The pattern of a spring peak in flowering seen in the Lancelin heaths is typical of that of other heathlands in Mediterranean-type climates (Bell and Stephens 1984). The timing of the peak, however, shows some variation within Western Australian heaths and shrublands. The greatest number of species flowering in the Lancelin area was in early October. However, the greatest flowering intensity was earlier and in these heathlands species in the Fabaceae, particularly *Acacia*, are some of the earliest to flower, beginning in mid-winter (pers obs). In the Mt Lesueur area 100 km to the north the peak was earlier, in August (Wills 1989), at Badgingara 80 km north-east it was in late September (van der Moezel & al. 1987) and in the Perth region, 125 km south, flowering peaked mid-October (Bell & Stephens 1984; Gentilli 1996). Therefore, the peak number of species flowering is later with distance to the south. Bell and Stephens (1984) related this to interactions of the environmental factors daylength, temperature and soil moisture and Gentilli (1996) demonstrated a very good correlation between flowering and monthly rainfall lagged by 2-3 months plus an influence of low winter temperatures. This correlates with results from the cool temperate climate of Chile under a rainfall regime of 1600 mm/a where flowering occurs much later in the year, in late spring extending into summer, and is primarily related to temperature (Smith-Ramirez and Armesto 1994).

The spring onset flowering pattern in the south-western Australian heaths is similar to that seen in southern California, Israel, Chile (Bell and Stephens 1984), Spain (Hererra 1986), Greece (Petanidou & al. 1995), France (Segrestin & al. 2018) and to the winter rainfall area of the South African Cape (Johnson 1993). The Lancelin dune community was more similar to the pattern found in the non-seasonal rainfall area of the eastern Cape (Johnson 1993) with flowering extending more into the summer.

In contrast the single peak in flowering in heathlands in the south western Australian Mediterranean climate does not match with the bimodal flowering and fruiting activity in subtropical heaths in Queensland (Specht & al. 1981; McFarland 1990) and lacks the late spring and summer secondary peak of mostly woody species in France (Segrestin & al. 2018) or any autumn subsidiary peak of flowering as recorded for phrygana in Greece (Petanidou & al. 1995).

Time Since Fire

The visual impression of abundant flowering in the early years post-fire (Specht 1981) which can be apparent from southern Australian heathlands is not an accurate representation of the majority of the community. It is the result of flowering in a few specialised (but often abundant) members of the community (eg. *Xanthorrhoea* spp., Gill 1981; *Nuytsia* Lamont & Downes 2011) plus fire ephemerals, particularly grasses. Flowering intensity in the Lancelin kwongan was greatest in the oldest sites (although not significant), more than 6 years post-fire and occurred earlier than at the one year since fire site. This accords with similar peaks in flowering and fruiting intensity at 8 years post-fire in subtropical heathlands (McFarland 1990). In contrast there is poor correlation with South African fynbos in which a rich suite of geophytes produces an impressive post-fire floral display (Johnson 1992). Geophytes are prominent in both fynbos and Australian heath, but analysis of closely matched sites shows geophytes are more common in the Cape (Cowling and Witkowski 1994) and the hysteranthos habit is rare in Kwongan (le Maitre & Midgley 1992), contributing to the contrast in flowering behaviour between the African and Australian communities. In Brazilian cerrado flowering of grasses after fire is very pronounced (Fontenele & al. 2020) and this is similar to the frequent abundance of *Austrostipa compressa* the first year after fire in kwongan (Baker & al. 2005).

Differences in reproductive activity in the Lancelin heath were due largely to life history characteristics and age structure of individuals, which in turn were related to fire history. Annuals, geophytes, chamaephytes, sub-shrubs, multi-stemmed shrubs and single stemmed shrubs represent the approximate order of time from regeneration to flowering (Griffin pers comm). The earlier and more peaked flowering and fruiting on the most recently burnt site reflected the greater representation of annuals on that site, than on other sites, and the rapid completion of their life cycle before the dry summer in this markedly seasonal environment.

From 2.5 years (site 2) after fire the community phenological pattern in terms of seasonal behaviour showed little change, although number of species flowering decreased (but would eventually plateau) with time since fire. The higher total flowering intensity scores for the older sites, in particular for the pre-1985 site is related to the more protracted flowering of woody perennial species and the greater reproductive effort required to attract pollinators in self-incompatible species (Wills 1989). The fact that flowering intensity was highest in the late winter may be related to greater competition for pollinators at this time of the year when adverse weather conditions limit pollinator foraging.

Peak fruiting activity was more narrowly confined than was flowering, perhaps related to the need by shallow rooted plants to complete fruit set before conditions became excessively dry in summer (Bell & Stephens 1984). The fact that the longer unburnt sites had higher fruiting intensities in summer than more recently burnt sites is related to the increasingly greater proportion, in biomass terms, of large (deep rooted) woody plants on the long unburnt sites. Lower intensity scores, in general, in comparison with flowering reflects the fact that in many species a low proportion of flowers set fruit (Vaughton 1991).

Fruit production after flowering will be related to the type of fruit/seed produced. Fruit maturation in annuals will be much quicker than in perennials (Segrestin & al. 2018). Fruiting followed relatively rapidly (one month) after flowering in comparison to fruiting at a site in southern Spain (Herrera 1986) where the main fruiting peak followed flowering by 3 months. Seeds that are destined for the soil seed bank may mature more quickly than those in serotinous infructescences where the woody fruit will take longer to mature than a less substantial fruit. In Spain there was a bimodal peak in fruiting related to nonfleshy (first mature) and fleshy (matured later) fruits. This same trend was apparent in a study of phenology in rainforest in Chile at 40°S with a winter maximum rainfall. Shrub species which were mainly zoochorous showed a 3-month separation between peak flowering and fruiting. For tree species which were evenly divided between anemochorous and zoochorous species the peak flowering was later in the season and preceded peak fruiting by only one month (Smith-Ramirez & Armesto 1994). In Lancelin heaths there are few plants with fleshy fruits and most have small fruits requiring only a short time for development. The fruiting curve is more peaked than the flowering curve with a tail into the autumn indicating longer fruit development in a proportion of the flora, such as those with woody capsules or follicles. Species with myrmecochorous seeds may need to mature in late spring to early summer to coincide with ant activity and such species are common in kwongan vegetation (Lubertazzi & al. 2010).

The main trend in fruiting intensity in relation to time since fire was sites longer since fire tended to have higher intensity later in the year than sites burnt more recently. The high fruit numbers, rapid development and fruiting intensity of the recently burnt sites seems to be related to the seeding characteristics of annuals, which, due to phenological cycles, mating systems and post-fire regeneration strategy, tend to produce large quantities of seed (Willson 1983; Wills 1989). The monocarpic fire ephemerals of the kwongan have been found to produce smaller, more numerous seed than the polycarpic ephemerals, which commence reproduction in the second season post-fire (Pate & al. 1985). In the majority of months the site burnt in 1986 (five years previously) had higher seed production than Site 2 (burnt 2.5 years previously in 1988), but was also generally slightly higher than the site burnt six years previously in 1985 (Site 4). Fruit production of sites burnt in 1985 (site 4) and before 1985 (site 5) were generally similar except in February and October. It seems that fruit production reaches a stable level by at least five years after a fire episode and may even decline in long unburnt heathland (Whelan & Ayre 2020).

Time to first flowering after fire has been examined for a large number of Western Australian species (Burrows & al. 2008). While the juvenile period for most forest species was 3 years; seeder species in drier kwongan may be considerably longer (Wooller & al. 2002). Even if flowering begins 3 years after fire fruit production may take longer, as with sparse flowers from young plants, pollen transfer may be limited, so outcrossing plants in particular may have delayed fruiting. Serotinous species will build up a retained seed bank once flowering is of a sufficient density to attract pollinators. However after a period of production retained seed loses viability or is damaged by predators (e.g. Lamont & Barker 1988; Whelan & Ayre 2020) so the seed bank capital will plateau at a certain level, depending on the species involved.

Plant community flowering pattern is clearly most strongly influenced by climatic factors (Herrera 1986; Johnson 1993; Petanidou & al. 1995; Segrastin & al. 2018) but fire changes the reproductive phenology spectrum by enabling annuals to enter the community, removing adult tissue of sprouting species and initiating flowering in a minority of species such as monocots (McFarland 1990) which are cued to flower by disturbance. Flowering intensity and number of species flowering shows the same pattern for the early post fire period but after about four years the number of species flowering decreases while peak flowering intensity does not alter from the early spring pattern. From a community point of view there seem to be two components. Firstly, taxa which flower profusely in the first (possibly 2) years after fire, flower early in spring and set seed before summer - most are annuals. These have limited root mass so need to mature fruit and seeds while soil moisture is still available in the upper part of the soil profile. Secondly, there are the core taxa of the heathland, which mostly begin flowering at least 2 years after fire, flower later in spring and continue to fruit into summer. Shrubs with more extensive root run and access to deeper soil moisture can take longer to mature fruit.

Substrate

Although the edaphic differences between sites were not large, the coastal dune sites contrasted most markedly with the sites on other substrates. They were notable for their more protracted flowering and fruiting activity and the lack of flowering and fruiting synchrony in certain species. Similar asynchrony has been observed in dune thicket species of the South African Fynbos (Pierce 1984). In species which fruited asynchronously in fynbos dune thicket, there was variation in the quantity of fruit produced at different times of the year (Pierce 1984). There was a similar trend in fruit production in this study. Lower fruit production in winter may reflect inadequate pollination at this time.

A comparison of reproductive activity at sites on different soils types but with similar fire histories, albeit limited, showed similarities in flowering and fruiting patterns, suggesting that the effect of fire history or fire history combined with other factors influencing reproductive phenology, such as climate may be more important than substrate. A phenological study of three shrubland types in climatically similar sites in South Africa showed that substrate had minimal effect on phenophases (Pierce & Cowling 1984). Temperature and soil moisture may be more important in determining phenophases than nutrient availability (Heinsohn & Pammenter 1988; Segrestin & al. 2018). However, the phenological contrast between the dune and the heathland flora may reflect the cosmopolitan origin of many dune species which is different from the heath species that are part of the autochthonous element of the Australian flora. Johnson (1993) and Linder (2020) have emphasised that there is a relationship between phenological patterns and the phylogeny of species so the prominence of different groups in the different floras might be expected to produce different phenological patterns.

In conclusion, our study emphasises the influence fire on reproductive phenology. From a fire management perspective, the timing and intensity of peak reproductive activity are important aspects to consider in relation to both fire interval and season of fire.

References

Baker, K. S., Steadman, K. J., Plummer, J. & Dixon, K. W. 2005: Seed dormancy and germination responses of nine Australian fire ephemerals. – Pl. Soil **277:** 345-358.

Beard, J. S. & Pate, J. S. 1984: Forward. – Pp. xvii-xxii in: Pate, J. S. & Beard, J. S. (eds), UKwongan - Plant Life of the Sandplain'. – Perth.

Bell, D. T. & Koch, J. M. 1980: Post-fire succession in the northern jarrah forest of Western Australia. – Australian J. Ecol. **5:** 9-14.

— & Stephens, L. J. 1984: Seasonality and Phenology of Kwongan Species. – Pp. 205-225 in: Pate, J. S. & Beard, J. S. (eds), Kwongan - Plant Life of the Sandplain. – Perth.

Benson, D. H. 1985: Maturation periods for fire-sensitive shrub species in Hawkesbury sandstone vegetation. – Cunninghamia **1:** 339-49.

Bogusch, P., Blazej, L., Tryzna, M. & Heneberg, P. 2015: Forgotten role of fires in central European forests: critical importance of early post-fire successional stages for bees and wasps (*Hymenoptera*: *Aculeata*). – Europ. J. Forest Res.**134:** 153-166.

Burrows, N. D., Wardell-Johnson, G. & Ward, B. 2008: Post-fire juvenile period of plants in the south-west Australian forests and implications for fire management. – J. Roy. Soc. Western Australia **91:** 163-174.

Carbone, L. M. & Aguilar, R. 2017: Fire frequency effects on soil and pollinators: what shapes sexual reproduction? – Pl. Ecol. **218:** 1283-1297.

Cowling, R. M. & Witkowski, E. T. F. 1994: Convergence and non-convergence of plant traits in climatically and edaphically matched sites in mediterranean Australia and South Africa. – Australian J. Ecol. **19:** 220-232.

Dunn, E. L., Shropshire, F. M., Song, L. C. & Mooney, H. A. 1976: The water factor and convergent evolution in Mediterranean-type vegetation.— Pp. 492-505 in: Lange, O. L., Kappen, L. & Schulze, E.-D. (eds), Water and Plant Life. – Heidelberg.

Fontenele, H. G. V., Cruz-Lima, L. F. S., Pacheco-Filho, J. L. & Miranda, H. S. 2020: Burning grasses, poor seeds: post-fire reproduction of early-flowering Neotropical savanna grasses produces low-quality seeds. – Pl. Ecol. **221:** 1265-1274.

Gentilli, J. 1996: Seasonal climates and flowering time. – Western Australian Naturalist **21:** 103-118.

Gill, A. M. 1981: Adaptive responses of Australian plant species to fire. – Pp. 234-72 in: Gill, A. M., Groves, R. H. & Noble, I. R. (eds), Fire and the Australian Biota. – Canberra.

— & Groves, R. H. 1981: Fire regimes in heathlands and their plant-ecological effects. – Pp. 61-84 in: Specht, R. L. (ed.), Ecosystems of the World: Heathlands and Related Shrublands. – Amsterdam.

— & Ingwerson, I. 1976: Growth of *Xanthorrhoea australis* R. Br. in relation to fire. – J. Appl. Ecol. **13:** 195-203.

Heinsohn, R. D. & Pammenter, N. W. 1988: Seasonality of shoot growth and flowering in the fynbos shrub *Protea neriifolia* cultivated in a summer rainfall area. – South African Journal of Botany **54:** 440-444.

Herrera, J. 1986: Flowering and fruiting phenology in the coastal shrublands of Donana, south Spain. – Vegetatio **68:** 91-98.

Johnson, S. J. 1992: Plant animal relationships. – Pp. 175-205 in: Cowling, R. M. (ed.), The ecology of fynbos: Nutrients, fire and diversity. – Cape Town.

— 1993: Climatic and phylogenetic determinants of flowering seasonality in the Cape flora. – J. Ecol. **81:** 567-575.

Lamont, B. B. & Barker, M. J. 1988: Seed bank dynamics of a serotinous, fire sensitive *Banksia* species. – Australian J. Bot. **36:** 193-203.

— & Downes, K. S. 2011: Fire-stimulated flowering among resprouters and geophytes in Australia and South Africa. – Pl. Ecol. **212:** 2111– 2125. https://doi.org/10.1007/s11258-011-9987-y

—, He, T. & Yan, Z. 2019: Evolutionary history of fire-stimulated resprouting, flowering, seed release and germination. – Biol. Rev. **94:** 903-928. https://doi.org/10.1111/brv.12483

Lazarina, M., Sgerdelis, S. P., Tscheulin, T., Devalez, J., Mizerakis, V., Kallimanis, A. S., Papakonstantinou, S., Kyriazis, T. & Petanidou, T. 2017: The effects of fire history in shaping diversity patterns of flower visiting insects in post-fire Mediterranean pine forests. – Biodiv. Conserv. **26:** 115-131. https://doi.org/10.1007/s10531-016-1228-1

Le Maitre, C. D. & Midgely, J. J. 1992: Plant reproductive ecology. – Pp. 135-174 in: Cowling, R. M. (ed.), The ecology of fynbos: Nutrients, fire and diversity'. – Cape Town.

Li, L., Li, Z., Cadotte, M. W., Jia, P., Chen, G., Jin, L. S. & Du, G. 2016: Phylogenetic conservatism and climatic factors shape flowering phenology in alpine meadows. – Oecologia **182:** 419-428.

Linder, H. P. 2020: The evolution of flowering phenology: an example from the wind-pollinated Restionaceae. – Ann. Bot. **126:** 1141-1153. https://doi.org/10.1093/aob/mcaa129

Lubertazzi, D., Lubertazzi, M. A. A., McCoy, N., Gove, A. D., Majer, J. D. & Dunn, R. R. 2010: The ecology of a keystone seed disperser, the ant *Rhytidoponera violacea*. – Journal of Insect Science **10:** 158. doi.org/10.1673/031.010.14118

McFarland, D. C. 1990: Flower and seed phenology of some plants in the subtropical heathlands of Cooloola National Park, Queensland, Australia. – Australian Journal of Botany **38:** 501-509.

Milewski, A. V. & Davidge, C. 1981: The physical environment, floristics and phenology of a *Banksia* woodland near Perth, Western Australia. – Western Australian Herb. Res. Notes **5:** 29-48.

Muir, B. G. 1987: Time between germination and first flowering of some perennial plants. – Kingia **1:** 75-83.

O'Dowd, D. J. & Gill, A. M. 1984: Predator satiation and site alteration following fire: Mass reproduction in alpine ash (*Eucalyptus delegatensis*) in south-eastern Australia. – Ecology **65:** 52-66.

Pate, J. S., Casson, N. E. & Kuo, J. 1985: Biology of fire ephemerals of the sandplain of the Kwongan of south-western Australia. – Australian J. Pl. Physiol. **12:** 654-655.

Petanidou, T., Ellis, W. N., Margaris, N. S. & Vokou, D. 1995: Constraints on flowering phenology in a phryganic (east Mediterranean shrub) community. – American J. Bot. **82:** 607-620. https://doi.org/10.1002/j.1537-2197.1995.tb11505.x

Pierce, S. M. 1984: A synthesis of plant phenology in the fynbos biome. – Pretoria.

— & Cowling, R. M. 1984: Phenology of fynbos, renosterveld and subtropical thicket in the south-eastern cape. – South African J. Bot. **3:** 1-16.

Pignatti, E., Pignatti, S. & Ladd, P. G. 2002: Comparison of ecosystems in the Mediterranean basin and Western Australia. – Pl. Ecol. **163:** 177-186. https://doi.org/10.1023/A:1020968010349

Pyke, G. H. 1983: Relationship between time since last fire and flowering in *Telopea speciosissima* R. Br. and *Lambertia formosa* Sm. – Australian J. Bot. **31:** 293-296.

— 2017: Fire-stimulated flowering: a review and look to the future. – Critical Rev. Pl. Sci. **36:** 179-189.

Rafferty, N. E. & Nabity, P. D. 2017: A global test for phylogenetic signal in shifts in flowering time under climate change. – J. Ecol. **105:** 627-633. https://doi.org/10.1111/1365-2745.12701

Segrestin, J., Bernard-Verdier, M., Violle, C., Richarte, J., Navas, M.-L. & Gernier, E. 2018: When is the best time to flower and disperse? A comparative analysis of plant reproductive phenology in the Mediterranean. – Functional Ecol. **32:** 1770-1783. https://doi.org/10.1111/1365-2435.13098

Smith-Ramirez, C. & Armesto, J. J. 1994: Flowering and fruiting patterns in the temperate rainforest of Chiloe, Chile - ecologies and climate constraints. – J. Ecol. **82:** 353-365.

Specht, R. L. 1981: Responses to fire in heathlands and related shrublands. – Pp. 395-415 in: Gill, A. M., Groves, R. H. & Noble, I. R. (eds), Fire and the Australian Biota. – Canberra.

—, Rogers, R. W. & Hopkins, A. J. M. 1981: Seasonal growth and flowering rhythms: Australian heathlands. – Pp. 5-13 in: Specht, R. L. (ed.), Heathlands and related shrublands. – Amsterdam.

—, Moll, E. J., Pressinger, F. & Sommerville, J. E. M. 1983: Moisture regime and nutrient control of seasonal growth in mediterranean ecosystems. – Pp. 120-132 in: Kruger, F. J., Mitchell, D. T. & Jarvis, J. U. M. (eds), Mediterranean-Type Ecosystems: The Role of Nutrients'. – Berlin.

SPSS Inc. 1986: SPSS Users Guide, 2nd edition. – Chicago.

Turner, B. L., Hayes, P. E. & Laliberte, E. 2018: A climosequence of chronosequences in southwestern Australia. – European J. Soil Sci. **69:** 69-85. https://doi.org/10.1111/ejss.12507

Van der Moezel, P. G., Loneragan, W. A. & Bell, D. T. 1987: Northern sandplain Kwongan: regeneration following fire, juvenile period and flowering phenology. – J. Roy. Soc. Western Australia **69:** 123-132.

Vaughton, G. 1991: Variation between years in pollen and nutrient limitation of fruit-set in *Banksia spinulosa.* – J. Ecol. **78:** 389-400.

Whelan, R. J. & Ayre, D. J. 2020: Long inter-fire intervals do not guarantee a large seed bank in a serotinous shrub (*Banksia spinulosa* SM.) – J. Ecol. **108:** 1690-1702. https://doi.org/10.1111/1365-2745.13357

Wills, T. R. 1989: Management of the flora utilised by the European honeybee in Kwongan of the northern sandplain of Western Australia. – PhD Thesis, University of Western Australia: Perth.

Willson, M. F. 1983: Plant Reproductive Ecology. – New York.

Wooller, S. J., Wooller, R. D. & Brown, K. L. 2002: Regeneration by three species of Banksia on the south coast of Western Australia in relation to fire interval. – Australian J. Bot. **50:** 311-317.

Wright, S. J. & Calderon, O. 1995: Phylogenetic patterns among tropical flowering phenologies – J. Ecol. **83:** 937-948.

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Article

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Spatial phylogenetic diversity of pteridophytes in Latium (Central Italy): a tool for conservation planning at regional scale

Abstract

Bartoli, F., Iocchi, M. & Lucchese, F.: Spatial phylogenetic diversity of pteridophytes in Latium (Central Italy): a tool for conservation planning at regional scale. — Fl. Medit. 31 (Special Issue): 297-315. 2021. — ISSN: 1120-4052 printed, 2240-4538 online.

The spatial phylogenetic metrics of pteridophyte diversity and endemism may provide useful information to prioritize protected areas for conservation planning. We analysed spatial patterns of phylogenetic diversity (PD) and phylogenetic endemism (PE) of native pteridophytes across Latium, to recognise diversity and endemism centres. and to discuss implications for conservation in the region. We identified the main PD and PE centres that should be considered as valuable biodiversity hotspots, due to their high evolutionary and conservation value. Most, but not all of them correspond to protected areas Monitoring programmes of the rarest taxa are proposed.

Key words: phylogenetic endemism, ferns, protected areas, ecology optimization, biodiversity, hotspot priority.

Introduction

Presently, we are facing the sixth species mass extinction on Earth (Barnosky & al. 2011), biodiversity being currently threatened by human-induced climate change and other anthropogenic factors such as alien species invasions, habitat loss and fragmentation, pollution and over-consumption of natural resources (Myers & al. 2000; Sarkar & al. 2006; Devictor & al. 2012; Fenker & al. 2014; Jantz & al. 2015; Arnan & al. 2016; Pyšek & al. 2020). Therefore, measuring and quantifying the spatial patterns of biodiversity is a very important goal for conservation planning (Arnan & al. 2016), also useful in identifying areas of high conservation priority as well as in optimization of conservation strategies (Ceballos & Ehrlich 2006; Diniz-Filho & Telles, 2006; Lostia 2018). Biodiversity studies traditionally use species as a unit of analysis (i.e., species richness: SR). SR, the number of species in a given area (Faith 1992; Magurran & McGill 2011), was traditionally used to define areas of conservation importance (MacArthur & Wilson 1967; Connell 1978; Gotelli & Colwell 2001). However, SR alone is not sufficient to assess the biodiversity of an area, because it provides limited insight into the underlying characteristics of taxa and, fails to incorporate information about the relationships among species (Lee & Mishler 2014; Rosauer & Jetz 2015; Lean & Maclaurin 2016). Species endemism is another commonly used biodiversity metric (Mittermeier & al. 2011). Endemism refers to the geographic restriction of a species (Crisp & al. 2001) and is a key factor to map the distribution of biological diversity and to identify areas of priority for conservation, such as biodiversity hotspots (Myers & al. 2000; Crisp & al. 2001; Rosauer & Jetz 2015). Endemism is also a good estimator of extinction risks, since geographically restricted species are irreplaceable and cannot be found anywhere else (Gaston & Fuller 2009; Gudde & al. 2013). Unfortunately, also endemism-related metrics are often measured by looking at species alone, this approach giving an incomplete picture of endemism itself (Mishler & al. 2014). The traditional biodiversity metrics do not reveal areas where a few species represent a significant amount of evolutionary history (Mooers 2007; Yek & al. 2009), they only consider the terminal taxa on the phylogenetic tree, without taking into account the evolutionary relationships among taxa (Lee & Mishler 2014; Rosauer & Jetz 2015).

Knowledge of phylogenetic relationships may illuminate the origin of diversity patterns as well as the drivers that gave rise to them (Hawkins & al. 2014; Lagomarsino & al. 2016). Taking species phylogenetic relatedness into consideration in conservation assessment is also crucial because closely related species are often more similar functionally and ecologically than distantly related ones (i.e., phylogenetic autocorrelation; Gittleman & Kot 1990). Spatial phylogenetics combines species occurrence data with molecular phylogenetics to recover information about the spatial distribution of phylogenetic diversity (PD) and phylogenetic endemism (PE) across geographic regions. Faith (1992) described PD as the sum of the lengths of the phylogenetic branches separating all species occurring in a region. Accordingly, an area with low PD has less genetic diversity than an area with high PD (i.e., more distantly related species). PE is the sum of branch lengths weighted by the proportion of the range of each branch that is found in the area; in other words, high PE values are found where long branches on the phylogenetic tree are restricted to a small geographic range (Rosauer & Jetz 2015). Areas of high PE are very important to conserve, as they harbour evolutionary history that is at risk of extinction (Jetz & al. 2012; Rosauer & Jetz 2015; Laity & al. 2015). The evolutionary history of species is relevant for various measures of endemicity, such as neo-endemism (i.e., recently evolved) or paleo-endemism (i.e., anciently evolved), and is informative about the biogeographic history of an area (Casal-Lopez & al. 2018), aiding in identifying areas of potential biological interest (Nieto-Blázquez & al. 2017). Mishler & al. (2014) proposed a quantitative measure to clearly distinguish centres of neo- and paleo-endemism and to discover areas that are centres of both neo- and paleo-endemism (named centres of mixed-endemism). All these phylogenetic metrics offer an improvement over traditional biodiversity metrics, because they incorporate the evolutionary relationships of taxa, thus providing a more accurate assessment of biodiversity (Diniz-Filho & al. 2013; González-Orozco & al. 2015).

Several studies have been provided both at the national and regional level. A first main monograph was published by Fiori (1943), and later other authors, such as Arrigoni, Ciampolini, Chiarugi, Ferrarini, Marchetti, Nardi, Pichi-Sermolli, Pignatti, Ricceri, Tommei, Zangheri provided general studies on pteridophyte taxonomy, morphology and distribution.

At regional level, several studies exist for the following administrative regions of Italy: Molise (Lucchese 1995), Liguria (Bernardello & Martini 2004), Abruzzo (Conti & al. 2011), Friuli Venezia Giulia (Martini & al. 1977; Bona & al. 2005), Emilia-Romagna (Bonafede & al. 2016), Trentino-Alto Adige (Prosser & al. 2019), Veneto, Friuli Venezia Giulia e Trentino-Alto Adige (Bona & al. 2005), Sicily (Troìa & al. 2012), Tuscany (Arrigoni 2016; Carta & al. 2018) and Central Italy (Mayer 2017).

For the Latium region, a single paper about the phytogeography of ferns is that by Lusina (1951). Thus, the present paper is the first study about the diversity and distribution of pteridophytes for this region.

Latium is one of the 20 administrative regions of Italy; it is located at the centre of the Italian peninsula facing to the Tyrrhenian sea. Central Italy is considered one of the most important hotspots within the Mediterranean region both for endemic vascular plants (van Gils & al. 2012) and for invertebrates (Balletto & al. 2010). During the late Pleistocene and the early Holocene, the vegetation history of Latium has faced a very complex scenario with several arboreal phases due to volcanic activities and climatic glacial oscillations (Giardini 2007). During the Late Glacial and the early Holocene, the Central Apennines have acted as a crucial refugium for several tree genera (Brown & al. 2013; Krebs & al. 2019). A highly inclusive biogeographical study of the distribution of the present vascular flora of Latium was recently provided by Lucchese (2017, 2018). The plant diversity of Latium is very high (almost 3,000 native taxa) mainly due to the highly heterogeneous landscape with a high variation in topography and climate (Lucchese 2017). Pteridophytes are a suitable group for biogeographic studies because of their long evolutionary history, wide distribution, high variation of ecological niches and independence from biotic pollination and distribution vectors (Kessler 2010). With the term “pteridophytes” we intend here all the spore-producing vascular plants, which belong to two different clades commonly called lycopods and ferns. Besides producing spores, both clades share a similar life cycle, and were usually joined within a singular monophyletic group named “pteridophytes”. However, it has recently been found that these clades do not share a common evolutionary ancestor or ancestral group, since ferns are more closely related to seed plants than to lycopods (Christenhusz & Chase 2014). In this study, however, we have decided to join lycopods and ferns in a single group. The same approach and similar methodology have been previously adopted by Carta & al. (2018) for the neighbouring Tuscany Region, hosting 94 taxa and largely richer than Latium. Within the pteridophyte pool of taxa which occurs in the Latium region, both ancient taxa, that show long terminal branches of the phylogenetic tree (e.g., *Selaginella*, *Isoetes*, *Huperzia*, *Botrychium* and *Ophioglossum*), and more recent taxa with short terminal branches (e.g., *Polystichum*, *Equisetum*, *Polypodium* and *Cystopteris*) coexist. In both cases there are taxa that occur widely within the region and others that are present in more restricted areas. Thus, phylogenetic metrics of pteridophyte diversity and endemism of Latium may provide very useful information to prioritize protected areas for conservation planning.

Accordingly, the aims of this study were: (1) to estimate, analyse and map the PD and PE spatial patterns of native pteridophytes across Latium; (2) to identify and distinguish centres of diversity and endemism that should be prioritised in conservation planning; (3) to compare the centres of endemism and to discuss the implications for conservation.

Material and methods

Geographic data

Latium (in italian “Lazio”) extends for 17.227 km^2 within the latitudinal band of 42°53’-40°42’ N-S and longitudinal one of 11°20’-14°10’ W-E. This region is a part of the Central Apennines (0-2.458 m) with carbonate, flysch and volcanic deposits, a part of the peri-Mediterranean orogenic belt built up mainly in Neogene times as a consequence of the collision and convergence between the European and African macroplates (Cosentino & al. 2010).

5,148 geo-referenced unique occurrence data of 61 native pteridophyte were extracted from the geodatabase of the vascular flora of Latium, that includes field (5,538 occurrences), literature (4,867 occurrences) and herbarium (713 occurrences) data (Lucchese 2017). Only recently confirmed and accepted occurrence data were included, excluding doubtful ones. Field surveys were carried out by Lucchese from 1980 until today, recording species on cards within “quadrant” units of CCEF system (Cartography of Central European Flora; Ehrendorfer & Hamann 1965; Niklfeld 1971; Pignatti 1978) that consist of equal-area cells of 5’ x 3’ E longitude and N latitude (approx. 7 km x 5,5 km). In these occasions, we have to pay tribute to Pignatti for starting the flora survey in Lazio (Pignatti 1978). The completeness of the source geodatabase is very high (Lucchese 2017), thus the selected pool of pteridophyte records may be considered as a presence-absence geodata and not only as a presence data. Native pteridophytes occur in 533 of the total 544-cells grid that covers the Latium region. Distribution data of subspecies of *Asplenium obovatum*, *A. ceterach* and *A. trichomanes* were merged at species level because of their restricted taxonomic distinctiveness. In contrast, we decided to maintain separate distribution data of three hybrids (*Polystichum* x *bicknellii*, *Equisetum* x *moorei* and *Asplenium* x *tyrrhenicum*), that are well differentiated from their parental taxa.

Phylogenetic structure

All the occurrence data were geo-referenced and projected within the CCEF grid in equal-area cells of 0,08333 x 0,05 decimal degrees of E longitude and N latitude (7 km x 5,5 km). A phylogenetic tree of the native pteridophytes of Latium (Fig. 1) was assembled using Phylomatic (Webb & Donoghue 2005). As a source mega-tree we used the dated phylogeny for the Central European Flora (Durka & Michalski 2012). In order to define the phylogenetic relationship within the *Lycophytes*, we also considered additional phylogenetic information on *Isoetes* and *Selaginella* (Smith & al. 2006; Christenhusz & al. 2011).

Phylogenetic biodiversity analyses

The Biodiverse software (version 3.1; Laffan & al. 2010) was used to calculate species richness (SR), weighted endemism (WE), phylogenetic diversity (PD), phylogenetic endemism (PE), relative phylogenetic diversity (RPD) and relative phylogenetic endemism (RPE) for each grid cell.

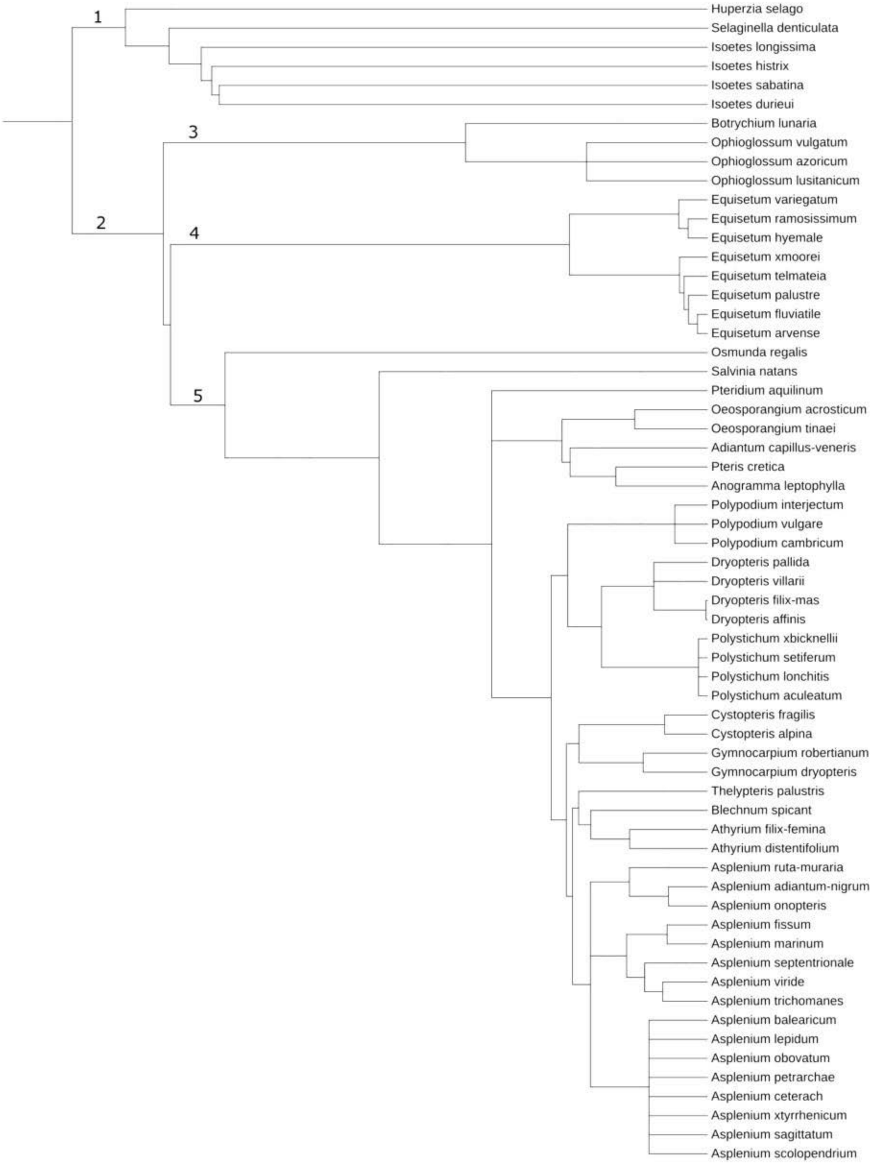


Fig. 1. Phylogenetic tree of native Pteridopyhtes of Latium. Notes: lycopods and ferns clades do not share a common evolutionary ancestor or ancestral group, since ferns are more closely related to seed plants than to lycopods (Christenhusz & Chase 2014). However, within this study we have decided to follow the old phylogenetic approach joining lycopods and ferns in a unique monophyletic clade. Branches of clades marked with numbers are: 1) *Lycophytes*; 2) *Pteridophytes* 3) *Psilotopsida*; 4) *Equisetopsida*; 5) *Polypodiopsida*.

The last two metrics compare respectively PD and PE observed values, calculated on the actual phylogenetic tree, with estimated values calculated on a comparison tree that retain the actual topology but has all branches of equal length (Mishler & al. 2014; Carta & al. 2018). The statistical significance of PD, PE, RPD and RPE were assessed using a randomization test (999 trials) with a null model that randomly reassign species occurrence to grid cells without replacement and that keeps constant both the total number of grid cells for each species and the SR of each grid cell (Laffan & Crisp 2003). The estimated values of PD, PE, RPD and RPE obtained from the randomisation test formed a null distribution for each cell that was used in two-tailed non-parametric tests to obtain the significance of the observed values. Thus, we identified, for each index, which cells have significantly higher and lower values than the null model.

Assessment of pteridophyte centres of diversity and endemism

To identify and distinguish different centres of endemism we followed the CANAPE (Categorial Analysis of “Neo-” And “Paleo-” Endemism) two-step procedure (Mishler & al. 2014). In the first step, to establish which grid cells are centres of endemism, all cells that show significantly high values (one tailed, $\alpha = 0.05$) for either the numerator or denominator of RPE were selected. Grid cells that passed the first step but that have SR < 4 were removed from the selection. In the second step, the RPE significance (two tailed, $\alpha = 0.05$) of the selected areas was evaluated in order to classify grid cells: (i) as centres of neo-endemism if they show significant low values of RPE, indicating the major presence of range-restricted taxa having short terminal branches; (ii) as centres of paleo-endemism if they show significant high values of RPE, indicating the major presence of range-restricted taxa having long terminal branches; (iii) as centres of mixed endemism if they do not show significance for RPE values, indicating the co-occurrence of range-restricted taxa with both short- and long- terminal branches. These latter centres of Mixed Endemism were further subdivided and named as centres of Super Endemism if both the numerator and the denominator of the RPE ratio are highly significant.

Finally, biodiversity hotspots for conservation planning (*sensu* Myers & al. 2000) were identified by comparing and selecting those grid cells which are centres of diversity and/or endemism. Preliminary insights on the conservation status of the most rare pteridophyte populations were also provided.

Results

Phylogenetic biodiversity analyses

Maps of SR, WE, PD and PE are shown in Fig. 2. PD and SR values are significatively positively correlated ($R^2 = 0.615$), but the two spatial patterns show different trends.

Higher SR values are mainly located in Temperate mountain areas, with some isolated exceptions in volcanic sub-coastal areas and in the Mediterranean zone. Higher PD values are mainly located in Mediterranean areas and in some internal areas which include water bodies, with some isolated exceptions in Temperate mountain areas and in volcanic sub-coastal areas.

Spatial differences between these two patterns may be explained by two factors: (i) ancient taxa (e.g., *Lycophytes*) show relatively more restricted distributions that are mainly placed in the Mediterranean zone, as for *Selaginella* or *Isoetes*; *Huperzia selago* is restricted (singleton) only in high mountain dwarf (*Vaccinium*) heaths in the Laga district; (ii) recent taxa (e.g., *Eupolypods* which include *Polypodiineae* and *Aspleniineae*) have relatively wider distributions, mainly in Temperate internal areas.

PE and WE are significatively positively correlated ($R^2 = 0.568$), with very similar spatial patterns. Higher WE and PE values do not show a typical trend but are sparsely located in several isolated areas with very different lithology, elevation and climatic zones (Table 1). A first area with very high values of WE and PE is placed on the Western and South-Western slopes of Pizzitello, Pizzo di Sevo and Cima Lepri Mounts (Laga Mountains) on siliceous and marly-arenaceous soils from Flysch. Within this area, three singletons occur (*Equisetum variegatum*, *Huperzia selago* and *Athyrium distentifolium*), as well as other very restricted taxa (e.g., *Gymnocarpium dryopteris, Polystichum* x *bicknellii* and *Cystopteris alpina*). Another centre of endemism is the area near the eastern shore of the volcanic Bracciano Lake where a very important singleton occurs (*Isoetes sabatina*), which is not just a “relative endemism”, but rather a very restricted endemic taxon that actually occurs just in this site and not elsewhere in the world (i.e., “absolute endemism”).

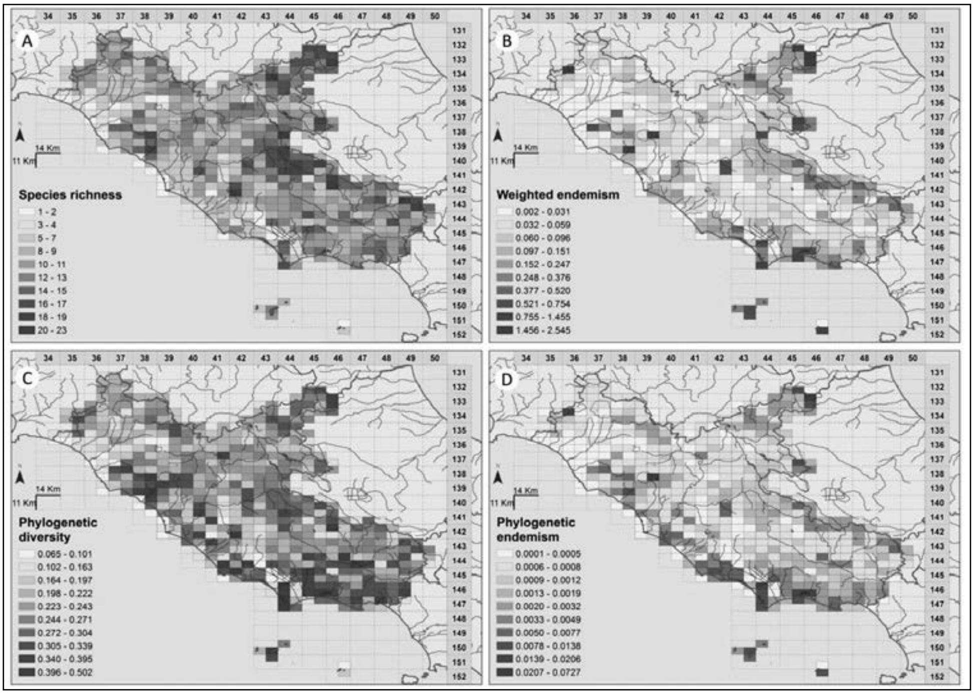
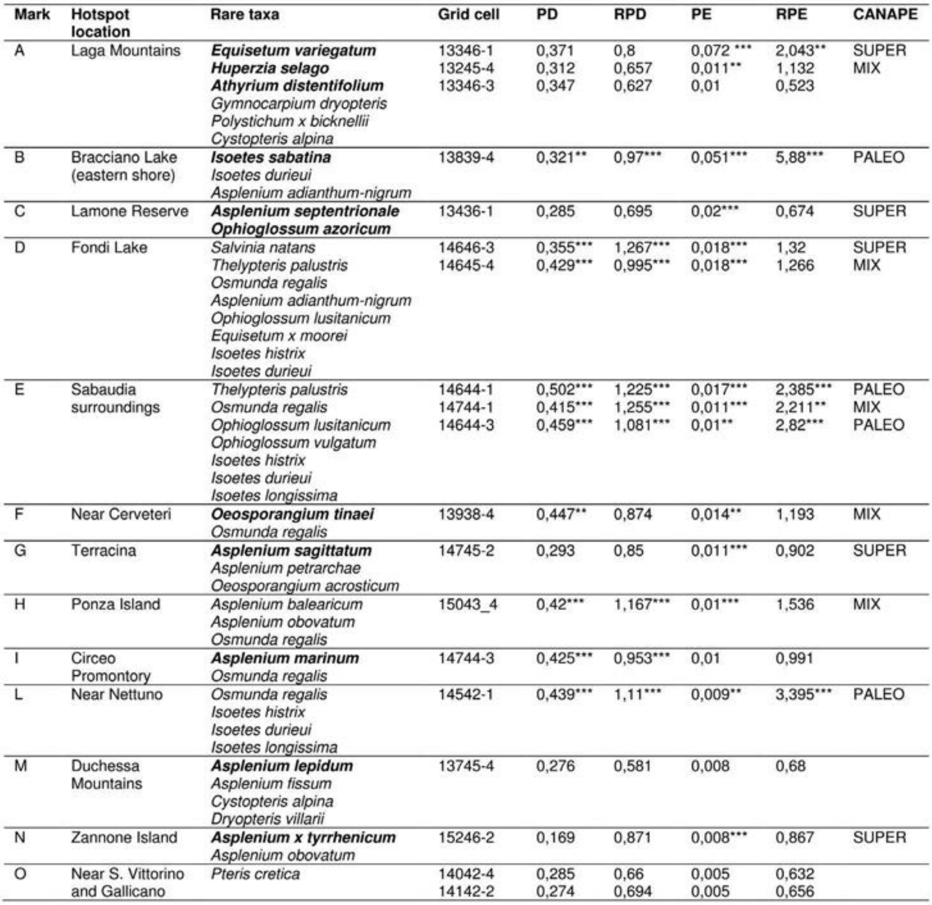


Fig. 2. Maps of basic and phylogenetic biodiversity patterns of native pteridophytes in Latium. Notes: A: SR (species richness) values; B: WE (weighted endemism); C: PD (phylogenetic diversity); D: PE (phylogenetic endemism).

Table 1. Hotspot locations, very rare taxa list, PD, RPD, PE, RPE index values and results of the CANAPE classification for the selected grid cells showing higher PE values. Notes: grid cells code format is provided as in Lucchese (2017); bold taxa indicate singletons; significance of index values is marked with ** and *** for p values > 0,95 and > 0,975 respectively.



Mark	Hotspot location	Rare taxa	Grid cell	PD	RPD	PE	RPE	CANAPE
A	Laga Mountains	***Equisetum variegatum*** ***Huperzia selago*** ***Athyrium distentifolium*** *Gymnocarpium dryopteris* *Polystichum x bicknellii* *Cystopteris alpina*	13346-1 13245-4 13346-3	0,371 0,312 0,347	0,8 0,657 0,627	0,072 *** 0,011** 0,01	2,043** 1,132 0,523	SUPER MIX
B	Bracciano Lake (eastern shore)	***Isoetes sabatina*** *Isoetes durieui* *Asplenium adianthum-nigrum*	13839-4	0,321**	0,97***	0,051***	5,88***	PALEO
C	Lamone Reserve	***Asplenium septentrionale*** ***Ophioglossum azoricum***	13436-1	0,285	0,695	0,02***	0,674	SUPER
D	Fondi Lake	*Salvinia natans* *Thelypteris palustris* *Osmunda regalis* *Asplenium adianthum-nigrum* *Ophioglossum lusitanicum* *Equisetum x moorei* *Isoetes histrix* *Isoetes durieui*	14646-3 14645-4	0,355*** 0,429***	1,267*** 0,995***	0,018*** 0,018***	1,32 1,266	SUPER MIX
E	Sabaudia surroundings	*Thelypteris palustris* *Osmunda regalis* *Ophioglossum lusitanicum* *Ophioglossum vulgatum* *Isoetes histrix* *Isoetes durieui* *Isoetes longissima*	14644-1 14744-1 14644-3	0,502*** 0,415*** 0,459***	1,225*** 1,255*** 1,081***	0,017*** 0,011*** 0,01**	2,385*** 2,211** 2,82***	PALEO MIX PALEO
F	Near Cerveteri	***Oeosporangium tinaei*** *Osmunda regalis*	13938-4	0,447**	0,874	0,014**	1,193	MIX
G	Terracina	***Asplenium sagittatum*** *Asplenium petrarchae* *Oeosporangium acrosticum*	14745-2	0,293	0,85	0,011***	0,902	SUPER
H	Ponza Island	*Asplenium balearicum* *Asplenium obovatum* *Osmunda regalis*	15043_4	0,42***	1,167***	0,01***	1,536	MIX
I	Circeo Promontory	***Asplenium marinum*** *Osmunda regalis*	14744-3	0,425***	0,953***	0,01	0,991	
L	Near Nettuno	*Osmunda regalis* *Isoetes histrix* *Isoetes durieui* *Isoetes longissima*	14542-1	0,439***	1,11***	0,009**	3,395***	PALEO
M	Duchessa Mountains	***Asplenium lepidum*** *Asplenium fissum* *Cystopteris alpina* *Dryopteris villarii*	13745-4	0,276	0,581	0,008	0,68	
N	Zannone Island	***Asplenium x tyrrhenicum*** *Asplenium obovatum*	15246-2	0,169	0,871	0,008***	0,867	SUPER
O	Near S. Vittorino and Gallicano	*Pteris cretica*	14042-4 14142-2	0,285 0,274	0,66 0,694	0,005 0,005	0,632 0,656	

Other very important areas with high values of WE and PE are located in the volcanic district of the Lamone Reserve (two singletons: *Asplenium septentrionale* and *Ophioglossum azoricum*), on the Fondi coastal Lake (one doubleton: *Salvinia natans*, and other very rare taxa e.g., *Thelypteris palustris*, *Osmunda regalis* and *Isoetes* spp. near Sabaudia in a lowland forest (very rare taxa e.g., *Thelypteris palustris*, *Osmunda regalis*, *Ophioglossum lusitanicum*, *O. vulgatum* and *Isoetes* spp.), near Cerveteri on coastal trachytic outcrops (one singleton: *Oeosporangium tinaei*, and other very rare taxa e.g., *Osmunda regalis*), near Terracina on limestone rocks (one singleton: *Asplenium sagittatum*, and other very rare taxa e.g., *Asplenium petrarchae* and

Oeosporangium acrosticum), on pumice and tuff deposits in the Ponza island (where very rare taxa occur e.g., *Asplenium balearicum*, *A. obovatum* and *Osmunda regalis*), in the Circeo Promontory on sea limestone cliffs (one singleton: *Asplenium marinum*, and other very rare taxa e.g., *Osmunda regalis* in bodies of water), near Nettuno (very rare taxa e.g., *Osmunda regalis* and *Isoetes* spp.), in the Duchessa Mountains on limestone rocks (one singleton: *Asplenium lepidum*, and other very rare taxa e.g., *Asplenium fissum, Cystopteris alpina* and *Dryopteris villarii*), in the Zannone island on pumice and tuff deposits (one singleton: *Asplenium* x *tyrrhenicum*, and other very rare taxa e.g., *Asplenium obovatum*) and near San Vittorino and Gallicano on volcanic tuffs (one doubleton: *Pteris cretica*).

Spatial patterns of significance values of PD, PE, RPD and RPE based on randomization analyses are shown in Fig. 3.

Areas of significantly high PD and PE values include mainly Mediterranean coastal and insular sectors of Latium and some isolated internal areas located near some river valleys; areas of significantly low PD and PE values include mainly Temperate mountain sectors and volcanic areas located between Temperate and Mediterranean zones.

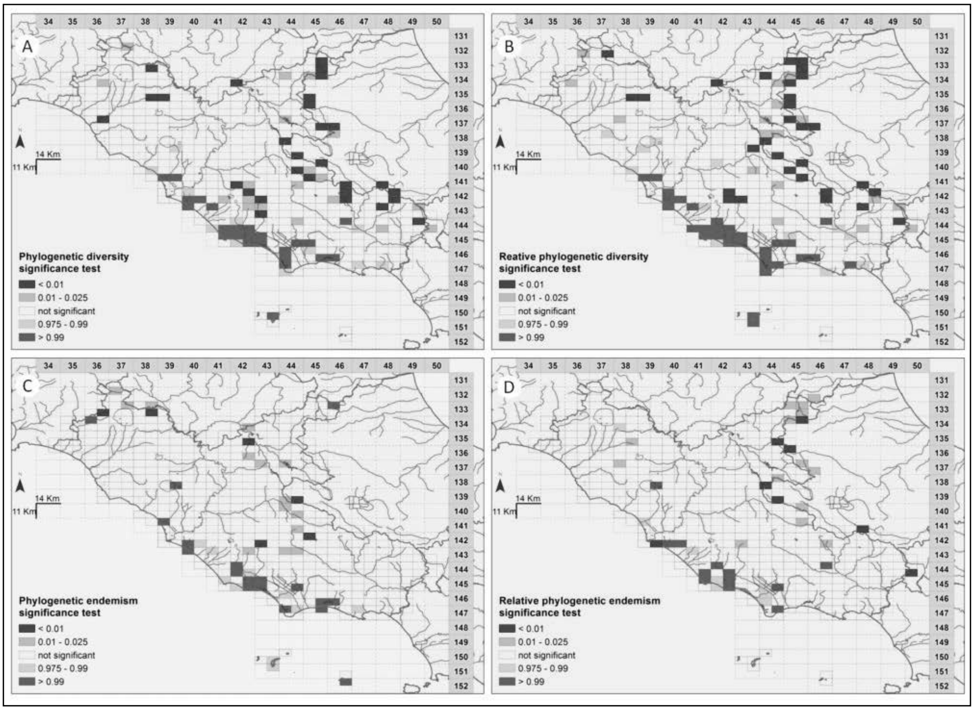


Fig. 3. Maps of the significance values resulting from a randomization test of native pteridophytes in Latium. Notes: transparent cells contain no data; grey cells indicate not significant values or areas with less than 4 taxa; red and orange grid cells contain significantly lower PD, RPD, PE and RPE values than expected; light blue and dark blue grid cells contain significantly higher PD, RPD, PE and RPE values than expected (as indicated).

Three important exceptions that do not follow the above-mentioned trends are represented by Laga Mountains, Lamone and Bracciano Lake. The significantly high PE values reached by these non-Mediterranean areas may probably be explained by the relative high presence of singletons and other range-restricted taxa in the observed distribution which are not likely estimated within the null distribution. Surprisingly, the Duchessa Mountains, the areas near San Vittorino and Gallicano and the Circeo promontory show non-significant PE values. In these cases, despite the presence of singleton, doubleton and other very rare taxa, the observed values fall between the 2-tails of the null distribution.

The spatial pattern of the RPD significance values shows the same general trend observed for PD. Also, the spatial pattern of the RPE significance values shows the same general trend as PE, albeit with some exceptions: (i) Lamone, Ponza and Ventotene islands show significantly high values only in PE; (ii) the surroundings of Ostia and Castelfusano show significantly low values only in RPE; (iii) the Laga Mountains show significantly high PE values but significantly low RPE values.

Assessment of pteridophyte centres of diversity and endemism

A total of 47 grid cells have been identified as centres of phylogenetic endemism. Applying the CANAPE procedure, we identified 1 centre of neo-endemism, 18 centres of paleo-endemism, 23 centres of mixed-endemism and 5 centres of super-endemism (Fig. 4). The grid cell identified as being dominated by neo-endemism is located along the coastal surroundings of Ostia, in the lowland Castel Fusano forest.

This area only includes 4 taxa, *Adiantum capillus-veneris*, *Equisetum telmateia*, *E. ramosissimum*, that are very common, and *E. fluviatile* that only occurs in 5 grid cells. Despite these taxa have relatively short terminal branches within the phylogenetic tree, we believe that this area cannot be a valuable centre of endemism (see Figs. 2b, 2d and 3c). Centres of paleo-endemism are mainly located along the coastal Mediterranean areas, except for the Eastern shore of Bracciano Lake which are placed on a volcanic area between the Mediterranean and the Temperate climatic zones. Several rare taxa with relatively long terminal branches, *e.g.*, *Isoetes* spp. and *Osmunda regalis*, occur in these areas. Severe human-made land use changes (*e.g.*, drainage and reclamation of coastal swamps and marshes, and deforestation) probably have reduced the distribution of these taxa during the last Century. Thus, we believe that these areas may represent proper centres of paleo-endemism.

Centres of mixed endemism are also mainly located in Mediterranean areas, but with several isolated exceptions in internal and mountainous areas within the Temperate climatic zone. A large number of rare pteridophytes with both short (e.g., *Thelypteris palustris*, *Oeosporangium acrosticum*, *Asplenium petrarchae* and *A. obovatum*) and long terminal branches (e.g., *Isoetes* spp. and *Osmunda regalis*) co-exist in most of these areas.

Centres of super-endemism are located in areas that are extremely different in both climates, lithologies and elevation belts. A first centre of super-endemism is the area of the Laga Mountains, having three singletons and other very rare taxa.

Changes in the occupancy area of rare species are usually due to artificial (*e.g.*, human-made land use changes) and natural (e.g., competition or isolation) processes, but they may also be due to the restrictedness of suitable niches. Unlike the other mountainous massifs of Latium, which are mainly formed by carbonate lithology, the Laga Mountains are composed by arenaceous, pelithic-arenaceous and marly litofacies. Thus, the singular occurrence of acidophilous taxa e.g., *Huperzia selago*, *Gymnocarpium dryopteris* and *Athyrium distentifolium* in this site is mainly a consequence of its peculiar lithology, probably as glacial relicts. Another important centre of super-endemism is the volcanic area of Lamone, where two very valuable singletons co-exist: *Asplenium septentrionale*, with a relatively short terminal branch, and *Ophioglossum azoricum*, with a long branch. *Asplenium septentrionale* is a typical circumboreal acidophilous and orophilous species which is very rare in the Italian peninsula and usually occurs at higher elevations (more than 1,200 m). The population of the Lamone Reserve is placed at 300 m, thus this taxon may be considered as an acidophilous glacial relict and the Lamone site may be interpreted as a suitable climatic refuge. *Ophioglossum azoricum* is a typical W-European Atlantic acidophilous species.

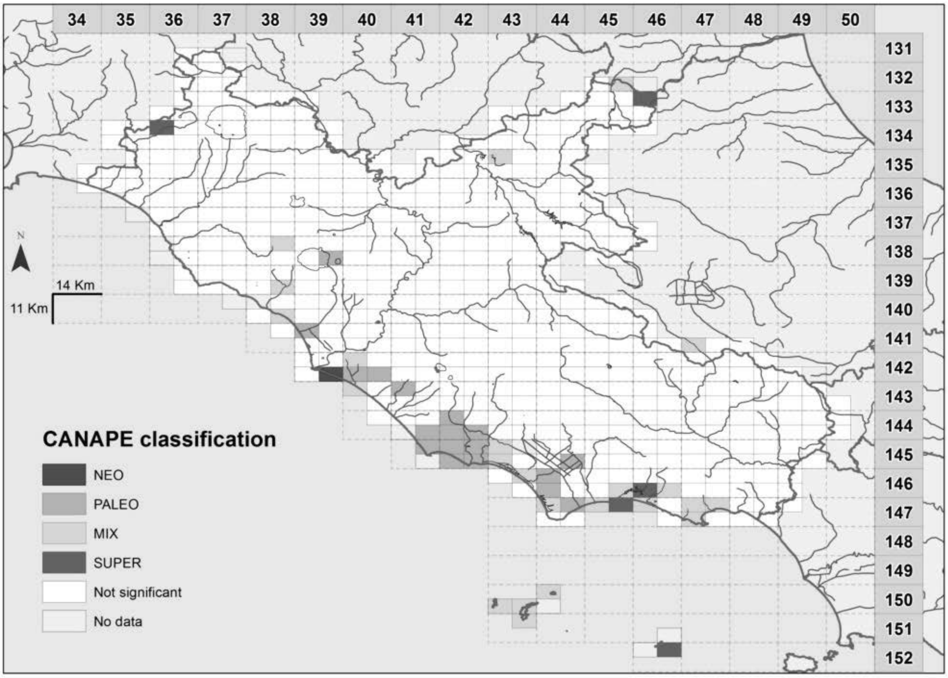


Fig. 4. Map of centres of endemism that also denote potential biodiversity hotspots for conservation planning (*sensu* Myers & al. 2000). Notes: grey cells contain no data; white cells are not significant or show less than 4 taxa; red cells indicate centres of neo-endemism that contain significantly lower RPE values than expected; blue cells indicate centres of paleo-endemism that contain significantly higher RPE values than expected; light green cells indicate centres of mixed-endemism that show not significantly lower or higher RPE values than expected; dark green cells indicate centres of super-endemism that are special cases of “mixed” showing the most highly significantly values of the numerator and denominator of the RPE ratio.

The few individuals found at the Lamone Reserve are highly isolated from the main distributional range, thus this population should be considered as the main target for regional and local conservation planning. Recently, Peruzzi & al. (2015) proposed a new taxonomic attribution, referring this population to a new pentaploid hybrid named *Ophioglossum* x *pseudoazoricum* (a reverse hybrid of the *O. azoricum* x *O. vulgatum* combination). Accordingly, this hybrid should be considered as extremely rare (occurring only in few localities of southern France, Tuscany and Latium) and a biogeographically valuable taxon of the regional flora. A third centre of super-endemism includes Terracina and its surroundings, with the occurrence of *Asplenium sagittatum*, a Mediterranean taxon which has gone extinct in several localities of Latium and Italy during the last two Centuries. Recently, the IUCN risk category for this taxon in Latium has been assessed as Critically Endangered (Iocchi & Lucchese 2018). Thus, also this taxon should be considered as a topic target for regional and local conservation planning.

Another centre of super-endemism is the eastern sector of the Fondi Lake.

Several very rare aquatic and semi-aquatic taxa occur within this area. Among these, the most endangered is probably *Salvinia natans*, an Eurasiatic taxon with a very long terminal branch in the phylogenetic tree. The populations near the Fondi Lake are the southernmost of the natural range in the Italian peninsula and are also very isolated (the nearest population is in Tuscany, 200 km away). Several human-induced threats (e.g., alien species invasions, water pollution and water capture for agricultural irrigation) might cause the local extinction of this taxon in the next decades. Thus, we believe that this area should be considered as a high-priority in conservation planning.

The last centre of super-endemism is the Zannone island, with only 5 taxa, including *Asplenium* × *tyrrhenicum* (the natural hybrid of *A. balearicum* × *A. onopteris*) and *Asplenium obovatum*. Both are endemisms, mainly occurring on Mediterranean islands. Accordingly, their distribution within Latium is restricted to the Pontine Archipelago. They show relatively short terminal branches within the phylogenetic tree, indicating a relatively recent origin, that in both cases took place by polyploidy and hybridization (Sessa & al. 2018). Thus, we believe that this area should be considered as a very important centre of endemism.

Discussion

The use of phylogenetic metrics, that take into consideration the evolutionary relationships between taxa, offers an improvement over traditional biodiversity pattern assessments that consider species diversity alone. *Lycophytes* include several ancient lineages formed by rare taxa with relatively longer terminal branches, which occur mainly in the Mediterranean zone of Latium (*Selaginella* and *Isoetes*). *Pteridophytes* may be further subdivided in three subclades: *Psilotopsida*, *Equisetopsida* and *Polypodiopsida*. The first clade includes rare, ancient taxa with relatively longer terminal branches (i.e., *Botrychium* and *Ophioglossum*), whereas within the *Equisetopsida,* all taxa have relatively shorter terminal branches (i.e., *Equisetum*). Most pteridophytes (43 of the 61 selected taxa) are part of the *Polypodiopsida* clade. Also, within this clade, ancient taxa with relatively longer terminal branches (e.g., *Osmunda*, *Salvinia*, *Oeosporangium*, *Pteridium* and *Adianthum*) mainly occur in the Mediterranean zone of Latium, whereas several recent taxa with relatively shorter terminal branches (e.g., *Polystichum*, *Dryopteris*, *Cystopteris* and some orophilous *Asplenium*) mainly occur in the Temperate zone of Latium. These different spatial trends explain the observed dissimilarities between the spatial patterns of SR and PD, highlighting the relatively higher phylogenetic value of several Mediterranean areas, as well as of some internal grid cells which host water bodies (*i.e.*, rivers and lakes). We may define as centre of phylogenetic diversity of native pteridophytes the following Mediterranean areas: (i) Sabaudia (lake and forest), Fondi Lake surroundings, Circeo Promontory and Ponza island; (ii) Nettuno (Foglino and Padiglione forests); (iii) Cerveteri, surroundings; (iv) Scauri-Minturno, surroundings. Higher PD values are also observed in the following internal areas which include water bodies: Liri valley near Ceprano, Amaseno valley near Priverno and Albano and Nemi lakes.

Concerning the range restrictedness of taxa (or “relative endemism”), we focused on four overlapping main causes: (i) artificial impacts (e.g., human-made land use changes and water pollution); (ii) natural processes (e.g., competition, hybridization, and polyploidy); (iii) historical processes (e.g., relict isolation); (iv) rarity of suitable niches. We believe that the first two causes are mainly responsible for the restricted occurrence of several Mediterranean, very rare taxa (i.e., most aquatic or semi-aquatic pteridophytes such as *Isoetes* spp., *Salvinia natans*, *Ophioglossum* spp. and *Osmunda regalis*). In contrast, the latter two causes are mainly responsible for the restricted occurrence of some very rare taxa in Temperate areas (e.g., *Huperzia selago*, *Athyrium distentifolium* and *Equisetum variegatum* on the Laga Mountains and *Asplenium septentrionale* on the Lamone Reserve). Thus, the spatial patterns of WE and PE may mainly be due to the different effects (in space and time) of these overlapping causes. We identified a total of 47 centres of endemism, which should be considered as valuable biodiversity hotspots (sensu Myers & al. 2000) because of their high evolutionary and conservation value. Most of them match with protected areas (e.g., Gran Sasso and Laga Mountains National Park, Circeo National Park, “Selva del Lamone” Regional Natural Reserve; Bracciano and Martignano Regional Park), thus both habitat and species should benefit from adequate conservation actions (e.g.*,* monitoring, threats and extinction risk assessment). Two other selected hotspots (marked with D and L in Table 1) encompass two “Natura 2000” sites (“Bosco di Foglino” IT6030047 and “Lago di Fondi” IT6040010).

Unfortunately, the spatial localization of the rarest populations does not always fall within the boundaries of protected areas. Moreover, several very rare taxa are not listed as “important species” in the standard data forms of the two sites, and therefore do not receive any specific attention. Even if suitable habitats of these very rare taxa formally should benefit from conservation actions, we believe that in these cases monitoring and extinction risk assessment should be performed at species level. We suggest providing monitoring programmes in order to understand population sizes and trends of hygrophilous pteridophytes which occur in aquatic habitats such as lake shores, swamps, marshes, and hygrophilous woods. These species may also be used as bioindicators, because they are very sensitive to specific abiotic factors such as water drainage and salinity changes, eutrophication and pollution. This is the case of *Salvinia natans,* which occurs at the Fondi Lake (outside the protected area boundaries). At the European level, *S. natans* is considered as NT (“Near threatened”; García Criado & al. 2017), whereas at the Italian national level its extinction risk is reported as VU ("Vulnerable"; Rossi & al. 2013). As suggested before, the Fondi Lake site is the southernmost in the Italian peninsula and it is also very isolated from the natural range of the species. Over the last Century, *S. natans* has disappeared from several sites of Latium and other Italian regions (Lucchese 2018). Scientific studies on the biology of this threatened species are needed, in order to better define the most important biotic and abiotic factors that may impact its occurrence, and to perform adequate conservation actions.

Another important hotspot is placed near Cerveteri (marked with F in Table 1). Unfortunately, the very rare taxa which occur within this area do not receive any specific protection or conservation actions. In this case, establishing a new protected reserve is needed, in order to provide an adequate management plan for conservation of the species. The occurrence within Latium of *Oeosporangium tinaei* (singleton) has been recently detected (Rosati & al. 2020). We have performed a preliminary field census in order to assess the population size and we have found just a single individual, thus the extinction risk at regional scale is extremely high. A specific study of the major threats which affect this taxon in the site is needed. The *O. tinaei* individual has been found inside a rocky fissure on a south-facing steep slope dominated by sparse Mediterranean dwarf shrubs and bushes. Goats and sheep grazing and the increase in fire frequency are the two reasonable major threats to this taxon. In this case, an urgent action of *ex-situ* conservation is needed, such as collecting and conserving spores in a seed bank.

During the last two Centuries, a high number of taxa became extinct in Latium, mostly in the Mediterranean zone (Lucchese 2018). Among these, 3 aquatic and semi-aquatic pteridophytes have been identified: *Pilularia minuta*, *Marsilea quadrifolia* and *Thelypteris limbosperma*. Following the precept "learn from the past to plan a better future", we suggest focusing the attention of researchers on the conservation of both hygrophilous species and water habitats occurring within the observed centres of endemism. A more detailed monitoring of population sizes and trends, as well as fully comprehensive overviews of the potential threats are needed. Moreover, habitat protection and restoration are also required, especially in aquatic habitats and wetlands that are highly affected by pollution, canalisation, eutrophication, drainage and changes in hydrological regime.

Conclusion

Very rare pteridophytes do not receive any specific protection or conservation actions. Spatial phylogenetic metrics of pteridophyte diversity and endemism allowed us to identify the main native pteridophytes PD and PE centres, valuable as biodiversity hotspots due to their high evolutionary and conservation value.

We suggest performing monitoring programmes to understand population sizes and trends and focusing research plan on the conservation of both hygrophilous species and water habitats occurring within the observed centres. Among the several species, we highlight that *Salvinia natans* and *Oeosporangium tinaei* should be priority species for Latium.

References

Arnan, X., Cerdá, X. & Retana, J. 2016: Relationships among taxonomic, functional, and phylogenetic ant diversity across the biogeographic regions of Europe. – Ecography **5(6):** 110-115. https://doi.org/10.1111/ecog.01938

Arrigoni, P. V. 2016: Flora Analitica della Toscana, **1.** – Firenze.

Balletto, E., Bonelli, S., Borghesio, L., Casale, A., Brandmayr, P. & Vigna Taglianti, A. 2010: Hotspots of biodiversity and conservation priorities: A methodological approach. – Italian J. Zool. **77(1):** 2-13. https://doi.org/10.1080/11250000902758923

Barnosky, A. D., Matzke, N., Tomiya, S., Wogan, G. O. U., Swartz, B., Quental, T. B., Marshall, C., McGuire, J. L., Lindsey, E. L., Maguire, K. C., Mersey, B. & Ferrer, E. A. 2011: Has the Earth's sixth mass extinction already arrived? – Nature **471:** 51-57. https://doi.org/10.1038/nature09678

Bernardello, R. & Martini, E. 2004: Felci e piante affini in Liguria e in Italia. Le Mani – Recco (GE).

Bona, E., Martini, F., Niklfeld, H. & Prosser, F. 2005: Atlante corologico delle Pteridofite nell'Italia nordorientale. – Rovereto.

Bonafede, F., Vignodelli, M., Marchetti, D. & Alessandrini, A. 2016: Felci dell'Emilia Romagna, distribuzione, monitoraggio e conservazione. – Bologna.

Brown, A. G., Hatton, J., Selby, K. A., Leng, M. J. & Christie, N. 2013: Multi-proxy study of Holocene environmental change and human activity in the Central Apennine Mountains, Italy. – J. Quaternary Sci. **28(1):** 71-82. https://doi.org/10.1002/jqs.2591

Carta, A, Pierini, B., Roma-Marzio, F., Bedini, G. & Peruzzi, L. 2018: Phylogenetic measures of biodiversity uncover pteridophyte centres of diversity and hotspots in Tuscany. – Pl. Biosyst. **152(4):** 831-839. https://doi.org/10.1080/11263504.2017.1353550

Casal-Lopez, M., Perea, S., Sousa-Santos, C., Robalo, J. I., Torralva, M., Oliva-Paterna, F. J. & Doadrio, I. 2018: Paleobiogeography of an Iberian endemic species, *Luciobarbus sclateri* (Gunther, 1868) (*Actinopterygii*, *Cyprinidae*), inferred from mitochondrial and nuclear markers. – J. Zool. Syst. Evol. Res. **56(2):** 127-147. https://doi.org/10.1111/jzs.12192

Ceballos, G. & Ehrlich, P. R. 2006: Global mammal distributions, biodiversity hotspots, and conservation. – Proc. Nat. Acad. Sci. **103(51):** 19374-19379. https://doi.org/10.1073/pnas.0609334103

Christenhusz, M. J. M. & Chase, M. W. 2014: Trends and concepts in fern classification. – Ann. Bot. **113(4):** 571-594. https://doi.org/10.1093/aob/mct299

—, Zhang, X. C. & Schneider, H. 2011: A linear sequence of extant families and genera of lycophytes and ferns. – Phytotaxa **19:** 7-54. https://doi.org/10.11646/phytotaxa.19.1.2

Connell, J. H. 1978: Diversity in tropical rain forests and coral reefs. – Science **199(4335):** 1302-1310. https://doi.org/10.1126/science.199.4335.1302

Conti, F., Bartolucci, F., Iocchi, M. & Tinti, D. 2011: Atlas of the pteridological knowledge of Abruzzo (Central Italy). – Webbia **66(2):** 51-305.

Cosentino, D., Cipollari, P. & Scrocca, D. 2010: Geology of the Central Apennines: A regional review. – Journal of the Virtual Explorer **36(11):** 1-37.

Crisp, M. D., Laffan, S., Linder, H. P. & Monro, A. 2001: Endemism in the Australian flora. – J. Biogeogr. **28(2):** 183-198. https://doi.org/10.1046/j.1365-2699.2001.00524.x

Devictor, V., Van Swaay, C., Brereton, T., Chamberlain, D., Heliölä, J., Herrando, S., Julliard, R., Kuussaari, M., Lindström, Å. & Roy, D. B. 2012: Differences in the climatic debts of birds and butterflies at a continental scale. – Nat. Clim. Change **2(2):** 121-124. https://doi.org/10.1038/nclimate1347

Diniz-Filho, J. A. F. & Telles, M. P. C. 2006: Optimization procedure of establishing reserve networks for biodiversity conservation taking into account population genetic structure. – Genet. Molec. Biol. **29(2):** 207-214.

—, Loyola, R. D., Raia, P., Mooers, A. O. & Bini, L. M. 2013: Darwinian shortfalls in biodiversity conservation. – Trends Ecol. Evol. **28(12):** 689-95. https://doi.org/10.1016/j.tree.2013.09.003

Durka, W. & Michalski, S. G. 2012: Daphne: a dated phylogeny of a large European flora for phylogenetically informed ecological analyses. – Ecology **93(10):** 2297. https://doi.org/10.1890/12-0743.1

Ehrendorfer, F. & Hamann, U. 1965: Vorschläge zu einer floristischen Kartierung von Mitteleuropa. – Ber. Deutsch. Bot. Ges. **78:** 35-50.

Faith, D. P. 1992: Conservation evaluation and phylogenetic diversity. – Biol. Conserv. **61(1):** 1-10. https://doi.org/10.1016/0006-3207(92)91201-3

Fenker, J., Tedeschi, L. G., Pyron, R. A. & Nogueira, C. D. C. 2014: Phylogenetic diversity, habitat loss and conservation in South American pitvipers (Crotalinae: Bothrops and Bothrocophias). – Div. Distr. **20(10):** 1108-1119. https://doi.org/10.1111/ddi.12217

Ferrarini, E., Ciampolini, F., Pichi Sermolli, E. E. G., Marchetti, D. 1986: Iconografia Palynologica Pteridophytorum Italiae. – Webbia **40(1):** 1-202.

Fiori, A. 1943: Flora Italica Cryptogama. Pars V: Pteridophyta. – Firenze.

García Criado, M., Väre, H., Nieto, A., Bento Elias, R., Dyer, R., Ivanenko, Y., Ivanova, D., Lansdown, R., Molina, J. A., Rouhan, G., Rumsey, F., Troìa, A., Vrba, J. & Christenhusz, M. J. M. 2017: European Red List of Lycopods and Ferns – Brussels.

Gaston, K. J. & Fuller R. A. 2009: The sizes of species' geographic ranges. – J. Appl. Ecol. **46(1):** 1-9. https://doi.org/10.1111/j.1365-2664.2008.01596.x

Geri, F., Lastrucci, L., Viciani, D., Foggi, B., Ferretti, G., Maccherini, S., Bonini, I., Amici, V. & Chiarucci, A. 2013: Mapping patterns of ferns species richness through the use of herbarium data. – Biodiv. Conserv. **22:** 1679-1690.

Giardini, M. 2007: Late Quaternary vegetation history at Stracciacappa (Rome, central Italy). – Veg. Hist. Archaeobot. **16(4):** 301-316. https://doi.org/10.1007/s00334-006-0037-y

Gittleman, J. L. & Kot, M. 1990: Adaptation: statistics and a null model for estimating phylogenetic effects. – Systematic Zoology **39(3):** 227-241. https://doi.org/10.2307/2992183

González-Orozco, C. E., Mishler, B. D., Miller, J. T., Laffan, S. W., Knerr, N., Unmack, P., Georges, A., Thornhill, A. H., Rosauer, D. F. & Gruber, B. 2015: Assessing biodiversity and endemism using phylogenetic methods across multiple taxonomic groups. – Ecology and Evolution **5(22):** 5177-5192. https://doi.org/10.1002/ece3.1747

Gotelli, N. J. & Colwell, R. K. 2001: Quantifying biodiversity: procedures and pitfalls in the measurement and comparison of species richness. – Ecology Letters **4(4):** 379-391. https://doi.org/10.1046/j.1461-0248.2001.00230.x

Gudde, R. M., Joy, J. B. & Mooers, A. O. 2013: Imperilled phylogenetic endemism of Malagasy lemuriformes. – Div. Distrib. **19(7):** 664-675. https://doi.org/10.1111/ddi.12023

Hawkins, B. A., Rueda, M., Rangel, T. F., Field, R. & Diniz-Filho, J. A. F. 2014: Community phylogenetics at the biogeographical scale: cold tolerance, niche conservatism and the structure of North American forests. – J. Biogeogr. **41:** 23-38. https://doi.org/10.1111/jbi.12171

Iocchi, M. & Lucchese, F. 2018: *Asplenium sagittatum* (DC.) Bange. – Pp. 121-123 in: Lucchese, F.: Atlante della flora vascolare del Lazio: Cartografia, Ecologia e Biogeografia, **2.** – Roma. https://www.parchilazio.it/pubblicazioni-441-atlante_della_flora_vascolare_del_lazio_2

Jantz, S. M., Barker, B., Brooks, T. M., Chini, L. P., Huang, Q., Moore, R. M., Noel, J. & Hurtt, G. C. 2015: Future habitat loss and extinctions driven by land-use change in biodiversity hotspots under four scenarios of climate-change mitigation. – Conserv. Biol. **29(4):** 1122-1131. https://doi.org/10.1111/cobi.12549

Jetz, W., Thomas, G., Joy, J., Hartmann, K. & Mooers, A. 2012: The global diversity of birds in space and time. – Nature **491(7424):** 444-448. https://doi.org/10.1038/nature11631

Kessler, M. 2010: Biogeography of ferns. – Pp: 23-60 in: Mehltreter, K., Walker, L. R., & Sharpe, J. M. (eds), Fern Ecology. – Cambridge.

Krebs, P., Boris Pezzatti, G., Beffa, G., Tinner, W. & Conedera, M. 2019: Revising the sweet chestnut (*Castanea sativa* Mill.) refugia history of the last glacial period with extended pollen and macrofossil evidence. – Quaternary Sci. Rev. **206:** 111-128. https://doi.org/10.1016/j.quascirev.2019.01.002

Laffan, S.W. & Crisp, M. D. 2003: Assessing endemism at multiple spatial scale, with an example from the Australian vascular flora. – J. Biogeogr. **30:** 511-520. https://doi.org/10.1046/j.1365-2699.2003.00875.x

—, Lubarsky, E. & Rosauer, D. F. 2010: Biodiverse, a tool for the spatial analysis of biological and related diversity. – Ecography **33(4):** 643-647. https://doi.org/10.1111/j.1600-0587.2010.06237.x

Lagomarsino, L. P., Condamine, F. L., Antonelli, A., Mulch, A. & Davis, C. C. 2016: The abiotic and biotic drivers of rapid diversification in Andean bellflowers (*Campanulaceae*). – New Phytologist **210:** 1430-1442. https://doi.org/10.1111/nph.13920

Laity, T., Laffan, S. W., González-Orozco, C. E., Faith, D. P., Rosauer, D. F., Byrne, M., Miller, J. T., Crayn, D., Costion, C. & Moritz, C. C. 2015: Phylodiversity to inform conservation policy: An Australian example. – Sci. Total Environ. **534:** 131-143. https://doi.org/10.1016/j.scitotenv.2015.04.113

Lean, C. & Maclaurin, J. 2016: The value of phylogenetic diversity. – Biodiv. Conserv. Phylogenet. Syst. **58:** 19-37. https://doi.org/10.1007/978-3-319-22461-9

Lee, A. C. & Mishler, B. 2014: Phylogenetic diversity and endemism: metrics for identifying critical regions of conifer conservation in Australia. – Berkeley Sci. J. **18(2):** 48-58. https://escholarship.org/uc/item/6dd8f67t

Lostia, D. 2018: The OMBOSS method (optimization method based on singleton species). – Pp. 138-151 in: Lucchese, F. 2018: Atlante della flora vascolare del Lazio: Cartografia, Ecologia e Biogeografia. Vol. 2: La flora di maggiore interesse conservazionistico. – Roma. https://www.parchilazio.it/pubblicazioni-441-atlante_della_flora_vascolare_del_lazio_2

Lucchese, F. 1995: Elenco preliminare della flora spontanea del Molise. – Ann. Bot. - Studi sul Territorio (Suppl. Vol. LIII). Univ. “La Sapienza”. Roma.

— 2017: Atlante della flora vascolare del Lazio: Cartografia, Ecologia e Biogeografia. Vol. 1: Parte generale e Flora Alloctona. – Roma. https://www.parchilazio.it/pubblicazioni-355-atlante_della_flora_vascolare_del_lazio

— 2018: Atlante della flora vascolare del Lazio: Cartografia, Ecologia e Biogeografia. Vol. 2: La flora di maggiore interesse conservazionistico. – Roma. https://www.parchilazio.it/pubblicazioni-441-atlante_della_flora_vascolare_del_lazio_2

Lusina, G. 1951: Fitogeografia delle felci del Lazio. – Pp 2. in: XLII Riunione Soc. Ital. Progr. Scienze, 29 Nov.-1 Dic. 1949, Roma.

MacArthur, R. & Wilson, E. 1967: The theory of island biogeography. – New Jersey.

Magurran, A. E. & McGill, B. J. 2011: Biological diversity: frontiers in measurement and assessment. – Oxford.

Marchetti, D. 2004: Le pteridofite d’Italia. – Ann. Mus. Civ. Rovereto, Sez. Arch., St., Sc. Nat. **19(2003):** 71-231.

Martini, F., Nardini, S. & Rizzardini, S. 1997: Appunti sulla flora del Friuli-Venezia Giulia (NE Italia). – Gortiana. Atti Museo Friul. Storia Nat. **19(1992):** 151-166.

Mayer, A. 2015: Flora Escursionistica dell’Italia. Prima Parte - Italia Centrale. – München.

Mishler, B. D., Knerr, N., González-Orozco, C. E., Thornhill, A. H., Laffan, S. W. & Miller, J. T. 2014: Phylogenetic measures of biodiversity and neo-and paleo-endemism in Australian Acacia. – Nat. Comm.**5(4473).** https://doi.org/10.1038/ncomms5473

Mittermeier, R. A., Turner, W. R., Larsen, F. W., Brooks, T. M. & Gascon, C. 2011: Global biodiversity conservation: the critical role of hotspots. – Biodiv. Hotspots **25:** 3-22. https://doi.org/10.1007/978-3-642-20992-5_1

Mooers, A. Ø. 2007: The diversity of biodiversity. – Nature **445(7129):** 717-718. https://doi.org/10.1038/445717a

Myers, N., Mittermeier, R. A., Mittermeier, C. G., da Fonseca, G. A. & Kent, J. 2000: Biodiversity hotspots for conservation priorities. – Nature **403(6772):** 853-8. https://doi.org/10.1038/35002501

Nieto-Blázquez, M. E., Antonelli, A. & Roncal, J. 2017: Historical Biogeography of endemic seed plant genera in the Caribbean: Did GAARlandia play a role? – Ecol. Evol. **7:** 10158-10174. https://doi.org/10.1002/ece3.3521

Niklfeld, H. G. 1971: Bericht uber die Kartierung der Flora Mittleuropas. – Taxon **20(4):** 549-571.

Peruzzi, L., Pierini, B., Magrini, S., Andreucci, A., Marchetti, D. & Viane, R. 2015: Three new hybrids of *Ophioglossum* (*Ophioglossaceae*) from Monte Pisano, Tuscany (Central Italy). – Pl. Biosyst. **149(4):** 737-746. https://doi.org/10.1080/11263504.2015.1057264

Pignatti, S. 1978: Dieci anni di cartografia floristica nell'Italia di Nord-Est. – Inform. Bot. Ital. **10:** 212-219.

— 2017: Flora d'Italia, 2° ed., **1.** – Milano.

Prosser, F., Bertolli, A., Festi, F. & Perazza, G. 2019: Flora del Trentino. – Rovereto.

Pyšek, P., Hulme, P. E., Simberloff, D., Bacher, S., Blackburn, T. M., Carlton, J. T., Dawson, W., Essl, F., Foxcroft, L. C., Genovesi, P., Jeschke, J. M., Kühn, I., Liebhold, A. M., Mandrak, N. E., Meyerson, L. A., Pauchard, A., Pergl, J., Roy, H. E., Seebens, H., van Kleunen, M., Vilà, M., Wingfield, M. J. & Richardson, D. M. 2020: Scientists' warning on invasive alien species. – Biol Rev. **95(6):** 1511-1534. https://doi.org/10.1111/brv.12627

Rosati, L., Fascetti, S., Romano, V. A., Potenza, G., Lapenna, M. R., Capano, A., Nicoletti, P., Farris, E., de Lange, P. J., Del Vico, E., Facioni, L., Fanfarillo, E., Lattanzi, E., Cano-Ortiz, A., Marignani, M., Fogu, M. C., Bazzato, E., Lallai, E., Laface, V. L. A., Musarella, C. M., Spampinato, G., Mei, G., Misano, G., Salerno, G., Esposito, A. & Stinca, A. 2020: New Chorological Data for the Italian Vascular Flora. – Diversity **12(1):** 22. https://doi.org/10.3390/d12010022

Rosauer, D. F. & Jetz, W. 2015: Phylogenetic endemism in terrestrial mammals. – Global Ecol. Biogeogr. **24(2):** 168-179. https://doi.org/10.1111/geb.12237

Rossi, G., Montagnani, C., Gargano, D., Peruzzi, L., Abeli, T., Ravera, S., Cogoni, A., Fenu, G., Magrini, S., Gennai, M., Foggi, B., Wagensommer, R. P., Venturella, G., Blasi, C., Raimondo, F. M. & Orsenigo, S. (eds) 2013: Lista Rossa della Flora Italiana. 1. Policy Species e altre specie minacciate. – Roma.

Sarkar, S., Pressey, R. L., Faith, D. P., Margules, C. R., Fuller, T., Stoms, D. M., Moffett, A., Wilson, K. A., Williams, K. J. & Williams, P. H. 2006: Biodiversity conservation planning tools: present status and challenges for the future. – Ann. Rev. Environ. Res. **31:** 123-159. https://doi.org/10.1146/annurev.energy.31.042606.085844

Sessa, E. B., Vicent, M., Chambers, S. M. & Gabriel y Galán, J. M. 2018: Evolution and Reciprocal Origins in Mediterranean Ferns: The *Asplenium obovatum* and *A. adiantum-nigrum* Complexes. – Ann. Missouri Bot. Gard. **103(2):** 175-187. https://doi.org/10.3417/2018108

Smith, A. R., Pryer, K. M., Schuettpelz, E., Korall, P., Schneider, H. & Wolf, P. G. 2006: A classification for extant ferns. – Taxon **55(3):** 705-731. https://doi.org/10.2307/25065646

Troìa, A. & Greuter, W. 2015: *Isoetaceae*. – Firenze. https://floraitaliana.it/Media?c=e9a27860-d7e7-4d4f-bcb2-6acba491f84a

—, Raimondo, F. M. & Mazzola, P. 2012: Mediterranean island biogeography: Analysis of fern species distribution in the system of islets around Sicily. – Pl. Biosyst. **146(3):** 576-585. https://doi.org/10.1080/11263504.2011.596168 van Gils, H., Conti, F., Ciaschetti, G. & Westinga, E. 2012: Fine resolution distribution modelling of endemics in Majella National Park, Central Italy. – Pl. Biosyst. **146(s1):** 276-287, https://doi.org/10.1080/11263504.2012.685194

Webb, C. O. & Donoghue, M. J. 2005: Phylomatic: tree assembly for applied phylogentics. – Molec. Ecol. Notes **5(1):** 181-183. https://doi.org/10.1111/j.1471-8286.2004.00829.x

Yek, S. H., Willliams, S. E., Burwell, C. J., Robson, S. K. & Crozier, R. H. 2009: Ground dwelling ants as surrogates for establishing conservation priorities in the Australian wet tropics. –J. Insect Sci. **9(1):** 12. https://doi.org/10.1673/031.009.1201

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Article

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Can ecoindicators be a tool to reduce and understand complexity of plant communities?

Abstract

Testi, A., Fanelli, G., De Nicola, C., D'Angeli, D. & De Sanctis, M.: Can ecoindicators be a tool to reduce and understand complexity of plant communities? — Fl. Medit. 31 (Special Issue): 317-337. 2021. — ISSN: 1120-4052 printed, 2240-4538 online.

In this study we consider the use of ecoindicators to explain the complex relationships between vegetation and humus in forest ecosystem from all the Italian Peninsula. In particular we concentrate the study on the rarely applied indicators of Rogister's: RxN and R/N, that would represent the humus quality of soil. They are derived from the Ellenberg Indicator Values (EIV), R and N (R = Reaction, N = Nutrients). The aim of the study was to test their effectiveness to distinguish vegetation types and to define meaningful gradients related to humus quality (forms). The focus on the role of humus is justified by the fact that it is a direct result from the interaction between the type of soils and the components of ecological communities of which the plants are playing the primary role. We considered a dataset of 789 forest vegetation relevés (489 obtained from a data base and 300 made by us) and 847 species that we described by all the EIV and by the two Rogister indicators (RO). We grouped the relevés in 9 vegetation types according to the dominance of the most important and common tree species of Italy (1. *Quercus suber*, 2. *Q. ilex*, 3. *Q. pubescens*, 4. *Q. cerris* and *Q. cerris-Q. Frainetto*, 5. *Carpinus betulus*, 6. *Fagus sylvatica*, 7. *Picea abies*, 8. *Abies alba*, 9. Hygrophilous woodlands with *Salix* spp., *Populus* spp., *Fraxinus oxycarpa* and *Alnus glutinosa*) and we have used the evenness of the eigenvalues of the similarity matrices (Eλ), obtained by EIV and RO to test the separation between the 9 types. Eλ proved that the two Rogister's indexes resulted more predictive than EIV. The analysis of the collected humus forms in the field confirms that the Rogister's indicators are effective to identify the functionality of the humus forms and proves their correspondence with vegetation types: the Amphi humus is dominating in evergreen Mediterranean forests, Moder in mixed deciduous forests, Mull in *Fagus sylvatica/Carpinus betulus* and in hygrophilous forests, Mor in boreal forests.

Key words: Italian forests, Rogister Model, Humus, Vegetation.

This we know
That all things are related
like blood
that unifies a family.
Everything that happens to the Earth
it happens to the sons and daughters of the Earth.
Man does not weave the weft of life;
in it he is only a thread.
Whatever it does to the weft,
man does it to himself.

Chief Seattle

Initial Remarks

The study of complexity as well as of ecoindicators is much loved by Sandro Pignatti, who has never been satisfied with the mere classification of species and communities, searching in systems theory explanations and insights for the plant ecology. So, starting from single elements of a whole set, like species getting to flora and then to vegetation, he pursued an often innovative and courageous thought, that at least part of the academic world has found it difficult to recognize and admit. On the other hand, in the development of human thought, especially in the scientific field, the transitions to new paradigms have entailed considerable challenges and efforts. So, we hope to please our teacher and friend Sandro with this contribution trying to combine the two topics.

Introduction

The history of bioindication is quite recent. Johnson & al. (1992) assessed the definitions on this topic mainly in relation to water and air pollution. However, Pignatti (1988) considers its origin at the beginning of phytosociology, when Braun-Blanquet (1926) and Ellenberg (1963) foresaw the development of a multi-methodological analysis of vegetation based on the knowledge of the ecology and morphology (functional traits) of the species. So, following Pignatti (1988;1994a, b, 1995, 2001a), the life forms as well as the chorological types, represented the first bioindicators of climate and geographical distribution of the vegetation types. Ellenberg (1974-1979) considered directly the relationships between species and the ecological factors and developed his consolidated bioindication model that represented a starting point for the studies to calibrate the six indicator values [light (L), temperature (T), continentality (K), soil moisture (F), reaction (R), nitrogen (N)] with respect to the measures directly done on soil and climate physico-chemical parameters (Schaffers & Sýkora 2000; Pignatti & al. 2001b; Diekmann & Dupré 1997; Testi & al. 2008-2009, 2012). Many scientists, who have dealt with this issue, have made a lot of physical and chemical measurements to validate the model and to assign reliable indicator values to each species of the floras in different temperate European countries (Zarzycky 1984; Borhidi 1995; Hill & al. 2000; Böhling & al. 2002; Pignatti & al. 2005).

One of the most useful application of the Ellenberg Indicator Values (EIV) are the eco-maps, that can be used as powerful tools to monitor the changes of vegetation in function of the changes of the main ecological factors (Austin & Gaywood 1994; Testi & al. 2006; Fanelli & al. 2007). Mapping EIV instead species or communities, is a sort of "quantum jumping" which would show the states of ecological factors of plant communities in a given time. In this respect the following question would arise: "May we reduce and understand the ecosystem complexity just shifting from the description of plant communities by a floristic matrix, very rich in species, to a matrix with few ecological variables that describe the species in terms of their indicator values with respect the climate and the soil main factors?".

In this paper we try to answer to this question by concentrating our study on two composite indicators proposed by Rogister (1978): RxN (Reaction x Nutrient) and R/N (ratio between Reaction and Nutrient). He correlated the description of forestry vegetation types from Belgium based on EIV with their humus quality types and discovered that the composite index RxN can be considered an indicator of humus quality, while the ratio R/N can be considered an indicator of nitrogen availability (Rogister 1978; Godefroid & al. 2005; Muys & Granval 1997). We show in Fig. 1 how the ordination of Rogister (1978) of the forestry vegetation types of Belgium reflects the forms of humus as the results of the climate-soil-vegetation interactions.

As shown in Fig. 1, the classification developed by Rogister (1978) recognises six humus types, ordered along ranges of the humus indexes RxN on axis *x*. This composite index shows a negative correlation with the ratio R/N (nitrogen availability) placed on axis y: 1) Mor (humus index RxN 6.4); 2) Moder (6.4-14.4); 3) transition zone Moder/Mull (14.4-18.2); 4) Acid Mull (18.2-23.0); 5) Typical Mull (23.0-27.5); 6) Basic Mull (27.5-36). The six classes correspond to those given by the Biogeoclimatic Ecosystem Classification in British Columbia (Wilson & al. 2001).

We think that the work of Rogister has been overlooked, because, notwithstanding it showed to be useful by offering significant tools to foresters to forecast growth and production of trees and to select the most suitable tree species for given sites (Aertsen & al. 2012), it was published in Flemish. Another obstacle in the application of the two indices could be certainly due to a limited knowledge about the humus forms, particularly in the Mediterranean environment (Andreetta & al. 2013).

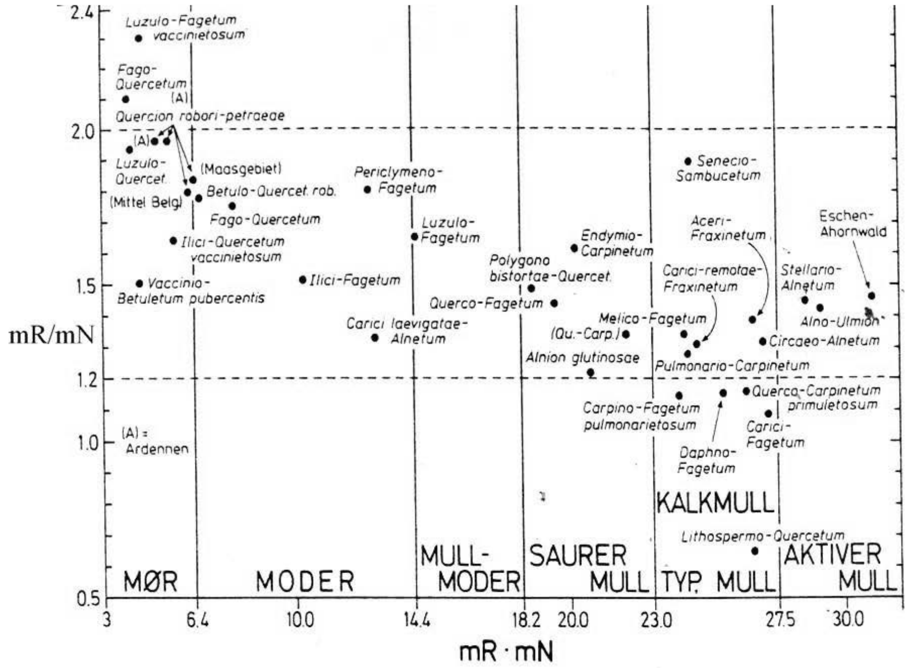


Fig. 1. Rogister's diagram (1978) referred to the ordination of forest vegetation in Belgium: humus forms and correspondent vegetation types are distributed along the *x,y* coordinates represented by values of humus quality-RxN and Nitrogen availability-R/N indexes.

The high correlation between measured parameters of soil and humus and the two Rogister's indices have been already shown in previous studies (De Nicola & al. 2014, 2015, 2018), here we offer the results of a study dedicated to test the performance of the Rogister's indices in terms of predictivity with respect vegetation classification (Pausas & Feoli 1996; Feoli & Ganis 2019 and references therein) with the aim to improve the knowledge of the plant-climate-soil interactions that would had produced the major humus forms: Mor, Moder, Mull and Amphi (Wilson & al. 2001; Ponge 2003) in the Italian forests.

Data and Methods

Data

Vegetation data

We have considered a set of 489 relevés of Italian forest already stored in the database "EVSItalia Database Habitat of Italy" (De Sanctis & al. 2012), EVA project repository (European Vegetation Archive; Chytrý & al. 2016) and 300 relevés done *ex novo* in sampling areas of central-southern Italy for a synchronic study of soil/humus and vegetation, in the course of International Projects of Forest Service in Abruzzo-Molise (Life Project on Habitat Conservation within the framework *Nature2000*), ISPRA (European Project PROFORMIOMED "Promotion of residual forestry biomass in the Mediterranean Basin") and Castelporziano Presidential Estate (Rome) for a long-term Project of Environmental Monitoring.

Such a set of 789 relevés is distributed in almost all the Italian regions (Fig. 2) and represents the 39 plant associations reported in Table 1. The nomenclature of the associations follows Mucina & al. (2016). The relevés were extracted by the program Turboveg (Hennekens & Schaminée 2001).

Soil-Humus data

We have collected the soil-humus data for each of the 300 new phytosociological relevé in Tuscany, Latium, Abruzzo, Campania. Others 100 descriptions of soil samples, that find correspondence with the considered forest types, have been obtained from literature (Bernier & Ponge 1994; Bonanomi & al. 2010; Bonifacio & al. 2011; Andreetta & al. 2013). The soil-humus samples are classified considering the sequence and morphological characteristics of organic (OL-litter, OF-fragmentated, OH-humic) and/or organo-mineral (A) horizons, including morphological evidence of biological activity and structures (Zanella & al. 2011; Jabiol & al. 2013).

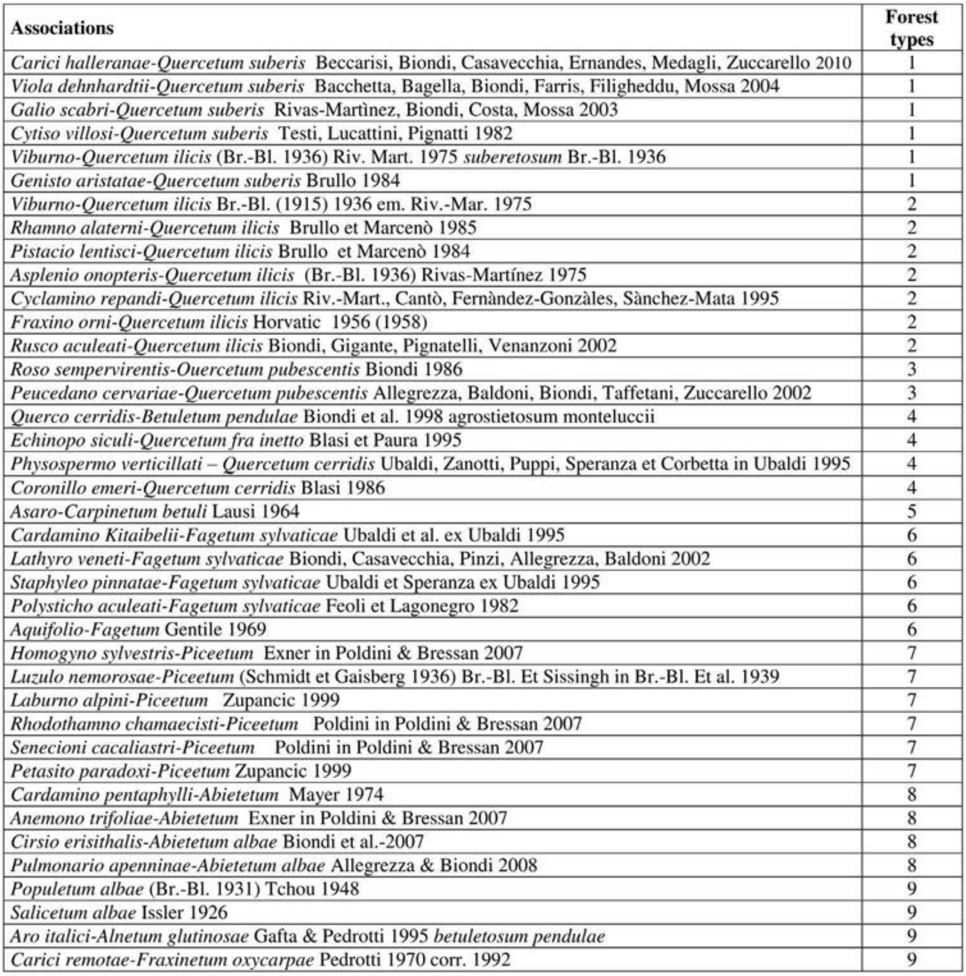
We have done the physico-chemical analyses according to the methods adopted by the Italian Society of Soil Science (Società Italiana della Scienza del Suolo 1985) and by the USDA Soil Survey Staff (Soil Survey Staff 1975, 1993, 1998).

Fig. 2. Distribution in Italy of the forest types classified on the basis of 789 relevés: 489 derived from the Database "EVSItalia Database Habitat of Italy" and 300 done *ex novo*.

EIV and Rogister's indices data

We have described each of the 847 species found in the relevés by its ecological indicator values (EIV) of Ellenberg (1974-1979) revised by Pignatti (2005). The mean EIV [light (L), temperature (T), continentality (K), soil moisture (F), reaction (R), nitrogen (N)] were calculated for each relevé by the program Turboveg using the cover data of the species. From the indices of reaction (R) and nutrients (N) we have calculated the indices of Rogister: RxN and R/N.

Table 1. List of the 39 plant associations extracted from the 789 relevés of Database. For each association the correspondent forest type was reported by progressive number.



Associations	**Forest types**
Carici halleranae-Quercetum suberis Beccarisi, Biondi, Casavecchia, Ernandes, Medagli, Zuccarello 2010	1
Viola dehnhardtii-Quercetum suberis Bacchetta, Bagella, Biondi, Farris, Filigheddu, Mossa 2004	1
Galio scabri-Quercetum suberis Rivas-Martìnez, Biondi, Costa, Mossa 2003	1
Cytiso villosi-Quercetum suberis Testi, Lucattini, Pignatti 1982	1
Viburno-Quercetum ilicis (Br.-Bl. 1936) Riv. Mart. 1975 *suberetosum* Br.-Bl. 1936	1
Genisto aristatae-Quercetum suberis Brullo 1984	1
Viburno-Quercetum ilicis Br.-Bl. (1915) 1936 em. Riv.-Mar. 1975	2
Rhamno alaterni-Quercetum ilicis Brullo et Marcenò 1985	2
Pistacio lentisci-Quercetum ilicis Brullo et Marcenò 1984	2
Asplenio onopteris-Quercetum ilicis (Br.-Bl. 1936) Rivas-Martínez 1975	2
Cyclamino repandi-Quercetum ilicis Riv.-Mart., Cantò, Fernàndez-Gonzàles, Sànchez-Mata 1995	2
Fraxino orni-Quercetum ilicis Horvatic 1956 (1958)	2
Rusco aculeati-Quercetum ilicis Biondi, Gigante, Pignatelli, Venanzoni 2002	2
Roso sempervirentis-Ouercetum pubescentis Biondi 1986	3
Peucedano cervariae-Quercetum pubescentis Allegrezza, Baldoni, Biondi, Taffetani, Zuccarello 2002	3
Querco cerridis-Betuletum pendulae Biondi et al. 1998 agrostietosum monteluccii	4
Echinopo siculi-Quercetum fra inetto Blasi et Paura 1995	4
Physospermo verticillati – Quercetum cerridis Ubaldi, Zanotti, Puppi, Speranza et Corbetta in Ubaldi 1995	4
Coronillo emeri-Quercetum cerridis Blasi 1986	4
Asaro-Carpinetum betuli Lausi 1964	5
Cardamino Kitaibelii-Fagetum sylvaticae Ubaldi et al. ex Ubaldi 1995	6
Lathyro veneti-Fagetum sylvaticae Biondi, Casavecchia, Pinzi, Allegrezza, Baldoni 2002	6
Staphyleo pinnatae-Fagetum sylvaticae Ubaldi et Speranza ex Ubaldi 1995	6
Polysticho aculeati-Fagetum sylvaticae Feoli et Lagonegro 1982	6
Aquifolio-Fagetum Gentile 1969	6
Homogyno sylvestris-Piceetum Exner in Poldini & Bressan 2007	7
Luzulo nemorosae-Piceetum (Schmidt et Gaisberg 1936) Br.-Bl. Et Sissingh in Br.-Bl. Et al. 1939	7
Laburno alpini-Piceetum Zupancic 1999	7
Rhodothamno chamaecisti-Piceetum Poldini in Poldini & Bressan 2007	7
Senecioni cacaliastri-Piceetum Poldini in Poldini & Bressan 2007	7
Petasito paradoxi-Piceetum Zupancic 1999	7
Cardamino pentaphylli-Abietetum Mayer 1974	8
Anemono trifoliae-Abietetum Exner in Poldini & Bressan 2007	8
Cirsio erisithalis-Abietetum albae Biondi et al.-2007	8
Pulmonario apenninae-Abietetum albae Allegrezza & Biondi 2008	8
Populetum albae (Br.-Bl. 1931) Tchou 1948	9
Salicetum albae Issler 1926	9
Aro italici-Alnetum glutinosae Gafta & Pedrotti 1995 *betuletosum pendulae*	9
Carici remotae-Fraxinetum oxycarpae Pedrotti 1970 corr. 1992	9

Chorological data

We have calculated an average index of Mediterranean climate, MI, for each forest type by the ratio between Steno+Eurimediterranean and Eurasiatic chorotypes by using the program Turboveg.

Data Analysis

The 789 relevés of the 39 associations (Table 1) described by EIV and Rogister's indices have been ordered in an ordination scattergram according to the two Rogister indices (RO). To test the predictivity of the indicator values EIV and the two RO indices with respect to vegetation classification, the relevés have been grouped into 9 main vegetation types of forests according to the dominance of the main species of trees (Mucina 2016; Pignatti 1998), one of them include all the azonal hygrophilous woodlands (Table 1):

1. *Quercus suber*, 2. *Quercus ilex*, 3. *Quercus pubescens*, 4. *Quercus cerris and Q.cerris-Q. frainetto*, 5. *Carpinus betulus*, 6. *Fagus sylvatica*, 7. *Picea abies*, 8. *Abies alba*, 9. Hygrophilous woodlands with *Salix* spp., *Populus* spp., *Fraxinus oxycarpa* and *Alnus glutinosa.*

For doing the predictivity analysis we have considered two data matrices, one where the relevés are described by RxN and R/N and the one where the relevés are described by the 6 EIV. In both cases the relevés have been compared by the cosine as similarity function (Orloci 1978) after standardization of the indices. In this way we have obtained a similarity matrix 789x789 based on RO (**S**(RO)) and a similarity matrix 789x789 based on EIV (**S**(EIV)). To compare the predictivity of the Rogister indices (RO) with that of EIV with respect to the classification of the relevés in 9 vegetation types, we have calculated the evenness of the eigenvalues (Eλ) (Feoli & Ganis 2019) of the similarity matrices (**S**(RO)) and (**S**(EIV)). The method tests the significance of Eλ by a permutation technique (Pillar & Orlòci 1996). To identify the factors responsible for the ecological differences between the 9 vegetation types we have calculated the correlation between the indices (EIV and RO) and the fuzzy sets corresponding to the 9 vegetation types as shown by Feoli & Ganis (2019). The fuzzy sets have been obtained by averaging the similarity the relevés have within and between the 9 groups of relevés corresponding to the vegetation types (Feoli & Zuccarello 1986). The index of Mediterraneity (MI) has been correlated with the other indices by using the average values they have in the 9 types. The matrices of correlation between the indices using the average values in the 9 types and using the all values of the 789 relevès have been compared by Mantel's test (Mantel 1967).

In order to facilitate the interpretation of the results of the ordination based on the two RO indices in terms of syntaxonomy, we have considered the correspondence of the 9 vegetation types, except for the hygrophilous vegetation type-9, with syntaxonomic classes as follows:

Quercetea ilicis including *Quercus suber-1* and *Q. ilex-2* forests;
Quercetea pubescentis including *Quercus pubescens-3* and *Q. cerris-4*;
Carpino-Fagetea including *Carpinus betulus-5*, *Fagus sylvatica-6*, *Abies alba*-8;
Vaccinio-Picetea including *Picea abies-7;*
Hygrophilous including forest type-9.

For each of these 5 classes we have superimposed one ellipsis in the ordination scattergram.

To test if species diversity is correlated with the EIV and Rogister indices (RO) we have calculated the following well known indices of diversity: Species richness, Shannon Index, Eveness, Simpson dominance λ.

Finally, we have grouped the relevés by their humus forms and we have calculated the significance of the separation between the groups by Eλ.

Results

The humus samples, classified in a total of 14 different humus sub-forms, belong to four main stable forms: Mor, Moder, Amphi, Mull, according to the classification of the terrestrial humus (Zanella & al. 2011; Jabiol 2013).

Following Rogister, the main humus forms fit well with the vegetation types along the RxN and R/N axes of the diagram (Fig. 3). Their distribution along the ranges of values is easily recognizable: Mor in *Picea abies* forest type- 7 with the lowest values of RxN and R/N values < 1; Amphi in evergreen Mediterranean forest, *Quercus suber* and *Quercus ilex* forest types (1,2) with low values of RxN as in Mor and higher values of R/N, ranged between 1.3 and 1.4; Moder in *Quercus pubescens* and *Quercus cerris* forest types (3, 4) displaying higher RxN values up to 27.20 and intermediate R/N values ranged between 1.1 and 1.5; Mull in *Carpinus betulus* (5), *Fagus sylvatica* (6) and azonal humid forest types (9) with the highest RxN values and R/N intermediate values. Interestingly, in our dataset *Abies alba* forest type (8) showed the Mull form with the indexes values as in beech forest (Fig. 3, Table 2).

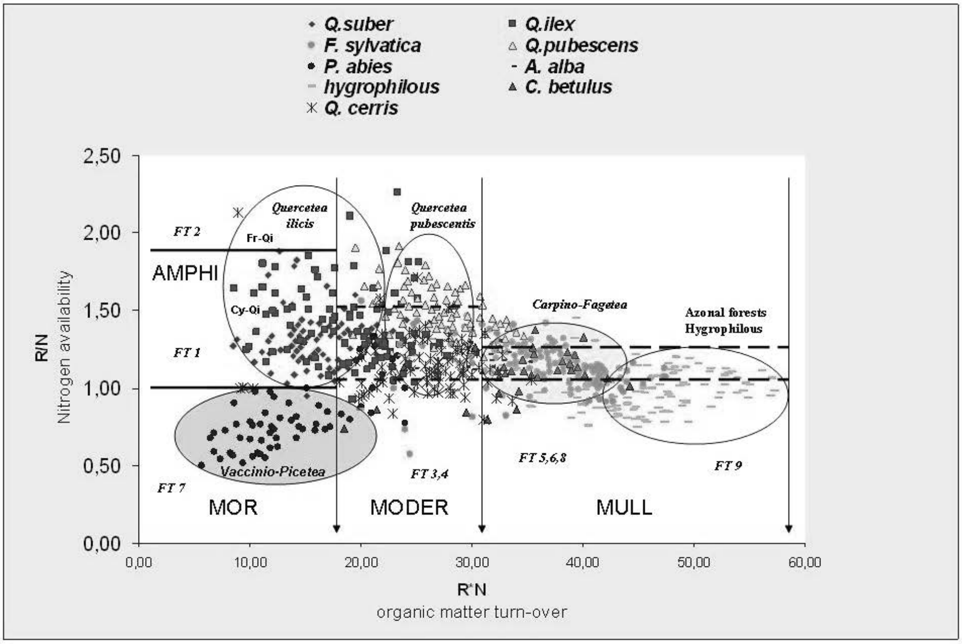
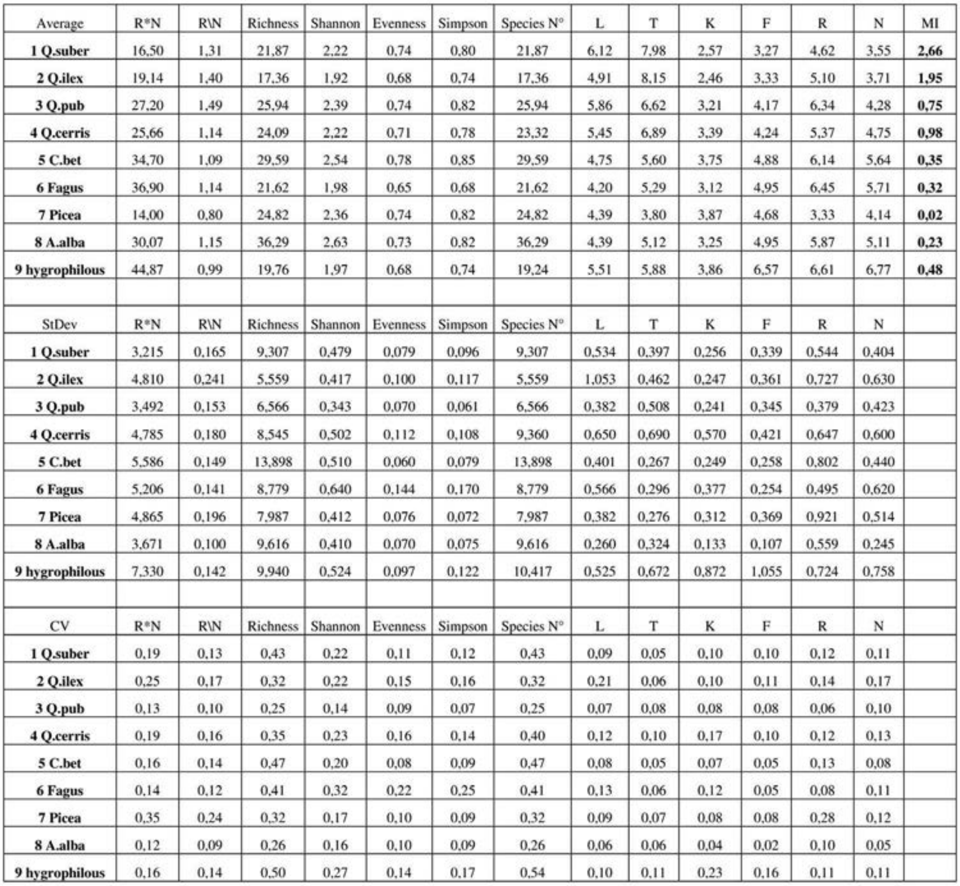


Fig. 3. Diagram of the Italian woodlands according to Rogister: the *x, y* axes were respectively represented by RxN and R/N indexes. The main sociological *syntaxa* and correspondent humus forms are reported along the gradients of the two humus indexes. Number of each Forest Type (FT) are indicated. Two associations of *Quercus ilex* forest are respectively indicated as Fr-Qi (*Fraxino orni-Quercetum ilicis*) and Cy-Qi (*Cyclamino repandi-Quercetum ilicis*). as they are discussed.

Table 2. Average values, standard deviations (StDev) and coefficient of variation (CV) of each of the EIV indicators and RxN and R/N indices.



Average	R*N	R\N	Richness	Shannon	Evenness	Simpson	Species N°	L	T	K	F	R	N	MI
1 Q.suber	16,50	1,31	21,87	2,22	0,74	0,80	21,87	6,12	7,98	2,57	3,27	4,62	3,55	**2,66**
2 Q.ilex	19,14	1,40	17,36	1,92	0,68	0,74	17,36	4,91	8,15	2,46	3,33	5,10	3,71	**1,95**
3 Q.pub	27,20	1,49	25,94	2,39	0,74	0,82	25,94	5,86	6,62	3,21	4,17	6,34	4,28	**0,75**
4 Q.cerris	25,66	1,14	24,09	2,22	0,71	0,78	23,32	5,45	6,89	3,39	4,24	5,37	4,75	**0,98**
5 C.bet	34,70	1,09	29,59	2,54	0,78	0,85	29,59	4,75	5,60	3,75	4,88	6,14	5,64	**0,35**
6 Fagus	36,90	1,14	21,62	1,98	0,65	0,68	21,62	4,20	5,29	3,12	4,95	6,45	5,71	**0,32**
7 Picea	14,00	0,80	24,82	2,36	0,74	0,82	24,82	4,39	3,80	3,87	4,68	3,33	4,14	**0,02**
8 A.alba	30,07	1,15	36,29	2,63	0,73	0,82	36,29	4,39	5,12	3,25	4,95	5,87	5,11	**0,23**
9 hygrophilous	44,87	0,99	19,76	1,97	0,68	0,74	19,24	5,51	5,88	3,86	6,57	6,61	6,77	**0,48**
StDev	R*N	R\N	Richness	Shannon	Evenness	Simpson	Species N°	L	T	K	F	R	N	
1 Q.suber	3,215	0,165	9,307	0,479	0,079	0,096	9,307	0,534	0,397	0,256	0,339	0,544	0,404	
2 Q.ilex	4,810	0,241	5,559	0,417	0,100	0,117	5,559	1,053	0,462	0,247	0,361	0,727	0,630	
3 Q.pub	3,492	0,153	6,566	0,343	0,070	0,061	6,566	0,382	0,508	0,241	0,345	0,379	0,423	
4 Q.cerris	4,785	0,180	8,545	0,502	0,112	0,108	9,360	0,650	0,690	0,570	0,421	0,647	0,600	
5 C.bet	5,586	0,149	13,898	0,510	0,060	0,079	13,898	0,401	0,267	0,249	0,258	0,802	0,440	
6 Fagus	5,206	0,141	8,779	0,640	0,144	0,170	8,779	0,566	0,296	0,377	0,254	0,495	0,620	
7 Picea	4,865	0,196	7,987	0,412	0,076	0,072	7,987	0,382	0,276	0,312	0,369	0,921	0,514	
8 A.alba	3,671	0,100	9,616	0,410	0,070	0,075	9,616	0,260	0,324	0,133	0,107	0,559	0,245	
9 hygrophilous	7,330	0,142	9,940	0,524	0,097	0,122	10,417	0,525	0,672	0,872	1,055	0,724	0,758	
CV	R*N	R\N	Richness	Shannon	Evenness	Simpson	Species N°	L	T	K	F	R	N	
1 Q.suber	0,19	0,13	0,43	0,22	0,11	0,12	0,43	0,09	0,05	0,10	0,10	0,12	0,11	
2 Q.ilex	0,25	0,17	0,32	0,22	0,15	0,16	0,32	0,21	0,06	0,10	0,11	0,14	0,17	
3 Q.pub	0,13	0,10	0,25	0,14	0,09	0,07	0,25	0,07	0,08	0,08	0,08	0,06	0,10	
4 Q.cerris	0,19	0,16	0,35	0,23	0,16	0,14	0,40	0,12	0,10	0,17	0,10	0,12	0,13	
5 C.bet	0,16	0,14	0,47	0,20	0,08	0,09	0,47	0,08	0,05	0,07	0,05	0,13	0,08	
6 Fagus	0,14	0,12	0,41	0,32	0,22	0,25	0,41	0,13	0,06	0,12	0,05	0,08	0,11	
7 Picea	0,35	0,24	0,32	0,17	0,10	0,09	0,32	0,09	0,07	0,08	0,08	0,28	0,12	
8 A.alba	0,12	0,09	0,26	0,16	0,10	0,09	0,26	0,06	0,06	0,04	0,02	0,10	0,05	
9 hygrophilous	0,16	0,14	0,50	0,27	0,14	0,17	0,54	0,10	0,11	0,23	0,16	0,11	0,11	

Along the two axes of Fig. 3, there is a clear overlap between the more thermophile *Quercus cerris* woodlands of central Italy and *Quercus ilex* woodlands, while *Carpinus betulus* forest occupies an intermediate position between *Fagus sylvatica* and *Q. cerris*. The latter is partially overlapping with *F. sylvatica*. The pattern of ordination shows a clear triangular shape, with evergreen Mediterranean forests (*Quercetea ilicis* Br.-Bl- 1952) on the upper left side, mixed deciduous forests (*Quercetea pubescentis* Oberd. 1948; Doing Kraft 1955) in the middle sector between evergreen Mediterranean and deciduous forests of *Carpino-Fagetea* Br.-Bl. & Vlieg. 1937; Jakucs 1960; cool and boreal forests (Class *Vaccinio-Picetea* Br.-Bl. 1939) on the bottom left corner. *Abies alba* woodlands are distributed within the *Fagus sylvatica* cloud of the relevés; azonal humid forests on the right and extreme sector of the diagram.

Synthesizing these results, the RxN showed the highest values in beech forests and in hygrophilous woodlands where Mull forms, with rapid organic matter turn-over, characterize the humus; on the contrary in the Mediterranean sclerophyllous woodlands, such as in boreal Alpine woodlands, values were the lowest in correspondence of the prevalence of Amphi and Mor forms respectively with slow turn-over of organic matter (Fig. 3, Table 2). [*]

The average values, the standard deviations and the variation coefficient of each of the EIV indices and RxN and R/N in the 9 vegetation types are presented in Table 2 (Average, StDev standard deviation, CV coefficient of variation).

The correlation coefficients between the indices are reported in Table 3 according to all the relevés (a) and to the average values in the 9 main vegetation types (b) displayed in Table 1. Mantel test between the two matrices (excluding MI that was considered only as average value for the 9 vegetation types) is highly significant, $r= 0.94$ $p< 0.0001$.

A lot of significant correlations emerged: RxN is highly correlated with soil moisture-F, Reaction-R and Nutrients-N indicators (0.81, 0.89, 0.95). R/N is correlated with climatic indicators: temperature T indicator, light L indicator, and MI index by high coefficients values (0.78, 0.50 and 0.61). All EIV, except for R, were correlated with MI. Among the diversity indices, Richness and Species N° were negatively correlated with T indicator and MI (Table 3b).

The separation of the 9 types based only on RxN and R/N indices was 0.816 (in Table 4a), while the separation based on the 6 EIV was 0.576 (in Table 4b). Both the separations were highly significant ($p<0.0001$) by the permutation test, but the one based on RxN and R/N was superior.

The correlations between fuzzy sets of the 9 vegetation types with all the indices (Table 5), both considering the average values of the 9 types a) and all the data b), showed that the mediterranean (*Q. suber* and *Q. ilex*) and submediterranean (*Q. pubescens* and *Q. cerris*) forest types were correlated with climatic indicators of light-L and temperature-T, while mesophile deciduous forests (*Carpinus betulus* and *Fagus sylvatica)* were correlated with the soil indicators F, R, N as well as with the combined RxN index of humus quality. *Abies alba* type with F indicator, hygrophilous forest type with K, F, N and RxN indices. *Q. suber, Q. ilex* and *Q. cerris* forest types were correlated with MI (Table 5a).

Correlation of R/N nitrogen availability emerged when all the data were considered (Table 5b) with *Q. suber, Q. ilex, Q. pubescens, Q. cerris* types. The mesophile forest types of *C. betulus, Fagus, Abies alba* and hygrophilous woodlands show the same correlation pattern. *Picea abies* forest type shows correlation with continentality-K and soil moisture-F.

Laboratory measurements of total nitrogen -Ntot-, calculated in the different OL, OF, OH, A horizons in previous studies, showed lower values in Mull, where OH horizon is lacking and turn-over faster, against the higher values in Amphi with slower turn-over and consequently nitrogen accumulation in all the horizons (De Nicola & al. 2018). The correspondent index of nitrogen availability R/N showed, actually, coherent values: the narrowest range in Mull against the highest values in Amphi forms (Fig. 3).

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[*] In Appendix we show pictures of some sampling sites that put in evidence the correspondence between the humus forms and vegetation types; the pictures derived from data published concerning the study conducted in the Castelporziano Reserve (De Nicola & al. 2018).

Table 3a, b. Correlation coefficients between RxN and R/N considering all the relevés a) and considering the average values in the 9 main vegetation types b) as indicated in Table 1. In bold the discussed correlations. The Mantel test between the two matrices (by excluding MI) is highly significant r = 0.94 p<0.0001.

a) Correlation on values of all the relevés	R*N	R\N	Richness	Shannon	Evenness	Simpson	Species N°	L	T	K	F	R	N
R*N	1,000	**-0,218**	0,038	-0,064	**-0,140**	**-0,165**	0,036	**-0,221**	-0,325	**0,364**	**0,732**	**0,849**	**0,928**
R\N	**-0,218**	1,000	0,054	0,090	0,087	0,080	0,059	**0,354**	**0,579**	**-0,317**	**-0,503**	**0,303**	**-0,541**
Richness	0,038	0,054	1,000	**0,834**	**0,458**	**0,600**	**0,976**	0,013	**-0,174**	0,036	0,010	**0,111**	0,020
Shannon	-0,064	0,090	**0,834**	1,000	**0,852**	**0,899**	**0,819**	**0,136**	-0,060	0,029	-0,092	0,017	-0,084
Evenness	**-0,140**	0,087	**0,458**	**0,852**	1,000	0,919	**0,456**	**0,239**	0,064	0,038	**-0,140**	-0,086	**-0,154**
Simpson	**-0,165**	0,080	**0,600**	**0,899**	**0,919**	1,000	**0,590**	**0,250**	0,062	0,042	**-0,146**	**-0,106**	**-0,166**
Species N°	0,036	0,059	**0,976**	**0,819**	**0,456**	**0,590**	1,000	0,005	**-0,177**	0,037	0,007	**0,110**	0,016
L	**-0,221**	**0,354**	0,013	**0,136**	**0,239**	**0,250**	0,005	1,000	**0,435**	0,029	**-0,158**	-0,063	**-0,313**
T	**-0,325**	**0,579**	**-0,174**	-0,060	0,064	0,062	**-0,177**	**0,435**	1,000	**-0,508**	**-0,632**	-0,052	**-0,471**
K	**0,364**	**-0,317**	0,036	0,029	0,038	0,042	0,037	0,029	-0,508	1,000	**0,544**	**0,198**	**0,389**
F	**0,732**	**-0,503**	0,010	-0,092	**-0,140**	**-0,146**	0,007	**-0,158**	**-0,632**	**0,544**	1,000	**0,436**	**0,806**
R	**0,849**	**0,303**	**0,111**	0,017	-0,086	**-0,106**	**0,110**	-0,063	-0,052	**0,198**	**0,436**	1,000	**0,612**
N	**0,928**	**-0,541**	0,020	-0,084	**-0,154**	**-0,166**	0,016	**-0,313**	**-0,471**	**0,389**	**0,806**	**0,612**	1,000

b) Correlation on averages in the 9 Forest types	RxN	R\N	Richness	Shannon	Evenness	Simpson	Species N°	L	T	K	F	R	N	MI
R*N	1,000	-0,156	0,092	-0,131	-0,306	-0,307	0,074	-0,116	-0,227	0,438	**0,811**	**0,880**	**0,950**	**-0,485**
R\N	-0,156	1,000	-0,142	-0,103	-0,051	-0,048	-0,129	0,502	**0,784**	**-0,774**	**-0,624**	0,317	-0,457	**0,614**
Richness	0,092	-0,142	1,000	0,929	0,608	0,679	0,999	-0,321	**-0,483**	0,322	0,164	0,111	0,126	**-0,491**
Shannon	-0,131	-0,103	0,929	1,000	0,845	0,888	0,932	-0,139	**-0,405**	0,329	-0,009	-0,090	-0,086	-0,363
Evenness	-0,306	-0,051	0,608	0,845	1,000	0,978	0,614	0,164	-0,146	0,271	-0,180	-0,276	-0,258	-0,052
Simpson	-0,307	-0,048	0,679	0,888	0,978	1,000	0,681	0,161	-0,174	0,294	-0,141	-0,270	-0,257	-0,106
Species N°	0,074	-0,129	0,999	0,932	0,614	0,681	1,000	-0,334	**-0,483**	0,301	0,144	0,100	0,106	**-0,482**
L	-0,116	0,502	-0,321	-0,139	0,164	0,161	-0,334	1,000	0,683	-0,263	-0,268	0,073	-0,258	**0,637**
T	-0,227	0,784	-0,483	-0,405	-0,146	-0,174	-0,483	0,683	1,000	-0,779	-0,625	0,097	-0,444	**0,902**
K	0,438	-0,774	0,322	0,329	0,271	0,294	0,301	-0,263	-0,779	1,000	0,788	0,082	0,642	**-0,821**
F	0,811	-0,624	0,164	-0,009	-0,180	-0,141	0,144	-0,268	-0,625	0,788	1,000	0,476	0,928	**-0,733**
R	0,880	0,317	0,111	-0,090	-0,276	-0,270	0,100	0,073	0,097	0,082	0,476	1,000	0,691	-0,240
N	0,950	-0,457	0,126	-0,086	-0,258	-0,257	0,106	-0,258	-0,444	0,642	0,928	0,691	1,000	**-0,629**
MI	-0,485	0,614	-0,491	-0,363	-0,052	-0,106	-0,482	0,637	0,902	-0,821	-0,733	-0,240	-0,629	1,000

The comparison between the humus forms obtained by the evenness of the eigenvalues of the similarity matrix calculated by similarity ratio on the basis of the two Rogister indices, reflected the differences among the averages indicator values of the humus forms. The distance between each form was high, with the maximum Eλ value between Amphi and Mull (Table 6). Mor forms were not included in this test since related data came from literature and not from our vegetation relevés and associated humus profiles.

If we consider the ordination of Rogister in Fig. 1, we can note that generally in Belgium forests the RxN range values were lower (Fig. 1) than in Italian ones (Fig. 3), particularly for Mor and Moder humus forms: Mor had the extreme value at 6.4 and Moder at 14.4 in Belgium *vs.* 14 and 27.20 respectively in Italy (see Table 2).

The ordination based on Rogister indices shows a gradient of Mediterraneity (index-MI) from evergreen Mediterranean forests of *Quercetea ilicis* to sub-Mediterranean deciduous *Quercetea pubescentis* forests and to *Carpino-Fagetea*, with the lowest values in boreal *Vaccinio-Picetea* forests and maximum in *Quercus suber* forest type-1 (Fig. 4). In this ordination the type of Azonal hygrophilous woodlands does not follow the general MI gradient.

Table 4. Matrices of within/between similarity of the 9 vegetation types based only on RxN and R/N a) and on the 6 EIV b). The Eveness value of the two matrices (Eλ) is 0.81 ($p<0.0001$) for the matrix a) and 0.576 for matrix b).

a) Similarity on only R*N and R/N	1 Q.suber	2 Q.ilex	3 Q.pubescens	4 Q.cerris	7 Picea	5 C.betulus	9 Hygrophilous	6 Fagus	8 Abies alba
1 Q.suber	0,907	0,860	0,666	0,572	0,665	0,170	0,111	0,163	0,289
2 Q.ilex	0,860	0,835	0,731	0,527	0,561	0,203	0,146	0,222	0,303
3 Q.pubescens	0,666	0,731	0,935	0,371	0,198	0,340	0,296	0,445	0,367
4 Q.cerris	0,572	0,527	0,371	0,577	0,688	0,453	0,451	0,405	0,483
7 Picea abies	0,665	0,561	0,198	0,688	0,936	0,392	0,389	0,281	0,462
5 C.betulus	0,170	0,203	0,340	0,453	0,392	0,762	0,818	0,767	0,674
9 Hygrophilous	0,111	0,146	0,296	0,451	0,389	0,818	0,876	0,811	0,707
6 Fagus sylv.	0,163	0,222	0,445	0,405	0,281	0,767	0,811	0,795	0,664
8 Abies alba	0,289	0,303	0,367	0,483	0,462	0,674	0,707	0,664	0,591

b) Similarity on EIV	1 Q. suber	2 Q. ilex	3 Q.pubescens	4 Q.cerris	5 C.betulus	9 Hygrophilous	6 Fagus	8 Abies alba	7 Picea abies
1 Q. suber	**0,9586**	**0,8555**	**0,6785**	**0,6723**	0,1193	0,2037	0,1470	0,1395	0,3817
2 Q. ilex	**0,8555**	**0,8785**	**0,5807**	**0,6191**	0,1838	0,2049	0,2952	0,2696	0,3611
3 Q. pubescens	**0,6785**	**0,5807**	**0,8431**	**0,5874**	0,3876	0,4465	0,3543	0,2918	0,2709
4 Q. cerris	**0,6723**	**0,6191**	**0,5874**	**0,6075**	0,3919	0,4275	0,3297	0,2984	0,4119
5 C. betulus	0,1193	0,1838	0,3876	0,3919	**0,8478**	**0,7516**	**0,7633**	**0,7584**	**0,5946**
9 Hygrophilous	0,2037	0,2049	0,4465	0,4275	**0,7516**	**0,8435**	**0,6684**	**0,6159**	0,4333
6 Fagus sylvatica	0,1470	0,2952	0,3543	0,3297	**0,7633**	**0,6684**	**0,8630**	**0,8481**	**0,5395**
8 Abies alba	0,1395	0,2696	0,2918	0,2984	**0,7584**	**0,6159**	**0,8481**	**0,9017**	**0,7076**
7 Picea abies	0,3817	0,3611	0,2709	0,4119	**0,5946**	0,4333	0,5395	**0,7076**	**0,9443**

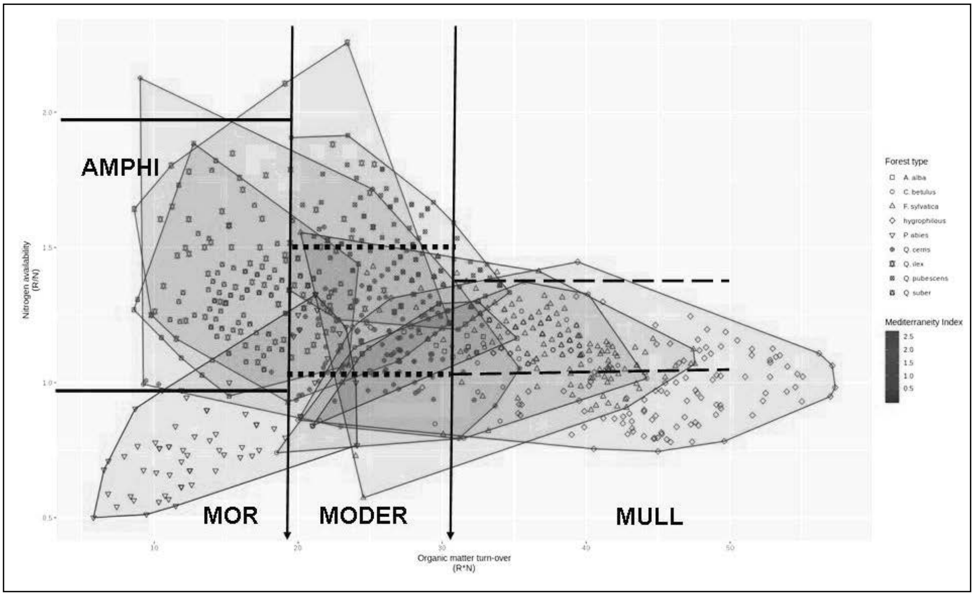

Fig. 4. Diagram of the Italian woodlands according to Rogister in which the phytogeographical gradient expressed by the Mediterraneity index-MI is indicated through a different intensity of colour from the *Quercetea ilicis* Mediterranean forests (red) to boreal *Vaccinio-Picetea* (blue) and *Carpino-Fagetea* (violet). Nine polygons correspondent to the 9 forest types are recognizable.

Table 5a, b. Correlation between fuzzy sets of the 9 vegetation types with the indicator values considering the average values of the 9 types a) and all the data b). In the first case the index of mediterraneity is included.

a) average data	1Q.suberE	2Q.ilexE	3Q.pubE	4Q.cerrisE	5C.betE	6FagusE	7PiceaE	8A.albaE	9HygrE	1 Q.suberE	2 Q.ilexE	3 Q.pubE	4 Q.cerrisE	5 C. betE	6 FagusE	7 PiceaE	8 A.albaE	9 HygrE
L	0,675	0,544	0,853	0,798	-0,626	-0,751	-0,735	-0,831	-0,350	0,454	0,506	0,547	-0,075	-0,473	-0,387	-0,075	-0,491	-0,482
T	0,802	0,830	0,771	0,839	-0,798	-0,741	-0,851	-0,848	-0,608	0,572	0,639	0,705	-0,110	-0,597	-0,484	-0,111	-0,630	-0,608
K	-0,702	-0,822	-0,501	-0,567	0,751	0,537	0,537	0,574	0,745	-0,631	-0,693	-0,718	0,053	0,653	0,548	0,059	0,700	0,665
F	-0,818	-0,873	-0,523	-0,699	0,831	0,725	0,294	0,668	0,925	-0,866	-0,880	-0,627	-0,300	0,875	0,825	-0,295	0,883	0,876
R	-0,419	-0,395	0,148	-0,277	0,438	0,455	-0,504	0,233	0,638	-0,668	-0,548	0,184	-0,935	0,630	0,776	-0,930	0,554	0,609
N	-0,818	-0,833	-0,452	-0,664	0,834	0,760	0,096	0,638	0,961	-0,955	-0,942	-0,540	-0,492	0,954	0,942	-0,485	0,949	0,951
R*N	-0,698	-0,698	-0,220	-0,536	0,715	0,675	-0,172	0,499	0,893	-0,900	-0,839	-0,261	-0,723	0,883	0,939	-0,717	0,847	0,872
R\N	0,616	0,662	0,815	0,600	-0,616	-0,503	-0,811	-0,625	-0,502	0,465	0,594	0,952	-0,485	-0,511	-0,316	-0,489	-0,594	-0,533
Richness	-0,487	-0,485	-0,346	-0,529	0,490	0,488	0,453	0,532	0,327	-0,336	-0,343	-0,252	-0,107	0,337	0,319	-0,105	0,308	0,341
Shannon	-0,285	-0,333	-0,176	-0,306	0,310	0,244	0,429	0,320	0,149	-0,106	-0,121	-0,149	0,039	0,108	0,087	0,039	0,095	0,115
Evenness	0,009	-0,090	0,050	0,049	0,039	-0,106	0,267	-0,021	-0,051	0,151	0,126	-0,034	0,204	-0,149	-0,173	0,201	-0,136	-0,138
Simpson	0,005	-0,097	0,051	0,033	0,040	-0,101	0,280	-0,011	-0,051	0,157	0,130	-0,038	0,215	-0,153	-0,180	0,213	-0,146	-0,143
Species N°	-0,483	-0,477	-0,347	-0,533	0,483	0,489	0,461	0,536	0,312	-0,322	-0,327	-0,232	-0,113	0,323	0,308	-0,111	0,293	0,326
MI	0,866	0,891	0,632	0,832	-0,880	-0,808	-0,608	-0,832	-0,766	0,732	0,757	0,594	0,188	-0,744	-0,685	0,183	-0,752	-0,748

b) all the data	1Q.suberE	2Q.ilexE	3Q.pubE	4Q.cerrisE	5C.betE	6FagusE	7PiceaE	8A.albaE	9HygrE	1 Q.suberE	2 Q.ilexE	3 Q.pubE	4 Q.cerrisE	5 C. betE	6 FagusE	7 PiceaE	8 A.albaE	9 HygrE
L	0,537	0,297	0,744	0,645	**-0,468**	**-0,668**	**-0,428**	**-0,702**	**-0,222**	0,409	0,431	0,342	0,026	**-0,418**	**-0,367**	0,025	**-0,428**	**-0,423**
T	0,769	0,799	0,614	0,810	**-0,752**	**-0,701**	**-0,703**	**-0,803**	**-0,612**	0,535	0,567	0,462	0,020	**-0,549**	**-0,478**	0,019	**-0,564**	**-0,554**
K	**-0,519**	**-0,663**	**-0,188**	**-0,302**	0,615	0,294	0,389	0,339	0,568	**-0,388**	**-0,399**	**-0,280**	-0,075	0,393	0,361	-0,072	0,399	0,395
F	**-0,758**	**-0,813**	**-0,451**	**-0,663**	0,750	0,641	0,241	0,617	0,854	**-0,713**	**-0,716**	**-0,442**	**-0,212**	0,717	0,680	-0,209	0,716	0,717
R	**-0,480**	**-0,435**	0,140	**-0,341**	0,504	0,510	**-0,488**	0,312	0,616	**-0,598**	**-0,463**	0,233	**-0,823**	0,555	0,717	**-0,821**	0,469	0,531
N	**-0,782**	**-0,756**	**-0,486**	**-0,643**	0,777	0,734	0,034	0,627	0,883	**-0,891**	**-0,889**	**-0,525**	**-0,295**	0,894	0,856	**-0,290**	0,890	0,894
R*N	**-0,732**	**-0,697**	**-0,257**	**-0,575**	0,740	0,709	**-0,193**	0,551	0,861	**-0,858**	**-0,794**	**-0,234**	**-0,575**	0,840	0,891	**-0,570**	0,798	0,829
R\N	0,471	0,481	0,731	0,450	**-0,445**	**-0,384**	**-0,585**	**-0,469**	**-0,422**	0,452	0,588	0,869	**-0,493**	-0,500	**-0,288**	**-0,497**	**-0,583**	**-0,524**
Richness	-0,113	-0,142	0,070	-0,114	0,125	0,109	0,012	0,102	0,108	-0,051	-0,029	0,065	-0,120	0,043	0,072	-0,119	0,026	0,040
Shannon	0,029	-0,025	0,162	0,052	-0,004	-0,052	-0,043	-0,057	0,003	0,050	0,065	0,094	-0,053	-0,056	-0,032	-0,053	-0,066	-0,058
Evenness	0,143	0,072	0,194	0,186	-0,112	**-0,189**	-0,060	**-0,186**	-0,080	0,126	0,127	0,077	0,038	-0,128	-0,120	0,038	-0,127	-0,127
Simpson	0,162	0,083	0,220	0,207	-0,128	**-0,212**	-0,068	**-0,208**	-0,092	0,155	0,153	0,084	0,059	**-0,156**	**-0,151**	0,059	**-0,155**	**-0,155**
Species N°	-0,116	-0,141	0,063	-0,122	0,126	0,116	0,022	0,111	0,101	-0,047	-0,022	0,079	-0,130	0,039	0,071	-0,130	0,020	0,035

Table 6. Complement Euclidean distances among the sampled humus forms Amphi, Moder, Mull. Jaccard similarity ratio was completely significant.

Average	RxN	R\N	SD	RxN	R\N	CV	RxN	R\N	Min	RxN	R\N	Max	RxN	R\N
AMPHI	20.75	1.31	AMPHI	4.12	0.17	AMPHI	0.20	0.13	AMPHI	10.64	1.04	AMPHI	27.84	1.81
MODER	26.41	1.23	MODER	3.66	0.20	MODER	0.14	0.16	MODER	18.14	0.84	MODER	35.38	1.72
MULL	34.09	1.17	MULL	5.64	0.14	MULL	0.17	0.12	MULL	18.50	0.74	MULL	47.45	1.56
	> max. in Mull	<		max.in Mull	max.in Moder		max.in Amphi	max.in Moder		>	<		>	<

Discussion

The soundness of RO is supported by the fact that the indices are highly correlated with measured parameters of soil and humus as was found in previous studies (De Nicola & al. 2014, 2015); furthermore, the separation of the 9 vegetation types in the ordination space given by the RxN and R/N indices (Table 4a) is higher (Eλ=0.816) than that based on the 6 EIV of Ellenberg (Eλ = 0.576) (Table 4b). This proves that the two RO indices are more predictive that the 6 EIV with respect the classification of the Italian forests in the 9 vegetation types.

The ordination of the relevés of the Italian woodlands based on the Rogister indices displayed a significant distribution pattern along the RxN and R/N axes (Fig. 3). From this ordination it is evident that nitrogen availability is indeed one of the most crucial soil factor influencing structure and eco-physiology of the vegetation (Anas & al. 2020). So, nevertheless the litter of both *Picea abies* cool forest and *Quercus ilex/Quercus suber* thermophile forest is composed by evergreen leaves and therefore the turn-over of organic matter is slowed down, nitrogen availability is higher in the sclerophillous woodlands where we find the Amphi humus form.

This evidence was supported by the quantity of the total nitrogen –Ntot- measured in the different organic and organo-mineral horizons of the soil/humus compound (De Nicola & al. 2018). This result is consistent with Callesen & al. (2007) who found a positive relationship between total soil N pools and both temperature and precipitation in forests of north and central Europe. By following the RxN gradient, we can see that the relevés of *Quercetea pubescentis* (deciduous forests) are characterized by higher values of this index with respect to Amphi forests of *Quercetea ilicis* (Fig. 3). This is due to the faster organic matter turn-over in Moder humus forms that can be explained by climate factors like (1) the heavy rainfall that favours the intensity of leaching, nutrient losses and thus topsoil impoverishment (Turner & al. 2010), and (2) lower temperatures at higher altitude, that slow down the organic matter turnover (Roe 2005), as in the case of the mountain *Q. cerris* woodlands of our dataset.

From floristic and phytosociological point of view *Quercetalia/Quercetea pubescentis* forests are very diversified, but the soil indicators here utilized, suggest that they would have the same structure and dynamic of the soil/humus system.

In correspondence with the highest RxN values (> 30), we have found continental and cooler woodlands of *Carpino-Fagetea* where the organic matter turn-over is the fastest in Mull humus forms, without OH horizon (Ponge 2003). The same humus dynamic concerns azonal humid forests distributed on the extreme pole of the RxN gradient.

The other index R/N showed a rather small range of values in all the forest types with humus Mull (Fig. 3): this pattern is confirmed by the measurements of the chemical parameter Ntot that displays lower quantity in OF+OH+A horizons than in Amphi Mediterranean forests (De Nicola & al. 2018).

The influence of climate to define the Mull forms can be understood by considering the stimulatory influence of temperature on most chemical processes, in particular those involved in organic matter decomposition (Aerts 1997) and mineral weathering (Turner & al. 2010). The heat beside offering benefits to the activity of cold-blooded animals (Briones & al. 2010), is also influencing positively the invertebrates involved in mull-forming (Zhang & al. 2008), at least in the absence of any drought limitations (Cortez 1998) as it happens in hygrophilous forest type.

It is, moreover, remarkable that the ordination of the Italian forest types along the Rogister axes is well supported by their relationships with climatic and soil factors, expressed by the fuzzy set correlation output (Table 5a, b): mediterranean and sub-mediterranean woodlands of *Quercetea ilicis* and *Quercetea pubescentis*, linked to climatic indicators and to nitrogen availability in the soil-R/N, were separated from mesophile deciduous woodlands of *Carpino-Fagetea* correlated with soil (F,R,N) and humus-RxN indicators (Table 5a, b).

By examining the gradients related to Rogister's indexes, we can detect a discrimination of Italian woodlands at a broader scale, but also we can find discrimination at the level of associations (Fig. 3). In this respect the following three points deserve to be put in evidence:

A. The two main *Quercus ilex* associations in Italy (Biondi & al. 2003) are the supramediterranean *Fraxino orni-Quercetum ilicis* (Horvatic 1939) Horvatic 1958, and mesomediterranean *Cyclamino repandi-Quercetum ilicis* Riv.-Mart., Cantó, Fernández-González & Sánchez-Mata 1995, the former with many deciduous species and affinities with *Quercetalia pubescentis*. In the ordination scattergram *Fraxino-Quercetum* (Fr-Qi) is located in correspondence of higher values of R/N, and *Cyclamino-Quercetum* (Cy-Qi) in correspondence of lower values of R/N. The former association in fact has a higher nitrogen availability-N and higher pH-R (Biondi & al. 2003).

B. Woodlands with *Abies alba*, are completely included within the cloud of the relevés of *Fagus sylvatica* , in correspondence with low R/N and high RxN values. Actually, these relevés belong to the belt of *Fagion sylvaticae* in central-southern Apennines of Abruzzo and Molise (Abbate 1990; Rovelli 2008) on moist soils and humus Mull with fast organic matter turn-over. Humus is in fact a Mull form and not Mor, like in the other coniferous forest with *Picea abies* all characterized by Mor humus form with low organic matter turn-over.

C. Beech forests at Apennines lower altitudes overlapped with rich *Quercus cerris* woodlands with *Carpinus betulus* on eutrophic soils. These woodlands showed intermediate R/N values. Typical beech woodlands referred to *Fagion* (Boublik & al. 2007) are in correspondence with higher R/N values (Fig. 3).

Therefore, at a broader scale the four sociological classes including the Italian woodlands analyzed (except for the azonal humid vegetation), completely fit with the four main humus forms -Mor, Amphi, Moder, Mull- (Fig. 3) giving support to humus theory (Ponge 2003).

In summary we can conclude that according to the ordination given by the two humus indexes (RO) we can see that along the RxN and R/N gradients, like for the Belgium forest vegetation (Fig. 1), we can recognize the following sequence of correspondences between vegetation and humus (Fig. 3):

1. *Quercetea ilicis* evergreen Mediterranean woodlands fit with Amphi, a twin humus form showing both characters of Mull (crumby organo-mineral horizon) and Moder (accumulated organic humus), due to a seasonal alternation between phases of high and low biological activity in strongly seasonal Mediterranean environments.
2. *Vaccinio-Picetea* boreal woodlands on Mor forms with slow transformation and accumulation of undecayed plant debris, with a sharp transition to the mineral soil.
3. *Quercetea pubescentis* sub-mediterranean and mesophile woodlands, distributed in fact between *Quercetea ilicis* and *Carpino-Fagetea* forests, fit with Moder humus with a velocity of litter transformation by litter-dwelling animals and fungi intermediate between Amphi and Mull.
4. *Carpino-Fagetea* woodlands on moist soils correspond to humus Mull with fast organic matter turn-over, characterized by a higher nutrient release per unit time, even if all forms would have equal turn-over rates. Here, in fact, the organic layers, accessible to earthworms, disappeared rapidly replaced by well transformed organic matter, integrated in well structured, thick and rich in nutrients A horizon (Klinka & al. 1990; De Nicola & al. 2018).
5. Azonal vegetation of hygrophilous *Alnus glutinosa, Fraxinus oxycarpa, Salix* and *Populus* spp. woodlands showed the highest RxN values on the extreme sector of the gradient: here soil water regime - from very moist up to flooded soils - was well supported by the correlation between RxN with soil moisture-F indicator (*coefficient* = 0.8 in Table 3b).

These ordered correspondences confirm that RxN is indeed an index of humus overall functionality as the result of the total interactions between humus and vegetation (De Nicola & al. 2013).

Along the R/N- nitrogen availability gradient the evergreen forest types were well discriminated. The boreal *Picea abies* relevés are separated from the *Quercus ilex/Q.suber* mediterranean forest due to the differences in nitrogen availability that in Amphi humus is higher than in Mor where low temperatures slow down the litter decomposition, and consequently N release (Turner & al. 2010). R/N resulted in fact correlated with temperature-T indicator (*coefficient* = 0.8) and with Mediterranean Index-MI (0.6) (Table 3b). Higher temperatures in the Mediterranean Amphi forests help the process of nitrogen plant availability (R/N) where Ntot tends to accumulate in OF+OH+A horizons.

In Italian woodlands ordination the correspondences found between the four vegetation classes and the four main humus forms confirmed that vegetation and humus are both dependent by climate that influences the water and nutrient cycles. These influences are well evident by comparing the ordinations of Italy and Belgium forests. In Belgium there aren't the Amphi Mediterranean forms and boreal coniferous woodlands of *Vaccinio-Picetea*; therefore, RxN range for Mor and for Moder forms was lower than in Italy. Climate of Belgium is typically middle-European, characterized by the dominance of mesophile deciduous vegetation on moist eutrophic soils and Mull humus forms with fast organic matter turn-over (Wilson & al. 2001; Godefroid & al. 2005).

In the Italian woodlands we found that, among the humus forms, the maximum distance was between Amphi and Mull (Table 6) distributed in fact on the opposite limit of the RxN gradient in Fig. 3. This is due to the Mediterraneity acting as a powerful constrain for soil and vegetation diversity *versus* the greater homogeneity of Central-European forests (Pignatti 1998).

On the basis of the results we can assume that humus is a fundamental component of soil- vegetation interaction, supporting the study of Ponge (2013) on this topic.

Conclusion

The spatial pattern of the relevés in the ordination scattergram given by the two indices of Rogister and the high correlation between these two indices and the data collected on humus in the field, confirm that the information content in the species combinations of plant communities can be summarized by ecological indicators, so the complexity related to a great number of species, that produces an ecological space of many dimensions, can be reduced efficiently to few dimensions. We have shown that the reduction of the space defined by 847 species and 789 relevés into a space defined by only two indices (RO), that actually are respectively different combination of only two indicators, i.e. R (Reaction) and N (Nutrients), does not limit the information regarding the mutual position of vegetation types in the ecological multidimensional space. The predictivity of both EIV and RO is statistically significant, however RO show to be even more predictive than EIV (Eλ for RO=0.816 for EIV=0.576).

We can conclude that our question "Can ecoindicators be a tool to reduce and understand complexity of plant communities?" can have a YES answer providing a good support to the Pignatti's (1996; 2003) views.

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References

Abbate, G. 1990: Le foreste della Riserva MAB "Collemeluccio-Montedimezzo" (Molise - Italia meridionale). – Doc. Phytosociol. **12:** 289-304.

Aerts, R. 1997: Climate, leaf litter chemistry and leaf litter decomposition in terrestrial ecosystems: a triangular relationship. – Oikos **79:** 439-449.

Aertsen, W., Kint, V., De Vos, B., Deckers, J., van Orshoven, J. & Muys, B. 2012: Predicting forest site productivity in temperate lowland from forest floor, soil and litterfall characteristics using boosted regression trees. – Pl. Soil **354(1-2):** 157-172. https://doi.org/10.1007/s11104-011-1052-z

Anas, M., Liao, F., Verma, K. K., Sarwar, M., Mahmood, A., Chen, Z., Li, Q., Zeng, X., Liu, Y. & Li, Y. 2020: Fate of nitrogen in agriculture and environment: agronomic, eco-physiological and molecular approaches to improve nitrogen use efficiency. – Biol. Res. **53**, 47. https://doi.org/10.1186/s40659-020-00312-4

Andreetta, A., Macci, C., Giansoldati, V., Masciandaro, G. & Carnicelli, S. 2013: Microbial activity and organic matter composition in Mediterranean humus forms. – Geoderma **209-210:** 198-208.

Austin, M. P. & Gaywood, M. J. 1994: Current problems of environmental gradients and species response curves in relation to continuum theory. – J. Veg. Sci. **5:** 473-482.

Bernier, N. & Ponge, J. F. 1994: Humus form dynamics during the sylvogenetic cycle in a mountain spruce forest. – Soil Biol. Biochem. **26:** 183-220.

Biondi, E., Casavecchia, S., & Gigante, D. 2003: Contribution to the syntaxonomic knowledge of the *Quercus ilex* L. woods of the Central European Mediterranean Basin. – Fitosociologia **40(1):** 129-156.

Böhling, N., Greuter, W. & Raus, T. 2002: Zeigerwerte der Gefässpflanzen der Südaegeis (Griechenland). Indicator values of the vascular plants in Southern Aegean (Greece). – Braun-Blanquetia **32:** 1-106.

Bonanomi, G., Incerti, G., Antignani, V., Capodilupo, M. & Mazzoleni, S. 2010: Decomposition and nutrient dynamics in mixed litter of Mediterranean species. – Pl. Soil **331:** 481-496.

Bonifacio, E., Falsone, G. & Petrillo, M. 2011: Humus forms, organic matter stocks and carbon fractions in forest soils of north-western Italy. – Biol. Fertil. Soils **47:** 555-566.

Borhidi, A. 1995: Social behaviour types, the naturalness and relative ecological indicator values of the higher plants in the Hungarian flora. – Acta Bot. Hungar. **39:** 97-181.

Boublik, K., Petrik, P., Sadlo, J., Hedl, R., Willner, W., Cerny, T., & Kolbek, J. 2007: Calcicolous beech forests and related vegetation in the Czech Republic: a comparison of formalized classifications. – Preslia **79(2):** 141-161.

Braun-Blanquet, J. & Jenny, H. 1926: Vegetations-Entwicklung und Bodenbildung in der Alpinen Stufe der Zentralalpen. – Schweiz. Naturforsch. Gesell. Bd. LXIII- Abh. **2**.

Briones, M. J. I., Garnett, M. H. & Inseon, P. 2010: Soil biology and warming play a key role in the release of 'old C' from organic soils. – Soil Biol. Biochem. **42:** 960-967.

Callesen, I., Raulund-Rasmussen, K., Westman, C. J. & Tau-Strand, L. 2007: Nitrogen poolsand C: N ratios in well-drained nordic forest soils related to climate and soil texture. – Boreal Environ. Res. **12(6):** 681-692.

Chytrý, M., Hennekens, S. M., Jiménez Alfaro, B., Knollová, I., Dengler, J., Jansen, F. & Ambarlı, D. 2016: European Vegetation Archive (EVA): an integrated database of European vegetation plots. – Appl. Veg. Sci. **19(1):** 173-180.

Cortez, J. 1998: Field decomposition of leaf litters: relationships between decomposition rates and soil moisture, soil temperature and earthworm activity. – Soil Biol. Biochem. **30:** 783-793.

De Nicola, C., Testi, A., Crosti, R. & Fanelli, G. 2015: Can the flora-based humus functionality index (RxN) predict humus forms in Mediterranean plant communities? A case study in Castelporziano State Natural Reserve. – Rend. Fis. Accad. Lincei https://doi.org/10.1007/s12210-014-0375-0.

—, —, Zanella, A. & Pignatti, S. 2018: Factors influence on humus forming in Castelporziano Reserve, Mediterranean forest ecosystem. – Applied Soil Ecology **123:** 601-616 https://doi.org/10.1016/j.apsoil.2017.10.002.

—, Zanella, A., Testi, A., Fanelli, G. & Pignatti, S. 2014: Humus forms in a Mediterranean area (Castelporziano Reserve, Rome, Italy): classification, functioning and organic carbon storage. – Geoderma **235-236:** 90-99. http://dx.doi.org/10.1016/j.geoderma.2014.06.033 0016-7061/

—, Testi, A., Crosti, R., Zanella, A., D'Angeli, D., Fanelli, G. & Pignatti, S. 2013: Humus e vegetazione come indicatori della qualità dell'habitat nella Tenuta di Castelporziano. – Accad. Sci. Roma. **46:** 27-68.

Diekmann, M. & Dupré, C. 1997: Acidification and eutrophication of deciduous forests in northwestern Germany demonstrated by indicator species analysis. – J. Veg. Sci. **8:** 855-864.

Ellenberg, H. 1963: Vegetation Mitteleuropas mit den Alpen. – Einführung in die Phytologie IV, **2.** Stuttgart.

— 1974-1979: Zeigerwerte der Gefäßpflanzen Mitteleuropas (Indicator values of vascular plants in Central Europe). – Scripta Geobot **9** (2° eds, 1979). Göttingen.

Fanelli, G., Pignatti, S. & Testi, A. 2007: An application case of ecological indicator values (Zeigerwerte) calculated with a simple algorithmic approach. – Pl. Biosyst. **141:** 15-21. https://doi.org/10.1080/11263500601153685

Feoli, E. & Ganis, P. 2019: The Use of the Evenness of Eigenvalues of Similarity Matrices to Test for Predictivity of Ecosystem Classifications. – Mathematics **7:** 245. https://doi.org/10.3390/math7030245.

— & Zuccarello, V. 1986: Ordination based on classification: yet another solution. – Abstr. Bot. **1/1:** 203-219.

Godefroid, S., Massant, W. & Koedam, N. 2005: Variation in the herb species response and the humus quality across a 200-year chronosequence of beech and oak plantations in Belgium. – Ecography **28:** 223-235.

Hennekens, S. M. & Schaminée, J. H. J. 2001: *TURBOVEG,* a comprehensive data base management system for vegetation data. – J. Veg. Sci. **12:** 589-591.

Hill, M. O., Roy, D. B., Owen Mountford, J. & Bunce, R.G.H. 2000: Extending Ellenberg's indicator values to a new area: an algorithmic approach. – J. Appl Ecology **37:** 315. https://doi.org/10.1046/j.1365-2664.2000.

Jabiol, B., Zanella, A., Ponge, J. F., Sartori, G., Englisch, M., Delft van, B., Waal de, R. & Le Bayon, R. C. 2013: A proposal for including humus forms in the World Reference Base for Soil Resources (WRB-FAO). – Geoderma **192:** 286-294.

Johnson, R. K., Wiederholm, T. & Rosenberg, D. M. 1992: Freshwater biomonitoring using individual organisms, populations and species assemblages of benthic macroinvertebrates. – Pp. 41-104 in: Rosenberg, D. M. & Resh, V. H. (eds), Freshwater biomonitoring and benthic macroinvertebrates. – New York.

Klinka, K., Wang, Q. & Carter, R. E. 1990: Relationships among humus forms, forest floor nutrient properties, and understory vegetation. – For. Sci. **36:** 564-581.

Mantel, N. 1967: The detection of disease clustering and a generalized regression approach. – Cancer Res. **27:** 209-220.

Mucina, L., Bültmann, H., Dierßen, K., Theurillat, J. P., Raus, T., Čarni, A. & Chytrý, M. 2016: Vegetation of Europe: hierarchical floristic classification system of vascular plant, bryophyte, lichen, and algal communities. – Appl. Veg. Sci. **19:** 3-264.

Muys, B. & Granval, Ph. 1997: Earthworms as bio-indicators of forest site quality. – Soil Biol. Biochem. **29(3-4):** 323-328.

Orlóci, L. 1978: Multivariate Analysis in Vegetation Research, 2nd ed. – Junk.

Pausas, J. C. & Feoli, E. 1996: Environment-vegetation relationships in the understorey of Pyrenean Pinus sylvestris forest. II A classification approach. – Coenoses **11:** 45-51.

Pignatti, S. 1988: Phytogeography and chorology – Definitions and problems. – Ann. Bot. **46:** 7-23.
— 1994a: Ecologia del paesaggio. – Torino.
— 1994b: Ecologia Vegetale. – Torino.
— 1995: A complex approach in phytosociology. – Ann. Bot. (Roma) **52:** 65-80.
— 1996: Some notes on complexity in vegetation. – J. Veg. Sci. **7:** 7-12.
— 1998: Boschi d'Italia. – Torino.
— 2003: La vegetazione come sistema auto-organizzante. – Acc. Naz. Lincei, Contr. Centro Linceo Interdisc. B. Segre **106:** 89-112.
—, Menegoni, P. & Pietrosanti, S. 2005: Bioindicazione attraverso le piante vascolari. Valori di indicazione second Ellenberg (Zeigerwerte) per le specie della flora d'Italia. – Braun-Blanquetia **39:** 97 pp. (Camerino).
—, Bianco, P. M., Fanelli, G., Paglia, S., Pietrosanti, S. & Tescarollo, P. 2001a: Le piante come indicatori ambientali. Manuale tecnico- scientifico. – Aosta.
—, —, —, Guarino, R., Petersen, J. & Tescarollo, 2001b: Reliability and effectiveness of Ellenberg's indices in cheking flora and vegetation changes induced by climatic variations. – Pp. 281-304 in: Walter, J. R., Burga, C. A. & Edwards, P. J. (eds), Fingerprints of climate changes: adapted behaviour and shifting species ranges. – New York and London.
Pillar, V. D. P. & Orlóci, L. 1996: On randomization testing in vegetation science: Multifactor comparisons of relevé groups. – J. Veg. Sci. **7:** 585-592.
Ponge, J. F. 2003: Humus forms in terrestrial ecosystems: a framework to biodiversity. – Soil Biol. Biochem. **35:** 935-945.
— 2013: Plant-soil feedbacks mediated by humus forms: A review. – Soil Biol. Biochem. **57:** 1048-1060.
Roe, G. H. 2005: Orographic precipitation. – Ann. Rev. Earth Planet. Sci. **33:** 645-671.
Rogister, J. 1978: De ekologische mR-en mN-waarden van dekruidlaag en de humuskwaliteit van bosplantengezelschappen. – Bossen.
Rovelli, E. 2008: L'abete bianco (*Abies alba* Mill.) nell'ecosistema appenninico. – Biodiv. Italiana **2:** 10-17.
Schaffers, A. P. & Sykora, K. V. 2000: Reliability of Ellenberg indicator values for moisture, nutrients and soil reaction: a comparison with field measurements. – J. Veg. Sci. **11:** 225-244.
Soil Survey Staff 1975: Soil Taxonomy. A Basic System of Soil Classification for Making and Interpreting Soil Surveys. – Washington D.C.
— 1993: Soil Survey Manual. – Washington D.C.
— 1998: Keys to Soil Taxonomy, 8th ed. – Washington D.C.
Testi, A., Cara, E. & Fanelli, G. 2006: An example of realization of Gis ecological maps derived from Ellenberg indicator values in the Biological Reserve of Doñana National Park (Spain). – Rend. Fis. Acc. Lincei **9(18):** 1-17.
—, Bisceglie, S., Guidotti, S. & Fanelli, G. 2008-2009: Detecting river environmental quality through plant and macroinvertebrate bioindicators in the Aniene River (Central Italy). – Aquatic Ecol. **43:** 477-486. https://doi.org/10.1046/10.1007/s10452-008-9205-8.
—, Fanelli, G., Crosti, R., Castigliani, V. & D'Angeli, D. 2012: Characterizing river habitat quality using plant and animal bioindicators: a case study of Tirino River (Abruzzo Region, Central Italy). – Ecological Indicators **20:** 24-33. https://doi.org/10.1046/10.1016/j.ecolind.2012.01.027.
Turner, B. F., White, A. F. & Brantley, S. L. 2010: Effects of temperature on silicate weathering: solute fluxes and chemical weathering in a temperate rain forest watershed, Jamieson Creek, British Columbia. – Chem. Geol. **269:** 62-78.
Wilson, S. McG., Pyatt, D. G., Malcolm, D. C. & Connolly, T. 2001: The use of ground vegetation and humus type as indicators of soil nutrient regime for an ecological site classification of British forests. – Forest Ecol. Managem. **140(2-3):**101-116.

Zanella, A., Jabiol, B., Ponge, J. F., Sartori, G., De Waal, R., Van Delft, B., Graefe, U., Cools, N., Katzensteiner, K., Hager, H., Englisch, M., Brethes, A., Broll, G., Gobat, J. M., Brun, J.-J., Milbert, G., Kolb, E., Wolf, U., Frizzera, L., Galvan, P., Kollir, R., Baritz, R., Kemmers, R., Vacca, A., Serra, G., Banas, D., Garlato, A., Chersich, S., Klimo, E. & Langohr, R. 2011: European Humus Forms Reference Base. http://hal.archivesouvertes.fr/docs/00/56/17/95/PDF/Humus_Forms_ERB_31_01_2011.pdf.

Zarzycky, K. 1984: Indicator values of vascular plants in Poland (in polish). – Krakowia.

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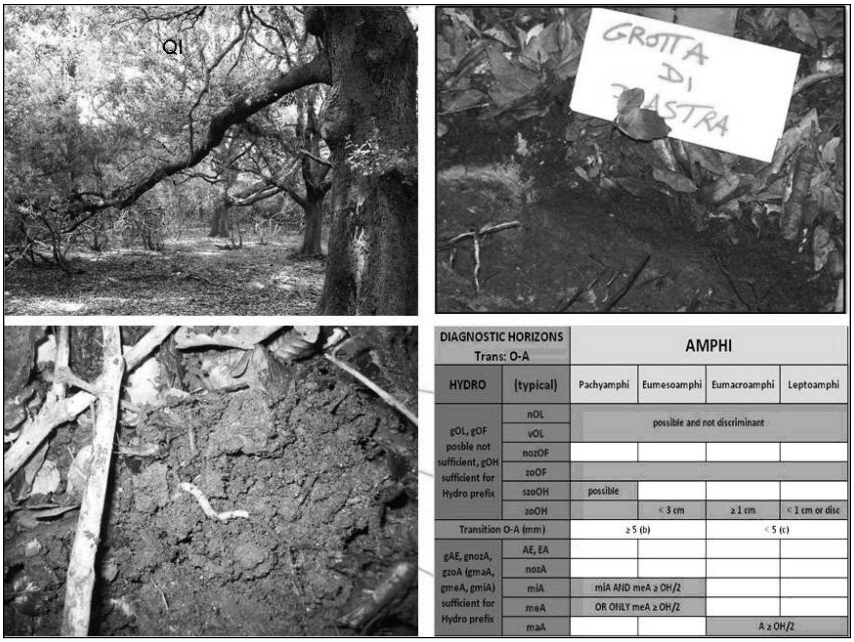
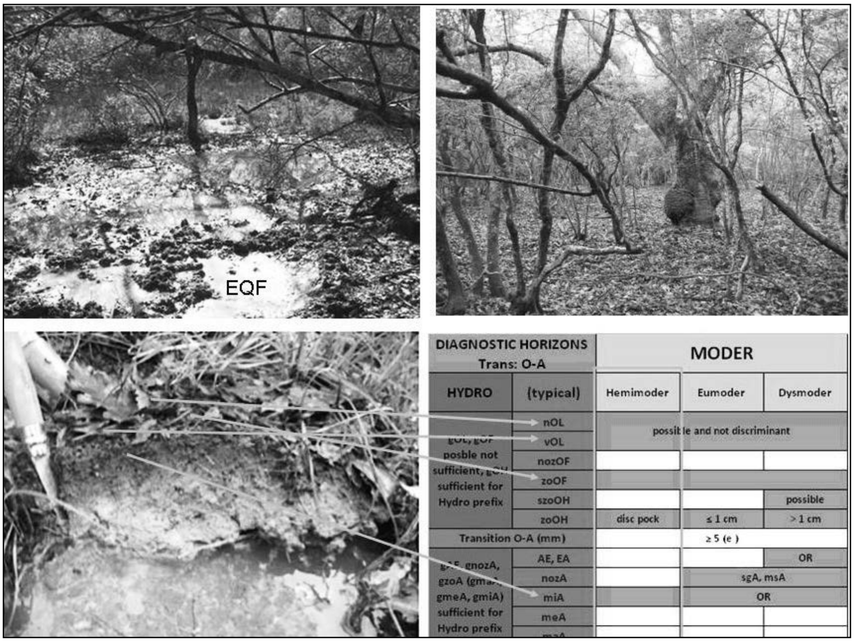
APPENDICES



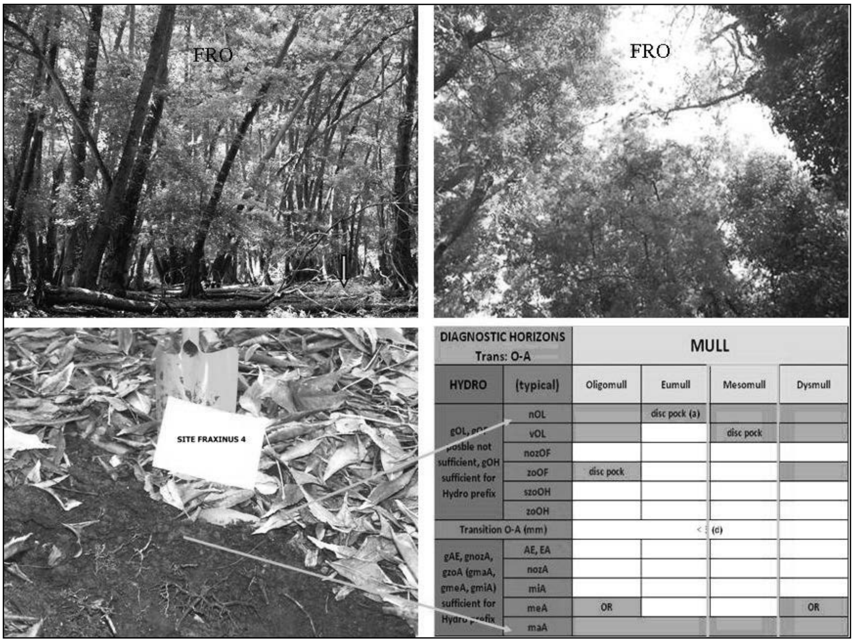
DIAGNOSTIC HORIZONS Trans: O-A		AMPHI			
HYDRO	(typical)	Pachyamphi	Eumesoamphi	Eumacroamphi	Leptoamphi
gOL, gOF posble not sufficient, gOH sufficient for Hydro prefix	nOL	possible and not discriminant			
	vOL				
	nozOF				
	zoOF				
	szoOH	possible			
	zoOH		< 3 cm	≥ 1 cm	< 1 cm or disc
Transition O-A (mm)		≥ 5 (b)		< 5 (c)	
gAE, gnozA, gzoA (gmaA, gmeA, gmiA) sufficient for Hydro prefix	AE, EA				
	nozA				
	miA	miA AND meA ≥ OH/2			
	meA	OR ONLY meA ≥ OH/2			
	maA			A ≥ OH/2	

APP. Fig. 1. *Viburno-Quercetum ilicis* (QI) on Amphi humus form (*Quercus ilex* Forest Type 2 in this article).



DIAGNOSTIC HORIZONS Trans: O-A		MODER		
HYDRO	(typical)	Hemimoder	Eumoder	Dysmoder
gOL, gOF posble not sufficient, gOH sufficient for Hydro prefix	nOL	possible and not discriminant		
	vOL			
	nozOF			
	zoOF			
	szoOH			possible
	zoOH	disc pock	≤ 1 cm	> 1 cm
Transition O-A (mm)			≥ 5 (e)	
gAE, gnozA, gzoA (gmaA, gmeA, gmiA) sufficient for Hydro prefix	AE, EA			OR
	nozA		sgA, msA	
	miA		OR	
	meA			
	maA			

APP. Fig. 2. *Echinopo siculi-Quercetum frainetto* (EQF) on Moder humus form (*Quercus cerris* Forest Type 4 in this article).



DIAGNOSTIC HORIZONS Trans: O-A		MULL			
HYDRO	(typical)	Oligomull	Eumull	Mesomull	Dysmull
gOL, gOF posble not sufficient, gOH sufficient for Hydro prefix	nOL		disc pock (a)		
	vOL			disc pock	
	nozOF				
	zoOF	disc pock			
	szoOH				
	zoOH				
Transition O-A (mm)		< 5 (d)			
gAE, gnozA, gzoA (gmaA, gmeA, gmiA) sufficient for Hydro prefix	AE, EA				
	nozA				
	miA				
	meA	OR			OR
	maA				

APP. Fig. 3. *Carici remotae-Fraxinetum oxycarpae* (FRO) on Mull humus form (Hygrophilous Forest Type 9 in this article).

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Elgene O. Box

Evaluating General Vegetation Models using Floristic Data

Abstract

Box, E.: Evaluating General Vegetation Models using Floristic Data. — Fl. Medit. 31 (Special Issue): 339-360. 2021. — ISSN: 1120-4052 printed, 2240-4538 online.

This volume invites papers that connect floras, i.e. species, with concepts of vegetation, which may or may not be based directly on species. There is a long history of attempts to relate vegetation to climatic conditions, but only a very few attempts to relate species to climate. This study demonstrates how widely available floristic data can be used to evaluate non-floristic models that describe vegetation by means of its structure and constituent plant types, using the climatic limits of those types. Climatic envelopes have been criticized strongly as based only on "empirical" relationships, and the accuracy of the first world climatic-envelope model, for 90 plant types, was only "fair". That first envelope model, however, was improved by adding better estimates of potential evapotranspiration and critical minimum temperatures, better representation of foliage types; and by increasing to 115 the number of plant types. That model, now much more accurate, still lacks a formal, global validation. This short paper demonstrates how such a worldwide validation might be done, where the necessary floristic and pheno-morphological data are available.

Key words: basic ecological plant types, climatic envelope models, field-site climates, model validation, PFORMS model.

Introduction

Few researchers have made such major contributions as has our honoree Sandro Pignatti to the study of *both* floristics (*Flora d'Italia*, Pignatti 1982) and vegetation (*I Boschi d'Italia*, Pignatti 1998). So it is especially fitting that the theme of this volume invite papers that connect floras (i.e. plant species) with vegetation types, which are often described non-floristically. Relatively few treatments have attempted to compare floristic vs structural classifications of vegetation (e.g. Werger & Sprangers 1982). This study demonstrates how widely available floristic data can be used to evaluate non-floristic models that describe vegetation by means of its structure and constituent plant types, using the climatic limits of those plant types.

A system for identifying and naming plant species has existed since the time of Linnaeus, and most parts of the world have inventoried their plant species to some extent. From these data, systems of floristic units have been derived by the rules of phytosociology (Braun-Blanquet 1964; Mueller-Dombois & Ellenberg 1974) and arranged hierarchically and named according to the rules of phytosociological nomenclature (Theurillat & al. 2020). Records of species occurrence, in the form of Braun-Blanquet relevés or other common formats, are available for many thousands of sites worldwide, as collected in the GIVD (Dengler & al. 2011) and other data bases. Floristic richness has been mapped at global scale by Barthlott & al. (1996). Floras and species, however, are regional if not local, and only a handful of the world's species extend their ranges to different continents or other large regions, especially across the Equator.

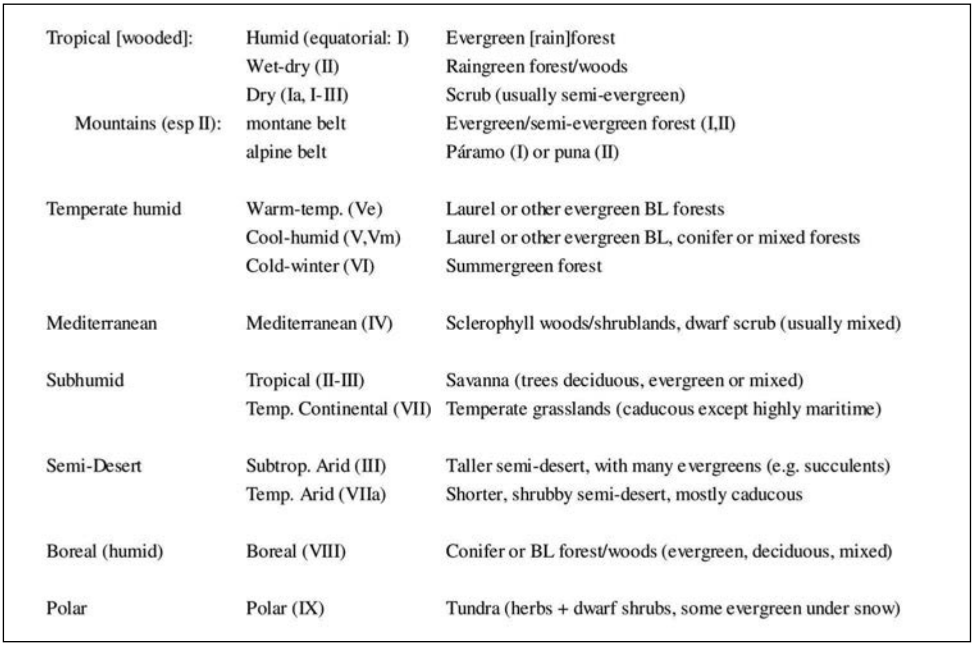
Vegetation, on the other hand, may be described by floristic units or by pheno-physiognomy, dominance types, strata, synusiae, or by main constituent plant types (Poore 1962; Whittaker 1973; Beard 1978; Barkman 1979; Werger 1988). Plant types defined entirely by structure, such as deciduous broad-leaved trees, stem-succulents or graminoids, had been called "growth forms" (*Wuchsformen*) by Drude, based on the *Hauptformen* of Humboldt (1806), the 54 types of Grisebach (1872), and his own 55 postulated forms (Drude 1896; Barkman 1988). Structural types interpreted as ecologically significant adaptations to environmental conditions were called 'life forms' (*Lebensformen*) by Warming (1895) and could be interpreted as basic ecological types, grouping taxa with similar form and ecological requirements, resulting from similar morphological responses to similar environmental conditions. A very comprehensive, global classification of plant life forms is found as Appendix A in Mueller-Dombois and Ellenberg (1974). Attempts to relate plants and plant types quantitatively to climatic conditions began in the late 1800s, focusing especially on temperature limitations. Studies in northern Europe, for example, suggested that temperate-zone deciduous trees require four months of mean temperature above 10°C in order to reproduce (Enquist 1924, 1929, 1933; Rubinstein 1924).

Vegetation types have been recognized, mapped and related, however qualitatively, to climatic conditions since the mid-1800s (e.g. Grisebach 1838, 1866, 1872; Schimper 1898; see de Laubenfels 1975). Systems of vegetation types are usually defined fairly generally, especially over large areas, and may be at least as numerous as there are or have been different researchers. The best world maps of "natural" vegetation (Schmithüsen 1976) are based on a legend with about 175 types, most defined without reference to floristics. There are many other noteworthy world-scale vegetation classifications (e.g. Rübel 1930; Schmithüsen 1968; Mueller-Dombois & Ellenberg 1974: Appendix B) or other treatments (e.g. Eyre 1968; Walter 1968, 1973; Archibold 1995).

Models of vegetation over large areas are also necessarily quite general, due to the overwhelming number of individual local species and the often subjective nature of vegetation descriptions and classifications. Some, usually smaller sets of vegetation types can be predicted over large regions with some degree of accuracy from climatic relationships (e.g. Box 1978; Emanuel & al. 1985; Prentice & al. 1992; Box 1995c) and with less accuracy from satellite data (e.g. Poulter & al. 2011; Strahler & al. 1999; Tateishi & Kajiwara 1991). But it is inherently difficult to use species to evaluate vegetation models, due to the differences in concept and classificatory rigor. This obstacle can be overcome by use of an intermediary, namely the basic ecological plant types that compose the vegetation, have functional roles in vegetation (cf Gillison 1981, 2013; Chapin 1993), and can be matched with actual species. Basic ecological types, such as summergreen broad-leaved trees or tall grasses, are generally described by pheno-physiognomy, i.e. combinations of plant architecture and seasonal foliation or other activity pattern. Over broader areas, the occurrence of such basic plant types can also be related to climatic factors (Box 1981a). Despite the long history of attempts to relate vegetation types to climate, there have been relatively few attempts to relate species to climate (e.g. Box & al. 1993; Iverson & al. 1999).

The purpose of this paper is to demonstrate how available floristic data can be used, even over very large areas, to evaluate predictive, non-floristic models of vegetation based on concepts of basic ecological plant types. As a demonstration, this is done herein only at a few geographically scattered sites, where the necessary data were available to the author. The procedure is simple: sites were selected within the world's main bioclimatic macro-regions (see Table 1; Walter 1970) based on data availability and balanced geographic representation of the world's main climatic regions. Then, local species are matched to the different plant forms predicted by the model, and results are shown for five sites ranging from Northern high latitude to tropical mountains to southern Hemisphere woodland.

Table 1. Minimum Location Needs for Evaluating World Vegetation Models.
This list totals 15 major climatic situations that should be represented in even the most minimal attempts to evaluate global vegetation models. The Roman numerals indicate corresponding Walter climate types (Walter 1970). A more detailed list of world bioclimatic types and regions, based on Walter, was given in Box (2016).



Tropical [wooded]:	Humid (equatorial: I)	Evergreen [rain]forest
	Wet-dry (II)	Raingreen forest/woods
	Dry (Ia, I-III)	Scrub (usually semi-evergreen)
Mountains (esp II):	montane belt	Evergreen/semi-evergreen forest (I,II)
	alpine belt	Páramo (I) or puna (II)
Temperate humid	Warm-temp. (Ve)	Laurel or other evergreen BL forests
	Cool-humid (V,Vm)	Laurel or other evergreen BL, conifer or mixed forests
	Cold-winter (VI)	Summergreen forest
Mediterranean	Mediterranean (IV)	Sclerophyll woods/shrublands, dwarf scrub (usually mixed)
Subhumid	Tropical (II-III)	Savanna (trees deciduous, evergreen or mixed)
	Temp. Continental (VII)	Temperate grasslands (caducous except highly maritime)
Semi-Desert	Subtrop. Arid (III)	Taller semi-desert, with many evergreens (e.g. succulents)
	Temp. Arid (VIIa)	Shorter, shrubby semi-desert, mostly caducous
Boreal (humid)	Boreal (VIII)	Conifer or BL forest/woods (evergreen, deciduous, mixed)
Polar	Polar (IX)	Tundra (herbs + dwarf shrubs, some evergreen under snow)

Background

In order to explore the advantages and environmental relationships of particular plant forms and adaptations, plant types must be described by identifiable form characters with hypothesized functional significance. Literature (e.g. Schimper 1898; Rübel 1930; Schmithüsen 1968; Walter 1968, 1973) and experience both suggest that the most important form characters should involve aspects of the:

- permanence of above-ground, light-capturing plant structure (e.g. woody versus non-woody);
- overall size of plants, especially relative to other plants;
- architecture of plant structure, including attributes of leaves or other photosynthetic surfaces; and
- seasonal activity of the plants, which may be much more complex than just evergreenness or deciduousness.

These characters are paramount since plant metabolism, transpiration and other processes operate largely through the size, green surface area, and surface consistency of plants, and their seasonal variations. The apparent main characters needed for identifying basic plant types have been summarized, *inter alia*, by Box (1995a) and incorporated in the original concept of "plant functional types" (e.g. Smith & al. 1993; Box 1996).

The distributions of particular plant species and more general ecological types are determined by adaptations to environmental factors, especially climate. As a result, basic plant types should be described largely by pheno-morphology (or pheno-physiognomy), involving the characters identified above. Relationships between plant form, climate, and plant function have been summarized by many authors (and contradicted by others). The first systematic attempt to relate general vegetation types to climate, at global scale, was probably that of Rübel (1930), which postulated upper and lower limits relative to the most commonly available measures of temperature and water availability; a more unified but otherwise similar approach was the life zones of Holdridge (1947). This limitation approach was eventually applied by means of hypothesized climatic envelopes to vegetation types (Box 1978) and then expanded to predict the worldwide occurrence of structurally defined plant growth forms (Box 1981a). This initial growth-form model involved:

1) a set of 90 plant forms, each defined by pheno-morphologic characters and together representing the main growth forms in world vegetation;
2) a model of the effective climate, using eight variables for which data can be obtained or estimated reliably worldwide; and
3) a climatic envelope for each plant type, for predicting where it could occur, based on climatic limits.

The types for the world model were generated by a sort of "geographic regression" that postulated the growth forms needed to represent world vegetation and then filled in the gaps iteratively. The procedure started with basic structural types (trees, shrubs, graminoids, etc.) and added leaf types, seasonality patterns and leaf consistencies in known species, with examples of each type postulated (see Appendix A in Box 1981a). Each plant form is defined by six form characters, which means that this information must be available for species in order to match them with their corresponding form (or forms). For each plant type, a hypothesized climatic envelope was constructed, based on apparent theoretical and empirical climatic limits to the geographic ranges of prototype species. This combined model of plant types, effective climate, and climatic limits was then used to predict the possible occurrence of the plant types at climatic sites worldwide (Box 1981a). The original purpose of that model was to demonstrate the great degree to which the geographic occurrences of basic ecological plant types (as defined above) are delimited by climatic conditions. Beyond that, though, the model also proved to be a useful means of clarifying climatic (and other environmental) limits and limiting factors, and for testing related hypotheses.

Ever since their introduction, climatic envelopes have been criticized strongly as being "empirical" and not sufficiently theoretical for coupling with the global climate models (GCMs) being developed (cf Levis & al. 2000). The criticism was largely justified, and the predictive accuracy of that first world climatic-envelope model for plant types was rightly judged as only "fair" by Mucina (2018). That first envelope model, however, was improved greatly by adding:

1) a more globally reliable estimate of potential evapotranspiration (Box 1986, 1987);
2) absolute minimum temperature as an envelope variable (Box 1995b, c; cf Sakai 1971); and
3) shade-tolerant laurophylls as a basic leaf type (Box 1997; cf Box & Fujiwara 2005, 2013).

Accuracy was also improved through re-calibration of limiting values based on field checks, however brief, in about 50 countries on all continents except Antarctica. As a result, the model is now fairly accurate, although it still lacks a new, global validation.

Each envelope (plant form) is a separate model, which was calibrated by another sort of "regression", which predicts plant-form spectra at sites and checks them against known occurrences of taxa that correspond to the particular plant forms. Calibration involved adjusting envelope limits, iteratively and worldwide, to include known occurrences and exclude errors. The whole set of plant forms was also made more geographically balanced by including more understorey forms in all regions. The combined model, now known as PFORMS, is constantly being modified and now includes about 115 plant forms (see list in Box & Fujiwara 2005), defined by basic structural type, relative plant size, type of leaf or other photosynthetic organ, relative leaf size, seasonality habit, and consistency of the photosynthetic surface (see table in Box 2019). This model is fairly well known, having been cited in works on plant functional types (e.g. Smith & al. 1997), world vegetation modeling (e.g. Peng 2000; Poulter & al. 2011), and shortcomings of ecological research in general (e.g. Peters 1991; Mucina 2018). The idea (Box 1984) to use basic ecological plant types in a first dynamic model of the growth and structural development of vegetation stands worldwide (cf Box 1980, 1981b) could not be pursued at the time, but this idea was adopted by subsequent global modeling efforts (Cramer & Leemans 1993; Foley 1995; Cramer 1997).

Model accuracy has not been formally quantified, since evaluation of this and other large-area models would require decades of travel, money, field experience, and data from most parts of the world. Since this is obviously not possible in the short term, the purpose of this paper is only to give some examples.

Methodology and Data

The methodology requires sites with relevés or other adequate field data and good familiarity (to the author) with local species and their pheno-morphological attributes, which permits assigning species to particular plant forms. The procedure involved the following steps:

- Construction of a world data file for climatic conditions at available field sites;
- Prediction by model PFORMS of the plant forms possible climatically at these sites;
- Identification of actual local species that correspond to the plant forms predicted;
- Identification also of species that occur but do not correspond to any plant form predicted;
- Selection of a small but geographically representative sample of these results to present herein.

This is not an attempted model validation, only a demonstration of how such model evaluations could be done with available data. The most minimal model evaluation would require well-chosen locations in at least 15 of the world's main climatic regions (Table 1; see Conclusion section).

Since climatic models automatically imply areas of some size around climate sites (or across pixels), all kinds of species occurrence data are valid, provided only that the species occur on sites that are not unusual topographically, edaphically or otherwise (e.g. wetlands). Species occurrence can thus be determined from any combination of relevés, local species lists (as from protected areas), species range maps, and targeted field observations. Assigning species to plant types, however, requires reliable knowledge of the main pheno-morphological characters of the species. This must be based on field observation by the author (with local botanists) but may also involve photos and verbal descriptions (as on the Internet) and the rare literature treatments that do describe the pheno-morphological characteristics of the species. Nevertheless, the relevés made by the author and colleagues, following the Braun-Blanquet methodology (Fujiwara 1987), plus field notes on form characters, do provide some data from many world regions and most major climatic situations (cf Table 1). These records are from 37 countries or other large regions, often with multiple local areas, and include the roughly 1400 relevés from the Eastern North American Vegetation Survey (1988-90; see Miyawaki & al. 1994); extensive fieldwork across much of East Asia (cf Fujiwara 2008; Fujiwara & Harada 2015); fieldwork in all five of the world's regions of Mediterranean-type climate; and fieldwork in tropical and subtropical areas including Kenya, Brazil, the tropical and subtropical Andes, Mexico, Kerala, Myanmar, northern Borneo, and Australia. Field data are also available from much of Europe, Georgia (Caucasus), Argentina and New Zealand, as well as the USA and Canada.

Candidate field sites for the examples herein were selected, with increased density in areas of greater topographic or climatic complexity, and numbered about 300. Each site had to have species lists and other descriptions available (on line or in printed literature), and had to have been visited and described by the author (with local colleagues) with at least one formal relevé. Climatic data were then gathered (from the author's data-base) from stations at or near these field sites. All climate data are from before 1980, in order to minimize effects of differential global warming. Since most field sites were not at meteorological stations, their climatic profiles had to be estimated by triangulation from nearby sites coupled with projection of mostly lowland data to the elevations of the field inventories. This was done by program POLATE, described briefly in Box (2019), using a value of 5.6ºC/1000m for the terrestrial lapse rate over terrain (as opposed to 6.4ºC/km in the free atmosphere).

Absolute minimum temperature is a much-overlooked factor (Sakai & Larcher 1987) and is not recorded everywhere (and often for only a few years even where it is recorded). It is also not "strongly correlated" with mean temperature minima (as stated erroneously by Woodward & al. 2004) but rather has a geography of its own (Box 1995b). Absolute minimum temperature is thus estimated for all sites herein based on the difference between mean monthly minimum and absolute minimum at nearby sites where this difference is known (model TXTRAP); then the lower of the measured or estimated values is used. This procedure recognizes, for example, the much greater difference between mean minima and absolute minima in eastern North America than in East Asia at the same latitudes (see Box 1995b). The climatic moisture balance is defined as annual precipitation divided by annual potential evapotranspiration.

Prediction of plant forms at sites is done by applying the PFORMS model to the climatic data for the field sites, with results expressed as stand profiles organized by synusiae. Results consist of predicted plant-form profiles with corresponding, actually occurring corresponding species juxtaposed. Examples are shown in the next section. About 20 sites had relatively complete results, but this short paper shows detailed results for only five widely separated sites, selected to represent quite different climates on four continents and based mainly on ability to get the necessary information on species occurrence and characters quickly, while retaining geographic scattering. The first three sites selected are near meteorological stations, but the other two rely on estimation of site climatic conditions from nearby data.

The first site selected was Palermo (coastal northwestern Sicily), since its form-species matching had already been done (Box 2019). The natural vegetation around Palermo is open, semi-evergreen Mediterranean scrub with a diverse mix of sclerophyllous, deciduous and caducous forms (Guarino & Pasta 2017). Matches of plant taxa to particular plant forms were based on field notes from four visits to Palermo, supplemented by images and verbal descriptions from numerous websites, including Wikipedia. Species names and verification of native or naturalized status were based largely on the checklist of the Sicilian flora by Raimondo & al. (2010), greatly assisted by Riccardo Guarino. Palermo is representative of model results and potential accuracy at most sites studied. It is used here as an example because: 1) its species had already been determined from an earlier study; and 2) it is representative for open vegetation in a Mediterranean-type climate. It also illustrates the premise that warm, subhumid climates, such as the Mediterranean type in southern Italy, have unusually high richness in co-existing plant types (Box 2019).

Athens, in the upper piedmont of northern Georgia (southeastern USA), was selected because its species-form matchings could be done quickly (the author's home) and because it is a typical example for [warmer] temperate deciduous forest in the Northern Hemisphere. The natural vegetation is summergreen deciduous *Quercus*-*Carya* forest, with *Acer*, *Fraxinus*, *Liriodendron* and *Nyssa* (all deciduous) plus mainly summergreen understorey trees (e.g. *Cornus florida*, *Prunus serotina*), shrubs and forbs. Matches of plant taxa to particular plant forms were determined from experience with the local species, local fieldwork, and from range maps in Radford & al. (1968, for the nearby

Carolinas). Species names are from Radford & al. (1968) and Jones & Coile (1988); lichen names are from CRMS (2011) and CNALH (no date).

The other three sites were selected for geographic diversity but had to include some representation of tropical and high-latitude vegetation. For high latitude, Tromsø (near-coastal northern Norway) was selected because: 1) it is representative of interesting high-latitude maritime situations (as also in Beringia and even Tierra del Fuego); and 2) it has a manageable number of species that could be understood quickly. Its natural vegetation is low birch woods (Dierßen 1996), as found also in some other maritime boreal areas (Walter 1974; Krestov 2003). Matches of plant taxa to particular plant forms were determined from two short field visits, from descriptions in Lid (1985) and Nilsson (1991), and from images on the Internet. Species names are as used at the time and place; lichen names are from Frisch & al. (2020).

For the tropics two sites were selected, one in equatorial high mountains and the other in a tropical wet-dry lowland. The mountain site is in the inner-tropical but seasonal alpine belt at Piedras Blancas (4150 m), in the Venezuelan Andes above Mérida. The actual vegetation, called páramo, is an open scrubland dominated by *frailejones*, i.e. *Espeletia* tuft treelets (caulirosettes) of up to 2 m. This is a relatively well studied site (e.g. Cuatrecasas 1968; Baruch 1984; Calero & Baruch 1986; Luteyn 1999; Marquez & al. 2004, 2006; Rada & al. 2019). The dominant vegetation was described by Baruch (1984) as involving three vegetation strata: an arborescent layer dominated by *Espeletia* spp. and *Hypericum*; a shrub-herb layer involving especially *Senecio*, *Castilleja*, other forbs, graminoids and seedlings; and a herb layer with acaulescent rosettes, cushions (both woody and herbaceous), mosses and lichens. This site is included here as an example because: 1) it is quite different from most other parts of the world; 2) its model results are representative of the world's few tropical alpine areas (e.g. Andine puna and alpine East Africa); and 3) its species are few enough that they could be determined quickly. Matches of plant taxa to particular plant forms were determined from information available on the Internet (especially from Luteyn, no date) and from two páramo visits, the latter with field assistance by Alejandro Velázquez. Species names are as used at the time and place; lichen names are from Pérez (1987), Sipman (2002) and other references therein.

The other tropical site is Forty Mile Scrub, a semi-evergreen low-woodland site in northern Queensland, Australia. Data for its highly seasonal wet-dry climate were extrapolated (by program POLATE) from Mt. Surprise, where the annual precipitation is about 800mm and absolute minimum temperature was estimated as 1.6ºC by TXTRAP. Based on those data and its somewhat higher elevation, the [infrequent] absolute minimum temperature at Forty Mile Scrub was estimated as slightly below freezing: -0.2ºC. The actual vegetation is a variably open, semi-evergreen woodland dominated by a mix of raingreen and sclerophyll trees and arborescents; it was called "dry rainforest" by Fensham (1996). The site was visited and described in 1990 along with Andy Gillison, who provided many of the species identifications and much ecological insight. It has since become a national park and is relatively well studied (e.g. Westoby 1988; Bowman and Prior 2005, Dept Envt. Sci. [no date], Prior & al. 2003, 2004). This site is included because: 1) it represents the tropics and the Southern Hemisphere, at least somewhat; 2) it is quite different from other tropical wet-dry areas, and as such is both interesting and a challenge; and 3) its species could be determined and matched to predicted plant forms more quickly than could other tropical candidate sites. Matches of plant taxa to particular plant forms were determined (assisted greatly by Andy Gillison) from field notes, information available on the Internet (e.g. Dept. Envt. Sci., no date), and from Fensham (1996), Prior & al. (2003, 2004), and Williams & al. (1997) (cf Beadle 1981). Lichen names were from Archer & Elix (2017) and Sipman (2018).

This set of examples thus has some degree of global-scale representation among its five sites. The site climates were estimated as described above, by triangulation (POLATE) for the páramo and Queensland sites. Although climatic measurements may actually be available for some sites, they would be short-term and probably for later years with less stable climatic conditions. Matches of plant taxa to particular plant forms are based on the six plant characters that define the particular forms. This is necessarily an expert system, since only the author of a global system may be able to match plant forms to species consistently. Evaluation looks at the number of plant forms predicted correctly, the number predicted wrongly (i.e. not occurring), and the number occurring but not predicted.

Results

The first example is for the mediterranean climate of Palermo, in northwestern Sicily (Table 2), where the natural vegetation is a form-diverse, open, semi-evergreen scrub. With predicted woody cover of 62% maximum, the predicted result could be interpreted as open vegetation dominated by Mediterranean-type shrubs and dwarf shrubs (sclerophyll and summergreen), with scattered smaller trees and arborescents – plus exotics such as *Eucalyptus* and cacti (*Opuntia* sp. pl.). Native or naturalized species examples are apparent for most predicted plant forms, but some species that do occur are not represented by predicted plant forms. Plant forms most likely to be predicted but not occurring locally are forms with inherently fewer species, including arborescents, leafless stemgreen forms, tuft forms (e.g. palms, *Yucca*), leaf- and stem-succulents, vines, ferns and epiphytes. Unpredicted but occurring widely (mainly on special microsites) are pines (*Pinus*) plus species that are hard to classify, such as the tall, tussocky cane grass *Ampelodesmus mauritanicus* and the forb *Eryngium campestre*, which though sclerophyllous could also be considered raingreen, since it does generally dry out rather completely in late summer.

Predicted plant forms and corresponding species are shown in Table 3 for Athens (Georgia, USA), where the potential natural vegetation is summergreen deciduous oak-hickory (*Quercus*-*Carya*) forest. Several evergreen plant forms are predicted to be at or near their northern range boundaries here, limited by extreme winter cold. Athens is beyond the natural range of lauro-sclerophyll *Magnolia grandiflora* and quasi-sclerophyll *Quercus virginiana*, but these evergreen trees do survive where planted (e.g. on campus or near old houses); *Magnolia grandiflora* also survives as escapes into nearby woods. With predicted woody cover of 75% maximum, the predicted result would be interpreted as summergreen forest, dominated (plus signs) by tree species from common summergreen tree genera such as *Quercus*, *Acer*, *Fraxinus* and *Carya*, along with typical, mainly summergreen understorey shrubs, forbs, etc. Among the lichens, *Xanthoparmelia* occurs on rocks, *Cladina* on soil, *Rimelia* on trees or rocks, and *Canoparmelia* on pines (CRMS 2011).

For Tromsø (near-coastal northern Norway), predicted plant forms and corresponding

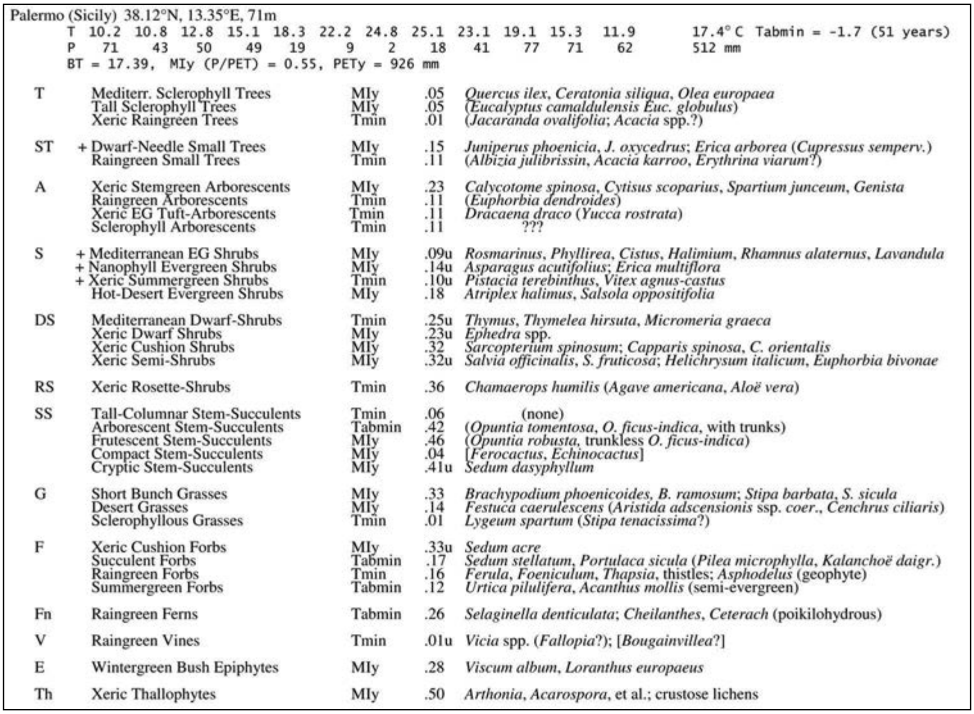
Table 2. Predicted PFORMS Model Results for Palermo.

Palermo is in coastal northwestern Sicily, where the climate is Mediterranean and the natural vegetation is a form-diverse open scrub involving both evergreen (mostly sclerophyllous) and caducous forms. Mean temperature (T) and average precipitation (P) for each month are shown across the top, followed by the annual values. The climatic variables in the PFORMS envelope model include monthly extreme values of temperature (Tmax, Tmin) and precipitation (Pmin, Pmtmax) plus annual biotemperature (BT), the absolute minimum temperature (Tabmin, i.e. the lowest ever measured, in this case over 51 years), and an annual moisture index (MIy, = P/PET, where PETy is the estimated annual potential evapotranspiration) (see main text, as well as Box 1981a, 1987, 2019).

The plant forms (EG = evergreen) predicted for Palermo are listed by their structural type: T = trees, ST = small trees, A = arborescents, S = shrubs, DS = dwarf shrubs (including cushions and semi-shrubs), RS = rosette-shrubs, SS = stem-succulents, G = graminoids, F = forbs, Fn = ferns, V = vines, E = epiphytes, Th = thallophytes (i.e. cryptogams). The closest limiting factor in the envelope design is shown in the third column (e.g. MIy, for moisture index), followed by the relative proximity of the form to that closest envelope limit (0-1 scale, u = upper value limiting).

The right-most column shows plant taxa at Palermo that correspond to the predicted plant forms. Non-native but perhaps well naturalized taxa are shown in parentheses; probably not naturalized but widely planted ornamental taxa (including some taxa from the famous local botanical garden) are shown in brackets. Question marks indicate missing information or, for particular taxa, unknown occurrence or naturalization status. With predicted woody cover of 62% maximum, this result could be interpreted as open vegetation dominated (model-generated plus signs) by Mediterranean-type shrubs and dwarf shrubs (sclerophyll and summergreen), with scattered smaller trees and arborescents – plus exotics such as *Eucalyptus* and cacti (*Opuntia* spp.). Unpredicted but occurring widely (mainly on special microsites) are *Pinus* spp., plus species that are hard to classify, such as the tall, tussocky cane grass *Ampelodesmus mauritanicus* and the forb *Eryngium campestre*.

Matches of plant taxa to particular plant forms were based on field notes from four visits to Palermo, supplemented by images and verbal descriptions from numerous websites, including Wikipedia. Species names and verification of native or naturalized status were based largely on the checklist of the Sicilian flora by Raimondo & al. (2010), greatly assisted by Riccardo Guarino.



Palermo (Sicily) 38.12°N, 13.35°E, 71m

```
      T  10.2  10.8  12.8  15.1  18.3  22.2  24.8  25.1  23.1  19.1  15.3   11.9       17.4° C  Tabmin = -1.7 (51 years)
      P    71    43    50    49    19     9     2    18    41    77    71     62       512 mm
      BT = 17.39,  MIy (P/PET) = 0.55, PETy = 926 mm
```

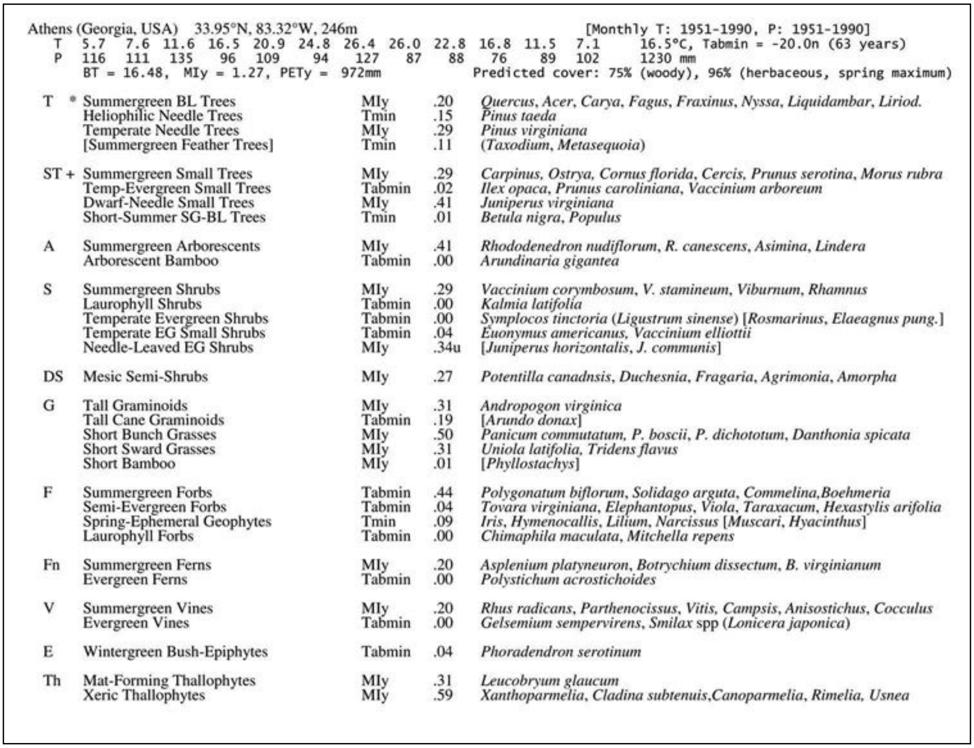
T	Mediterr. Sclerophyll Trees	MIy	.05	*Quercus ilex*, *Ceratonia siliqua*, *Olea europaea*
	Tall Sclerophyll Trees	MIy	.05	(*Eucalyptus camaldulensis Euc. globulus*)
	Xeric Raingreen Trees	Tmin	.01	(*Jacaranda ovalifolia*; *Acacia* spp.?)
ST	+ Dwarf-Needle Small Trees	MIy	.15	*Juniperus phoenicia*, *J. oxycedrus*; *Erica arborea* (*Cupressus semperv.*)
	Raingreen Small Trees	Tmin	.11	(*Albizia julibrissin*, *Acacia karroo*, *Erythrina viarum*?)
A	Xeric Stemgreen Arborescents	MIy	.23	*Calycotome spinosa*, *Cytisus scoparius*, *Spartium junceum*, *Genista*
	Raingreen Arborescents	Tmin	.11	(*Euphorbia dendroides*)
	Xeric EG Tuft-Arborescents	Tmin	.11	*Dracaena draco* (*Yucca rostrata*)
	Sclerophyll Arborescents	Tmin	.11	???
S	+ Mediterranean EG Shrubs	MIy	.09u	*Rosmarinus*, *Phyllirea*, *Cistus*, *Halimium*, *Rhamnus alaternus*, *Lavandula*
	+ Nanophyll Evergreen Shrubs	MIy	.14u	*Asparagus acutifolius*; *Erica multiflora*
	+ Xeric Summergreen Shrubs	Tmin	.10u	*Pistacia terebinthus*, *Vitex agnus-castus*
	Hot-Desert Evergreen Shrubs	MIy	.18	*Atriplex halimus*, *Salsola oppositifolia*
DS	Mediterranean Dwarf-Shrubs	Tmin	.25u	*Thymus*, *Thymelea hirsuta*, *Micromeria graeca*
	Xeric Dwarf Shrubs	MIy	.23u	*Ephedra* spp.
	Xeric Cushion Shrubs	MIy	.32	*Sarcopterium spinosum*; *Capparis spinosa*, *C. orientalis*
	Xeric Semi-Shrubs	MIy	.32u	*Salvia officinalis*, *S. fruticosa*; *Helichrysum italicum*, *Euphorbia bivonae*
RS	Xeric Rosette-Shrubs	Tmin	.36	*Chamaerops humilis* (*Agave americana*, *Aloë vera*)
SS	Tall-Columnar Stem-Succulents	Tmin	.06	(none)
	Arborescent Stem-Succulents	Tabmin	.42	(*Opuntia tomentosa*, *O. ficus-indica*, with trunks)
	Frutescent Stem-Succulents	MIy	.46	(*Opuntia robusta*, trunkless *O. ficus-indica*)
	Compact Stem-Succulents	MIy	.04	[*Ferocactus*, *Echinocactus*]
	Cryptic Stem-Succulents	MIy	.41u	*Sedum dasyphyllum*
G	Short Bunch Grasses	MIy	.33	*Brachypodium phoenicoides*, *B. ramosum*; *Stipa barbata*, *S. sicula*
	Desert Grasses	MIy	.14	*Festuca caerulescens* (*Aristida adscensionis* ssp. *coer.*, *Cenchrus ciliaris*)
	Sclerophyllous Grasses	Tmin	.01	*Lygeum spartum* (*Stipa tenacissima*?)
F	Xeric Cushion Forbs	MIy	.33u	*Sedum acre*
	Succulent Forbs	Tabmin	.17	*Sedum stellatum*, *Portulaca sicula* (*Pilea microphylla*, *Kalanchoë daigr.*)
	Raingreen Forbs	Tmin	.16	*Ferula*, *Foeniculum*, *Thapsia*, thistles; *Asphodelus* (geophyte)
	Summergreen Forbs	Tabmin	.12	*Urtica pilulifera*, *Acanthus mollis* (semi-evergreen)
Fn	Raingreen Ferns	Tabmin	.26	*Selaginella denticulata*; *Cheilanthes*, *Ceterach* (poikilohydrous)
V	Raingreen Vines	Tmin	.01u	*Vicia* spp. (*Fallopia*?); [*Bougainvillea*?]
E	Wintergreen Bush Epiphytes	MIy	.28	*Viscum album*, *Loranthus europaeus*
Th	Xeric Thallophytes	MIy	.50	*Arthonia*, *Acarospora*, et al.; crustose lichens

Table 3. Predicted PFORMS Model Results for Athens (Georgia, USA)

Athens is in the upper piedmont of northeastern Georgia (southeastern USA), where the climate is typical humid-temperate and the natural vegetation is summergreen deciduous forest (see Delcourt & Delcourt 2000; cf Miyawaki & al. 1994). The table, format, methodology, and abbreviations are as explained in Table 2. At left are the plant forms predicted for Athens, listed by plant structural type. One topo-specific form (wetlands) is shown in brackets. The closest limiting factor is shown in the third column (e.g. Tabmin, for absolute minimum temperature), followed by the relative proximity of that form to its closest envelope limit (u = upper value limiting).

The right-hand column shows plant taxa occurring in the Athens area that correspond to the predicted plant forms. Non-native but perhaps well naturalized taxa are shown in parentheses; probably not naturalized but widely planted ornamental taxa are shown in brackets. With predicted woody cover of 75% maximum, this result would be interpreted as forest, dominated (plus signs) by tree species from common summergreen tree genera such as *Quercus*, *Acer*, *Fraxinus* and *Carya*, along with typical, mainly summergreen understorey shrubs, forbs, etc. Not predicted but occurring in slightly less cold urban areas are some evergreens such as *Magnolia grandiflora* and *Quercus virginiana*, which were planted or escaped.

Matches of plant taxa to particular plant forms were based on relevés and other experience with the local flora. Species names, verbal plant descriptions, and verification of native or naturalized status were from Radford & al. (1968) for the nearby Carolinas and from Jones & Coile (1988) for Georgia. Among the lichens, *Xanthoparmelia* occurs on rocks, *Cladina* on soil, *Rimelia* on trees or rocks, and *Canoparmelia* on pines. Lichen names are from CRMS (2011) and CNALH (no date).



```
Athens (Georgia, USA)   33.95°N, 83.32°W, 246m                    [Monthly T: 1951-1990, P: 1951-1990]
   T   5.7   7.6  11.6  16.5  20.9  24.8  26.4  26.0  22.8  16.8  11.5   7.1     16.5°C, Tabmin = -20.0n (63 years)
   P   116   111   135    96   109    94   127    87    88    76    89   102     1230 mm
       BT = 16.48,  MIy = 1.27,  PETy =  972mm            Predicted cover: 75% (woody), 96% (herbaceous, spring maximum)
```

T *	Summergreen BL Trees	MIy	.20	*Quercus, Acer, Carya, Fagus, Fraxinus, Nyssa, Liquidambar, Liriod.*
	Heliophilic Needle Trees	Tmin	.15	*Pinus taeda*
	Temperate Needle Trees	MIy	.29	*Pinus virginiana*
	[Summergreen Feather Trees]	Tmin	.11	(*Taxodium, Metasequoia*)
ST +	Summergreen Small Trees	MIy	.29	*Carpinus, Ostrya, Cornus florida, Cercis, Prunus serotina, Morus rubra*
	Temp-Evergreen Small Trees	Tabmin	.02	*Ilex opaca, Prunus caroliniana, Vaccinium arboreum*
	Dwarf-Needle Small Trees	MIy	.41	*Juniperus virginiana*
	Short-Summer SG-BL Trees	Tmin	.01	*Betula nigra, Populus*
A	Summergreen Arborescents	MIy	.41	*Rhododenedron nudiflorum, R. canescens, Asimina, Lindera*
	Arborescent Bamboo	Tabmin	.00	*Arundinaria gigantea*
S	Summergreen Shrubs	MIy	.29	*Vaccinium corymbosum, V. stamineum, Viburnum, Rhamnus*
	Laurophyll Shrubs	Tabmin	.00	*Kalmia latifolia*
	Temperate Evergreen Shrubs	Tabmin	.00	*Symplocos tinctoria* (*Ligustrum sinense*) [*Rosmarinus, Elaeagnus pung.*]
	Temperate EG Small Shrubs	Tabmin	.04	*Euonymus americanus, Vaccinium elliottii*
	Needle-Leaved EG Shrubs	MIy	.34u	[*Juniperus horizontalis, J. communis*]
DS	Mesic Semi-Shrubs	MIy	.27	*Potentilla canadnsis, Duchesnia, Fragaria, Agrimonia, Amorpha*
G	Tall Graminoids	MIy	.31	*Andropogon virginica*
	Tall Cane Graminoids	Tabmin	.19	[*Arundo donax*]
	Short Bunch Grasses	MIy	.50	*Panicum commutatum, P. boscii, P. dichototum, Danthonia spicata*
	Short Sward Grasses	MIy	.31	*Uniola latifolia, Tridens flavus*
	Short Bamboo	MIy	.01	[*Phyllostachys*]
F	Summergreen Forbs	Tabmin	.44	*Polygonatum biflorum, Solidago arguta, Commelina,Boehmeria*
	Semi-Evergreen Forbs	Tabmin	.04	*Tovara virginiana, Elephantopus, Viola, Taraxacum, Hexastylis arifolia*
	Spring-Ephemeral Geophytes	Tmin	.09	*Iris, Hymenocallis, Lilium, Narcissus* [*Muscari, Hyacinthus*]
	Laurophyll Forbs	Tabmin	.00	*Chimaphila maculata, Mitchella repens*
Fn	Summergreen Ferns	MIy	.20	*Asplenium platyneuron, Botrychium dissectum, B. virginianum*
	Evergreen Ferns	Tabmin	.00	*Polystichum acrostichoides*
V	Summergreen Vines	MIy	.20	*Rhus radicans, Parthenocissus, Vitis, Campsis, Anisostichus, Cocculus*
	Evergreen Vines	Tabmin	.00	*Gelsemium sempervirens, Smilax* spp (*Lonicera japonica*)
E	Wintergreen Bush-Epiphytes	Tabmin	.04	*Phoradendron serotinum*
Th	Mat-Forming Thallophytes	MIy	.31	*Leucobryum glaucum*
	Xeric Thallophytes	MIy	.59	*Xanthoparmelia, Cladina subtenuis,Canoparmelia, Rimelia, Usnea*

species are shown in Table 4. The boreal climate there is quite maritime, and the potential natural vegetation is low *Betula* woods (Dierßen 1996), rather than the predicted conifer forest, as is also the case in Beringia (Krestov 2003), northernmost Sweden, Iceland, and some other maritime subpolar areas (cf Tierra del Fuego). With an annual moisture index (P/PET) of 2.50 this prediction would be interpreted as forest of conifers *Picea abies* (evergreen)

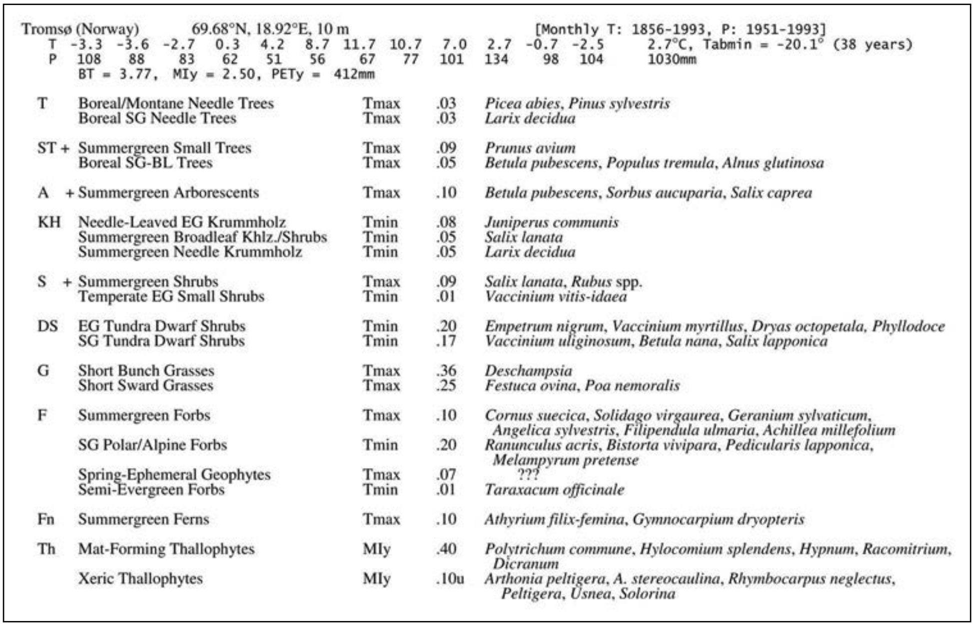
Table 4. Predicted PFORMS Model Results for Tromsø

Tromsø is a highly maritime site above the Arctic Circle near the Atlantic coast in northern Norway, where the natural vegetation is low birch (*Betula*) woods (Dierßen 1996, see pp 107-111; cf Walter 1973). The plant forms predicted for Tromsø by the PFORMS model are shown at left, listed by plant structural type (see Table 2 for explanation of table contents and abbreviations). The closest limiting factor in the envelope design is shown in the third column (e.g. Tmax, for warmest-month mean temperature), followed by the relative proximity to closest envelope limit (u = maximum value limiting).

The right-hand column shows plant taxa occurring in and around Tromsø that correspond to the plant forms predicted. All taxa listed appear to be native (not naturalized). Not predicted but occurring is *Calamagrostis*, a genus of taller grass common in boreal areas; predicted but not seen were spring-ephemeral geophytes.

With an annual moisture index (P/PET) of 2.50 this result would be interpreted as forest of conifers *Picea abies* (evergreen) and *Larix decidua* (deciduous), plus generally shorter but perhaps more important (plus signs) *Betula* spp., which are especially important in maritime boreal areas. In reality, conifers do occur but are less important around Tromsø; relevés from a natural area in the local botanical garden involved mainly low birch forests (*Betula*), with mainly summergreen understorey shrubs and forbs but also a few more truly boreo-polar dwarf shrubs such as *Betula nana* and *Vaccinium uliginosum* (summergreen) and *Vaccinium myrtillus* (evergreen).

Matches of plant taxa to particular plant forms were determined from two short field visits, from Lid (1985) and Nilsson (1991), plus images and verbal descriptions on the Internet, especially via Wikipedia. Species names are as used at the time and place; lichen names are from Frisch & al. (2020).



```
Tromsø (Norway)        69.68°N, 18.92°E, 10 m                 [Monthly T: 1856-1993, P: 1951-1993]
   T  -3.3  -3.6  -2.7   0.3   4.2   8.7  11.7  10.7   7.0   2.7  -0.7  -2.5     2.7°C, Tabmin = -20.1° (38 years)
   P   108    88    83    62    51    56    67    77   101   134    98   104     1030mm
       BT = 3.77,  MIy = 2.50,  PETy =  412mm
```

T	Boreal/Montane Needle Trees	Tmax	.03	*Picea abies, Pinus sylvestris*
	Boreal SG Needle Trees	Tmax	.03	*Larix decidua*
ST +	Summergreen Small Trees	Tmax	.09	*Prunus avium*
	Boreal SG-BL Trees	Tmax	.05	*Betula pubescens, Populus tremula, Alnus glutinosa*
A +	Summergreen Arborescents	Tmax	.10	*Betula pubescens, Sorbus aucuparia, Salix caprea*
KH	Needle-Leaved EG Krummholz	Tmin	.08	*Juniperus communis*
	Summergreen Broadleaf Khlz./Shrubs	Tmin	.05	*Salix lanata*
	Summergreen Needle Krummholz	Tmin	.05	*Larix decidua*
S +	Summergreen Shrubs	Tmax	.09	*Salix lanata, Rubus* spp.
	Temperate EG Small Shrubs	Tmin	.01	*Vaccinium vitis-idaea*
DS	EG Tundra Dwarf Shrubs	Tmin	.20	*Empetrum nigrum, Vaccinium myrtillus, Dryas octopetala, Phyllodoce*
	SG Tundra Dwarf Shrubs	Tmin	.17	*Vaccinium uliginosum, Betula nana, Salix lapponica*
G	Short Bunch Grasses	Tmax	.36	*Deschampsia*
	Short Sward Grasses	Tmax	.25	*Festuca ovina, Poa nemoralis*
F	Summergreen Forbs	Tmax	.10	*Cornus suecica, Solidago virgaurea, Geranium sylvaticum, Angelica sylvestris, Filipendula ulmaria, Achillea millefolium*
	SG Polar/Alpine Forbs	Tmin	.20	*Ranunculus acris, Bistorta vivipara, Pedicularis lapponica, Melampyrum pretense*
	Spring-Ephemeral Geophytes	Tmax	.07	???
	Semi-Evergreen Forbs	Tmin	.01	*Taraxacum officinale*
Fn	Summergreen Ferns	Tmax	.10	*Athyrium filix-femina, Gymnocarpium dryopteris*
Th	Mat-Forming Thallophytes	MIy	.40	*Polytrichum commune, Hylocomium splendens, Hypnum, Racomitrium, Dicranum*
	Xeric Thallophytes	MIy	.10u	*Arthonia peltigera, A. stereocaulina, Rhymbocarpus neglectus, Peltigera, Usnea, Solorina*

and *Larix decidua* (deciduous), plus generally shorter but perhaps more important (plus signs) *Betula* spp. In reality, conifers do occur in northern Norway but are less important in more maritime areas where growing seasons are longer and winters less cold. Actual species occurrence was determined from relevés in a natural area of the local botanical garden, which involved mainly low birch forest (*Betula*), with mainly summergreen understorey shrubs and forbs but also a few more truly boreo-polar dwarf shrubs such as summergreen *Betula nana* and *Vaccinium uliginosum*, and evergreen *Vaccinium myrtillus*.

Predicted plant forms and corresponding species are shown in Table 5 for the páramo at Piedras Blancas (4150 m). The actual vegetation is an open scrubland dominated by caulirosettes (*Espeletia* tuft treelets) up to 2m high, small-leaved shrubs (especially *Hypericum*) and dwarf shrubs, and bunch grasses (e.g. Calero & Baruch 1986; Pfitsch 1988). This area is famous for its caulirosettes, which are analogous to those of the high mountains in eastern Africa (Hedberg 1964). These high-equatorial caulirosettes have terminal tufts of large, pubescent leaves which open in the daytime (when temperatures are above freezing) and close at night (usually with frost). Surprising here was the occurrence also, at slightly lower elevation, of not so small bushes (30 cm) of *Vaccinium* (not predicted). The distinction between bunch and tussock grasses was especially difficult, since most authors seem to consider the terms synonymous. Bunch grasses are found almost everywhere; tussock grasses, on the other hand, are larger bunches, to 2 m high, as found where the densely bunched dead stems forming the tussock provide sufficient protection against winter temperatures not far below freezing, as in cool maritime climates, tropical mountains, and some temperate wetlands (e.g. in Atlantic Europe).

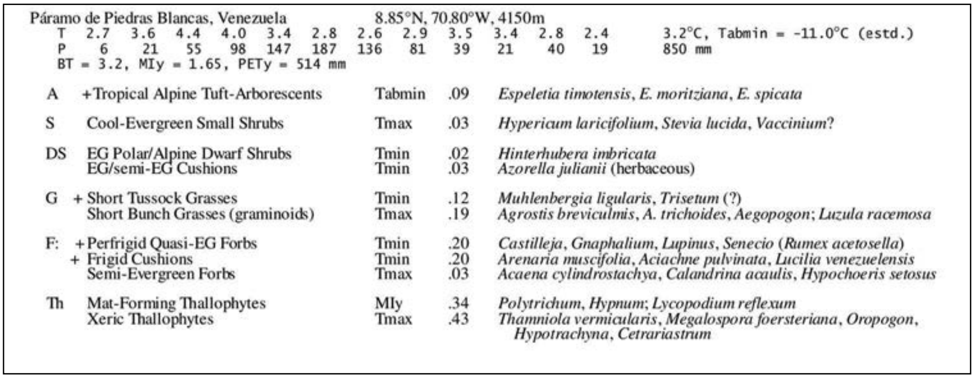
The most challenging of these five examples was Forty Mile Scrub, in northern Queensland (see Table 6). The natural vegetation there is described as “dry rainforest” (i.e. dry but non-eucalypt forest), with a low overstorey (5-7 m) dominated over most of the area by *Notelaea microcarpa* (*Oleaceae*), *Alectryon connatus* (*Sapindaceae*), *Austromyrtus* sp. pl., *Geijera salicifolia* (*Rutaceae*), and *Strychnos psilosperma* (*Loganiaceae*) (Fensham 1996). All of these species are evergreen, but vegetation across northern Australia is described as also including some deciduous woody species (Williams & al. 1997; Prior & al. 2003; Bowman & Prior 2005). Our one relevé was at a site with somewhat taller but still low (18 m), open (30% overstorey, 60% subcanopy), semi-evergreen woods that included *Geijera*, *Strychnos* and *Austromyrtus bidwellii*, plus deciduous *Pleiogynium timorense*, *Gyrocarpus americana*, and *Ailanthus* (none with cover greater than 25%). Also seen nearby was a deciduous eucalypt, probably *Eucalyptus alba*, with a green, photosynthetic layer under its white outer bark (cf Walter 1973, p. 283). With P/PET of 0.67, the prediction suggests a semi-evergreen woodland of fairly short stature. Most of the forms predicted have corresponding species that could be found or inferred from literature, but the succulent forms predicted do not occur naturally in Australia. Also, the *Xanthorrhoea* spp (“Xeric evergreen tuft arborescents”) that occur over much of Australia apparently do not occur in this area of northern Queensland, and there are no “Xeric rosette shrubs” (i.e. trunkless agavoids), although *Agave* spp. do survive well in plantings. Unpredicted forms that were observed (and their species) include: tropical non-microphyll coriaceous-leaved evergreen trees (*Ficus obliqua*), tropical evergreen lianas (*Parsonsia*), epiphytic orchids (*Dendrobium linguiforme*), tropical evergreen forbs (*Crinum*), and rolled-leaved tussock forbs (e.g. *Centrolepis*, *Lomandra*), this last of which is not represented at all as a separate form in the model system.

Table 5. Predicted PFORMS Model Results for the Páramo de Piedras Blancas.

The Páramo de Piedras Blancas is a relatively well studied, ridge-top site in the inner-tropical Andes above Mérida, Venezuela (1700 m). The actual vegetation is an open scrubland dominated by caulirosettes (*Espeletia* tuft treelets) up to 2m, small-leaved shrubs (especially *Hypericum*) and dwarf shrubs, and bunch grasses (see Calero & Baruch 1986; Pfitsch 1988 and other references in the main text). At left are the plant forms predicted for this site, listed by plant structural type (see Table 2 for key to table contents and abbreviations). The closest limiting factor in the envelope design is shown in the third column (e.g. Tmin for lowest monthly mean temperature), followed by the relative proximity to closest envelope limit (u = upper value limiting).

The right-hand column shows plant taxa occurring in this páramo that correspond to the plant forms predicted. Non-native but well naturalized taxa are shown in parentheses, e.g. *Rumex acetosella*. Question marks indicate missing information or, for particular taxa, unknown occurrence or naturalization status. Barely occurring, perhaps only at lower elevation, are small evergreen shrubs of *Vaccinium floribundum* or *V. meridionale*, which in the model are almost precluded by warmth criteria. (All summergreen forms are precluded by the small annual temperature variation.) Despite the mostly moist conditions year-round, the predicted vegetation in this alpine climate must be interpreted as a somewhat open scrub of shrubs, bunch and tussock grasses, plus the taller but more scattered tuft arborescents.

Matches of plant taxa to particular plant forms were determined from information available on the Internet (especially from Luteyn, no date) and from two páramo visits, the latter with field assistance by Alejandro Velázquez. Species names are as used at the time and place; lichen names are from Pérez (1987), Sipman (2002) and other references therein.



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Páramo de Piedras Blancas, Venezuela          8.85°N, 70.80°W, 4150m
   T   2.7   3.6   4.4   4.0   3.4   2.8   2.6   2.9   3.5   3.4   2.8   2.4      3.2°C, Tabmin = -11.0°C (estd.)
   P     6    21    55    98   147   187   136    81    39    21    40    19      850 mm
   BT = 3.2, MIy = 1.65, PETy = 514 mm
```

A	+Tropical Alpine Tuft-Arborescents	Tabmin	.09	*Espeletia timotensis*, *E. moritziana*, *E. spicata*
S	Cool-Evergreen Small Shrubs	Tmax	.03	*Hypericum laricifolium*, *Stevia lucida*, *Vaccinium*?
DS	EG Polar/Alpine Dwarf Shrubs	Tmin	.02	*Hinterhubera imbricata*
	EG/semi-EG Cushions	Tmin	.03	*Azorella julianii* (herbaceous)
G	+ Short Tussock Grasses	Tmin	.12	*Muhlenbergia ligularis*, *Trisetum* (?)
	Short Bunch Grasses (graminoids)	Tmax	.19	*Agrostis breviculmis*, *A. trichoides*, *Aegopogon*; *Luzula racemosa*
F:	+Perfrigid Quasi-EG Forbs	Tmin	.20	*Castilleja*, *Gnaphalium*, *Lupinus*, *Senecio* (*Rumex acetosella*)
	+ Frigid Cushions	Tmin	.20	*Arenaria muscifolia*, *Aciachne pulvinata*, *Lucilia venezuelensis*
	Semi-Evergreen Forbs	Tmax	.03	*Acaena cylindrostachya*, *Calandrina acaulis*, *Hypochoeris setosus*
Th	Mat-Forming Thallophytes	MIy	.34	*Polytrichum*, *Hypnum*; *Lycopodium reflexum*
	Xeric Thallophytes	Tmax	.43	*Thamniola vermicularis*, *Megalospora foersteriana*, *Oropogon*, *Hypotrachyna*, *Cetrariastrum*

Table 6. Predicted PFORMS Model Results for Forty Mile Scrub.

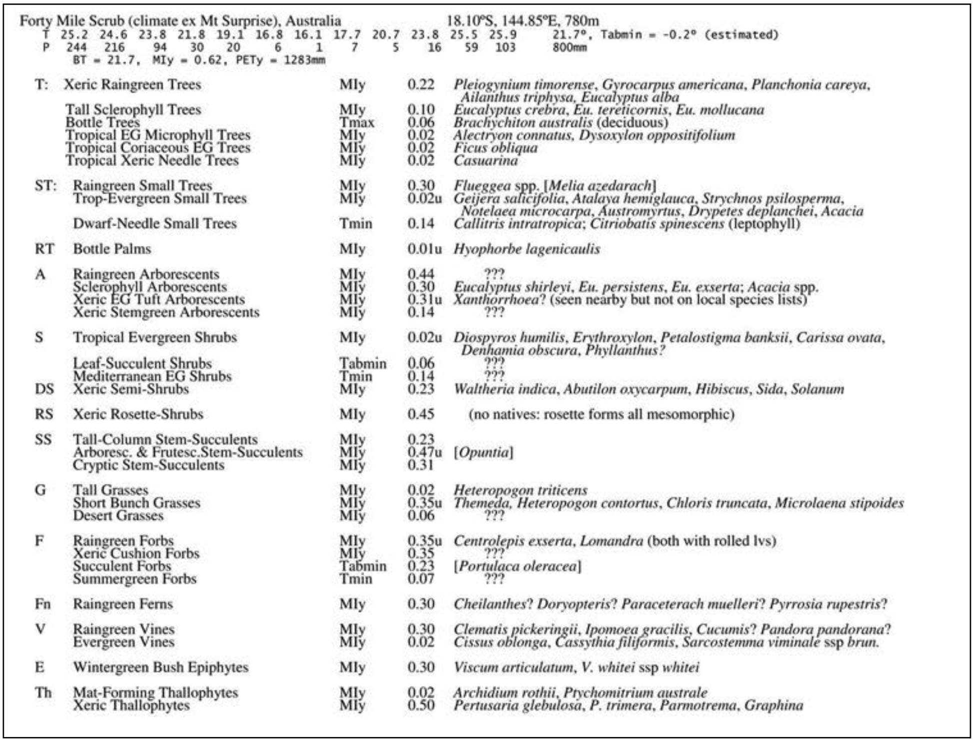
Forty Mile Scrub is a protected area in north-central Queensland (Australia), where the climate is tropical wet-dry, and the natural vegetation is a variably open, semi-evergreen woodland dominated by a mix of raingreen and sclerophyll trees and arborescents. This vegetation was called "dry rainforest" by Fensham (1996).

The left-hand column shows the plant forms predicted for this site by the PFORMS model, listed by plant structural type (see Table 2 for key to table contents and abbreviations). Topo-specific forms are shown in brackets. The closest limiting factor in the envelope design is shown in the third column (e.g. MIy for moisture index), followed by the relative proximity to closest envelope limit (u = upper value limiting).

The right-hand column shows plant taxa occurring in this area that correspond to the plant forms predicted. Non-native but perhaps well naturalized taxa are shown in parentheses; probably not naturalized but widely planted ornamental taxa are shown in brackets. Question marks indicate missing information or, for particular taxa, unknown occurrence or naturalization status. With an annual moisture balance (MIy) of 0.67, this prediction can be interpreted as a semi-evergreen woodland, in which sunlight reaches the ground commonly as frequent sunflecks (cover perhaps about 60%).

The largest error in climate-based models of Australia is the prediction of stem-succulents, which did not occur in the native flora (except *Sarcostemma*). In addition, no [predicted] Leaf-Succulent or distinctly Mediterranean Evergreen Shrubs, or Xeric Cushion or Summergreen Forbs, could be identified with any certainty; and Raingreen Arborescents may be represented only by immature potential trees. Not predicted but found were *Parsonsia* (an evergreen liana), epiphytic *Dendrobium linguiforme*, and evergreen *Crinum* (forb, probably evergreen).

Matches of plant taxa to particular plant forms were determined (assisted greatly by Andy Gillison) from notes taken on one field visit, plus information available on the Internet (e.g. Dept. Envt. Sci., no date), and from Fensham (1996), Prior & al. (2003, 2004), and Williams & al. (1997). Lichen names were from Archer and Elix (2017) and Sipman (2018).



Forty Mile Scrub (climate ex Mt Surprise), Australia 18.10°S, 144.85°E, 780m

T	25.2	24.6	23.8	21.8	19.1	16.8	16.1	17.7	20.7	23.8	25.5	25.9	21.7°, Tabmin = -0.2° (estimated)
P	244	216	94	30	20	6	1	7	5	16	59	103	800mm

BT = 21.7, MIy = 0.62, PETy = 1283mm

T:	Xeric Raingreen Trees	MIy	0.22	*Pleiogynium timorense, Gyrocarpus americana, Planchonia careya, Ailanthus triphysa, Eucalyptus alba*
	Tall Sclerophyll Trees	MIy	0.10	*Eucalyptus crebra, Eu. tereticornis, Eu. mollucana*
	Bottle Trees	Tmax	0.06	*Brachychiton australis* (deciduous)
	Tropical EG Microphyll Trees	MIy	0.02	*Alectryon connatus, Dysoxylon oppositifolium*
	Tropical Coriaceous EG Trees	MIy	0.02	*Ficus obliqua*
	Tropical Xeric Needle Trees	MIy	0.02	*Casuarina*
ST:	Raingreen Small Trees	MIy	0.30	*Flueggea* spp. [*Melia azedarach*]
	Trop-Evergreen Small Trees	MIy	0.02u	*Geijera salicifolia, Atalaya hemiglauca, Strychnos psilosperma, Notelaea microcarpa, Austromyrtus, Drypetes deplanchei, Acacia*
	Dwarf-Needle Small Trees	Tmin	0.14	*Callitris intratropica*; *Citriobatis spinescens* (leptophyll)
RT	Bottle Palms	MIy	0.01u	*Hyophorbe lagenicaulis*
A	Raingreen Arborescents	MIy	0.44	???
	Sclerophyll Arborescents	MIy	0.30	*Eucalyptus shirleyi, Eu. persistens, Eu. exserta*; *Acacia* spp.
	Xeric EG Tuft Arborescents	MIy	0.31u	*Xanthorrhoea*? (seen nearby but not on local species lists)
	Xeric Stemgreen Arborescents	MIy	0.14	???
S	Tropical Evergreen Shrubs	MIy	0.02u	*Diospyros humilis, Erythroxylon, Petalostigma banksii, Carissa ovata, Denhamia obscura, Phyllanthus?*
	Leaf-Succulent Shrubs	Tabmin	0.06	???
	Mediterranean EG Shrubs	Tmin	0.14	???
DS	Xeric Semi-Shrubs	MIy	0.23	*Waltheria indica, Abutilon oxycarpum, Hibiscus, Sida, Solanum*
RS	Xeric Rosette-Shrubs	MIy	0.45	(no natives: rosette forms all mesomorphic)
SS	Tall-Column Stem-Succulents	MIy	0.23	
	Arboresc. & Frutesc.Stem-Succulents	MIy	0.47u	[*Opuntia*]
	Cryptic Stem-Succulents	MIy	0.31	
G	Tall Grasses	MIy	0.02	*Heteropogon triticens*
	Short Bunch Grasses	MIy	0.35u	*Themeda, Heteropogon contortus, Chloris truncata, Microlaena stipoides*
	Desert Grasses	MIy	0.06	???
F	Raingreen Forbs	MIy	0.35u	*Centrolepis exserta, Lomandra* (both with rolled lvs)
	Xeric Cushion Forbs	MIy	0.35	???
	Succulent Forbs	Tabmin	0.23	[*Portulaca oleracea*]
	Summergreen Forbs	Tmin	0.07	???
Fn	Raingreen Ferns	MIy	0.30	*Cheilanthes*? *Doryopteris*? *Paraceterach muelleri*? *Pyrrosia rupestris*?
V	Raingreen Vines	MIy	0.30	*Clematis pickeringii, Ipomoea gracilis, Cucumis*? *Pandora pandorana*?
	Evergreen Vines	MIy	0.02	*Cissus oblonga, Cassythia filiformis, Sarcostemma viminale* ssp *brun.*
E	Wintergreen Bush Epiphytes	MIy	0.30	*Viscum articulatum, V. whitei* ssp *whitei*
Th	Mat-Forming Thallophytes	MIy	0.02	*Archidium rothii, Ptychomitrium australe*
	Xeric Thallophytes	MIy	0.50	*Pertusaria glebulosa, P. trimera, Parmotrema, Graphina*

Conclusion and Next Steps

This paper suggests a method for evaluating one kind of non-floristic vegetation model with floristic data, by using as intermediary the basic ecological plant types that compose the vegetation and which can be matched with actual species. This is a demonstration, and is not intended as an attempted or even implied model validation, which would require a large set of well distributed, geographically representative data sites and their field data. The above results, therefore, represent only a demonstration of how a fairly rigorous evaluation of general vegetation models could be done, with available data. There are a few gaps in the evaluation tables herein, but these missing (or incorrect) mismatches of plant forms to species do not alter the value of the above as a potential evaluation methodology.

Models should be validated, but this is not always done. The lack of rigor in model evaluation, or even of attempted evaluation, has been criticized perhaps most eloquently in the useful book *A Critique for Ecology* (Peters 1991). The validation problem was once central to ecological model building (e.g. Goodall 1972; Caswell 1976; Overton 1977; Holling 1978) and resulted in at least two main concepts: verification (does the model produce the intended results?) and validation (would the model work anywhere within its specified range?) (see summary by Rykiel 1996; cf Rastetter 1996; Power 1993). This last test, i.e. validation, is much more rigorous and is generally considered to require testing of model results against independent data, i.e. data not used in building the model. Unfortunately, the need for validation seems to be largely discarded nowadays as unnecessary for publication.

Few if any such treatments, however, have considered *geographic* models seriously, i.e. beyond superficial “kappa statistics”. But global and other large-area models are inherently geographic models, and should be validated geographically, i.e. in all the main geographic and physiographic regions in which such models are to be used (Box & Meentemeyer 1991). The first version of this climatic-envelope model was described as having “stood up to testing” (Peters 1991, p. 284), but in reality, even a moderate evaluation of a global model would require testing at several hundred sites worldwide, representing the world’s main climatic types and subtypes, and their different regional occurrences (see appendix in Box 2016). Since we have only one Earth, validation with independent data has generally been considered impossible, but suggestions have been made (e.g. Rastetter 1996).

Climatic-envelope models demonstrated climatic control of the geographic ranges of different general plant types. They also demonstrated what could be predicted with widely available climatic data and a global perspective, even in the early 1980s; and provided a means of generating and testing hypotheses or other questions of plant-environment relationships. This is especially true of PFORMS, which can be applied at any climatic site and which contains an order of magnitude more plant types than do most other models. Evaluation of predictive models for plant types, as demonstrated here, requires thinking in two directions:

1) What local examples (species) occur for the plant forms predicted?

2) To what forms (predicted or not) do the main species belong?

These criteria permit identifying not only successful predictions but also errors, both of omission and commission. Improvement and true evaluation of global vegetation models requires extensive field experience and data from most parts of the world, with results published as a monograph or book.

Formal evaluation of PFORMS must also await always ongoing revisions of plant types, climatic limits, and inclusion of more integrative variables, such as durations of favorable conditions, as suggested by the world climatic classification system of Lauer and Rafiqpoor (2002). There are of course many concepts of vegetation types and other (i.e. non-envelope) types of vegetation models. Models with vegetation types conceived as opaque "blocks" (e.g. Emanuel & al. 1985; Prentice & al. 1992) probably cannot be evaluated using floristic data. But types with some conceptualization of internal structure, such as main structural elements or more numerous main constituent plant types, can be evaluated rigorously by matching species and plant types, based on their morphological characters.

Finally, one of the biggest problems with species-based methodologies, phytosociology in particular, is that the resulting syntaxonomical names, for example a Corylo heterophyllae-Quercion mongolicae, are difficult, may be confusing, and may only be understood completely by people familiar with the scientific names in the local or regional flora (cf Rejmánek 1997). Phytosociology consists of three steps: collection of field data, tablework, and syntaxonomy, i.e. the placement of identified species clusters (communities) into an overall global hierarchy. This last step is the weakest, not only because it is often opaque, but also because it follows rules of correctness and priority rather than substance (Ewald 2003), and because there is no overall control on inflation of meanings or on unlimited proliferation of names (e.g. Pignatti 1968, 1995; Pignatti & al. 1995; Loidi 2020). These problems might be addressed with some success by wider but formalized use of parallel names using normal words, for example "beech-oak forest", or *Fagus*-*Quercus* forest, as a formally defined synonym for the phytosociological unit Querco-Fagetum. Rigorous parallel but quite different naming might also force decisions on the validity of different but overlapping or otherwise similar phytosociological units, thus reducing their overall redundancy and attendant confusion to a wider scientific audience.

Acknowledgements

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References

Archer, A. W. & Elix, J. A. 2017: Seven new species and a new record in the lichen genus Pertusaria from eastern Australia. – Austr. Lichenology **80:** 3-15.

Archibold, O. W. 1995: Ecology of World Vegetation. – Chapman and Hall, London. 510 pp.

Barkman, J. J. 1979: The Investigation of Vegetation Texture and Structure. – Pp 123-160 in: Werger, M. J. A. (ed.), The Study of Vegetation. – Boston.

— 1988. New Systems of Plant Growth Forms and Phenological Plant Types. – Pp. 9-44 in: Werger, M. J. A. & al. (eds), Plant Form and Vegetation Structure SPB Publ. – Boston.

Barthlott, W., Lauer, W. & Placke, A. 1996: Global distribution of species diversity in vascular plants: towards a world map of phytodiversity. – Erdkunde **50:** 317-327 + map.

Baruch, Z. 1984: Ordination and classification of vegetation along an altitudinal gradient in the Venezuelan paramos. – Vegetatio **55:** 115-126.

Beadle, N. C. W. 1981: The Vegetation of Australia. – Gustav-Fischer-Verlag, Stuttgart. 690 pp.

Beard, J. S. 1978: The Physiognomic Approach. – Pp 33-64 in: Whittaker, R. H. (ed.), Classification of Plant Communities. – Boston.

Bowman, D. M. J. S. & Prior, L. D. 2005: Why do evergreen trees dominate in the Australian seasonal tropics? – Austr. J. Bot. **53(5):** 379-399.

Box, E. O. 1978: Ecoclimatic Determination of Terrestrial Vegetation Physiognomy. – PhD dissertation, University of North Carolina. 134pp + 7 appendices and 22 world maps. University Microfilms, Ann Arbor.

— 1980: What determines the amount of leaf and total standing biomass of climax terrestrial vegetation? – Bull. Ecol. Soc. Amer. **61:** 76.

— 1981a: Macroclimate and Plant Forms: An Introduction to Predictive Modeling in Phytogeography. – Tasks for Vegetation Science, **1.** – Boston.

— 1981b: Climatic control of phytomass accumulation in terrestrial ecosystems. – Intl. J. Biometeorol. **8:** 230-231.

— 1984. Productivity and plant types – some thoughts on a synthesis. – Portugaliae Acta Biol., Series A, **17:** 129-148.

— 1986: Some climatic relations of the vegetation of Argentina, in global perspective. – Pp. 181-216 in: Veröff. Geobot. Inst. ETH, Stiftung Rübel. – Zürich.

— 1987: Modeling vegetation-environment relationships, with Mediterranean examples. – Ann. Bot. **45(1):** 7-36.

— 1995a: Factors determining distributions of tree species and plant functional types. – Vegetatio **121:** 101-116.

— 1995b: Climatic relationships of the forests of East and South-East Asia. – Pp. 23-55 in: Box, E. O., Peet, R. K., Masuzawa, T., Yamada, I., Fujiwara, K. & Maycock, P.F.(eds), Vegetation Science in Forestry: Global perspective based on forests ecosystems of East and Southeast Asia. – Dordrecht.

— 1995c: Global Potential Natural Vegetation: Dynamic Benchmark in the Era of Disruption. – Pp. 77-95 in: Murai, Sh. (ed.), Toward Global Planning of Sustainable Use of the Earth - Development of Global Eco-engineering. – Amsterdam.

— 1996: Plant functional types and climate at the global scale. – J. Vegetation Sci. **7:** 309-320.

— 1997: Bioclimatic Position of Evergreen Broad-Leaved Forests. – Pp 17-38 in: Island and High-Mountain Vegetation: Biodiversity, Bioclimate and Conservation. – Procs., annual IAVS meeting, Tenerife, April 1993. Universidad de La Laguna, Servicio de Publicaciones, Tenerife (Canary Islands, Spain).

— 2016: Global Bioclimatic Zonation. – Pp. 3-52 in: Box, E. O. (ed.), Vegetation Structure and Function at Multiple Spatial, Temporal and Conceptual Scales. – Basingstoke.

— 2019: Form and character diversity of potential world vegetation. – Flora **254:** 203-221.

— & Fujiwara, K. 2005, 2013: Vegetation Types and their Broad-Scale Distribution. – Pp. 106-128 in: van der Maarel, E. (ed.), Vegetation Ecology. – 2nd ed. Pp 455-485 + plate 15.1 (color) in: van der Maarel, E. & Franklin, J. (eds). – London.

— & Meentemeyer, V. 1991: Geographic Modeling and Modern Ecology. – Pp. 773-804 in: Esser, G. & Overdieck, D. (eds), Modern Ecology: Basic and Applied Aspects. – Amsterdam.

—, Crumpacker, D. W. & Hardin, E. D. 1993: A climatic model for location of plant species in Florida, USA. – J. Biogeography **20:** 629-644.

Braun-Blanquet, J. 1964: Pflanzensoziologie, Grundzüge der Vegetationskunde. 3rd ed. – Vienna.

Calero, A. G. & Baruch, Z.1986: Patterns in altitudinal and seasonal biomass allocation in two contrasting plant life forms from a tropical mountain biome. – BioTropica **18(3):** 189-194.

Caswell, H. 1976: The Validation Problem. – In: Patten, B. C. (ed.), Systems Analysis and Simulation in Ecology, **4.** – Cambridge.

Chapin, F. S. 1993: Functional Role of Growth Forms in Ecosystem and Global Processes. – Pp 287-312 in: Ehleringer, J. R. & Field, Ch. (eds), Scaling Physiological Processes: Leaf to Globe.

CNALH (Corsortium of North American Lichen Herbaria) (no date). www.lichenportal.org/cnalh/collections [last accessed 1/3/2021]

Cramer, W. 1997: Using plant functional types in a global vegetation model. – Pp 271-288 in: Smith, T. M. & al. (eds), Plant Functional Types: their relevance to ecosystem properties and global change. – Cambridge.

Cramer, W. P. & Leemans, R. 1993: Assessing Impacts of Climate Change on Vegetation using Climate Classification. – Pp 190-217 in: Solomon, A. M. & Shugart, H. H. (eds), Vegetation Dynamics and Global Change. – New York.

CRMS (Center for Remote Sensing and Mapping Science) 2011: "A Guide to 12 Common and Conspicuous Lichens of Georgia's Piedmont." www2.crms.uga.edu/lichens [last accessed 22/3/2021].

Cuatrecasas, J. 1968: Páramo vegetation and its life forms. – Colloq. Geographicum (Bonn) **9:** 91-116.

de Laubenfels, D. J. 1975: Mapping the World's Vegetation. – Syracuse.

Delcourt, H. R. & Delcourt, P. A. 2000: Eastern Deciduous Forests. – Pp 357-395 in: Barbour, M. G. & Billings, D. W. (eds), North American Terrestrial Vegetation 2nd ed. – Cambridge.

Dengler, J., Jansen, F., Glöckler, F., Peet, R. K., de Cáceres, M., Chytrý, M., Ewald, J., Oldeland, J., Lopez-Gonzalez, G., Finckh, M., Mucina, L., Rodwell, J. S., Schaminée, J. H. J. & Spencer, N. 2011: The global index of vegetation-plot databases (GIVD): a new resource for vegetation science. – J. Veg. Sci. **22(4):** 582-597.

Dept. of Environment and Science (no date): "Plants of Forty Mile Scrub National Park." – www.wetlandsinfo.des.qld.gov.au [last accessed 22/3/2021]

Dierßen, K. 1996: Vegetation Nordeuropas (see pp 107-111). – Stuttgart.

Drude, O. 1896: Deutschlands Pflanzengeographie. Handbuch Dt. Land-.u. – Stuttgart.

Emanuel, W. R., Shugart, H. H. & Stevenson, M. P. 1985: Climatic change and the broad-scale distribution of terrestrial ecosystem complexes. – Climatic Change **7:** 29-43.

Enquist, F. 1924: Sambandet mellan klimat och växtgränser. – Geol. För. Stockh. Förh. **46:** 202-213.

— 1929: Studier över samtidiga växlingar i klimat och växtlighet. – Svensk Geogr. Årsb. **1929:** 7-50.

— 1933: Trädgransundersökningar. – Svensk Skogsv.-För. Tidskr. **1933:** 145-214 (German summary).

Ewald, J. 2003: A critique for phytosociology. – J. Veg. Sci. **14:** 291-296.

Eyre, S. R. 1968: Vegetation and Soils: A World Picture. 2nd ed. – London.

Fensham, R. J. 1996: The floristics and structure of dry rainforest at Forty Mile Scrub National Park, north Queensland. – Cunninghamia **4(3):** 483-495.

Foley, J. A. 1995: Numerical models of the terrestrial biosphere. – J. Biogeogr. **22(4/5):** 837-842.

Frisch, A., Klepsland, J., Palice, Z., Bendiksby, M., Tønsberg, T. & Holien, H. 2020: New and noteworthy lichens and lichenicolous fungi from Norway. – Graphis Scripta **32(1):** 1-47.

Fujiwara, K. 1987: Aims and methods of phytosociology or “vegetation science”. – Pp. 607-628 in: Takeda, Y. (ed.), Papers on Plant Ecology and Taxonomy to the Memory of Dr. Satoshi Nakanishi. – Kôbe.

— 2008: Integrated Vegetation Mapping of Asia. – Research Report #16255003 for Monbushō (Japan Society for Promotion of Science). 189pp.

— & Harada, A. 2008: Character of Warm-Temperate Quercus Forests in Asia. – Pp 27-80 in: Box, E. O. & Fujiwara, K. (eds), Warm-Temperate Deciduous Forests around the Northern Hemisphere. – Berlin.

Gillison, A. N. 1981: Towards a Functional Vegetation Classification. – Pp 30-41 in: Gillison, A. N. & Anderson, D. J. (eds), Vegetation Classification in Australia. – Canberra.

— 2013: Plant Functional Types and Traits at the Community, Ecosystem and World Level. – Pp. 347-386 in: van der Maarel, E. & Franklin, J. (eds), Vegetation Ecology. – Hoboken

Goodall, D. W. 1972: Building and Testing Ecosystem Models. – Pp. 173-194 in: Jeffers, J. N. J. (ed.), Mathematical Models in Ecology. – Oxford.

Grisebach, A. R. H. 1838: Über den Einfluss des Klimas auf die Begrenzung der natürlichen Floren. – Linnea **12:** 159-200.

— 1866: Die Vegetationsgebiete der Erde, übersichtlich zusammengestellt. – Petermanns Mitt. **12:** 45-53.

— 1872: Die Vegetation der Erde nach ihrer klimatischen Anordnung. – Leipzig.

Guarino, R. & Pasta, S. 2017: Botanical Excursions in Central and Western Sicily. Field Guide for the 60th IAVS Symposium. – Palermo.

Hedberg, O. 1964: Features of Afroalpine plant ecology. – Acta Phytogeogr. Suecica **49:** 1-144.

Holdridge, L. R. 1947: Determination of world plant formations from simple climatic data. – Science **105:** 367-368.

Holling, C. S. 1978: Adaptive Environmental Assessment and Management. – New York.

Humboldt, A. von 1806: Ideen zu einer Physiognomik der Gewächse. – Tübingen.

Iverson, L. R., Prasad, A. M., Hale, B. J. & Sutherland, E. K. 1999: Atlas of Current and Potential Future Distributions of Common Trees of the Eastern United States. – Tech. Rept. NE-265. – Radnor.

Jones, S. B. & Coile, N. C. 1988: The Distribution of the Vascular Flora of Georgia. – Athens.

Krestov, P. 2003: Forest Vegetation of Easternmost Russia (Russian Far East). – Pp. 93-180 in: Kolbek, J. & al. (eds), Forest Vegetation of Northeast Asia. – Kluwer.

Larcher, W. 1973: Limiting Temperatures for Life Functions in Plants. – In: Precht, H. & al. (eds), Temperature and Life. – Berlin and New York.

Lauer, W. & Rafiqpoor, D.2002: Die Klimate der Erde: Eine Klassifikation auf der Grundlage der ökologischen Merkmale der realen Vegetation. – Stuttgart.

Levis, S., Foley, J. A. & Pollard, D. 2000: Large-scale vegetation feedbacks on a doubled CO2 climate. – J. Climate **13(7):** 1313-1325. https://doi.org/10.1175/1520-0442(2000)013

Lid, J. 1985: Norsk, Svensk, Finsk Flora. – Oslo.

Loidi, J. 2020: The concept of vegetation class and order in phytosociological syntaxonomy. – Veg. Classif. Survey **1:** 163-167.

Luteyn, J. L. (no date): Páramo Ecosystems. – Missouri Botanical Garden; downloaded (2021) from mobot.org/mobot/research/paramo_ecosystem/introduction.shtml.

— 1999: Páramos: A Checklist of Plant Diversity, Geographical Distribution, and Botanical Literature. – Mem. NY Bot. Gard. **84.** Bronx.

Márquez, E. J., Rada, F. & Fariñas, M. R. 2006: Freezing tolerance in grasses along an altitudinal gradient in the Venezuelan Andes. – Oecologia. https://doi.org/10.1007/s00442-006-0556-3

—, Fariñas, M. R., Briceño, B. & Rada, F. J. 2004: Distribution of grasses along an altitudinal gradient in a Venezuelan paramo. – Rev. Chilena Hist. Nat. **77:** 649-660.

Miyawaki, A., Iwatsuki, K. & Grandtner, M. M. (eds) 1994: Vegetation in Eastern North America. – Tokyo.

Mucina, L. 2018: Biome: evolution of a crucial ecological and biogeographical concept. – New Phytologist, https://doi.org/10.1111/nph.15609

Mueller-Dombois, D. & Ellenberg, H. 1974: Aims and Methods of Vegetation Ecology. – New York.

Nilsson, Ö. 1991: Nordisk Fjällflora. 3rd edition. – Bonnier Fakta Bokförlag, Stockholm. 272pp.

Overton, S. 1977: A Strategy of Model Construction. – Pp 49-73 in: Hall, Ch. & Day, J. (eds), Ecosystem Modeling in Theory and Practice. – New York.

Peng, Ch.-H. 2000: From static biogeographical model to dynamic global vegetation model: a global perspective on modeling vegetation dynamics. – Ecol. Modeling **135:** 33-54.

Pérez, F. 1987: Needle-ice activity and the distribution of stem-rosette species in a Venezuelan páramo. – Arctic Alpine Res. **19:** 135-153.

Peters, R. H. 1991: A Critique for Ecology. – Cambridge.

Pfitsch, W. A. 1988: Microenvironment and the distribution of two species of *Draba* (*Brassicaceae*) in the Venezuelan paramo. – Arctic Alpine Res. **20:** 333-341.

Pignatti, S. 1968: Inflation der höheren pflanzensoziologischen Einheiten. – Pp 85-97 in Tüxen, R. (ed.), Pflanzengeographische Systematik – Den Haag.

— 1982: Flora d'Italia, **1-3.** – Bologna.

— 1995: A new spirit in phytosociology. – Ann. Bot. **53:** 9-21.

— 1998: I Boschi d'Italia. – Torino.

—, Oberdorfer, E., Schaminée, J. H. J. & Westhoff, V. 1995: On the concept of vegetation class in phytosociology. – J. Veg. Sci. **6:** 143-152.

Poore, M. E. D. 1962: The method of successive approximation in descriptive ecology. – Advances Ecol. Res. **1:** 35-68.

Poulter, B., Ciais, P., Hodson, E., Lischke, H., Maignan, F., Plummer S. & Zimmermann, N. E. 2011: Plant functional type mapping for earth system models. – Geoscient. Model Dev. **4:** 993-1010.

Power, M. 1993: The predictive validation of ecological and environmental models. – Ecol. Modeling **68:** 33-50.

Prentice, I. C., Cramer, W., Harrison, S. P., Leemans, R., Monseruid, R. A. & Solomon, A. M.1992: A global biome model based on plant physiology and dominance, soil properties and climate. – J. Biogeogr. **19:** 117-134.

Prior, L. D., Eamus, D. & Bowman, D. M. J. S. 2003: Leaf attributes in the seasonally dry tropics: a comparison of four habitats in northern Australia. – Functional Ecol. **17:** 504-515, https://doi.org/10.1046/j.1365-2435.2003.00761.x

—, Bowman, D. M. J. S. & Eamus, D. 2004: Seasonal differences in leaf attributes in Australian tropical tree species: family and habitat comparisons. – Functional Ecol. 18:707-718, https://doi.org/10.1111/j.0269-8463.2004.00885.x

Rada, F., Azócar, A. & García-Nuñez, C. 2019. Plant functional diversity in tropical Andean páramos. – Pl. Ecol. Div. **12(6):** 539-553.

Radford, A. E., Ales, H. E. & Bell, C. R 1968: Manual of the Vascular Flora of the Carolinas. – Univ. N Carolina Press, Chapel Hill. 1183pp.

Raimondo, F. M, Domina, G. & Spadaro, V. 2010: Checklist of the Vascular Flora of Sicily. – Quad. Bot. Amb. Appl. **21:** 189-252.

Rastetter, E. B. 1996: Validating models of ecosystem response to global change. – BioScience **46(3):** 190-198.

Rejmánek, M. 1997: Towards simplification of phytosociological nomenclature. – Folia Geobot. Phytotax. **32:** 419-420.

Rübel, E. 1930: Pflanzengesellschaften der Erde. – Berlin.

Rubinstein, E. 1924: Beziehungen zwischen dem Klima und dem Pflanzenreich. – Meteorol. Z. **41:** 15-17.

Rykiel, E. J. 1996: Testing ecological models: the meaning of validation. – Ecol. Modeling **90:** 229-244.

Sakai, A. 1971: Freezing resistance of relicts from the Arcto-Tertiary flora. – New Phytol. **70:** 1199-1205.

— & Larcher, W. 1987: Frost Survival of Plants: Responses and Adaptation to Freezing Stress. – Berlin.

Schimper, A. F. W. 1898: Pflanzengeographie auf physiologischer Grundlage. – Jena (3rd ed. 1935, with von Faber, F. C.); English transl. 1903, by Fisher, W. R. – Oxford.

Schmithüsen, J. 1968: Vegetationsgeographie. 3rd ed. – Berlin.

— 1976: Atlas zur Biogeographie. – Bibliographisches Institut, Mannheim/Wien/Zürich. 80pp.

Sipman, H. J. M. 2002: The significance of the northern Andes for lichens. – Bot. Rev. **68(1):** 88-99.

— 2018: New species and new records of Australian lichens. – Austr. Lichenology **82:** 92-105.

Smith, T. M., Shugart, H. H., Woodward, F. I. & Burton, P. J. 1993: Plant Functional Types. – Pp. 272-292 in: Solomon, A. M. & Shugart, H. H. (eds), Vegetation Dynamics and Global Change. – New York.

Strahler, A. and co-workers 1999: MODIS prototype classification of North American land cover. Map at 1:10,000,000 (analysis: 2 August 1999). – Boston.

Tateishi, R. & Kajiwara, K.1991: Global land-cover classification by NOAA GVI data: thirteen land-cover types by cluster analysis. – Pp. 9-14 in: Murai, Sh. (ed.), Applications of Remote Sensing in Asia and Oceania. – Tokyo.

Theurillat, J.-P., Willner, W., Fernández-González, F., Bültmann, H., Čarni, A., Gigante, D., Mucina, L. & Weber. H. 2020: International code of phytosociological nomenclature. 4th edition. – Appl. Veg. Sci. **24(1).** https://doi.org/10.1111/avsc.12491.

Walter, H. 1968, 1973: Die Vegetation der Erde in öko Betrachtung, **1-2.** – Stuttgart.

— 1970: Vegetation und Klimazonen. – Stuttgart.

— 1974: Die Vegetation Osteuropas, Nord- und Zentralasiens. Vegetation der einzelnen Großsräume. – Stuttgart.

Warming, E. 1895: Plantesamfund: Grunträk af den ökologiske Plantgeografi. København. English version 1909: Oecology of Plants. – Oxford.

Werger, M. J. A.(ed.) 1988: Plant Form and Vegetation Structure. – The Hague.

— & Sprangers, J. T. C. 1982: Comparison of floristic and structural classification of vegetation. – Vegetatio **50:** 175-183.

Westoby, M. 1988: Comparing Australian ecosystems to those elsewhere. – BioScience **38(8):** 549-556.

Whittaker, R. H. (ed.) 1973: Ordination and Classification of Communities. – Handbook of Vegetation Science, **5.** – The Hague.

Williams, R. J., Myers, B. A., Muller, W. J., Duff, G. A. & Eamus, D. 1997: Leaf phenology of woody species in a north Australian tropical savanna. – Ecology **78(8):** 2542-2558.

Woodward, F. I., Lomas, M. R. & Kelly, C. K. 2004: Global climate and the distribution of plant biomes. – Phil. Trans. Royal Soc. London, series B, Biol. Sci., **359(1450):** 1465-1476, https://doi.org/10.1098/rstb.2004.1525.

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Syntaxonomic characterization of the vegetation belts from the South-eastern Carpathians (Romanian Carpathians)

Abstract

Coldea, G. & Cristea, V.: Syntaxonomic characterization of the vegetation belts from the South-eastern Carpathians (Romanian Carpathians). — Fl. Medit. 31 (Special Issue): 361-369. 2021. — ISSN: 1120-4052 printed, 2240-4538 online.

Based on studies carried out in the mountain ranges of the South-eastern Carpathians (Romanian Carpathians) and on local geobotanical (phytosociological) data, we present a detailed syntaxonomical characterization of the 4 vegetation belts (hill, montane, subalpine and alpine) of this region. The syntaxa for each vegetation belt are analogous to those described in the North-western Carpathians (Tatra Mountains) regarding the dominant species, but have different regional and local endemic species. The latter supported the description of new regional syntaxa by Romanian phytosociologists, which are employed in the characterization of each vegetation belt.

Key words: Plant communities, altitudinal belts, Romanian mountains.

Introduction

The South-eastern Carpathians, situated in the Carpathian chain between the Tisza and Danube rivers, stretch out in the center of Romania as a 910 km long arch of variable width (40-100 km), subdivided into different sectors. The geomorphologists who studied intensively the Romanian Carpathians (De Martonne 1907; Mihăilescu 1963; Ficheux 1996; etc.) divided them according to their tectonic character into three main branches: (Inner) Eastern Carpathians, Southern Carpathians and Western Carpathians (commonly called the Apuseni Mountains). The Eastern Carpathians, with the highest altitude over 2,000 m (Pietrosul Rodnei Peak - 2,305 m), are the most intricate in terms of structure, lithology and tectonics. They encompass Hercynian blocks in the upwarped mountains and volcanic areas in the northwest. The Southern branch ("*the Transylvanian Alps*", as De Martonne called them) is more uniform lithologically (being dominated by crystalline schists), but very diverse tectonically, which caused its highest rising during tectonic movements, to over 2,500 m altitude. The Western Carpathian (Apuseni Mountains) branch is the lowest of Romanian Carpathians (the Cucurbăta Peak reaching 1,848 m) and the most fragmented tectonically, but through its formation, structure and evolution, it shows affinities with the crystalline (Hercynian) chain of the Eastern Carpathians.

The intensive study of the Romanian Carpathians flora started in the early 19th century (Baumgarten 1816) and was then continued by Schur (1866), Brandză (1879-1883), Simonkai (1886), and Grecescu (1898), which allowed the botanists of the 20th century to delimit the floristic sub-provinces of the Romanian Carpathians (Pax 1919; Borza 1960; Meusel 1965; Georgescu & Doniţă 1965), based on the Carpathian endemic and sub-endemic plant species, along with some rare species with areal limited to some Carpathian massifs.

Of the 132 plant species endemic to the Carpathian chain, 105 are endemic to the Romanian Carpathians (Hurdu & al. 2012). Compared to the works discussing the delimitation of the floristic sub-provinces, those referring to the vegetation belts of the Romanian Carpathians are few and encompass only some mountain massifs (Borza 1934, 1959; Beldie 1967; Doniţă 1962; Boșcaiu 1971; Pușcaru-Soroceanu & al. 1981; Coldea 1990, 1991; Cristea 1993).

In this paper we present the vegetation belts of the Romanian Carpathians and characterize them based on specifically described regional syntaxa, following the laborious works published by Pignatti (1980), Zarzycki (1991), Ozenda (1994), Ellenberg (1996) and Rivas-Martinez (1988).

Materials and Method

Based on field research that we conducted over the years in numerous mountain ranges of the Romanian Carpathians and on geobotanical (phytosociological) data published recently by some botanists (Muică 1995; Drăgulescu 1995; Mihăilescu 2001; Nechita 2003; Oprea & Sîrbu 2009), we selected three mountain massifs that have different altitudes and geological structure from each of the three main branches of the Romanian Carpathians. The mountain ranges chosen for this study are (Fig. 1): Rodnei, Călimani, and Hășmaș Mts. - from the Eastern Carpathians branch; Bucegi, Făgăraș and Retezat Mts. - from the Southern Carpathians branch; and Poiana Ruscă, Biharia, and Plopiș Mts. - from the Western Carpathians branch (Apuseni Mts.) The main geological, geographical and climatic data regarding these mountain ranges are presented in Table 1.

The vegetation belts delimited for each analyzed massif, based on the identified syntaxa, and their altitudinal distribution are represented graphically (Fig. 2), following the model used by Ozenda (1994) in describing the vegetation belts of the Polish Carpathians.

Results and discussion

In the South-eastern Carpathians the following 4 vegetation belts are well-evident in terms of plant communities, soil, ecological, and climatic conditions: hill, montane, subalpine and alpine. The representative syntaxa for each vegetation belt cover a larger or smaller area in the selected mountains, in relation to their geographical position within the Carpathian branch, the geological substratum of the massifs and the basic orographic factors (altitude, aspect, and slope) which influence the vegetation composition (Boșcaiu 1971).

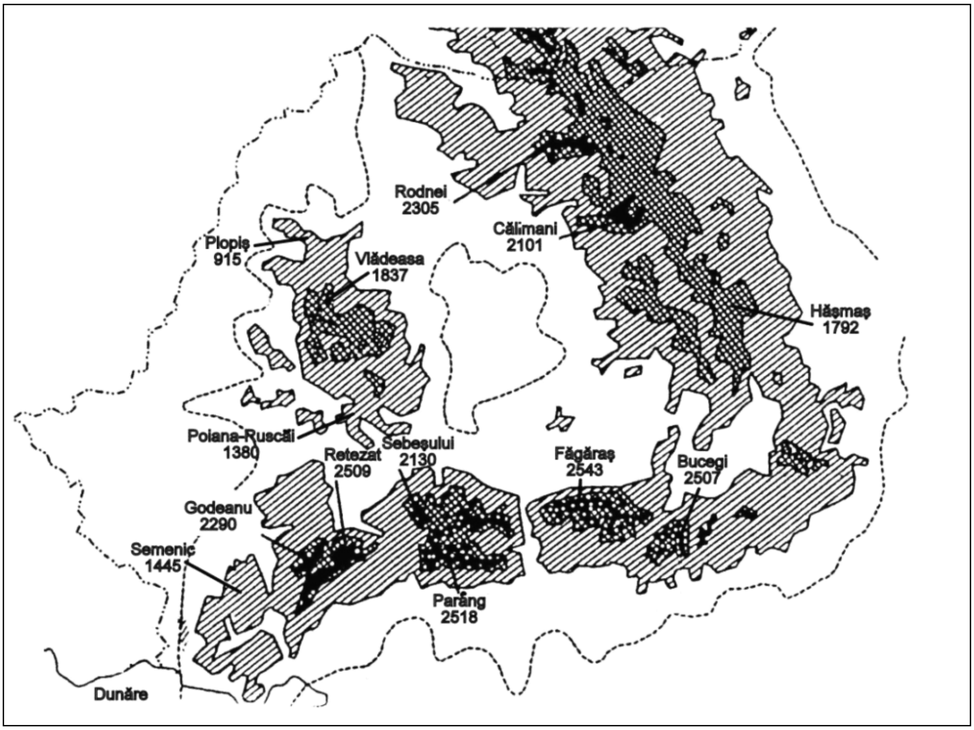

Fig. 1. Geographic location of the nine mountains under study within the South-eastern Carpathians.

Woody plant communities are the best to characterize the vegetation belts (Beldie 1967; Pignatti 1980; Zarzycki 1991). Since the current altitudinal limits of the belts changed considerably due to human activities in the last centuries, in their syntaxonomic characterization we also employed the secondary herbaceous vegetation, along with the zonal woody vegetation.

1. The hill belt, located in the outer areas of the massifs, between 400-700 m, has a temperate-moderate climate, with average annual temperatures of 6-7 °C and annual rainfall of 600-700 mm and is characterized by mesothermophilic forests, grouped in the regional alliance ***Lathyro hallersteinii-Carpinion*** Boșcaiu 1979 - including the associations *Lathyro hallersteinii-Carpinetum* Coldea 1975 and *Carpino-Fagetum* Paucă 1941- and the alliance ***Quercion petraeae*** Zólyomi et Jakus 1957 comprising the associations *Cytiso nigricantis-Quercetum petraeae* Paucă 1941 and *Luzulo luzuloidis-Quercetum petraeae* Hilitzer 1932. In some places, on the sunny slopes of the western part of the Apuseni Mountains and southwest of the Southern Carpathians, there are communities of thermophilic oaks grouped in the associations *Quercetum petraeae-cerris* Soó 1957 and *Quercetum frainetto-cerris* Rudski 1949. The communities of secondary grasslands, established after the felling of mesothermal forests, are grouped into the alliances ***Arrhenatherion elatioris*** W. Koch 1926 and ***Cynosurion*** Tx. 1947, while the thermophilic forests were replaced by xerophillic grasslands included in the alliance ***Festucion valesiacae*** Klika 1931.

Table 1. Geographical, geological and climatic data on the 9 investigated mountains of the South-eastern Carpathians.

N^o.	**Mountain Name**	**Summit**	**Altitude (m.s.m.)**	**Geographical Co-ordinate**	**Geological substratum**	**Mean Tempe-rature (°C)**	**Yearly precipi-tation (mm/m^2)**
1.	Rodnei	Pietrosul Mare	2,305	47°36'00"N 24°37'48"E	Crystalline and limestone rocks	- 1.6	1,330
2.	Călimani	Pietrosul Călimanilor	2,101	47°08'01"N 25°10'60"E	Volcanics rocks	- 1.2	1,200
3.	Hăşmaş	Hăşmaşul Mare	1,792	46°42'17"N 25°48'18"E	Crystalline and limestone rocks	1.3	1,000
4.	Bucegi	Omul	2,507	45°26'45"N 25°27'23"E	Pudding stone and granitic rocks	- 2.5	1,320
5.	Făgăraş	Moldoveanu	2,543	45°35'58"N 24°44'11"E	Crystalline and granitic rocks	- 2.6	1,330
6.	Retezat	Peleaga	2,509	45°21'57"N 22°53'33"E	Crystalline and limestone rocks	- 2.1	1,240
7.	Poiana Ruscă	Padeş	1,380	45°39'46"N 22°19'18"E	Crystalline rocks	5.1	900
8.	Apuseni	Vlădeasa	1,837	46°45'33"N 22°47'38"E	Crystalline and limestone rocks	1.1	1.200
9.	Plopiş	Măgura Mare	915	47°5'35"N 22°31'44"E	Crystalline rocks	6.0	830

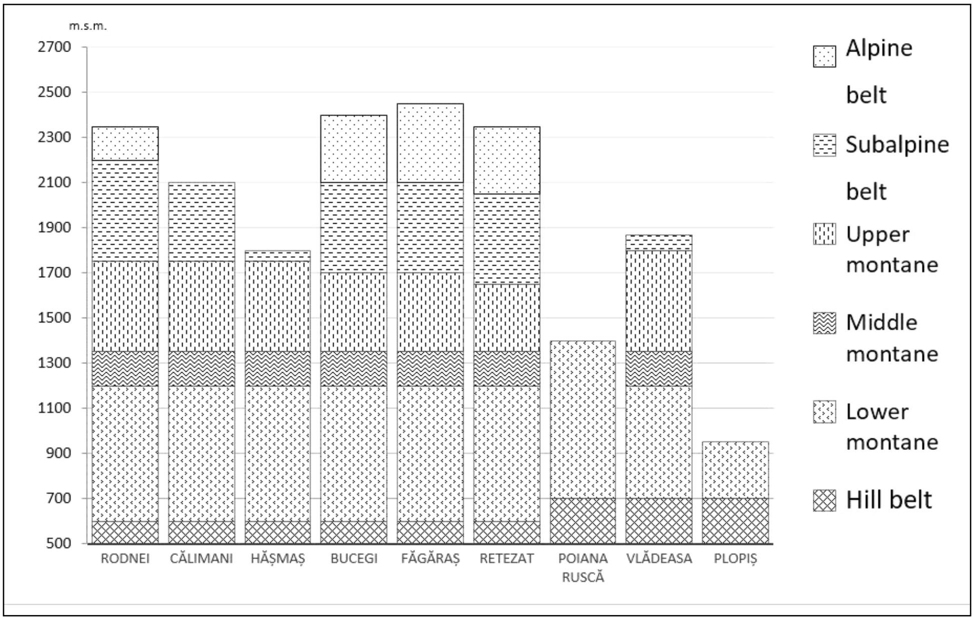

Fig. 2. Correspondence between elevation and vegetation belts in the South-eastern Carpathians.

2. The montane belt, situated between 700-1800 m, is characterized by a cooler climate, but with positive average annual temperatures (+ 2°C to 6°C) and annual rainfall between 700 and 1,100 mm, which is favorable for the development of beech forests, either pure or mixed with spruce and fir, and of boreal spruce forests (Doniţă 1965). Within this belt, as in the case of the Alps (Nikelfeld 1993), three sub-belts can be delimited, depending on the dominant woody vegetation, geological substrate and soil types (Beldie 1967; Boşcaiu 1971).

The lower montane sub-belt, between 700 and 1,100 m is dominated by pure beech forests, developed on acid brown soils, framed in the associations *Symphyto cordati-Fagetum* Vida 1959, *Festuco drymejae-Fagetum* Morariu ex Resmeriță 1977 and, in the southwestern part of the Southern Carpathians, *Aremonio agrimonioidi-Fagetum* Boşcaiu 1971.

The middle montane sub-belt, situated between 1,100 and 1,350 m comprises acidophilic forests of beech mixed with fir or with spruce, grouped in the regional associations *Pulmonario rubrae-Abietetum* Beldie ex Coldea 2015 and *Leucanthemo waldsteinii-Fagetum* (Soó 1964) Täuber 1987, and also the basophilic beech forests included in the associations *Phyllitidi-Fagetum* Vida 1963 and *Seslerio rigidae-Fagetum* Soó ex. Coldea 2015. All the woody communities with beech from the Romanian Carpathians are included in the regional alliance ***Symphyto cordati-Fagion*** Vida (1959) 1963. Scattered, with intrazonal distribution in the beech area there can be found communities of *Pinus sylvestris* grouped within the acidophilic alliance ***Dicrano-Pinion sylvestris*** Matusz. 1962 and in the basophilic alliance ***Seslerio rigidae-Pinion sylvestris*** Coldea 1991.

The upper montane sub-belt includes mainly spruce forests, distributed between 1,350 and 1,800 m. They vegetate on cryptopodzoles and superficial podzols, with a strong acid reaction (pH 4.2-4.7). The zonal spruce communities are grouped into the regional associations *Hieracio transsilvanici-Piceetum* Pawl. et Br.-Bl. 1939, *Soldanello oreodoxae-Piceetum* Coldea et Wagner 1998, and *Chrysanthemo rotundifolii-Piceetum* Krajina 1933, while the intrazonal ones, on limestone, are included in the association *Doronico columnae-Piceetum* Coldea 2002. At the upper limit of spruce forests, between 1,700-1,800 m, on the northern aspects of glacial cirques, and on the summits of some peaks, there can be found communities of *Picea abies* together with *Pinus cembra* and *Larix decidua*, described as *Rhododendro myrtifolii-Pinetum cembrae* (Borza 1934) Coldea 2015, *Rhododendro myrtifolii-Piceetum* Coldea et Pânzaru 1986, *Bruckenthalio-Piceetum* Borhidi 1971 and *Saxifrago cuneifolii-Laricetum* (Leandru 1954) Coldea 1991. These treeline forest communities make the transition towards the *Pinus mugo* communities that dominate the subalpine belt of the Eastern and Southern Carpathians. In the montane belt, after the felling of beech forests, mesophilic grasslands developed, grouped in the alliances ***Polygono-Trisetion*** Tx. et Marsch 1947 and ***Violion caninae*** Schwick 1944.

3. The subalpine belt, stretching between 1,800–2,200 m, is characterized climatically by average annual temperatures of 0°C to 2°C and annual precipitation between 1,100–1,200 mm, and pedologically by the dominance of podzolic soils. Physiognomically, the subalpine belt includes mainly coenoses grouped in order *Junipero-Pinetalia mugo* Boşcaiu 1971, respectively the alliances ***Pinion mugo*** Pawl. & al. 1928 and ***Bruckenthalio-Juniperion*** (Horv. 1949) Boşcaiu 1971.

The regional associations specific to the South-eastern Carpathians are *Rhododendro myrtifollii-Pinetum mugo* Coldea 1991, *Campanulo abietinae-Juniperetum nanae* Simon 1966 and *Bruckenthalio-Juniperetum nanae* Horvat ex Boşcaiu 1971. At altitudes higher than 2,100 m, due to the unfavorable climatic conditions, the communities of *Pinus mugo* and *Juniperus communis* ssp. *alpina* become dwarf and repent, resembling the coenoses of the shrub *Loiseleuria procumbens* specific to the alpine belt. Frequently, in contact with the *Pinus mugo* bushes, on the northern, steep slopes of the siliceous, moist rockeries along streams, there can be communities of *Alnus alnobetula* with *Salix silesiaca*, included in the alliance ***Alnion viridis*** Aichinger 1933. These shrub communities, along with the mesophilic grasslands grouped in alliances ***Calamagrostion villosae*** Pawl. 1928 and ***Potentillo ternatae-Nardion*** Simon 1958 and with the hygrophilic communities from the alliance ***Adenostylion alliariae*** Br.-Bl. 1925, complete the physiognomy of the subalpine belt of the Romanian Carpathians.

4. The alpine belt, extending between 2,200-2,543 m, is characterized by negative average annual temperatures (between -2°C and 0°C) and annual rainfall of 1,200–1,400 mm. The length of the growing season is, on average, 4 months. The alpine vegetation type is represented by the primary microthermic grasslands dominated by *Carex curvula, Juncus trifidus* and *Festuca supina* on acidic substrate (crystalline schists), grouped in the alliance ***Caricion curvulae*** Br.-Bl. 1925, and the oligothermic dwarf shrub communities grouped in the alliance ***Loiseleurio-Vaccinion*** Br.-Bl. in Br.-Bl. et Jenny 1926, while on calcareous substrates there are the primary basophilic grasslands dominated by *Elyna myosuroides, Sesleria bielzii, Festuca versicolor, F. amethystina, F. carpatica,* grouped in the alliances ***Oxytropido-Elynion*** Br.-Bl. 1949 and ***Festuco saxatilis-Seslerion bielzii*** (Pawl. & Walas 1948) Coldea 1984. Specific to the alpine belt are also the chionophilic, microthermic communities included in the alliance ***Salicion herbaceae*** Br.-Bl in Br.-Bl. et Jenny 1926 and the basophilic communities grouped in ***Salicion retusae*** Horv. 1949. Also, the saxicolous and rupicolous communities grouped in alliances ***Silenion lerchenfeldianae*** Simon 1957 and ***Veronicion baumgartenii*** Coldea 1991, complete the specificity of the alpine belt from the Southeastern Carpathians.

In the Eastern Carpathians branch, the alpine belt is limited to the highest peaks of the Rodna Mountains (Pietrosul Mare - 2,305 m, Rebra - 2,201 m, Puzdrele - 2,188 m, Gărgălău - 2,159 m, Ineu - 2,280 and Ineuț - 2,222 m). In the branch of the Southern Carpathians, the alpine belt is widely spread in all massifs with altitudes over 2,200 m (Bucegi, Făgăraș, Parâng, Retezat, Țarcu, Godeanu Mountains), where alpine phytocoenoses form 200-300 m wide "bands". In the Western Carpathians (Apuseni Mountains) the alpine belt is missing.

An analysis of the floristic structure of the syntaxa employed for the characterization of the vegetation belts from the Southeastern Carpathians, compared to the structure of the syntaxa described from the Northwestern Carpathians (Kornaś & Medwecka-Kornaś 1967; Zarzycki 1991; Matuszkiewicz 2008), reveals that the dominant species for montane and subalpine associations are largely the same, the syntaxa described in the two montane regions differing only as regards the presence of local and regional Carpathian endemics. More pronounced syntaxonomic differences are evident in the composition of the woody and herbaceous plant communities in the hill and alpine belts of the Carpathians. In the Northwestern Carpathians the hill belt is dominated mainly by the associations *Tilio-*

Carpinetum and *Pino-Quercetum* (Kornas 1968; Zarzycki 1991). In the Southeastern Carpathians, along with the mesophilic associations of the alliance ***Lathyro-Carpinion,*** mesoxerophilic phytocoenoses of the alliances ***Quercion petraeae*** and ***Quercion frainetto*** are also present, hosting many Balkan thermophilic species. Also, in the southwestern part of the Southern Carpathians (Cerna and Domogled Mts.), relict communities of *Pinus nigra* ssp. *pallasiana,* on limestone, were described, grouped in the association *Genisto radiatae-Pinetum pallasianae* Resmeriță 1972. These mesoxerophilic syntaxa widen the structural differences between the hill belts of the two mountain regions.

Syntaxonomic differences also exist in the structure of the alpine belt. In the South-eastern Carpathians the representative communities for the alpine belt are mainly those dominated by *Carex curvula,* as in the Alps (Nikelfeld 1993). Such microthermic communities, grouped in the association *Primulo-Caricetum curvulae* Br.-Bl. 1926 em. Oberd. 1959 are often found in all mountain ranges with altitudes between 2,200-2,500 m, but are missing from the North-western Carpathians (Matuszkiewicz 2008).

Also specific for the alpine belt of the Carpathian Mountains are the communities dominated by *Juncus trifidus, Oreochloa disticha* and *Festuca supina,* grouped in a specific alliance, ***Juncion trifidi*** Krajina 1933 (Grabherr 1993; Koči 2007; Dubravcova & Jarolimek 2007). These communities are also widespread in the alpine belt of the South-eastern Carpathians, where they populate mountain ridges and peaks. Based on the microthermic communities dominated by *Oreochloa disticha* from Tatra Mountains (2,400-2,660 m), Pawlowski (1925) highlighted a subnival vegetation belt, that he characterized through the association *Oreochloetum distichae* (*subnivale*) Pawl. 1926. Although all the alpine species included in this association are also present in the association *Oreochloo-Juncetum trifidi,* described from the South-eastern Carpathians, Romanian geobotanists assigned such plant communities to the alpine belt, (Beldie 1967; Boșcaiu 1971). As early as 1934, Borza, referring to the Retezat Mountains, points out that: "*One cannot speak of a proper subnival belt* ..." (p. 12).

Conclusion

In the South-eastern Carpathians 4 vegetation belts are well characterized regarding physiognomy, syntaxonomy and ecology.

The hill belt (400-700 m), situated at the base of the mountain massifs, is distinguished by mesophilic syntaxa grouped in the alliance *Lathyro hallersteinii-Carpinion* and by meso-xerophilic syntaxa of the alliances *Quercion petraeae* and *Quercion frainetto*.

The montane belt (700-1,800 m) is characterized by the presence of nemoral forest associations dominated by *Fagus sylvatica*, grouped in the alliance *Symphyto cordati-Fagion* and of the boreal forests with *Picea abies* grouped in the alliances *Soldanello majori-Piceion* and *Chrysanthemo rotundifolii-Piceion.*

The subalpine belt (1,800-2,200 m) is identifiable physiognomically through the shrub communities of *Pinus mugo* and *Juniperus communis* ssp. *alpina*, adapted to the microthermic climate and to snow accumulation in winter. The associations dominated by these shrub species are grouped in the alliances *Pinion mugo* and *Bruckenthalio-Juniperion.*

The alpine belt (2,200-2,540 m) is characterized, physiognomically and ecologically, by grasslands and oligothermic dwarf shrubs grouped in the alliances *Caricion curvulae* and *Loiseleurio-Vaccinion.*

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References

Baumgarten, J. Ch. 1816: Enumeratio stirpium Magno Transsilvaniae principatui, **1-2.** – Vindobanae.

Beldie, A. 1967: Flora şi vegetația munților Bucegi. – București.

Borza, A. 1934: Studii fitosociologice în Munții Retezatului. – Bul. Grăd. Bot. Muz. Bot. Univ. din Cluj, **14(1-2):** 1-84

— 1959: Flora şi vegetația Văii Sebeşului. – București.

— 1960: Gheobotaniceskoe rainoirovanie Rumînskii Karpat i sosednih oblastei. – Pp. 44-67 in: Flora i fauna Karpat. – Moscva.

Boşcaiu, N. 1971: Flora şi vegetația munților Țarcu, Godeanu şi Cernei. – Bucureşti.

Brândza, D. 1879-1883: Prodromul florei României. – București.

Coldea, G. 1990: Munții Rodnei. Studiu geobotanic. – Bucureşti.

— 1991: Prodrome des associations végétales des Carpates du sud-est (Carpates roumains). – Doc. Phytosociol. N.S. **XIII:** 317-539.

Cristea, V. 1993: Fitosociologie şi vegetaţia României. – Cluj-Napoca.

Doniță, N. 1962: Elemente pentru interpretarea zonalității vegetației din R.P.R. – Acta Bot. Horti Bucurestiensis, **1961-1962:** 919-935.

— 1965: Vegetationsstufen in den Karpaten Rumäniens. – Rev. Roum. Biol.-Botanique **10(60):** 455-467.

Drăgulescu, C. 1995: Flora şi vegetaţia din bazinul Văii Sadului. – Sibiu.

Dubravcova, Z. & Jarolimek, I. 2007: *Caricetea curvulae* Br.-Bl. 1948. – In: Kliment, J. & Valachović, M. (eds), Rastlinne spolocenstva Slovenska, **4.** Vysokohonska vegetacia. – Bratislava.

Ellenberg, H. 1996: Vegetation Mitteleuropas mit den Alpen, in ökologischer, dynamischer und historischer Sicht. – Stuttgart.

Georgescu, C. C. & Doniță, N. 1965: La division floristic des Carpates de Roumanie. – I. Rev. Roum. Biol.-Botanique **10(5):** 357-369.

Grabherr, G. 1993: *Caricetea curvulae* Br.-Bl. 1948. – In: Grabherr, G. & Mucina, L. (eds), Die Pflanzengesellschaften Österreich, 2. Natürliche waldfreie Vegetation. – Jena-Stuttgart-New York.

Grecescu, D. 1898: Conspectul Florei României. – București.

Hurdu, B. I., Puşcaş, M., Turtureanu, D., Niketić, M., Coldea, G. & Zimmermann, N. 2012: Patterns of plant endemism in the Romanian Carpathian (South-eastern Carpathians). – Contrib. Bot. **47:** 25-38.

Ivan, D. (ed.) 1993: Vegetation potentielle de la Roumanie. – Braun-Blanquetia **9:** 1-79.

Koči, M. 2007: Acidofilni al inské teávniky (*Juncetea trifidi*). – In Chytrý, M. (ed.), Vegetace Česke republiky **1.** Travina a keričkeva vegetace. – Praha.

Kornaś, J. 1968: Der Linden-Eichen-Heinbuchenwald (*Tilio-Carpinetum*) in den polnischen Karpaten. – Feddes Repert. **77:** 167-176.

— & Medwecka-Kornaś, A. 1967: Zespoty roślinne Gorców I. Naturalne i na wpól naturalne zespoty meleśne. – Fragm. Flor. Geobot. **13(2):** 167-316.
Martonne, E. de 1907: Recherches sur l'évolution morphologique des Alpes de la Transylvanie. – Paris.
Matuszkiewicz, W. 2008: Przewodnik do ozneczania zbiorowisk roślinnych Polski. – Warszawa.
Meusel, H. 1965: Die Gliederung Europas in Florenregionen und Florenprovinzen auf floristischer und pflanzengeographischer Grundlage. – Rev. Roum. Biol.-Botanique **10(1-2):** 99-107.
Mihăilescu, S. 2001: Flora şi vegetaţia masivului Piatra Craiului. – Bucureşti.
Mihăilescu, V. 1963: Carpații sud-estici de pe teritoriul R. P. Române. – București.
Muică, C. 1995: Munții Vâlcanului. Structura şi evoluția peisajului. – Bucureşti.
Nechita, N. 2003: Flora şi vegetaţia cormofitelor din masivul Hăşmaş, Cheile Bicazului şi lacul Roşu, Piatra Neamţ.
Nikelfeld, H. 1993: Pflanzengeographische Charakteristik Österreichs. – In: Mucina, L., Grabherr, G. & Ellmaner, T. (eds), Die Pflanzengesellschaften Österreich. I. Anthropogene Vegetation. – Jena.
Oprea, A. & Sîrbu, C. 2009: Munţii Stânişoarei (Carpaţii Orientali). Studiu fitosociologic. – Iaşi.
Ozenda, P. 1994: Végétation du Continent Européen Delachaux et Niestle. – Lausanne-Paris.
Pawlowski, B. 1925: Über die subnivale Vegetationsstufe im Tatragebirge. – Bull. Inst. Acad. Polon. Sci. Lett. et. SC. Math.-Nat., ser. B, Cracovie: 769-775.
Pax, F. 1898, 1909: Gründzuge der Pflanzenverbreitung in der Karpathen, 1-2**.** – Leipzig.
— 1919: Pflanzengeographie von Rumänien. – Nova Acta, Eop. **35.** – Halle.
Pignatti, S. 1980: Zur Probleme der Höhenstufen und Vegetationszonen. – Phytocoenologia **7:** 52-64.
Pușcaru-Soroceanu, E., Csűrös, Șt., Pușcaru, D. & Popova-Cucu, A. 1981: Die Vegetation der Wiesen und Weiden des Făgăraș-Gebirge in den Südkarpaten. – Phytocoenolgia **9(3):** 257-309.
Rivas-Martinez, S. 1988: La vegetación del piso alpino superior de los Pirineos. – Monogr. Inst. Piren. de Ecologia, Jaca **4:** 719-728.
Schur, F. 1866: Enumeratio plantarum Transsilvaniae. – Vindobonae.
Simonkai, L. 1886: Enumeratio florae Transsilvanicae vasculosae critica. – Budapesta.
Zarzycki, K. 1991: L'étagement de la végétation dans les Carpates du Nord. – Veröff. Geobot. Inst, ETH, Stiftung Rübel, Zürich **106:** 109-121.

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Can restored forests retrieve the flora of potential natural forests in urban areas? Comparison in 100, 500 and 45-year-old planted forests

Abstract

Fujiwara, K.: Can restored forests retrieve the flora of potential natural forests in urban areas? Comparison in 100, 500 and 45-year-old planted forests. — Fl. Medit. 31 (Special Issue): 371-406. 2021. — ISSN: 1120-4052 printed, 2240-4538 online.

There are three big restored forest areas in Tokyo and Yokohama. These were planted using the main trees of the natural forest for landscaping in Meguro (Tokyo), for restoring natural forest following succession in Shinjuku (Tokyo), and by planting saplings for developing natural forest directly in Yokohama. The biggest area is around the Meiji Jingu Shinto Shrine, which was constructed in 1915-1920 with a designed pine plantation and trees from the flora of selected natural forests, donated from throughout the whole Japanese Archipelago. Now this forest has developed into a semi-natural forest with landscaping trees and successional forests. The second large forest is around the Institute for Nature Study of the National Museum of Nature and Science in Meguro (Tokyo). It began as a lord's residence during the Kamakura Era, and the grounds became an Imperial estate from 1917. Since then the natural environment has been conserved. It was mostly a Japanese Garden, with old *Castanopsis cuspidata* var. *sieboldii* forest on the embankment (believed to have been built during the Muromachi period) and secondary forests. Tall, well-shaped pines (*Pinus thunbergii*), *C. cuspidata* var. *sieboldii* and *Quercus acuta* with 17 other species (totally 575 trees) were transported from here to the Meiji Jingu Shrine for its construction. Since 1947 the Institute for Nature Study belongs to the Ministry of Education, which opened it to the public. The third large forest is on the Tokiwadai Campus of Yokohama National University (YNU). This site was originally the third-oldest country-club golf course in the Kanto region. The oldest forest, a forest of *Castanopsis cuspidata* var. *sieboldii*, was planted on one part of the golf course in 1922. In 1976 and 1979, when all faculties of YNU moved to Tokiwadai, YNU planted saplings of species from the natural forest. Each of these sites developed increasingly natural forests, and many forest species came back. The forests with *Castanopsis* canopies, i.e. Meiji Jingu Shrine and Institute for Nature Study, have next-generation species on the forest floor. Unfortunately, in the forest of Yokohama National University, the main species planted were *Cinnamomum camphora, Quercus glauca, Machilus thunbergii*, and *Q. myrsinaefolia*.; later, a small amount of *Castanopsis cuspidata* var. *sieboldii* was planted. The oldest forest, a relic of the former golf-course period, had a canopy of *C. cuspidata* var. *sieboldini*, has successors in the forest, and formed a multi-layered forest despite its short history. For the restoration of natural forests, canopy and subcanopy species, plus some shrub species, from natural forests will become the key species. Otherwise there are no sources of seeds to be distributed in urban areas, and restoration of the species richness will take time.

Key words: dense mixed native-species plantation, evergreen broad-leaved forest, key forest-restoration species, Meiji Jingu Shrine, restoration of natural forest, urban forest.

Introduction

There are several methods for restoring natural forests: following succession, landscaping plantation, and plantation of saplings of canopy species from natural forest (mixed and densely: 1-3 individuals/m^2). Each method may use natural-forest species for plantation. This paper compares changes and development of native species based on potential natural forest within three Japanese examples. One is the roughly 100-year-old forest of the Meiji Jingu Shinto Shrine. The second example, from the Kamakura Era, is a landscaping plantation as a Japanese Garden of the so-called Shirokane (millionaire), which was afterward used by The Institute for Nature Study of the National Museum of Nature and Science, after having served as a samurai residence (Edo Era: 1964-1868), for navy and army powder storage (Meiji Era: 1872-1913), and as an imperial property (Taisho-Showa Era: 1917-1947) (Figs. 1, 2).

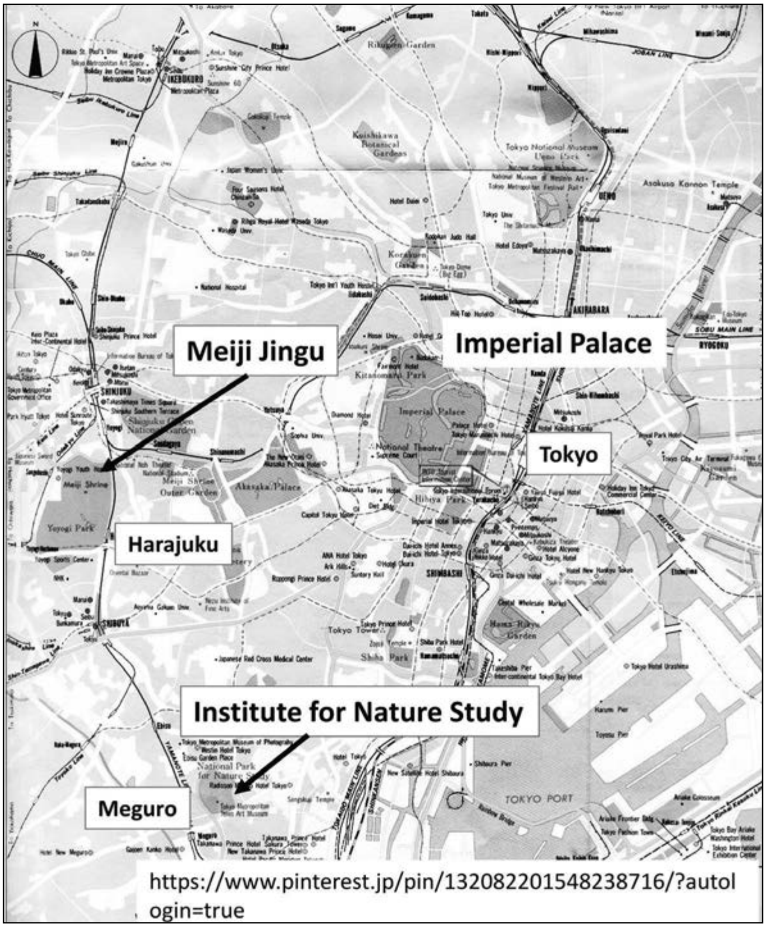

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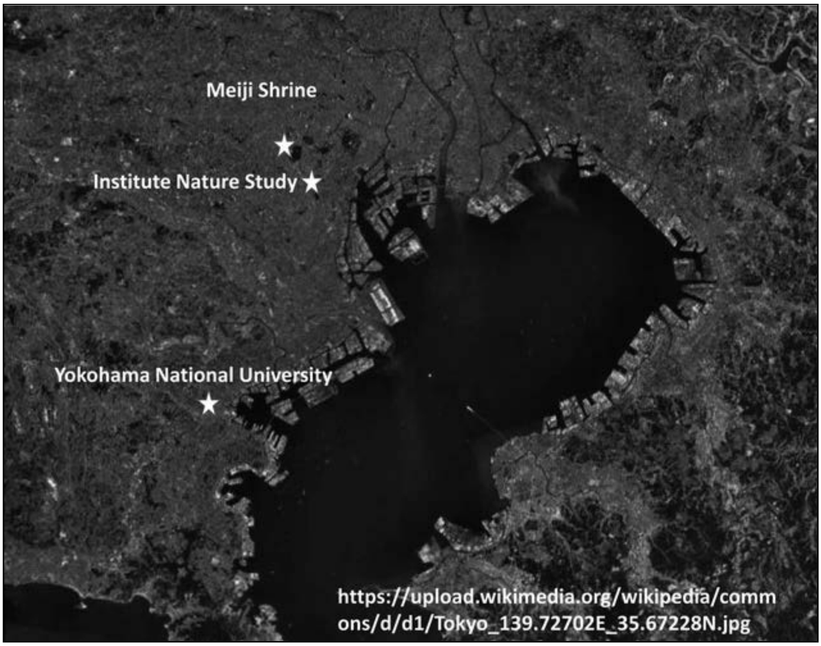
Fig. 1. Location of the Meiji-Jingu (Shito Shrine) and the Institute for Nature Study in Tokyo.



https://upload.wikimedia.org/wikipedia/commons/d/d1/Tokyo_139.72702E_35.67228N.jpg

Fig. 2. Location of Meiji-Jingu, the Institute for Nature Study, and Yokohama National University in the Kanto region.

The area of the Meiji Shinto Shrine, including the forest, is 70 ha and was begun in 1915 (a six-year project) for dedication to the deified spirits of Emperor Meiji and his wife, Empress Shoken. It is located in Shibuya (Tokyo: Fig. 3). The forest of Meiji Jingu Shrine was designed to follow succession over the next 100 years.

The Institute for Nature Study of the National Museum of Nature and Science has 20ha and had its beginnings as a lord’s residence during the Kamakura Era. The grounds became an Imperial estate from 1917, and since then the natural environment has been conserved. Now it belongs to the Ministry of Education, which opened it to the public. The forest was designed as a landscaping area and afterword developed several types of forests (Fig. 4). It even donated 475 black pines (*Pinus thunbergii*) for landscaping and several *Castanopsis cuspidata* var. *sieboldii* trees with tall, good shapes for planting at the Meiji Shinto Shrine. Individuals of *Castanopsis cuspidata* var. *sieboldii* on the embankments in the Institute for Nature Study are told to be 400 years old (Okuda 1972).

The third forest includes various tracts on the Tokiwadai Campus of Yokohama National University (45 ha) in Yokohama City (Fig. 5). This area was the third-oldest golf course (Hodogaya Country Club) in Kanto, built in 1923. Then Yokohama National University bought the land as a place to unify its various university faculties. The environmental protection forests (restoration of natural forest by Miyawaki method) were done in 1976 and 1979, and there are also relicts of the landscaping forests from 1923.

Fig. 3. Meiji-Jingu Shrine on Google Earth (photo on Dec. 16, 2020).

Fig. 4. Institute for Nature Study on Google Earth (photo on March 13, 2019).

History of plantation and developments:

The Meiji Shinto Shrine

The forest around the Meiji Jingu Shrine was designed to be a plantation of 100,000 trees dedicated from all over Japan. The species with the most individuals planted, in decreasing order, were 1. *Ilex crenata*, 2. *Pinus thunbergii*, 3. *Cinnamomum camphora*, 4. *Cleyera japonica*, 5. evergreen *Quercus* spp, 6. *Chamaecyparis obtusa*, 7. *Eurya japosica*, 8. *Pinus densiflora*, 9. *Cryptomeria japonica*, 10. *Rhododendoron* spp., 11. *Castanopsis cuspidata* var. *sieboldii*, 12. *Chamaecyparis picifera* and 13. *Zelkova serrata*, etc. (Table 1). Dr. Takanori Hongo (forester) designed the plantation to have coniferous species, especially *Pinus* spp. in the canopy (12-24 m height), with *Cryptomeria japonica, Chamaecyparis* spp. and

Fig. 5. Aerial photo of Yokohama National University (photo by Yokohama National University).

Abies firma in a sub-canopy layer (7-9 m). Then he put evergreen broad-leaved trees under the conifers to grow to a climax forest after succession (4-6 m). The fourth component is shrubs (Fig. 6 in Hongo 1923) (Ueda 2009). Pines already remained in the Forest Garden area, as well as *Cryptomeria* and *Chamaecyparis* spp. These species had good shapes for landscaping, and they were suitable for making a temporary canopy quickly. Evergreen broad-leaved trees, as the third layer, were ideal forest tree species and promised a good scenic effect.

The construction was begun in March 1915, with construction of the various precincts planned to be finished within six years.

An embankment was built on surrounding areas, but huge trees remained in this area, including *Aphananthe aspera* and *Zelkova serrata* (*Ulmaceae*). Outer masonry was built in the surroundings and piled up to avoid existing trees of *Z. serrata* and *A. aspera*, which totaled 35 individuals with more than one meter of circumference.

The length of the embankment is 3316m, and shrubby *Ilex crenata* was planted by donation of 10,000 individuals. The back-forest area of the shrine had filled soil, and evergreen broad-leaved species were planted for fire prevention and protection against smoke. The evergreen broad-leaved species were *Cleyera japonica, Quercus myrsinaefolia, Castanopsis cuspidata* var. *sieboldii, Cinnamomum camphora, Ilex integra, Osmanthus fragrans* and *Michelia compressa* (Hongo 1923). This area is a main part of the current *Cinnamomum camphora-Castanopsis cuspidata* var. *sieboldii* community. Maintenance after plantation was to prohibit collection of dropped leaves and for weeding. Cleaning of dropped leaves should be limited to the surroundings of buildings, on roads, in the garden, but not in the forests. Cleaning and weeding in the forest cause a decline in soil fertility and lead to forest devastation. When weeds grow over saplings, weeding is necessary several years after forestation.

Hongo (1923) also described details of 1) protection against storms, rain and snow, human hazards, damage to trees and smoke damage, against forest garden; 2) maintenance of garden roads, ponds, streams, etc.; 3) future measures for donated trees. Later Uehara (1971) described the entire planning and process of reforestation of the Meiji Jingu Shrine forest.

Table 1. Number of trees newly planted at the time of construction (more than 500 trees). (Meiji Jingu Building Document 1928).

Life form	Plant name	Numbers*
Conifers	*Pinus thunbergii*	12.317
	Chamaecyparis obtusa	6.243
	Pinus densiflora	4,054
	Cryptomeria japonica	3.938
	Chamaecyparis picifera	2.413
	Abies firma	1.493
	Taxus cuspidata	956
	Podocarpus nagi	619
	Platycladus orientalis	505
Evergreen broad-leaf trees	*Ilex crenata*	21.783
	Cinnamomum camphora	8.957
	Cleyera japonica	7.886
	Evergreen *Quercus* spp.	6,666
	Eurya japonica	5.989
	Rhododendron spp.	3.732
	Castanopsis cuspidata var. *sieboldii*	2.571
	Camellia sasanqua	1.623
	Camellia japonica	1.028
	Ilex integra	554
	Ternstroemia gymnanthera	531
Deciduous broad-leaf trees	*Zelkova serrata*	2.242
	Acer spp.	747
	Prunus spp.	707
	Ginkgo biloba	639
Herbs	*Cymbidium goeringii*	10.000

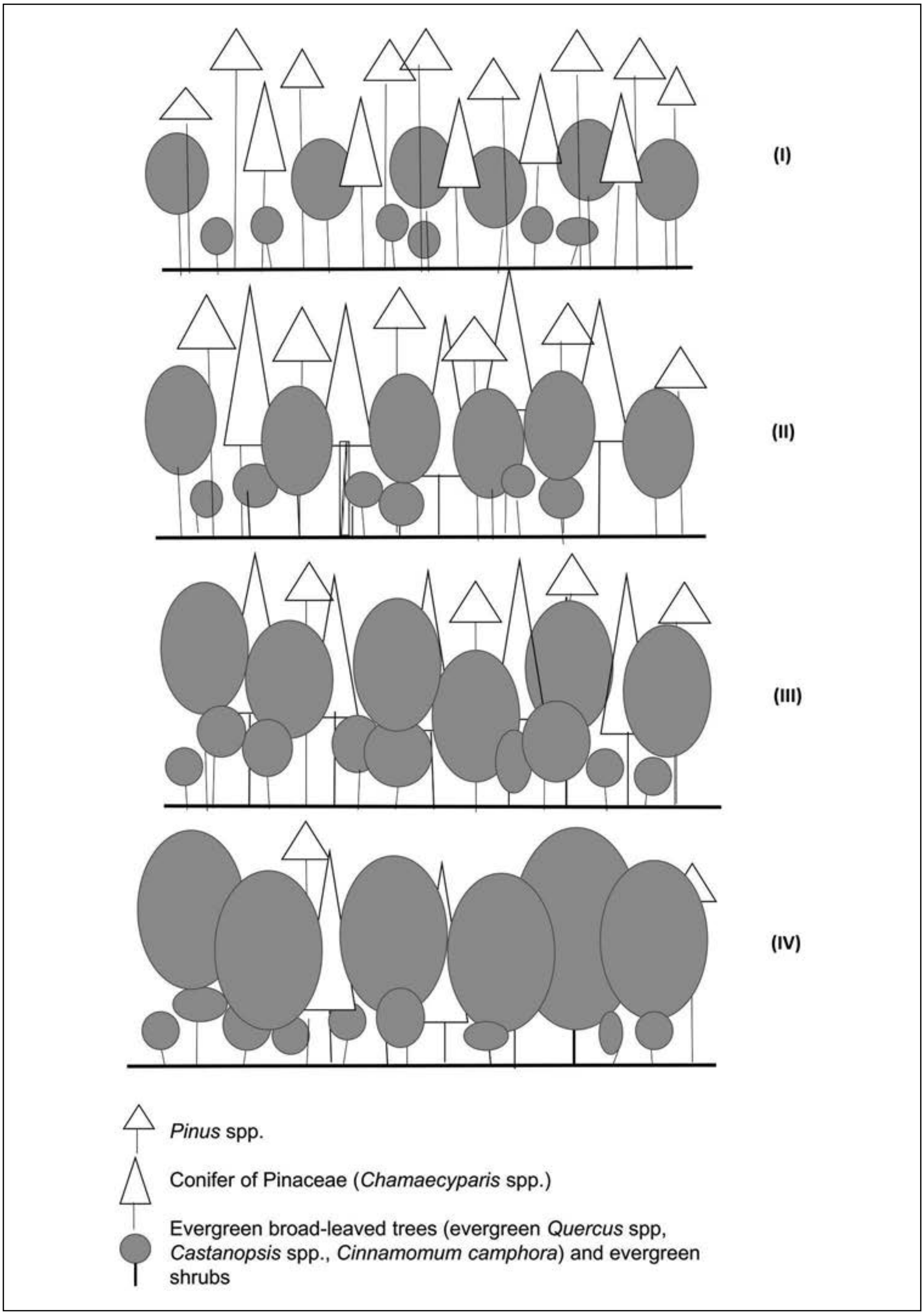


Fig. 6. Order of transition from establishment of the forest garden to the final (expected) appearance of the forest face (redrawn from Hongo 1923).

The Institute for Nature Study of the National Museum of Nature and Science

The Institute for Nature Study is located in Shirokanedai, a region of Tokyo that was created by marine erosion during a diluvial epoch some 200,000 to 500,000 years ago. In the Heian period (794-1185), it is thought that rice paddies were cultivated in the swampy lowlands of the Meguro and Shibuya Rivers, while gromwell, an essential ingredient in dyemaking, was grown in the broad plains above. With the start of the Muromachi period (1336-1573), the powerful clans of this area built residences here; earthen walls found in Shirokanedai are believed to be the remains of these houses. Though the masters of these houses are unknown, the place name “Shirokanedai” first appears in records dated to 1559, and one Shinrokuro, a grandson of military commander Ota Dokan (1432-1486), is listed as the area’s governor in period records. Moreover, legend has it that Shinrokuro was “rich in silver” (shirokane-choja). In the Edo period, Shirokanedai came under the control of Zojoji, a Buddhist temple. In 1664, it became the villa of Matsudaira Sanukinokami Yorishige (1622-1695), lord of Takamatsu and elder brother of the shogun Tokugawa Mitsukuni (1628-1701). Some of the older, larger pines in the Institute for Nature Study’s modern gardens are thought to have been among the very trees that grew in Matsudaira’s garden. In the Meiji period (1868-1912), the site was used as a gunpowder magazine, under the control of the Naval Ministry and Army Ministry. It was taken over by the Imperial Family Forests and Fields Bureau of the Imperial Household Ministry in 1917, whereupon it was renamed the Shirokane Imperial Estate (Fig. 4). http://www.ins.kahaku.go.jp/english/about/history/index.html

Uehara (1971) made a tree survey at the Institute for Nature Study before 1954 and decided to move 575 trees of 19 species from the Institute to Meiji Jingu Shrine. *Pinus thunbergii* had 475 individuals of large and small scenic trees. Conifer and evergreen broad-leaved trees, plus deciduous *Acer palmatum*, were 462 individuals. Transplantation and transportation work was carried out after two years of protective care (digging around the roots to foster the development of fibrous roots) before planting to the new site. This was carried out by over 1000 people for about a year (Uchida 1992).

The site passed to the Ministry of Education in 1949, whereupon it was designated a “national monument and historical landmark” and opened to the public as a national natural-education park (Fig. 4). It obtained its current status as the Institute for Nature Study of the National Museum of Nature and Science in 1962. http://www.ins.kahaku.go.jp/english/about/history/index.html

Yokohama National University

The Tokiwadai Campus of Yokohama National University (YNU) is located in the middle of Yokohama City (Fig. 5). Most of the forests were relicts of plantations from the previous golf course (Fig. 7), environmental protection forest which is origin of densely planted saplings (one to 1.5 saplings per square meter) (Fig. 8) and landscaping plantation. The golf course was named Hodogaya Country Club, was inaugurated in 1922, and was the third-oldest golf course in the Kanto region. Hodogaya Country Club moved to Asahi-ku (1967) in Yokohama after the Yokohama National University required the integrated land, and construction began in 1968. Therefore, relicts of forests were already 45 years old.

Fig. 7. Bird's-eye view of the Hodogaya Country Club before 1968.

Fig. 8. Planted saplings around the former Institute of Environment and Information Science and Technology (March 1977).

The construction of Yokohama National University was begun in 1968. The first reforestation was begun surrounding the former Institute of Environmental Information and Science* on March in 1976. The method of restoration of natural forest is the so-called Miyawaki method. It involves: 1) Using saplings (30-80 cm high) of natural forest species, especially canopy species, with root systems already well developed from growth in pots; 2) Planting different species in spatially random mixtures; and 3) Planting densely, with 1-3 individuals per square meter. Plantation at Yokohama National University used 1-1.5 individuals per square meter. In March 1979, the 30th Anniversary and Integrated Memorial Environmental Conservation Forest Creation Plan was carried out, based on the 30th Anniversary and Integrated Memorial Environmental Conservation Forest Creation Plan. It had four aspects: 1) The area around the school site would be surrounded by a border environmental conservation forest with a width of 10 m inside and outside. 2) For planting, we would use local species, especially evergreen broad-leaved trees, which will grow to a height of 20 m or more in the future depending on the location conditions. 3) The best use would be made of existing trees on the premises; single-tree value planting should be a three-dimensional green zone that forms a multi-layered structure. When single trees are planted, they should be as few as possible. 4) Around the school building of each faculty, independence of each faculty should be respected, based on the above basic principles (Miyawaki 1979). The university staff contributed for this plantation, with each Professor paying 3000 yen, each Associate Professor 2000 yen, and each Assistant 1000 yen. This plantation area was between the main gate to the executive office of YNU and the central square.

The other forests of Meiji Jingu and Institute for Nature Study were built to plant mature trees for landscaping.

Methodology of comparison and analysis

The Forest of Meiji Jingu shrine had three comprehensive field surveys; results from two recent surveys (Miyawaki & al. 1980; Okuromi & al. 2013) were compared and analyzed for the purpose. The forests, especially huge old *Castanopsis cuspidata* var. *sieboldii* forests, are kept on the old embankment at the Institute for Nature Study. The natural forests being restored were planted densely and randomly with saplings of canopy specie of natural evergreen broad-leaved forest.

The purposes of this paper are to compare each forest and analyze successors, comparing changes of height and cover, and growth behaviour of saplings.

1) Comparison of flora of different years at each site;
2) Comparison of successors was done by means of frequency tables for each stratum, based on phytosociological tables;
3) Tables for newcomers and disappearing species;
4) Comparison of height and cover range on graphs; and
5) For the sapling plantation, three different plantation sites were compared with data from two tree surveys.

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*Institute was integrated in Graduate School of Environment and Information Sciences on April, 2001.

Results

A. *Meiji Jingu Shrine*

1. *Forest development of Meiji Jingu Shrine*

The forest of Meiji Jingu was a planted site with 122,572 donated and transplanted trees (Table 1), and remaining trees before construction. These trees were planted based on a design by Hongo 1923 (Fig. 6). The tree survey in 2012 at the shrine forest of Meiji Jingu (Hamano & al. 2013) confirmed 1,764 conifer trees and found that 3,668 trees (68%) had disappeared from the first survey in 1980 (Ishigami 1980). Especially *Pinus thunbergii* and *Taxus cuspidata* decreased by more than 90%; *Pinus densiflora* decreased 80%; and *Chamecyparis obtusa, C. picifera*, *Cryptomeria japonica, Abies firma* and *Tsuga sieboldii* decreased around 50-60%. On the other hand, 26,192 evergreen broad-leaved trees were confirmed and 98,404 trees had disappeared (79%). Especially, *Ilex integra* and *Ternstroemia gymnanthera* decreased 30-40%; and *Castanopsis cuspidata* var. *sieboldii*, *Quercus myrsinaefolia, Q. acuta, Q. glauca, Cinnamomum camphora* and *Cleyera japonica* decreased 50-55%.

These results showed the first planting scheme developed close to the expected final forest face (Hongo 1923) in 2012; ca 100 years after plantation (Fig. 9).

Fig. 9. The main entrance of Meiji Jingu. Technology (March 1977).

2. *Comparison of forest composition*

1) *Flora*

The flora of shrine forest of Meiji Jingu was surveyed in 2012, confirming seed plants from 110 families and 586 species, with 234 woody plants, 352 herbs and 63 exotic species. Hamano 2012 compared the flora in 1980 (Honda & al. 1980): woody plants had decreased by 60 species from 294 species (1980) to 234 species (2012) (Hamano 2013), and ca 130,000 trees (Hamano & al. 2013). Families decreased from 150 families in 1980 to 110 families (2012). Herb species decreased a little, from 358 species (1980) to 352 species (2012). Exotic species increased from 34 species (1980) to 63 species (2012).

For species of evergreen broad-leaved forest rather than the total flora, several species increased, including *Quercus sessilifolia, Sarcandra glabra, Prunus spinulosa, Elaeagnus glabra, Ophiopogon jaburan*, *Cinnamomum sieboldii, Rhaphiolepis indica* var. *umbellata**, Symplocos prunifolia, Arisaema ringens*, and *Farfugium japonicum.* [*shows bird dispersal from garden.] Disappearing species were *Lithocarpus glaber, Quercus* × *yokohamensis, Celtis sinensis* var. *japonica* f. *longifolia*, *Michelia compressa, Daphniphyllum teijsmannii, Ilex pedunculosa* and *Pieris japonica**. These species are not native in Tokyo. Endangered species of secondary forest in Tokyo appeared well in 2012, including *Erythronium japonicum, Polygonatum odoratum* var. *pluriflorum, Carex oshimensis, Calanthe discolor, Cephalanthera erecta, Cephalanthera falcata, Cephalanthera longibracteata, Cymbidium macrorhizon*, *Epipogium roseum Liparis nervosa*. Even some secondary-forest species disappeared, including *Lindera glauca, Lindera umbellata, Kalopanax septemlobus, Pertya scandens*, and *Carex conic*a (Table 2).

2) *Community composition*

Okutomi & al. (2012) found newcomers in the evergreen broad-leaved forest, based on comparison of the *Cinnamomum camphora-Castanopsis cuspidata* var. *sieboldii* community surveyed in Miyawaki (1980) and Okutomi & al. (2012).

Newcomers were *Ophiopogon ohwii, O. yaburan, Sarcandera glabra, Euonymus japonucum*, *Pittosporum tobira, Distilium racemosum, Cinnamomum sieboldii* and *Tsuga sieboldii*. Newcomers are mostly bird-dispersed species, which may come from gardens surrounding the Meiji Jingu. *O. yaburan, Sarcandra glabra, Euonymus japonicum*, *Pittosporum tobira, Distilium racemosum,* and *Cinnamomum sieboldii* are considered escaped from gardens. On the other hand, *Symplocos lucida* (T2, S1, 2, H) was found in 32% of C*innamomum camphora-Castanopsis cuspidata* var. *sieboldii* community. *Symplocos lucida* would have been confused with *Ilex integra* in 1980, because *Ilex integra* disappeared in each stratum in 2012 (Table 3). Some species were described as newcomers, including *Torreya nucifera* in T2, H; *Aronia* (*Photinia*) *glabra* in T2; *Illicium anisatum* in S1; *Quercus phylliraeoides* in T2; and *Q. salicina* in S2. These were in only one stand and in the T2 layer. Therefore, these would have been overlooked in 1980. Other deciduous species were pioneers such as *Zanthoxylum ailanthoide, Elaeagnus umbellata, Melia azedarach, Botrychium japonicum, Oplismenus undulatifolius, Trichosanthes kirilowii* var. *japonica, Erechtites hieracifolia,* and *Akebia trifoliata*.

Table 2. Newcomer and disappearing natural-forest species in ca 40 years at Meiji Jingu, in the second flora survey by Hamano (2013).

Newcomer species	Disappearing species
Species of evergreen broad-leaved forest	
Quercus sessilifolia	*Lithocarpus glaber*
Sarcandra glabra	*Quercus* × *yokohamensis*
Prunus spinulosa	*Celtis sinensis* var. *japonica* f. *longifolia*
Elaeagnus glabra	*Michelia compressa*
Ophiopogon jaburan	*Daphniphyllum teijsmannii*
Cinnamomum sieboldii	*Ilex pedunculosa*
Rhaphiolepis indica var. *umbellata*	*Pieris japonica*
Symplocos prunifolia	etc.
Arisaema ringens	
Farfugium japonicum	
etc.	
Species of secondary forest and endangered species in Tokyo	
Erythronium japonicum	*Lindera glauca*
Polygonatum odoratum var. *pluriflorum*	*Lindera umbellata*
Carex oshimensis	*Kalopanax septemlobus*
Calanthe discolor	*Pertya scandens.*
Cephalanthera erecta	*Carex conica*
Cephalanthera falcata	etc.
Cephalanthera longibracteata	
Cymbidium macrorhizon	
Epipogium roseum	
Liparis nervosa	
etc.	

These species occur in gaps. In total, 47 new species appeared in 2012 (Okutomi & al. 2013). Species disappearing from 1980 to 2012 were 78 (Okutomi & al. 2013).

These were mostly pioneer species, but some evergreen broad-leaved species disappeared also, including *Michelia compressa, Ilex latifolia, Osmanthus ilicifolium, Rhodea japonica, Elaeocarpus sylvestris*, and *Ophiopogon planiscapus*. These species occurred in one or two stands.

Comparison of height and cover in each forest stratum at Meiji Jingu, in 1980 and 2012, is shown in Fig. 10. The canopy layer (T2) in 1980 changes to super-tree layer (ST) in 2012 with tree growth, but width of tree layer coverage is different within 10%. Shrub layer in 1980 grew up to tall shrub and short shrub layers in 2012. Width of coverage became half of the 1980 coverage. The seedlings of herb layer (H) in 1980 grew up to short shrub layer (S2) in 2012 and width of coverage is both similar. Mean coverage of 2012 is lower than 1980 because the herb layer (H) of 1980 includes seedlings and herbs.

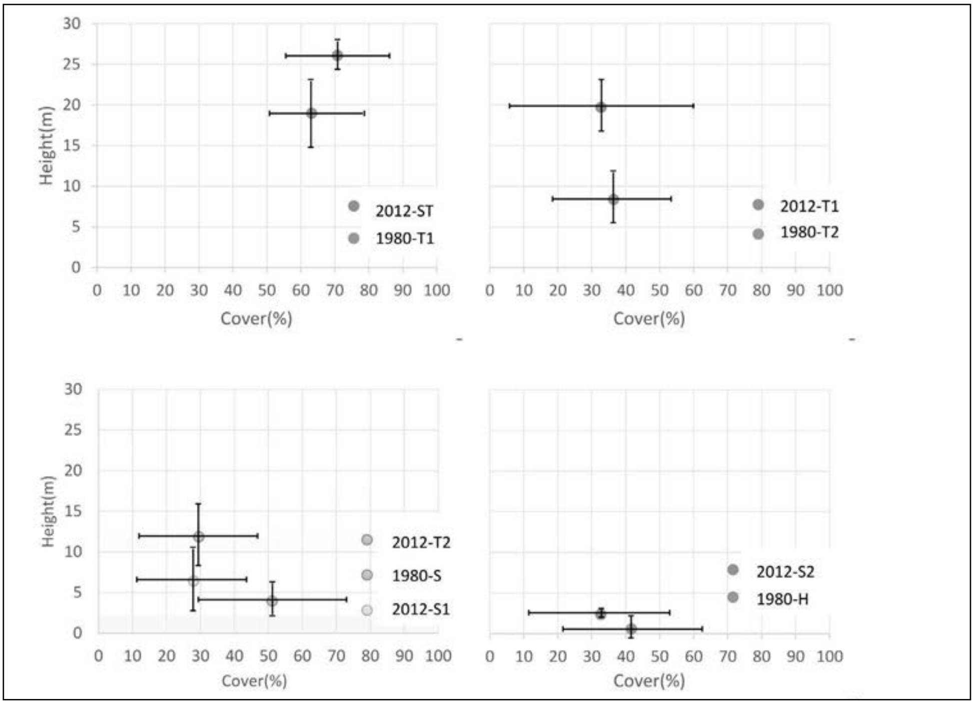


Fig. 10. Comparison of height and cover in each forest stratum at Meiji Jingu, in 1980 and 2013. ST: super tree layer; T1: Canopy layer; T2: Sub-canopy layer; S: shrub layer; S1: tall shrub layer; S2: short shrub layer; H: herb layer.

3) *Main species trends in each layer*

In order to see the trends of forest successors, the vegetation coverage of each layer for each species was compared by frequency numbers.

Trends of evergreen trees from 1980 to 2012 are very important to develop forest for the future. *Cinnamomum camphora* and *Castanopsis cuspidata* var. *sieboldii* are canopy trees, but *Cinnamomum camphora* is not native in Tokyo. The *Cinnamomum* frequency in the canopy layer is high (IV) and did not change in 30 years; its coverage increased since 1980. The frequency of *Cinnamomum* decreased in the shrub and herb layers. Successor seedlings also decreased (Table 3).

Castanopsis cuspidata var. *sieboldii* with *Quercus myrsinaefolia* composes one of the natural forest types in the Meiji Jingu area (Okutomi & al. 1987). Meiji Jingu is located on the borderline between the natural areas of Ardisio-Castanopsietum sieboldii and Quercetum myrsinaefoliae (Okutomi & al. 1987; Okutomi & al. 2013).

The frequency of *Castanopsis* in the T2 layer was high in 1980, but some trees of *Castanopsis* grew up to the ST layer, and the rest remained in the T1 layer. Half of the herb-layer individuals of *Castanopsis* grew up to the S2 layer in 2012, and the other half remained in the herb layer. *Castanopsis* occurs evenly in each layer. Usually *Castanopsis* cannot produce new seedlings so well because the acorns are eaten easily by insects. Seedlings in the forest are relatively few.

Table 3. Distribution of the main woody species in each stratum of the *Cinnamomum camphora-Castanopsis cuspidata* var. *sieboldii* community at Meiji Jingu.

Evergreen broad-leaved trees				Deciduous trees				Conifers			
Species name	layer	1980	2012	Species name	layer	1980	2012	Species name	layer	1980	2012
		27 relevés	47 relevés			27	47			27	47
Cinnamomum camphora	ST		IV (1-5）	*Zelkova serrata*	ST		III (1-4）	*Cryptomeria japonica*	ST		I (1-5）
	T1	IV (2-4)	II (1-5）		T1	III (+-3)	I (1-5）		T1	I (1-2)	r (+-3）
	T2	II (+-2)	r (+-1）		T2		r (+-1）		T2		
	S1		r (1）		S1				S1		
	S2	III (+-1)	r (+）		S2	II (+)	r (+）		S2		
	H	II (+)	I（+）		H		I（+）		H		
Castanopsis cuspidata var. *sieboldii*	ST		II (1-3）	*Aphananthe aspera*	ST		I (1-3）	*Chamaecyparis obtusa*	ST		II (+-4）
	T1	V (+-4)	III (1-4）		T1		II (1-2）		T1	IV (+-2)	I（+-1）
	T2		I (+-2）		T2	II (+-1)	II (+-2）		T2		r (+-1）
	S1	III (+)	II (+-3）		S1		II (+-2）		S1		
	S2		II (+-2）		S2	V (+-2)	I (+）		S2		
	H	III (+)	II (+-1）		H	II (+)	II (+-1）		H		
Quercus myrsinaefolia	ST			*Ginkgo biloba*	ST			Frequncy degree:			
	T1	III (+-3)	III (1-2）		T1	II (1-2)	r (2）	V(>80-100%), IV(>60-80%), III(>40-60%), II(>20-40%), I(>10-20%),			
	T2	II (+-2)			T2			+(>5-10%), r (>-5%)			
	S1		II (+-2）		S1						
	S2	III (+-1)	II (+-1）		S2						
	H	III (+)	III (+-2）		H	I (+)	III (+-2)				
Quercus glauca	ST			*Cornus controversa*	ST						
	T1	I (1-1)	r (1）		T1	+ (+-3)	I（1-3）				
	T2	r (1-1)	r (1）		T2	I (+-2)	+（1-2）				
	S1				S1						
	S2	I (+-1)			S2	III (+-1)	r (+）				
	H	II (+)	+（+）		H	+ (+)	I（+）				

Table 3. continued.

Quercus acuta	ST		r (1)		*Idesia polycarpa*	ST		1（1-2）
	T1	r (+)	+（1-2）			T1		+（1）
	T2	+ (1-2)	r (1)			T2	II (+-1)	
	S1		+（1-2）			S1		r (1）
	S2	I (+)	r (+）			S2	II (+)	r (+）
	H	+ (+)	r (+）			H		r (+）
Quercus gilba	ST		r (2）		*Acer palmatum*	ST		
	T1	r (3)				T1		r (2）
	T2					T2	I (1-2)	+（1-2）
	S1					S1		r (1-2）
	S2		r (+）			S2	II (+)	r (+）
	H		r (+）			H		
Machilus thunbergii	ST		r (1）		*Carpinus schonoskii*	ST		
	T1	r (1-1)	r (+）			T1	I (1-3)	+（+-1）
	T2					T2		+（+-1）
	S1		r (1）			S1		r (+）
	S2	I (+)	I（+）			S2	II (+-1)	r (+）
	H	I (+)	I（+）			H		
Ilex integra	ST				*Acer buergerianum*	ST		
	T1		r (1）			T1		r (1）
	T2	II (+-1)	r (2）			T2		
	S1		I（+-1）			S1		r (+）
	S2	III (+-1)	+（+-1）			S2	I (+)	
	H	II (+)	r (+）			H		
Neolitsea sericea	T2		r (+-1)		*Firmiana platanifolia* f. *tomentosa*	ST		
	S2	IV (+-2)	I (+)			T1		r (2）
	H	II (+-1)	I (+)			T2		
						S1		
						S2	+ (+)	
						H		r (+）

Quercus myrsinaefolia also occurs in each layer. Even the herb layer has the same frequency in 1980 and 2012. *Castanopsis* and *Q. myrsinaefolia* will have successors into the future.

On the other hand, *Q. glauca* and *Quercus acuta* have lower frequency than r-1.

Quercus gilva and *Machilus thunbergii* are similar. These species have few individuals and very fewer successors. *Ilex integra* and *Neolitsea sericea* were more than 25% in the shrub layer, but these decreased in the 2012 survey (Table 3).

The frequency of deciduous trees in canopy layer, such as *Zelkova*, is as high as in 1980. But *Zelkova* does not have successors. *Aphananthe aspera* and *Cornus controversa* had high frequency (III) in the shrub layer, but the frequency of these species decreased in each layer in 2021. The other deciduous tree species, such as *Idesia polycarpa, Acer palmatum*, and *Carpinus tschonoskii*, do not have successors. As the canopy layer of the *Cinnamomum camphora-Castanopsis cuspidata* var. *sieboldii* community closes, deciduous trees disappear. *Acer buergerianum* and *Firmina platanifolia* f. *tomentosa* are already less frequent (r-+) in some layers.

B. *The Institute for Nature Study of the National Museum of Nature and Science*

The Institute for Nature Study supplied trees for transplanting at the Meiji Jingu in 1915. Especially, huge trees of *Castanopsis cuspidata* var. *sieboldii* on the old embankment and *Pinus thunbergii* were transplanted. The *Castanopsis* trees remaining after transplanting to Meiji Jingu were 234, as measured and calculated in 1972 (Okuda 1972). The age of *Castanopsis* is estimated to be 400 years old (Fig. 11). Of these, 22 individuals were restored to the forest after being relocated during the standing towing work for highway construction.

1) *Newcomers and disappearing species*

Okuda described newcomers and disappearing species five years after forest restoration. Comparison of vegetation composition showed five new species of evergreen plants and 10 new deciduous species (Table 4). The newcomer species were seedlings of *Aucuba japonica, Neolitsea sericea, Ligustrum japonicum*, and shrubs of *Camellia japonica, Eryobotrya japonica* and *Hedera rhombea*. Deciduous new species were secondary species such as *Styrax japonica, Euonymus sieboldiana, Prunus grayana, Callicarpa japonica*, etc. Twenty pioneer or secondary species disappeared (Okuda 1972). When the canopy closes and the surrounding area has forests, forest species can come back in as little as five years.

Okuda (1980) compared vegetation change over 15 years since 1966 and compared forest change since then in 2013. The results were: 1. Old, gnarled *Castanopsis* trees had become remarkable (Okuda 1972), and tree vigor weakened (Okuda 1980, 2013); 2. Forests dominated by *Quercus acuta* are alive, but the *Castanopsis* canopy had weakened slightly; young trees of *Castanopsis* were growing well (Okuda 2013). The coverage of individual species changed. In the understorey there is remarkable growth of *Trachycarpus fortunei, Ligustrum japonicum* and the vine *Stauntonia hexaphylla*. Coverage of shrub-layer species such as *Ligustrum japonicum, Machilus thunbergii, Ternstroemia gymnanthera, Trachelospermum asiaticum,* and *Kadzura japonica* increased. Newcomers in the herb layer were *Ficus erecta, Cinnamomum japonicum, Zanthoxylum ailanthoides, Pollia japonica*, etc. (Okuda 2013).

Fig. 11. *Castanopsis cuspidata* var. *sieboldii* forest on the long old embankment at the Instutute for Nature Study.

Table 4. Newcomers and disappearing species after five years of the standing towing work for highway construction at the Institute for Nature Study.

Newcomers			
Shrub layer		Herb layer	
Evergreen species	Deciduous species	Evergreen species	Deciduous species
Camellia japonica	*Styrax japonica*	*Aucuba japonica*	*Prunus grayana*
Eryobotrya japonica	*Euonymus sieboldiana*	*Neolitsea sericea*	*Callicarpa japonica*
Hedera rhombea		*Ligustrum japonicum*	*Smilax china*
		Pleioblastus chino	*Akebia quinata*
			Oplismenus undulatifolius
			Arisaema urashima
			Parthenocissus tricuspidata
			Rubus hirsuta
Disappearing species			
Evergreen species	Deciduous species	Evergreen species	Deciduous species
Quercus myrsinaefolia	*Clerodendron japonicus*		*Macleaya cordata*
Pleioblastus chino	*Rhus javanica*		*Dioscorea tokoro*
	Mallotus japonicus		*D. japonica*
			Trichosanthes cucumeroides
			Viola grypoceras
			Eupatorium chinensis var. *simplicifolium*
			Conyza canadensis
			Thelypteris viridifrons
			Fatoua villosa
			Zanthoxylum schinifolium
			Solanum lyratum
			Thelypteris decursiva-pinnata
			Vibrunum dilatatum
			Celastrus obtusifolius
			Festuca paruigluma
			Boehmeria japonica var. *longispica*
			Solanum nigrum

2) *Successors in each layer in Castanopsis forests*

The *Castanopsis cuspidata* var. *sieboldii* forest at the Institute for Nature Study is classified in the *Quercus acuta-Castanopsis cuspidata* var. *sieboldii* community (Okuda 1969) and the Ardisio-Castanopsietum sieboldii (Okuda 1969, 1970).

Castanopsis forests at the Institute for Nature Study were classified into the *Camellia japonica* subunit (F1, F2) and the typical unit (F3) (Okuda 1966). The *Camellia* subunit was differentiated by *Camellia japonica* and *Ilex integra,* and occurred on the embankment that was believed to have been built in the Muromachi period (1336-1573) (Institute for Nature Study of National Museum of Nature and Science 1999). Some of the older, larger pines in the Institute for Nature Study's modern gardens are thought to have been among the very trees that grew in Matsudaira's garden in the Edo Period (1664). The *Camellia* subunit has a *Ternstroemia gymnanthera* sub-subunit of the subunit (F1) and a typical sub-subunit of the subunit (F2). The *Ternstroemia gymnanthera* sub-subunit has a mean species number of 44, the typical sub-subunit (F2) has 40, and the typical subunit (F3) has 38. *Castanopsis* and *Quercus acuta* occur in *Pinus thunbergii* forests too (F4). The *Pinus* forest has a mean species number of 47, which was the highest number (Table 5). Cover in each stratum of *Castanopsis cuspidata* var. *sieboldii* forest and *Pinus thunbergii* forest in 1966 is shown in Fig. 12.

The successors of *Castanopsis* forests were analyzed based on Okuda & Miyawaki 1966 (Table 5) and 2013 (Okusa 2013). Table 5 shows the frequency and cover of the main woody species for checking successors.

The important view is whether successors of canopy trees can keep a high frequency and coverage in the shrub and herb layers. *Castanopsis cuspidata* var. *sieboldii* in the Ardisio-Castanopsietum on the embankment has frequent seedlings in the herb layer in F1 and F4 (Table 5). The cover of the *Castanopsis* successors is less than 5% in F1 and F3, despite high frequency (IV, V) in the herb layer. *Castanopsis* occurs in the shrub layer with high frequency (IV, V) and relatively high coverage (+-4). Frequency (I) in the subcanopy tree layer (T2) is low. Even so, Okuda (2013) described that young *Castanopsis* grew up. *Quercus acuta* occurs with lower frequency in the canopy layer, shrub layer and herb layer. The *Camellia* subunit has high frequency of *Camellia* and *Ilex* in the shrub layer (IV, III), and *Ternstroemia* has high frequency in the herb layer (V). The *Pinus* forests were differentiated by *Pinus thunbergii* and *P. densiflora* (F4). *Pinus* occurs only in the canopy and subcanopy, with no successors in the shrub and herb layers. The canopy layer is relatively open (coverage 2-3). The frequency of *Castanopsis* in the shrub and herb layers of *Pinus* forests is high (IV-V) because the high penetration of sunlight helps the broad-leaved trees grow well. Even *Quercus acuta* has high frequency in the herb layer (III). Another evergreen broad-leaved species, *Machilus thunbergii,* has high frequency in the herb layer of the *Camellia* subunit (IV, 2) and subcanopy layer (IV) in the typical subunit of *Castanopsis* forest. *Machilus* has high frequency in the shrub layer of *Pinus* forest (III). *Quercus myrsinaefolia* occurs with high frequency (IV) in the herb and shrub layers of *Pinus* forests. Other evergreen broad-leaved woody species have low frequency.

The deciduous woody species, *Aphananthe aspera*, has high frequency (V) in the shrub layer of all forests. *Quercus serrata* occurs with high frequency in the herb layer (II, V) of all forests, but there is no guarantee that these seedlings will grow in the shade.

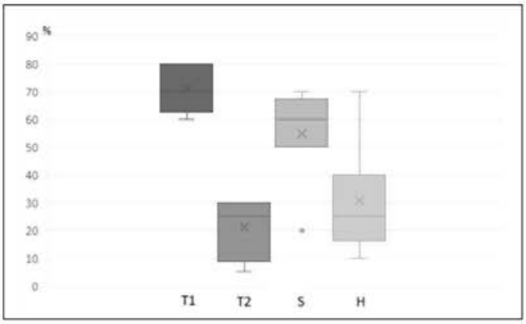
The successors in the *Castanopsis* forests in Institute for Nature Study were relatively good. And the situation is improved in Okuda (2013) without data.

Table 5. Comparison of woody species in various strata of *Castanopsis cuspidata* var. *sieboldii* forest and *Pinus thunbergii* forest at the Institute for Nature Study.

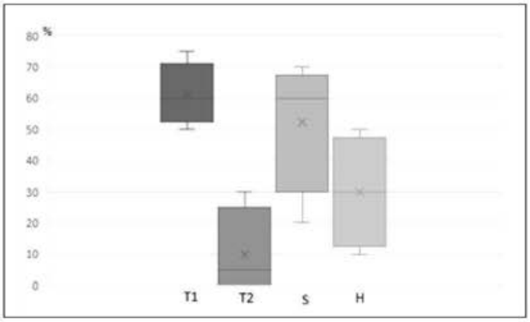
Running number		F1	F2	F3	F4
Number of relevés		8	4	5	5
Mean number of species		44	40	38	47
Differential species of *Castanopsis* forest and *Pinus* forest at the Institute for Nature Study					
Castanopsis cuspidata var. *sieboldii*	T1	V(3-5)	4(4)	V(3-5)	
	T2	I(3)	1(1)	I(1)	
	S	IV(1-3)	4(+-4)	IV(+-4)	V(+-3)
	H	V(+)	2(+-1)	II(1-2)	IV(+)
Quercus acuta	T1	II(+-2)	1(+)		I(+)
	T2				I(+)
	S	II(+-1)	2(+)	I(+)	I(+)
	H	II(+)	2(+)	I(+)	III(+)
Differential woody species of sub-units:					
Ilex integra	T1	II(1)	1(1)		
	T2	I(2)			
	S	III(+-2)	2(+)	II(+)	
	H	I(+)	1(+)		
Camellia japonica	T2	I(1)	1(1)	I(+)	
	S	IV(+-3)	3(+)		
	H	II(+)			
Ternstroemia gymnanthera	S	IV(+)			
	H	V(+)	1(+)		I(+)
Differential species of *Pinus* forest:					
Pinus thunbergii	T1				V(2-3)
Pinus densiflora	T1				III(1-3)
	T2				II(1-2)
Evergreen woody species:					
Machilus thunbergii	T1			I(2)	
	S	I(1)	1(+)	IV(+)	III(+)
	H	IV(+)	2(+)	II(+-1)	II(+-1)
Quercus myrsinaefolia	T2			I(+)	I(1)
	S	I(+)		I(1)	IV(+)
	H	I(+)	2(+)	II(+)	IV(+)
Cleyera japonica	S	I(+)			II(+-1)
	H	I(+)			I(+)
Dendropanax trifidus	S	II(+)			
	H		1(+)		
Quercus paucidentata	H	I(+)			
*Eriobotrya japonica**	H	II(+)	1(+)	I(+)	

Table 5. continued.

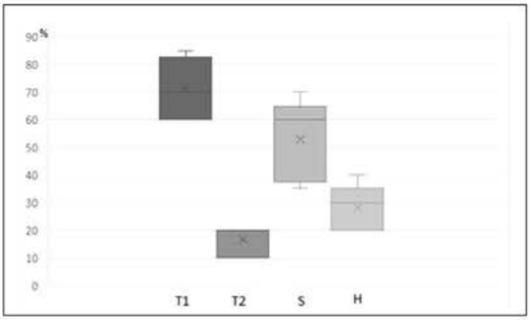
Deciduous woody species:					
Aphananthe aspera	T1	II(2)			
	T2	II(+)		I(+)	I(+)
	S	V(+-2)	3(+)	V(+-2)	V(+)
	H	II(+-1)	1(+)	I(+)	
Magnolia kobus	T2		1(1)	III(+-1)	I(1)
	S	V(+)	3(+-1)	II(+-1)	I(1)
	H	III(+)	1(+)	II(+)	III(+)
Quercus serrata	T1			II(1)	
	T2			I(1)	
	S	I(+)		I(+)	III(+-2)
	H	V(+)	3(+)	III(+)	III(+)
Cornus controversa	T1			I(1)	III(3-4)
	T2	I(+)	2(1-3)	II(+-1)	I(2)
	S	II(+)		III(+)	
	H	I(+)			
Prunus grayana	T1		1(2)	I(+)	I(3)
	T2	I(+)		II(1)	III(+-1)
	S	III(+-1)		I(2)	III(+)
	H	II(+)			I(+)
Celtis sinensis var. *japonica*	T2			I(+)	
	S	II(+)		I(+)	
	H	I(+)	1(+)		II(+)
Acer palmatum	S	I(+)	3(+)	II(+)	IV(+-1)
	H	I(+)		II(+)	I(+)
Styrax japonicus	T2				III(+-1)
	S	II(+)			II(+)
	H	I(+)	1(+)	II(+)	
Idesia polycarpa	T1	III(+-2)	2(1-2)		
	T2				II(+-4)
	S	II(+)		I(+)	II(+)
	H	II(+)			
Zelkova serrata	T1		1(2)		
	S	III(+-2)	1(+)		I(+)
	H	I(+)		I(+)	I(+)
Mallotus japonicus	T2	I(1)	1(2)		II(+-1)
	S	I(+)			
	H		1(+)		
Prunus jamasakura	T1		1(1)		
	T2	I(+)			II(+)
Cryptomeria japonica	T1			I(+)	
	H	I(+)			
Castanea crenata	H				I(+)
Carpinus tschonoskii	T1	I(1)			
	S			I(+)	
Padus buergeriana	S	II(+)		I(+)	
Phellodendron amurense	H	I(+)			
Styrax obassia	T1	II(1)			
	T2	I(1)			
Diospyros kaki	H	II(+)		I(+)	
Sapindus mukorossi	T2			I(+)	
	S		1(+)		
Robinia pseudoacacia	H	II(+)			
Maackia amurensis var. *buergeri*	H	I(+)			
Ilex serrata	S	I(+)			
	H	I(+)			
* escaped species					



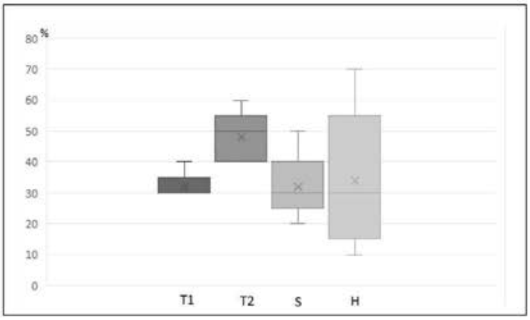
a. *Ilex integra* subunit, *Ternstroemia japonica* sub-subunit



b. *Ilex integra* subunit, typical* sub-subunit



c. Typical* subunit of *Castanopsis cuspidata* var. *sieboldii* forest.



d. *Pinus thunbergii* forest

Fig. 12. Cover (Y axis) in each stratum (x axis) of *Castanopsis cuspidata* var. *sieboldii* forest and *Pinus thunbergii* forest in 1966 at the Institute for Nature Survey (based on Okuda & Miyawaki 1966). *Typical means no differential species.

C. *Yokohama National University*

1) *Creation of environmental protection forests and their development*

Yokohama National University was constructed in 1968 on land that was formerly a golf course, with some forest fragments remaining (Fig. 11). After the Institute of Environmental Science and Technology was built (1973), a new idea and ecological technology were used surrounding the new building (March 1976). This idea was to create environmental protection forest from dense, spatially random, mixed-species plantation of native tree species grown as potted saplings in order to guarantee already well-developed root systems (Fig. 8) (Miyawaki & al. 1974). Planted seedlings grow faster by dense planting (Fig. 13) (Miyawaki & Fujiwara 1988; Miyawaki & al. 1993; Fujiwara & al. 1993).

The potential natural forest of the area of Yokohama National University is Ardisio-Castanopsietum sieboldii (Miyawaki & al. 1972; Miyawaki 1979). In spite of the potential forest, the production of seedling species was not enough. The planted species were *Quercus glauca, Cinnamomum camphora, Machilus thunbergii, Quercus myrsinaefolia* and some *Castanopsis cuspidata* var. *sieboldii.* These seedlings with 0.4-0.8m height were planted in 1976, at 1-1.5 individuals per square meter, around the building of the former Institute (current 4^{th} building of Graduate School of Environmental and Information Sciences) (Fig. 8); the result in 2018 is shown in Fig. 13.

To commemorate the integration of all faculties on the Tokiwadai campus and the 30th anniversary of the founding of Yokohama National University, the area of environmental protection forests was enlarged by donations of the university staff (professor: 3,000 yen; associate Professor: 2,000 yen; assistant 1,000 yen). An aerial photo of Yokohama National University in 2019 shows a green campus (Fig. 14).

Growth data in 1988 and 1993 show the pattern of growth (Miyawaki & Fujiwara 1988; Fujiwara & al. 1993) (Fig. 15). Green shows area UB-1, planted in 1976; blue shows area UB-2, planted on a slope in 1979; and brown shows area UB-3, planted on flat ground in 1979. The three year difference in age already showed big growth differences due to the dense plantation (Fig. 16).

UB-1 is flat topography, UB-2 is sloping and UB-3 is flat. The planting density was also different: UB-1 is $1.5/m^2$, UB-2 is $2.0/m^2$ and UB-3 is $1.0/m^2$. The UB-3 site does not have good drainage. From these results one can conclude that: 1. Dense plantation (more than $1.5/m^2$) shows a better growth rate; 2. Plantation on sloping ground also shows a better growth rate; 3. Drainage is an important key for good growth; and 4. *Cinnamomum camphora* has good growth rate in height and diameter both, but it is not native in Japan. *Machilus* has good growth rate for diameter, but its height is less than for *Cinnamomum camphora*. The diameter of *Quercus* species increases slowly, but height is similar to the average of *Cinnamomum camphora*. *Quercus* species grow slender and increase their diameter afterward. Now it is around 40 years after plantation. Measurement data will be expected.

Fig. 13. Environmental protection forest of Fig. 8 in Jan. 2018.

Fig. 14. Aerial photo of Yokohama National University (2019)..

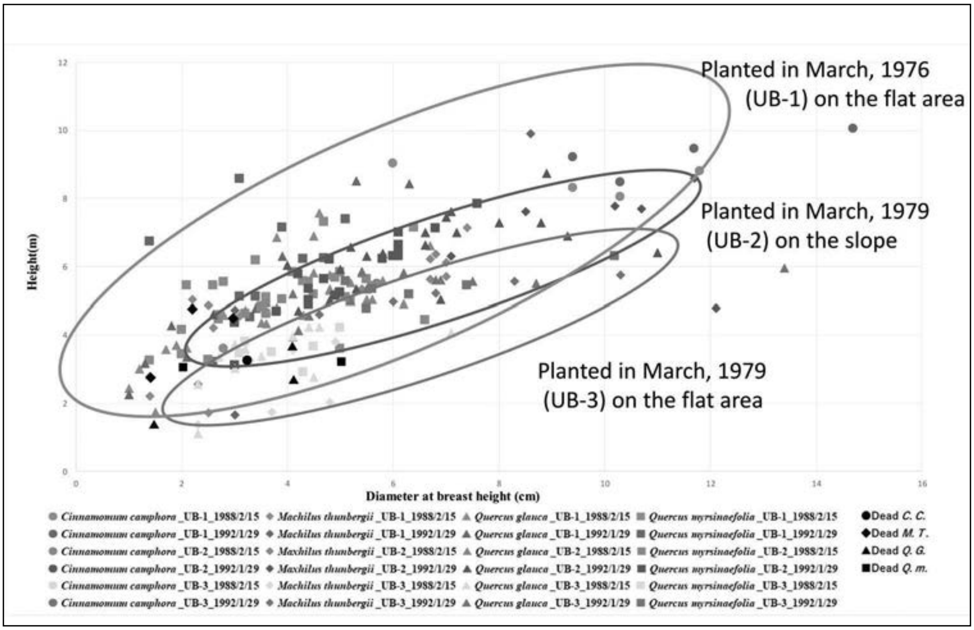


Fig. 15. Relationship of tree height and diameter at breast height in UB-1~3 based on data from 1988 and 1992 (Data from Fujiwara & al. 1993).

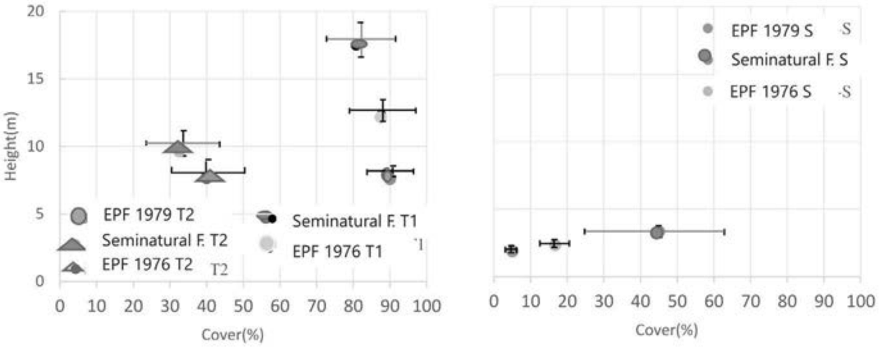
2) *Flora of Yokohama National University and Comparison of woody species in seminatural forests and environmental protection forests*

The flora of the Tokiwadai campus of Yokohama National University was surveyed before construction in 1968 of the university on the abandoned golf course (Kitagawa & al. 1968) and reported 274 species. After campus construction, Okuda reported 404 species in 1994, from a four-year survey. In 2000, Tohma and colleagues surveyed the entire campus area and compared the change in the flora since 1968, before and after university construction. Then natural species were 508 species in 108 families, and planted species were 132 species in 65 families (Tohma & al. 2000). Rare species and red-data species were 54 on the 45.5 ha of campus.

Meiji Jingu and the Institute for Nature Study had natural species occurring, and these have already 100 and 500 years of history. Densely planted forests show good growth rate, but the next target is the return of natural species.

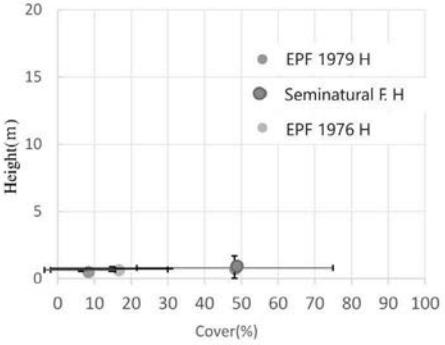
Here the woody species of environmental forests and seminatural forests that are remnants from a golf course (Fig. 11) are compared, and the presence or absence of successors in environmental forests is checked. Successors in the forests of Meiji Jingu and the Institute for Nature Study were reported (Tables 3, 5).

The compositions of the environmental protection forest and old seminatural forests were compared in Table 6. Forest patches were probably planted when the golf course was constructed in 1922 because old huge *Castanopsis* occur in lines, mixed with young trees. These are already multi-layered and composed of natural species.



a. Comparison of canopy and subcanopy layers

b. Comparison of shrub layers



b. Comparison of herb layers

Fig. 16. Difference of height and cover in different layers of environmental protection forest and relict *Castanopis cuspidata* var. *sieboldii* forest at Yokohama National University (Seminatural F.: Seminatural forest; EPF: Environmental protection forest).

The main natural species, i.e. *Castanopsis cuspidata* var. *sieboldii, Ilex crenata, Neolitsea sericea* and *Osmanthus heterophyllus*, are very few or do not occur in the environmental forest at all. *Quercus glauca*, a planted canopy species, does not occur in remnant *Castanopsis* forest. *Q. glauca* occurred in the Meiji Jingu forest but not in the *Castanopsis* forest at the Institute for Nature Study. On the other hand, *Machilus, Q. myrsinaefolia* and *Ligustrum japonicum* can be seen with high frequency.

Developed canopy trees had already had their seeds harvested, and these were germinated and became successors. But the mean species numbers of environmental forest (19-27) are half those in seminatural *Castanopsis* forests (39, 43).

Table 6. Comparison of woody species in various strata of a relict forest (*Castanopsis cuspidata* var. *sieboldii*) and restored forests (environmental protection forests) at Yokohama National University and in 1992 (Data from Fujiwara & al. 1993).

Forest type		Seminatural forest		Environmental protection forest		
Running number		1	2	3	4	5
Number of relevés		4	2	3	5	3
Mean total number of species		43	39	19	20	27
Number of EG-BL forest species		24	21	7	12	15
Species names of woody plants	Stratum					
Differential woody species:						
Castanopsis cuspidata var. *sieboldii*	T1	4(4-5)	2(4-5)		I(1-1)	
	T2	4(1-3)	1(2)	1(2-2)		
	S	4(+-2)			I(+)	
	H	3(+)	1(+)			
Ilex crenata	S	2(+)	1(+)			
	H	3(+)	2(+)			1(+)
Neolitsea sericea	T2	1(+)	1(1)			
	S	3(+)	2(1)		I(+)	
	H		2(+)			
Osmanthus heterophyllus	H	3(+)				
Callicarpa japonica	S	3(+)	1(+)			
	H		1(+)			
Thea sinensis	S		2(+-1)			
	H		1(1)			
*Acer palmatum**	T2		1(1)			
	S		1(2)			
	H		1(+)			
Quercus glauca	T1				II(1-2)	1(1)
	T2			3(2-3)	IV(1-3)	1(1)
	S				III(+-1)	1(1)
	H			1(+)	II(+)	
Cinnamomum camphora	T1				II(3-4)	2(2-3)
	T2			2(2-3)	II(1-2)	1(4)
	S	2(+-1)	1(+)	2(+)	I(+)	1(+)
	H		1(+)		I(1-1)	
Machilus thunbergii	T1		1(2)		IV(1-3)	2(1-2)
	T2			2(2-4)	IV(+-4)	2(2)
	S	1(+)	1(+)	2(+)	III(+-2)	2(+-1)
	H	1(+)			II(+)	1(+)
Quercus myrsinaefolia	T1				III(1-2)	2(2-4)
	T2		1(1)	2(2-4)	III(+-3)	2(1)
	S	1(+)	1(+)		II(+-1)	1(+)
	H	1(+)	1(+)	1(+)	III(+)	3(+)
*Pittosporum tobira**	S				III(+)	1(+)
	H	1(+)		1(+)	I(+)	1(+)
Ligustrum japonicum	S	1(1)	2(+-1)		I(+)	1(+)
	H	1(+)			IV(+)	3(+)
*Ligustrum lucidum**	S				I(+)	1(+)
	H				I(+)	
*Robinia pseudoacacia**	H				II(+)	1(+)
*Trachycarpus fortunei**	S	2(+)	2(+-1)			
	H	2(+)	2(+-1)		V(+)	3(+-1)
Ardisia crenata	H	4(+-1)				2(+)
Camellia japonica	S	1(+)				2(+)
	H					1(+)

Table 6. continued.

Camellia sasanqua	H		1(+)			1(+)
Aphananthe aspera	T1		1(1)			
	T2	1(1)				
	S	1(1)				1(+)
	H					2(+)
Evergreen woody species:						
Aucuba japonica	S	4(1-2)	2(2)			1(1)
	H	3(+-1)	1(+)	1(+)	IV(+)	1(+)
Euonymus japonicus	S	1(1)	1(+)		I(+)	1(+)
	H	2(+)			II(+)	2(+)
Eurya japonica	T2	3(+-1)				
	S	4(+-1)				1(+-1)
Fatsia japonica	S	4(1-2)			I(+)	
	H	4(1)	2(+)	1(+)	III(+)	2(+)
*Viburnum awabuki**	H	1(+)			I(+)	
*Pyracantha angustifolia**	S				I(+)	
	H					1(+)
Pinus densiflora	S	1(2)			I(+)	
Ilex integra	S	1(+)				
Dendropanax trifidus	H	1(+)				
Cinnamomum japonicum	S	1(+)				
*Ternstroemia gymnanthera**	S				I(+)	
	H				I(+)	
Rhaphiolepis umbellata var. *integerrima**	H				I(+)	
Deciduous woody species:						
Zelkova serrata	T2	1(+)				
	S	3(+)			II(+)	
	H	1(+)	1(+)	1(+)	III(+)	3(+)
Celtis sinensis var. *japonica*	T1		1(2)			
	T2	1(1)			I(+)	
	S	4(+-2)		1(+)	II(+)	2(+)
Magnolia kobus	H				I(+)	1(+)
Morus bombycis	S	3(+)		1(+)	III(+)	3(+)
	H		1(+)	1(+)	I(+)	
Cornus controversa	T1		1(1)			
	T2	3(1-2)				1(2)
	S	1(1)	1(1)			1(+)
	H			1(+)		
Prunus grayana	H	1(+)		1(+)		1(+)
Idesia polycarpa	T1	1(1)				
	T2	1(1)				
Pourthiaea villosa var. *laevis*	S	1(+)				
	H		1(+)			
Viburnum dilatatum	S	4(+)				
	H	1(+)	1(+)			
Cornus brachypoda	T2	1(1)				
	H	1(+)				
*Ginkgo biloba**	H			1(+)		1(+)
etc.						
** species escaped from gardens, including alien trees like Robinia pseudoacacia*						

Sites planted in 1979 still had low mean numbers of total species. Harada and Hayashi surveyed environmental forest species in 2017 (Harada & Hayashi 2019) and found only one species increased. Sample numbers were not reported, so this cannot be discussed here. It is discussed in the Discussion and Conclusion section.

Both forest types have *Trachycarpus fortunei, Aucuba japonica* and *Fatsia japonica* relatively frequently. These species are dispersed easily by birds from the surroundings.

Forest height and cover of remnant *Castanopsis* forests (seminatural forest) and environmental forests were compared in Fig. 16. The canopy layer of seminatural forests is tall, but environmental forest planted in 1976 is taller than the subcanopy layer of seminatural forests. Canopy coverage widths of seminatural and environmental protection forests are similar with that of the subcanopy layer. The subcanopy layer of seminatural forest has lower coverage than does the environmental forest planted in 1976.

The cover of the shrub layer of seminatural forests has a wider range, but the cover of environmental forests has a narrow range. This means that shrub-layer cover has not yet developed fully. The herb layer of seminatural forests also has a wider range and high coverage. It means that the herb layer of seminatural forest is developed and that of environmental forests is not yet developed (Fig. 16).

Discussion and Conclusion

The area of the Meiji Jingu forest is 70 ha, and it is the third-largest green area in the Tokyo metropolitan area. The area of the Institute for Nature Study is 18.9 ha (Hamano & al. 2013). The Meiji Jingu forest (evergreen broad-leaved forest) covers most of the area, except precincts and landscaping areas. The Institute for Nature Study has narrow *Castanopsis* forest on an embankment, secondary deciduous *Q. serrata* forest and *Cornus controversa* pioneer forest, and a relict of Japanese garden with pond and wetland. Successsors of *Castanopsis* forests on the embankment were discussed. The area of Yokohama National University is 45.5 ha, which is only half that of the Meiji Jingu forest. The relict forest from the old golf course and the forest restored by the new ecological method were compared. These three forest areas have different histories, but these are important models for restoration of natural forests.

The created forest of Meiji Jingu has 100 years of planning for forest development based on succession. It has succeeded with excellent basic planning as a scheme, a huge plantation operation, and detailed management planning for the future. The Institute for Nature Study has a long history since the Muromachi Period (1336-1573) and has been protected under several environmental changes (Institute for Nature Study of National Museum of Nature and Science 1999, http://www.ins.kahaku.go.jp/english/about/ history /index.html).

The plantation method by Hongo in 1923 (Fig. 8) succeeded in developing natural forest in 100 years. It is characterized by: 1) Expected succession to evergreen broad-leaved forest in 100 years; 2) Selection of species from conifer to evergreen broad-leaved species for growing to climax forest after succession; and 3) Guidelines for maintenance, such as prohibiting weeding and the collection of dropped leaves. Cleaning of dropped leaves should be done around buildings, on roads or in the garden, but not in the forests. Cleaning and weeding in the forest cause a decline in soil fertility and lead to forest impoverishment.

When weeds grow higher than new saplings, weeding is necessary – but only for a few years after planting. This maintenance guideline was used later by Prof. Miyawaki who developed the "Miyawaki method" for restoration of natural forest in shorter time. The forests at the Institute for Nature Study had a long history of protection after creation of the Japanese garden. There were also several other disturbances, including the gunpowder magazine, under the control of the Naval Ministry and Army Ministry in 1917; and export of trees for transplanting in the Meiji Jingu forest in 1973. After such history, the site passed to the Ministry of Education in 1949, whereupon it was designated a "national monument and historical landmark" and opened to the public as a national natural-education park. Then it obtained its current status as the Institute for Nature Study of the National Museum of Nature and Science in 1962. Many scientific studies have been done and recorded.

The environmental protection forests of Yokohama National University were planted based on the Miyawaki theory: 1) plant potted seedlings (30-80 cm height) with well-developed root systems, of canopy species of the potential natural forest (Tüxen 1958); 2) plant densely (1-3 individuals per square meter); 3. mix the plantation randomly; and 4. no need for management after three years.

The three models for forest creation were compared based on flora and development. The forest around the Meiji Jingu and the forest at the Institute for Nature Study have rich flora and biodiversity of fauna, based on areas, history and various landscaping as pond, garden, grassland and wetland.

Yokohama National University has mainly buildings and surrounding spaces, where environmental protection forest and landscaping plantation were begun in 1976.

The flora of the Meiji Jingu forest (*Cinnamomum camphora-Castanopsis cuspidata* var. *sieboldii* community) decreased from 166 species to 135 species over the last 40 years (Miyawaki & al. 1980; Okutomi & al. 2013). The species of evergreen broad-leaved forest increased from 38 to 45 species (Matsuzaki & Okutomi 2014), but these species included species that had escaped from gardens. Real natural species will be 36, as based on Fujiwara (1981, 1986). The evergreen 36-40 species of evergreen broad-leaved forest are optimum in the Kanto region. *Castanopsis* forest at the Institute for Nature Study (Okuda & Miyawaki 1966) has 33 species of the evergreen broad-leaved forest (Camellietea japonicae species in Kanto region). The forest of Miyazaki Jingu in Miyazaki Prefecture in Kyushu has a plantation history (Hattori & al. 2010) similar to that of Meiji Jingu. It also has 100 years of history after plantation. The big difference was the plantation method, with ca 30,000 trees of *Cinnamomum camphora, Pinus* spp., *Chamaecyparis obtusa*, etc. in 1907, but it looked like a "scattered" forest (Kuroki 2007 in Hattori & al. 2010).

Hattori & al. (2010) compared species richness to that of other lucidophyllous forests (primeval, natural and secondary forests), but the species richness was not as much as in primeval and natural forests because the species numbers and composition ratio of epiphytes and terrestrial pterophytes are low. These numbers are similar to those of secondary lucidophyllous forests (Hattori & Ishida 2000). Epiphytes and terrestrial pterophytes occur in moist environments. The Miyazaki Jingu Shrine has a forest of ca 15 ha on an alluvial area. Primeval and natural forests remain on hilly or low mountain areas. Miyazaki shrine cannot hold moisture like mountain areas. The forest of Miyazaki Jingu Shrine is multi-layered, with canopy spread and endangered species. When we expect more terrestrial ferns and epiphytes, though, edge community is required for closed forest.

The environmental protection forests of Yokohama National University have shorter history than do the forests of Meiji Jingu and the Institute for Nature Study. The species native to evergreen broad-leaved forests of these three places are roughly similar except for species that have escaped from gardens. Kuboyama surveyed forests around shrines and temples in Kanto and found them to have been invaded by ornamental and garden plants within 30 years (Kuboyama & Fujiwara 2008). The forests were 207 plots in 1970, but 69 plots disappeared, changing to Japanese cedar plantation, secondary forests in gaps, and to cemeteries. The number of species of evergreen broad-leaved forest and of ornamental and garden species increased, while species of secondary forests decreased. The Kanto region has the smallest number of species of evergreen broad-leaved forest in Japan, since it is near the northern limit for many such species. Environmental forests were investigated in the littoral area around the Seto Inland Sea and in Fukui on the Japan Sea coast (Hattori & al. 2001). People planted natural species at 9-18 species per 100 m^2 on these environmental forest sites. The authors compared with primeval forest in Kagoshima, Kyushu, and included all newcomers and total species number as their measure for species richness. This is not reasonable for restoration of evergreen broad-leaved forests because weeds, secondary species and pioneer species are indicators of forest disturbance. Later authors changed the focus to natural species in Miyazaki, Kyushu (Ishida & Hattori 2005). The species composing evergreen broad-leaved forests in Miyazaki are very many, especially terrestrial ferns and epiphytes, because of high temperature and moisture occurring on the complex topography. These species are different from the coastal area of the Seto Inland Sea and the Kanto region. Anyway, the authors ascertained that seed dispersal is largely by birds. Isolated forests were located more than 500 m from resource forests.

The species composing the evergreen broad-leaved forests of these three types varied according to width, forest history, and area. Isolated forests required bird food, water and nest areas in the forests.

Harada and Hayashi (2019) gave a hypothesis that thickly deposited fallen leaves on the forest floor hinder the recovery of the species composition in environmental protection forests. This hypothesis makes a paradox for maintenance, especially the suggestion by Hongo (1923) to prohibit cleaning dropped leaves. When we focus on natural forest, we should let the forest regulate itself.

This discussion suggests that we will be better off to think of forest restoration as plantation with many species, especially including bird-dispersed species, helped initially by creating good soil at the plantation sites. We would like to continue watching these forests and increase the restoration of natural forests in a better way.

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This paper is dedicated to Prof. Sandro Pignatti for his 90th birthday celebration. Prof. Pignatti required me to write for restoration of natural forest many years ago. Finally, I got an idea to compare the old restored forests and new ecological technology forest for him. I say thanks for giving ideas always and please lead us for a long time more. I also would like to thank Prof. Dr. Shin-ichi Suzuki, Tokyo University of Agriculture, who provided me huge reports on the Meiji Jingu forest in 2013.

It is difficult to get this information nowadays. I am grateful also to Mrs. Akiko Shimoda, who provided me lots of research reports on the Institute for Nature Study. I thank Mrs. Masami Sugita and Mrs. Rina Sakamoto who made the tables, and Prof. Dr. You Hai-Mei, Jiangsu Normal University, who made graphs. Finally I thank Prof. Elgene Box for editing the English and always encouraging me to finish this paper.

References

Fujiwara, K. 1981: Phytosociological investigation of the evergreen broad-leaved forest of Japan-1. – Bull. Inst. Environ. Sci. Technol., Yokohama Nat. Univ. **7(1):** 67-135 [in Japanese with English synopsis].

— 1986 (1): The evergreen broad-leaved forest. – Pp. 129-145 in: Miyawaki, A. (ed.), Vegetation of Japan, **7.** – Tokyo [in Japanese].

—, Hayashi, H. & Miyawaki, A. 1993: Restoration of natural environment by creation of environmental protection forests in urban areas. Growth and development of environmental protection forests on the Yokohama National University Campus. Second report. – Bull. Inst. Environ. Sci. Technol., Yokohama Nat. Univ. **19:** 51-60.

Hamano, C. 2013: Spermatophyta of the Shrine Forest of Meiji Jingu. – Pp. 69-87 in: Meiji Jingu Precincts Comprehensive Investigation Committee (ed.), Meiji Jingu Precincts Comprehensive Survey Report. – Tokyo [in Japanese with English abstract].

—, Nakatake, Y. & Okisawa, K. 2013: Tree measurement at the Shrine forest of Meiji Jingu. – Pp. 13-28 in: Meiji Jingu Precincts Comprehensive Investigation Committee (ed.), Meiji Jingu Precincts Comprehensive Survey Report. – Tokyo [in Japanese].

Hamao, S., Matsuura, K. & Hagiwara, S. 2013: Green space in the big urban: The forest of the Institute for Nature Study. – Pp. xvii-xxii in: Hamao, S. & Matsuura, K. (eds), Biodiversity and environment of the Institute for Nature Study. – Tokyo [in Japanese].

Harada, H. & Hayashi, H. 2019: Hypothesis that thickly deposited fallen leaves on the forest floor are hindering the recovery of the species composition of the environmental protection forest. – Pp. 24-26 in: JISE Report No. **2** [in Japanese].

Hattori, T. & Ishida, H. 2000: Relationship between species diversity, species composition and forest area of fragmented lucidophyllous forests in central Miyazaki Prefecture. – Japanese J. Ecol. **50:** 221-234 [in Japanese with English summary].

—, Iwakiri, K., Minamiyama, N., Kuroki, S. & Kuroda, A. 2010: Structure, species richness, and species composition of the shrine forest in Miyazaki-Jingu, Miyazaki Prefecture. – Jap. Jour. Conserv. Ecol. **15:** 47-59 [in Japanese with English abstract].

—, Ono, Y., Kaji, K., Ishida, H., Suzuki, T. & Iwasaki, M. 2001: Relationship between source in plant species follow and species richness in the lucidophyllous artificial forests on the littoral districts. – J. JILA **64(5):** 545-548 [in Japanese with English summary].

Hongo, T. 1923: Forest Garden planning of Meiji Jingu shrine. – Pp. 447-726 in: Meiji Jingu 2004. Meiji Jingu Series (Meiji Jingu Sousho) **13**. Construction edition-2. 731 pp. – Tokyo [in Japanese].

Honda, M., Yano, T. & Kato, N. 1980: Seed plants. – Pp. 208-228 in: Meiji Jingu Precincts Comprehensive Survey Report. – Tokyo [in Japanese].

Ishida, H., Hattori, T. & Hashimoto, Y. 2005: Comparison of species composition and richness among primeval, natural, and secondary lucidophyllous forests in southeastern Kyushu, Japan. – Veg. Sci. **22:** 71-86.

Ishigami, K. 1980: Tree survey report. – Pp. 1-205 in: Meiji Jingu Precincts Comprehensive Survey Report. – Tokyo [in Japanese].

Kitagawa, M., Miyawaki, A. & Kawamura, Y. 1968: Vegetation and ecological diagnosis in the integrated site of Yokohama National University. – Pp. 1-13 in: Newsletter of integrated campus of Yokohama National University. – Yokohama [in Japanese].

Kuboyama, E. & Fujiwara, K. 2008: Changes in species composition in lucidophyllous forests around Shinto shrines and temples in Kanto, Japan. – Papers Environ. Inform. Sci. **22:** 109-174 [in Japanese with English abstract].

Matuzaki, Y. & Okutomi, K. 2014: Forest vegetation of Meiji Jingu. – Pp. 12-14 in: Green Age 2014/7. – Tokyo [in Japanese].

Ministry of Home Affairs Shrine Bureau (Naimushou Jinjakyoku) 1930: Construction document of Meiji Jingu (Meiji Jingu Souei-shi). – Pp. 1-445 in: Meiji Jingu Series (Meiji Jingu Sousho) **13.** Construction edition-2. 731 pp. – Tokyo [in Japanese].

Miyawaki, A. 1979: Environmental improvement plan. – Pp. 32-35 in: 30th Anniversary of Yokohama National University: 30 years of history. – Yokohama [in Japanese].

— & Fujiwara, K. 1988: Restoration of natural environmental protection forests in urban areas. Growth and development of environmental protection forests on the Yokohama National University campus. – Bull. Inst. Environ. Sci. Technol., Yokohama Nat. Univ. **15:** 95-102.

—, — & Ozawa, M. 1993: Native forests by native trees. Restoration of indigenous forest ecosystem. (Reconstruction of environmental protection forest by Prof. Miyawaki's method). – Bull. Inst. Environ. Sci. Technol., Yokohama Nat. Univ. **19:** 73-107 [in Japanese and English].

—, Okuda, S. & Inoue, K. 1980: Pflanzensoziologische Untersuchungen in den Wäldern des Meiji-Schreins in Tokyo. – Pp. 269-333 in: Meiji Jingu Precincts Comprehensive Investigation Committee (ed.), Meiji Jingu Precincts Comprehensive Survey Report. – Tokyo [in Japanese with German summary].

—, Sasaki, Y., Okuda, S., Harada, H., Fujiwara, K., Suzuki, K. & Hotta, K. 1974: Phytosociological studies on creation of environmental protection forests around schools. - Based on field surveyes at 158 schools throughout Japan. – 116 pp. Contrib. of Dept. Veget. Scie., Inst. Envir. Scie. Tech., Yokohama National Univ. No. **12** [in Japanese].

—, Tohma, H., Fujiwara, K., Inoue, K., Furuya, M., Sasaki, Y., Harada, H., Ohno, K. & Suzuki, K. 1972: Vegetation der Stadt Yokohama – Eine pflanzensoziologische Studie fuer den Umbeltschut und die Dchaffung einer vegetationsreichen Stadt. – Yokohama [in Japanese with German summary].

Okuda, S. 1969: Die Vegetation des Naturrests in der Stadt Tokyo 1. – Misc. Reports Natl. Park Nat. Stu. **1:** 19-24 [in Japanese with German summary].

— 1970: Über die Vegetation der Umgebung des Naturparks für Naturstudien im südwestlichen Teil der Stadt Tokyo, Die Vegetation der Naturreste in der Stadt Tokyo 2. – Misc. Reports Natl. Park Nat. Stud. **2:** 9-15 [in Japanese with German summary].

— 1972: Growth of old huge Shii-trees (*Castanopsis cuspidata* var. *sieboldii*) and their conservation in the National Park for Nature Study. – Pp. 1-16 in: Misc. Reports Natl. Park Nat. Stud. **3** [in Japanese with English summary].

— 1980: Die Pflanzengesellschaften des Naturparks für Naturstudien in Tokyo. – Ihre Entwicklungen und Veränderungen in den letzten 15 Jahren. – Pp. 5-22 in: Misc. Reports Natl. Park Nat. Stud. **11** [in Japanese with German summary].

— 1994: Flora of Yokohama National University, Tokiwadai campus. – Bull. Inst. Environ. Sci. Technol., Yokohama Nat. Univ. **20:** 147-159 [in Japanese and English synopsis].

— 2001: Vegetation Map of the Institute for Nature Study. – Rep. Inst. Nat. Stu. **33:** 71-79 [in Japanese].

— 2013: Vegetation and flora of the Institute for Nature Study. Laurel forest alive in the big city. – Pp. 2-12 in: Hamao, S. & Matsuura, K. (eds), Biodiversity and environment of the Institute for Nature Study. – Tokyo [in Japanese].

— & Miyawaki, A. 1966: Reale Vegetationskarte des Staatlichen Naturparks für Naturstudien in Tokyo. – Pp. 1-14 in: Ecological Studies of Biotic Communities in the National Park for Nature Study. Foundation of Outdoor Nature Museum Supporters Association. – Tokyo [in Japanese with German summary].

Okutomi, K., Matsuzaki, Y. & Ikeda, H. 2013: Forest vegetation of Meiji Jingu. – Pp. 29-68 in: Second Meiji Jingu Precincts Comprehensive Investigation Committee for 100th anniversary of the enshrined seat (ed.), Report on the 100th anniversary of the enshrined seat in the precincts of the Meiji Jingu Shrine. – Tokyo [in Japanese with English abstract].

—, Okuda, S. Tsujii, S. & Hoshino, Y. 1987: Studies on the vegetation of Tokyo. 282 pp. – Tokyo [in Japanese with English summary].

The Institute for Nature Study of National Museum of Nature and Science 1999: 50 years history of the Institute for Nature Study. – Tokyo [in Japanese].

Tohma, H., Harada, A. & Fujiwara, K. 2001: The Flora and distribution of plants in the Tokiwadai campus of the Yokohama National University. – Bull. Inst. Environ. Sci. Technol., Yokohama Nat. Univ. **27:** 33-47 [in Japanese with English synopsis].

Tüxen, R. 1958: Die heutige potentielle natürliche Vegetation als Gegenstand der Vegetationskartierung. Berichte zur Deutschen Landeskunde herausgegeben von der Bundesanstalt für Landeskunde. Zentralarchiv für Landeskunde von Deutschland. 2 Heft. – pp. 200-225. – Remagen.

Uchida, M. 1992: Chapter 1. The Forest Was Created In This Way-Planning and Background of Construction. – Pp. 27-64 in: Matsui, M., Uchida, M., Tanimoto, T. & Kitamura, M.: Forest created in a big city-Learn from the forest of Meiji Jingu. – Tokyo [in Japanese].

Uehara, K. 1971: Forest made by people. - Record of construction of Meiji Jingu Forest. 77pp. (republished in 2009. Forest made by people. - Record of construction of Meiji Jingu Forest (forever forest). – Tokyo [in Japanese].

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Article

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Ignazio Camarda & Giuseppe Brundu

Monumental trees and old-growth forests in Sardinia (Italy)

Abstract

Camarda, I. & Brundu, G.: Monumental trees and old-growth forests in Sardinia (Italy). — Fl. Medit. 31 (Special Issue): 407-414. 2021. — ISSN: 1120-4052 printed, 2240-4538 online.

Old, veteran and notable trees are ecologically important keystone organisms, have tangible connections to folklore, history and, sociocultural practices, and functional characteristics fundamental for sustaining complex and unique assemblages of species. These trees can be found in different landscapes, ranging from remote mountain areas to cities, historical gardens and, agricultural areas.

In Italy, an official list of monumental trees was recently published under the national law no. 10/2013 and the ministerial Decree 23 October 2014. A number of criteria can be used to identify these trees such as age and/or size, shape and growth habit, ecological value, floristic rarity, interest for its architectural structure, landscape quality, and historical, cultural and religious value.

In this article we aim to provide some general information on monumental and notable trees in Sardinia, as well as on old-growth forest, based on the recent monograph published for Sardinia by I. Camarda.

Key words: monumental tree and shrubs, cultural heritage, Sardinia.

Introduction

Old, veteran and notable trees are ecologically important keystone organisms, have tangible connections to folklore, history and sociocultural practices (Nolan & al. 2020; Kabassi & al. 2021; Petruccelli & al. 2021), functional characteristics fundamental for sustaining complex and unique assemblages of species (Zapponi & al. 2017; Wetherbee & al. 2020), and play an important role in carbon storage and dynamics (Stephenson & al. 2014). These trees can be found in different landscapes, ranging from remote mountain areas to cities, historical gardens and agricultural areas (Anestiadou & al. 2017; Ninot & al. 2018, Camarero & al. 2021; Schicchi & al. 2021), and humans influence the distribution of veteran trees throughout their range, but in different ways in forests and open landscapes (Skarpaas & al. 2017).

In 1982, the Italian State Forestry Corps launched the first "National Census of trees of considerable interest", on the whole Italian territory to identify and catalog single plants or groups, which had peculiar characteristics: exceptional size compared to the species, singular shapes, aesthetic qualities and historical value. This census was not supported by a national regulatory system, and the State Forestry Corps collaborated with the forest services of the Italian regions (Farina 2018). The amount of data collected over time was surprising: from the 22,000 reports submitted by the assessors, 1,255 trees were selected and, of these, 150 of "exceptional historical and monumental value". The five species with most veteran trees in the data set were *Quercus pubescens* (211), *Fagus sylvatica* L. (112), *Cedrus libani* A. Rich. (58), *Castanea sativa* Mill. (52) and *Quercus ilex* L. (52). Species of the genus *Quercus* L. comprised 35% of the veteran trees reported (Pautasso & Chiarucci 2008; Farina 2018).

The Italian official list of monumental trees was recently published under the national Law no. 10/2013 and the ministerial Decree (October 23, 2014), and updated in the following years[1], with a final total number of 3,662 monumental trees in Italy in 2021. A number of criteria are used to identify these trees: age and/or size, shape and growth habit, ecological value, floristic rarity, interest for its architectural structure, landscape quality, and historical, cultural and religious value.

According to the Italian agreed definition (Blasi & al. 2010a, 2010b) old-growth forests are forests in which human disturbance is absent or negligible, and in which natural dynamics create a mosaic of all the forest regeneration phases, including the senescing one. Such phase is characterized by large old trees, deadwood (snags, logs, and coarse woody debris) and a vascular plant species composition that is consistent with the biogeographical context and includes highly specialized taxa related to the small-scale disturbance and the microhabitats resulting from structural heterogeneity. Within the Italian inventory (Blasi & al. 2010a) two sites were included for Sardinia, both included in the area of the Gennargentu massif. Old growth forests are increasingly considered and studied all around the world. However, the knowledge of such important forest systems is still limited in some bioclimatic regions, such as in the Mediterranean Basin (Badalamenti & al. 2018).

As it often occurs in the case of legislation and definitions in the forest and forestry sector (Pötzelsberger & al. 2020), also in the case of monumental trees and old-growth forest there is some puzzle resulting by a stratification of International, national, and regional legislation that have been implemented in different periods and for different purposes (Ferrucci 2021).

In this article we aim to provide some general information on monumental and notable trees in Sardinia, as well as on old-growth forest, based on the recent monograph published for Sardinia (Camarda 2020).

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[1] The national list "Elenco degli alberi monumentali d'Italia" was first approved by the "Decreto del Capo Dipartimento delle politiche europee e internazionali e dello sviluppo rurale del Ministero delle politiche agricole e forestali" no. 5450 of 19.12.2017, and published in the Gazzetta Ufficiale of February 12, 2018. It has been updated with Decreto Dirigenziale (DD) no. 661 of 09.08.2018, DD no. 757 of 19.4.2019, DD no. 9022657 of 24.07.2020, and – finally – with DD no. 0205016 of 05.05.2021.

The many steps towards a Sardinian inventory of monumental trees

The very first information on Sardinia trees is found in the work of Fara (1580-85) although it is reported without specific information on individual's size and age. Actually, Moris (1837) and other botanist of the XIX century which studied the flora of Sardinia did not pay much interest to monumental and veteran trees, although they highlighted the presence, distribution and uses of non-native tree species in the island. On the contrary, other writers and voyagers reported more information on monumental trees (e.g., Angius 1833, 1841, 1856; Valery 1837, 1838; Delessert 1855; Cugia 1892). A more careful description of monumental and veteran trees started at the end of the XX century, thanks to the work of regional botanist and forest experts (Camarda & Valsecchi 1985, 2008, Vannelli 1987, 1989, 1994; Camarda 1997), but it is only in the XXI century the Sardinian botanists started to investigate more systematically on this natural asset, often in collaboration with regional authorities such as the Sardinian Forest Agency and the National (CFS) and Sardinian (CFVA) Forestry Corps (Bacchetta 2006; Camarda & Valsecchi 2008).

More specifically, in 1982, the "National Census of trees of considerable interest" by the Italian State Forestry Corps included 44 monumental trees for Sardinia, belonging to 14 species. In addition, according to the Sardinian regional Law of the June 6, 1989, no. 31[2] a number of areas with natural trees or garden with trees have been included inside the protected category of "natural monuments", as in the case of the historical olive-groove of "S'Ortu Mannu" (DADA no. 73, 19.08.2008) and of Luras wild olive tree (DADA no. 32, 09.10.2013). During 2003, the Sardinian Forest Agency (DGR no. 48/42 30.12.2003) was in charge to deal with the regional inventory for Sardinia, producing an updated list with 611 records (Camarda, Lampreu, Murgia and Casula, 2010). In 2006, the Sardinian Regional Landscape Plan[3], included a definition for the monumental trees [art. 17] and a list of 100 trees belonging to 45 species, which were mainly those reported also by Vannelli's inventories (Vannelli 1989, 1994).

Later, information for Sardinia was included in "The Italian official list of monumental trees" produced and published under the national Law no. 10/2013, with the regional support of the Regional Forestry Corps. The Italian official list of monumental trees was published under the national Law no. 10/2013 and the ministerial decree of October 23, 2014 and updated in the following years, with a final total number of 410 monumental trees in Sardinia in 2021.

Meaningful, the Sardinian regional Law (April 27, 2016, no. 8), at its article 28.2.b promotes actions to preserve monumental trees.

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[2] Sardinia Region, Regional Law 7 June 1989, n. 31 "Rules for the establishment and management of parks, reserves and natural monuments, as well as areas of particular naturalistic and environmental importance".

[3] Sardinia Region, Resolution of the Regional Council, 5 September 2006, n. 36/7 "Regional Law no. 8 of 25.11.2004, article 1, paragraph 1. Approval of the Landscape Plan - First homogeneous area" (BURAS 8 September 2006, no. 30).

Monumental, notable trees, and old-growth forests in Sardinia

In 2020, based on the information available from previous inventories, and as a result of many years of systematic surveys along the whole territory of Sardinia, aiming to confirm and evaluate records, I. Camarda published a comprehensive synopsis of monumental and notable trees and old-growth forest of Sardinia (Camarda 2020). This synopsis included a total of 43 old-growth forests and 701 monumental or notable trees, belonging to 65 different native (Fig. 1A) and 63 exotic species (Fig. 1B).

The most common species among veteran trees in the data set were *Quercus ilex* (73), *Olea europaea* var. *sylvestris* (Mill.) Brot. (51), *Q. pubescens* (46), *Q. congesta* C. Presl (40) and *Q. suber* (38), *Taxus baccata* L. (31), *Pistacia lentiscus* L. (26), *Acer monspessulanum* L. (17), *Castanea sativa* (15) and *Ceratonia siliqua* L. (14). Species of the genus *Quercus* comprised 29 % of the 701 veteran trees reported.

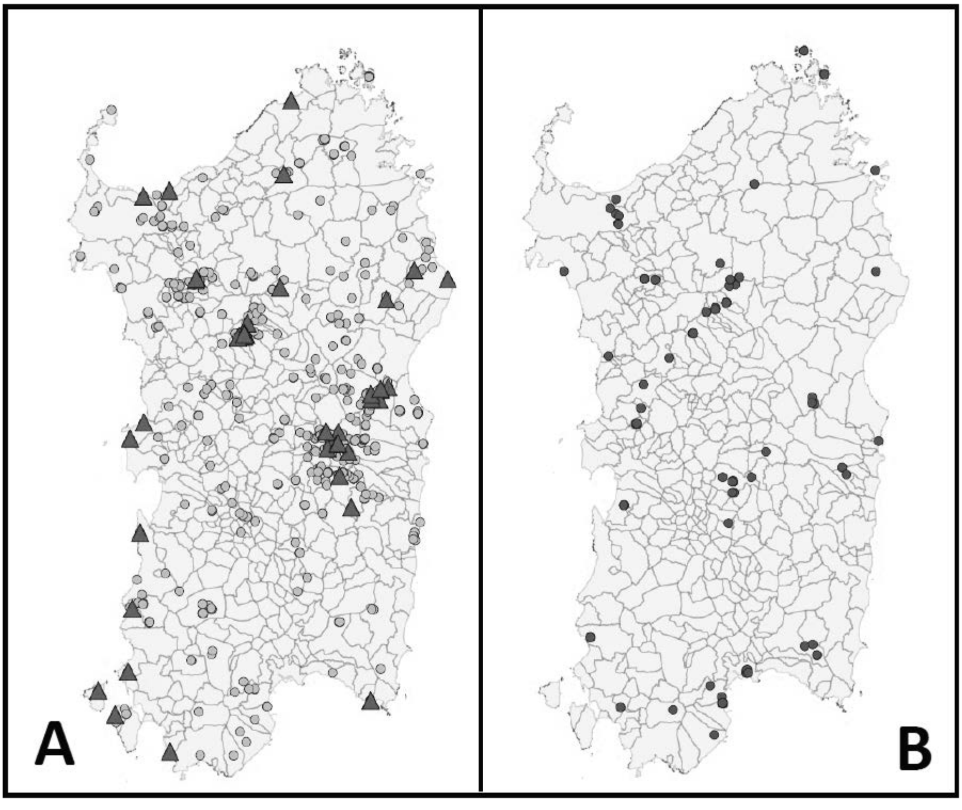

Fig. 1. A, B. Map from the synopsis of Camarda (2020). On the left (A) the distribution in Sardinia of the 43 old-growth forests (triangle) and of the native monumental trees (circle). On the right (B) the distribution of the non-native monumental trees.

The three types of most represented old-growth forests are the *Juniperus macrocarpa* Sm. forest (10), the *Quercus ilex* forest (t) and the *Taxus baccata – Ilex aquifolium* mixed forest (4). However, species of the genus *Quercus* comprised 29.5% of the 44 old-growth forests reported, while *Juniperus* scored 27%. Other important types of old-growth forest are those characterised by the presence of veteran trees of *Pistacia lentiscus* (Camarda & Ruiu 2021), *Arbutus unedo*, and *Phillyrea latifoli*a L. Although these species are more commonly observed as seedlings of shrubs, in a few sites they reach full monumental sizes as trees, both in height and diameters, and stably dominate the plant community.

The age of monumental and veteran trees is usually not always easy to establish, and the degree of accuracy of tree-age estimates can vary depending upon the previously available data on each tree species and upon the methods used (Altman & al. 2016; Ehrlich & al. 2017; Génova Fuster & Sadornil 2020). Annual growth rates of the trunk for some combinations of species and sites in Sardinia might be very low, and age estimation in evergreen species presents additional issues.

However, it is very likely that a number of trees of *Taxus* and *Olea* may reach and age of more than one thousand years, as in the case of *Olea europaea* var. *sylvestris* plants at Luras and Sarule villages, *Taxus baccata* at the site of Badde Salighes (Bolotana) and at Padente sas Iscalas (Fonni), and *Juniperus oxycedrus* L. at Erbelothori (Villagrande). Other trees reach an age of more than 500 year, as in the case of many monumental and veteran trees of *Quercus ilex, Q. pubescens*, *Ilex aquifolium*, *Acer monspessulanum, Q. suber*, *Alnus glutinosa* (L.) Gaertn., *Phillyrea latifolia*, and *Pistacia lentiscus.* Similarly, the monumental plants of *Myrtus communis* L. at San Pietro in Silki (town of Sassari), may have an age close to 500 years. In the case of trees planted in historical gardens, there is sometimes more precise information on the planting date, as in the case of *Pinus pinea* L. at Caprera, *Abies pinsapo* Boiss. at Badde Salighes, and *Ficus macrophylla* Desf. ex Pers. in Cagliari.

Non-native monumental and notable trees

The first and more relevant period of introduction of non-native trees in Sardinian dates back to the beginning of the XIX century, with the institution in 1866 of the Botanic Garden of Cagliari (Cavara 1901), and later of the Botanic Garden of Sassari. The most common non-native tree species (*Eucalyptus, Pinus, Abies, Pinus, Platanus*) have been largely planted in public and private gardens, in afforestation practices both in private and public land, and in a network of provenance trials (Pavari and De Philippis 1941). Single individual trees of the genera *Eucalyptus, Cedrus* and *Platanus* reached in many cases monumental sizes, while a few species, e.g., *Ailanthus altissima* (Mill.) Swingle escaped from plantation sites becoming highly invasive in several types of habitats.

A group of rare species is found outside the Botanic Garden of Cagliari, and are species commonly found in Italian and European gardens, such as *Taxus wallichiana* Zucc., *Ceiba speciosa* (A.St.-Hil.) Ravenna, *Cinnamomum camphora* (L.) J. Presl, *Chamaecyparis lawsoniana* (A. Murray bis) Parl., *Colletia paradoxa* (Spreng.) Escal., *Gleditsia triacanthos* L. and *Abies pinsapo*.

Final remarks

Monumental, veteran and notable trees in Sardinia include native and non-native trees species (both neophytes and archaeophytes), and have comparable sizes and relevance with the national monumental trees. Highly significant monumental trees are found among the species *Quercus ilex, Q. pubescens, Taxus baccata, Acer monspessulanum, Alnus glutinosa, Ostrya carpinifolia, Juniperus oxycedrus, Olea europaea* var. *sylvestris, Pyrus spinosa* Forssk*., Castanea sativa*, and *Juglans regia* L. Nevertheless, *Myrtus communis, Pistacia lentiscus, Arbutus unedo* L. and *Phillyrea latifolia*, although more commonly found as treelets of shrubs, do feature also monumental individuals. The system of monumental trees and old-growth forest of Sardinia is a fundamental asset for the study and conservation of Mediterranean biodiversity, history and culture.

References

Altman, J., Doležal, J., Čížek, L. 2016: Age estimation of large trees: New method based on partial increment core tested on an example of veteran oaks. – Forest Ecol. Managem. **380:** 82-89. https://doi.org/10.1016/j.foreco.2016.08.033

Anestiadou, K., Nikoloudakis, N., Hagidimitriou, M. & Katsiotis, A. 2017: Monumental olive trees of Cyprus contributed to the establishment of the contemporary olive germplasm. – In: Aravanopoulos, F. A. (ed.), PLoS ONE **12:** e0187697. https://doi.org/10.1371/journal.pone.0187697

Angius, V. 1833: Dizionario geografico, storico, statistico, commerciale degli stati di S.M. il re di Sardegna. – In: Casalis, G. 1833-1856: Dizionario geografico-storico- statistico-commerciale degli Stati di S. M. il Re di Sardegna, **1.** – Torino.

— 1841: Notizie Statistiche Storiche dei quattro Giudicati della Sardegna. – In: Casalis, G. 1833-1856: Dizionario geografico-storico- statistico-commerciale degli Stati di S. M. il Re di Sardegna. – Torino.

— 1856: Dizionario geografico, storico, statistico, commerciale degli stati di S. M. il re di Sardegna. – In: Casalis, G. 1833-1856: Dizionario geografico-storico- statistico-commerciale degli Stati di S. M. il Re di Sardegna, **28.** – Torino.

Bacchetta, G. 2006: Flora vascolare del Sulcis (Sardegna sud-occidentale, Italia). – Guineana **12:** 1-369.

Badalamenti, E., Pasta, S., La Mantia, T. & La Mela Veca, D. S. 2018: Criteria to identify old-growth forests in the Mediterranean: A case study from Sicily based on literature review and some management proposals. – Feddes Repert. **129:** 25-37. https://doi.org/10.1002/fedr.201700009

Blasi, C., Burrascano, S., Maturani, A. & Sabatini, F. M. 2010a: Old-growth Forests in Italy. A thematic contribution to the National Biodiversity Strategy. – Rome.

—, Marchetti, M., Chiavetta, U., Aleffi, M., Audisio, P., Azzella, M. M., Brunialti, G., Capotorti, G., Del Vico, E., Lattanzi, E., Persiani, A. M., Ravera, S., Tilia, A. & Burrascano, S. 2010b Multi-taxon and forest structure sampling for identification of indicators and monitoring of old-growth forest. – Pl. Biosyst. **144:** 160-170. https://doi.org/10.1080/11263500903560538

Camarda, I. 1997: Il Giardino Botanico montano di Badde Salighes. – Sassari.

— 2020: Grandi alberi e foreste vetuste della Sardegna. Biodiversità, Luoghi, Paesaggio, Storia. – Sassari.

— & Ruiu, D. 2021: La foresta vetusta di lentisco a Sa Cuilarja de Preda Longa (Loculi, Sardegna). – Sassari.

— & Valsecchi, F. 1985: Alberi e arbusti spontanei della Sardegna. – Sassari.

— & — 2008: Alberi e arbusti spontanei della Sardegna. – Sassari.

—, Lampreu, G., Murgia, E. & Casula, A. (eds) 2010: Censimento Grandi Alberi della Sardegna. Proposte per l'istituzione di monumenti naturali ai sensi della L.R. 31/89. Relazione Commissione Tecnica per la Valutazione degli Alberi Monumentali. – Cagliari.

Camarero, J. J., Colangelo, M., Gracia-Balaga, A., Ortega-Martínez, M. A. & Büntgen, U. 2021: Demystifying the age of old olive trees. – Dendrochronologia **65:** 125802. https://doi.org/10.1016/j.dendro.2020.125802

Cavara, F. 1901: L'Orto Botanico di Cagliari come Giardino di acclimatazione e come Istituto Scientifico. – Nuovo Giorn. Bot. Ital., n.s., **8:** 28-48.

Cugia, P. 1892: Nuovo itinerario dell'isola di Sardegna. – Ravenna.

Delessert, É. 1855: Six semaines dans l'île de Sardaigne. – Paris.

Ehrlich, Y., Regev, L., Kerem, Z. & Boaretto, E. 2017: Radiocarbon Dating of an Olive Tree Cross-Section: New Insights on Growth Patterns and Implications for Age Estimation of Olive Trees. – Frontiers Pl. Sci. **8:** 1918. https://doi.org/10.3389/fpls.2017.01918

Fara, G. F. 1580: De Chrorographia Sardiniae Libri duo. De Rebus Sardois Libri Quatuor edente Aloisio Cibrario equite curatore historiae patriae studiis promovendis ad Augustinum Lascaris Marchionem virium illustrem. – Torino.

Farina, A. 2018: La conoscenza e la tutela degli alberi monumentali prima della legge 14 gennaio 2013, n. 10. – Pp. 8-13 in: Farina, A. & Canini, L. (eds), Alberi Monumentali d'Italia - 100 esempi di monumentalità ai sensi della legge 14 gennaio 2013, n. 10. – Roma.

Ferrucci, N. 2021: La monumentalità vegetale sotto la lente del legislatore. – Aestimum: 181-194 https://doi.org/10.13128/AESTIM-9430

Génova Fuster, M. & Sadornil, E. 2020: The age of monumental trees. A case study of *Juniperus thurifera* L. in Spain. – Forest Syst. **29:** e007. https://doi.org/10.5424/fs/2020292-16172

Kabassi, K., Martinis, A. & Minotou, C. 2021: Estimating the value of monumental olive trees: Designing a tool using multi-criteria decision making. – Trees, Forests People **6:** 100151. https://doi.org/10.1016/j.tfp.2021.100151

Moris, G. G. 1837: Flora Sardoa, **1-3.** – Torino https://doi.org/10.5962/bhl.title.6355

Ninot, A., Howad, W., Aranzana, M. J., Senar, R., Romero, A., Mariotti, R., Baldoni, L. & Belaj, A. 2018: Survey of over 4, 500 monumental olive trees preserved on-farm in the northeast Iberian Peninsula, their genotyping and characterization. – Sci. Hort. **231:** 253-264. https://doi.org/10.1016/j.scienta.2017.11.025

Nolan, V., Reader, T., Gilbert, F. & Atkinson, N. 2020: The Ancient Tree Inventory: a summary of the results of a 15 year citizen science project recording ancient, veteran and notable trees across the UK. – Biodiv. Conserv. **29:** 3103-3129. https://doi.org/10.1007/s10531-020-02033-2

Pautasso, M. & Chiarucci, A. 2008: A Test of the Scale-dependence of the Species Abundance-People Correlation for Veteran Trees in Italy. – Ann. Bot. **101:** 709-715. https://doi.org/10.1093/aob/mcn010

Pavari, A. & De Philippis, A. 1941: La sperimentazione di specie forestali esotiche in Italia. Risultati del primo ventennio. – Ann. Sperim. Agrar. **38:** 1-648.

Petruccelli, R., Giordano, C., Salvatici, M. C., Beghè, D., Rodolfi, M., Fabbri, A. & Benelli, C. 2021 Characterization and conservation of "Olivo della Strega": an ancient olive tree, precious resource for natural and cultural heritage. – Rend. Lincei Sci. Fis. Nat. **32:** 311-324. https://doi.org/10.1007/s12210-021-00989-z

Pötzelsberger, E., Lapin, K., Brundu, G., Adriaens, T., Andonovski, V., Andrašev, S., Bastien, J.-C., Brus, R., Čurović, M., Čurović, Ž., Cvjetković, B., Đodan, M., Domingo-Santos, J. M., Gazda, A., Henin, J.-M., Hernea, C., Karlsson, B., Keča, L., Keren, S., Keserű, Z., Konstantara, T., Kroon, J., La Porta, N., Lavnyy, V., Lazdina, D., Lukjanova, A., Maaten, T., Madsen, P., Mandjukovski, D., Marín Pageo, F. J., Marozas, V., Martinik, A., Mason, W. L., Mohren, F., Monteverdi, M. C., Neophytou, C., Neville, P., Nicolescu, V.-N., Nygaard, P. H., Orazio, C., Parpan, T., Perić, S., Petkova, K., Popov, E. B., Power, M., Rédei, K., Rousi, M., Silva, J. S., Sivacioğlu, A., Socratous, M., Straigytė, L., Urban, J., Vandekerkhove, K., Wąsik, R., Westergren, M., Wohlgemuth, T., Ylioja, T. & Hasenauer, H. 2020: Mapping the patchy legislative landscape of non-native tree species in Europe. – Forestry **93:** 567-586. https://doi.org/10.1093/forestry/cpaa009

Schicchi, R., Speciale, C., Amato, F., Bazan, G., Di Noto, G., Marino, P., Ricciardo, P. & Geraci, A. 2021: The Monumental Olive Trees as Biocultural Heritage of Mediterranean Landscapes: The Case Study of Sicily. – Sustainability **13:** 6767. https://doi.org/10.3390/su13126767

Skarpaas, O., Blumentrath, S., Evju, M. & Sverdrup-Thygeson, A. 2017: Prediction of biodiversity hotspots in the Anthropocene: The case of veteran oaks. – Ecol. Evol. **7:** 7987-7997. https://doi.org/10.1002/ece3.3305

Stephenson, N. L., Das, A. J., Condit, R., Russo, S. E., Baker, P. J., Beckman, N. G., Coomes, D. A., Lines, E. R., Morris, W. K., Rüger, N., Álvarez, E., Blundo, C., Bunyavejchewin, S., Chuyong, G., Davies, S. J., Duque, Á., Ewango, C. N., Flores, O., Franklin, J. F., Grau, H. R., Hao, Z., Harmon, M. E., Hubbell, S. P., Kenfack, D., Lin, Y., Makana, J.-R., Malizia, A., Malizia, L. R., Pabst, R. J., Pongpattananurak, N., Su, S.-H., Sun, I.-F., Tan, S., Thomas, D., van Mantgem, P. J., Wang, X., Wiser, S. K. & Zavala, M. A. 2014: Rate of tree carbon accumulation increases continuously with tree size. – Nature **507:** 90-93. https://doi.org/10.1038/nature12914

Valery, A. C. P 1837: Voyage en Corse, à File de l'Elbe et en Sardaigne, **1.** – Paris.

— 1838: Voyage en Corse, à File de l'Elbe et en Sardaigne, **2.** – Paris.

Vannelli, S. 1987: Il verde di Cagliari: guida alle piante e ai giardini della citta. – Cagliari.

— 1989: Grandi alberi in Sardegna. – Cagliari.

— 1994: Grandi alberi della Sardegna. Monumenti verdi. – Cagliari.

Wetherbee, R., Birkemoe, T. & Sverdrup-Thygeson, A. 2020: Veteran trees are a source of natural enemies. – Sci. Rep. **10:** 18485. https://doi.org/10.1038/s41598-020-75723-0

Zapponi, L., Mazza, G., Farina, A., Fedrigoli, L., Mazzocchi, F., Roversi, P. F., Peverieri, G. S. & Mason, F. 2017: The role of monumental trees for the preservation of saproxylic biodiversity: re-thinking their management in cultural landscapes. – Nat. Conserv. **19:** 231-243. https://doi.org/10.3897/natureconservation.19.12464

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Article

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The vascular flora of the Marine Protected Area of "Capo Carbonara" (SE-Sardinia)

Abstract

Podda, L., Meloni, F., Fenu, G., Iiriti, G. & Bacchetta, G.: The vascular flora of the Marine Protected Area of "Capo Carbonara" (SE-Sardinia). — Fl. Medit. 31 (Special Issue): 415-449. 2021. — ISSN: 1120-4052 printed, 2240-4538 online.

This study aims at presenting an updated inventory of the vascular flora of the Capo Carbonara Marine Protected Area, including the Sites of Community Importance "Isola dei Cavoli, Serpentara, Punta Molentis e Campulongu" and partially of "Costa di Cagliari", in Sardinia (Italy). A total of 653 taxa are reported, 84% of which are native (5% endemics) and 16% non-native (10% neophytes, 6% archaeophytes). The native component includes 406 species, 135 subspecies, two variety and one hybrid, belonging to 75 families and 313 genera. The non-native taxa are 94 species, 13 subspecies, one variety and one hybrid, belonging to 40 families and 81 genera.
Life-form analysis of native species revealed a prevalence of therophytes (49%) followed by hemicryptophytes (21%), geophytes (14%) and chamaephytes (7%). Therophytes (33%) followed by phanerophytes (32%) are prevalent among the non-native taxa. Biogeographically, among native species, the Mediterranean element is largely prevailing (81%), mainly consisting of Circum-Mediterranean (39%) and Euro-Mediterranean (27%) taxa, while the American element (35%) prevails over the Mediterranean species (29%) among the non-native taxa. Among endemics, the Sardo-Corsican taxa are dominant (55%), followed by Sardo-Corsican-Tuscan Archipelago (14%) and Sardinian (10%) taxa.

Key words: Alien species, biodiversity, conservation, endemics, marine protected areas, Mediterranean Basin, Sardinia, vascular flora.

Introduction

The territory of the Marine Protected Area of Capo Carbonara (hereafter MPACC) is known as one of the most important coastal areas in Sardinia. Since 1998, the year of its legal establishment, it is also the only marine protected area in southern Sardinia. The institution of the MPACC, together with the previous establishment of the Sites of Community Importance (SCI) and Special Protection Areas (SPA) of the Natura 2000 Network, increased the protection level of this territory, which is very fragile due to touristic pressure, and have triggered several biodiversity conservation projects (AA.VV. 2014; Acunto & al. 2017; Pinna & al. 2017).

The territory shows a remarkable floristic diversity due to the richness of habitats and has attracted several botanists since the early 1800s. The first reports about the vascular flora of this area, from Capo Carbonara and Porto Giunco, are due to Moris (1827, 1837-1859). Subsequently, between 1894 and 1916, Martelli carried out some herborizations in different sites of south-eastern Sardinia, including the Isola dei Cavoli. The area of Capo Carbonara was frequently visited by botanists because it was accessible by a coastal road which, although defined at that time as very dangerous, allowed to reach this area (Bocchieri & Iiriti 2007a).

Some herborizations along the coast of Villasimius were carried out by Martinoli between 1940 and 1951 (Bocchieri & Iiriti 2007a). More recent investigations have focused on the Cavoli (Corsi 1963; Mossa & Tamponi 1978; Mossa & Fogu 1987) and Serpentara (Bocchieri 1988, 1989; Biondi & al. 1993) islands, Capo Carbonara, and the surrounding areas (Camarda & Ballero 1981; Mossa & al. 2000). Further floristic information for the study area are reported in studies addressing areas of south-eastern Sardinia or carried out at a regional scale (Chiappini & Diana 1978; Ballero 1982; Arrigoni & Bocchieri 1995; Mayer 1995; Bocchieri 2001; Palmese & al. 2001; Mossa & al. 2003; Bacchetta & al. 2005; Arrigoni 2006-2015; Iiriti 2006; Bocchieri & Iiriti 2007a, 2007b, 2008).

To date, however, there is no updated checklist of the vascular flora of this area (Bacchetta & al. 2006, 2007; Bacchetta & al. 2015; Pinna & al. 2017). In the framework of the project "Conservation of Plant Biodiversity in the Marine Protected Area of Capo Carbonara", funded by the Ministry of the Environment and Territory and Sea Protection (MATTM) (Bacchetta & al. 2006, 2007), the project LIFE07 NAT/IT/000519 PROVIDUNE (Durán & al. 2016; Pinna & al. 2015, 2017) and LIFE13 NAT/IT/000433 RES MARIS project (Acunto & al. 2017; Bacchetta & al. 2018), in the years from 2014 to 2018, a study was carried out on the vascular flora of the coastal territory of the municipality of Villasimius, which includes the SCI "Isola dei Cavoli, Serpentara, Punta Molentis and Campulongu", coinciding with MPACC.

This study brings an overview of the vascular flora in the MPACC and contributes to update the information on the native and exotic flora, thus providing a basis for conservation actions.

Study area

The study area includes coastal and insular areas of the MPACC in south-eastern Sardinia (Fig. 1). The MPACC, 8.598 hectares in surface, was founded by a Ministerial Decree on 15/09/98 (modified on 3/08/99) with the participation of the Sardinian Region and Villasimius municipality. It encloses the marine area in front of the Cavoli and Serpentara islands and the coast belonging to Villasimius. The coast is 41 km long and includes several beaches as Porto Giunco, Simius, Campu Longu and Campus, where rocky promontories alternate with small bays such as Porto Sa Ruxi or Punta Molentis.

The sea areas are characterized by a continuity of granite forms with emerging spots, while wide sandy expanses connect the islands interrupted by granitic shoals.

The lithologies are essentially referred to the Ercinic batholith of Sarrabus emerged at the end of the Ercinic orogenesis in the Middle Carboniferous (Carmignani & al. 1982). Rocks mainly

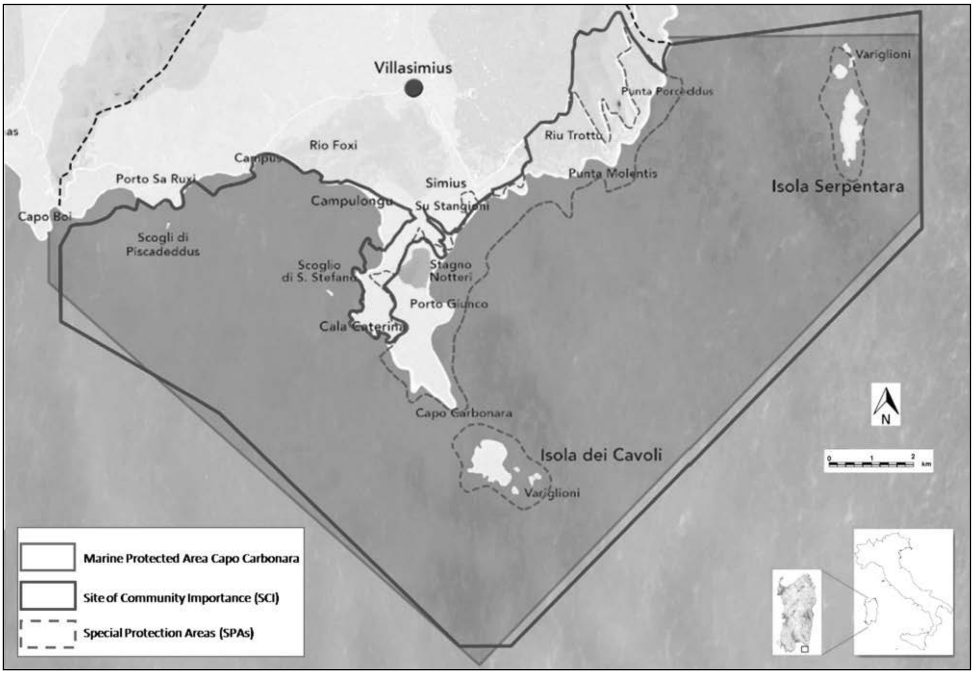
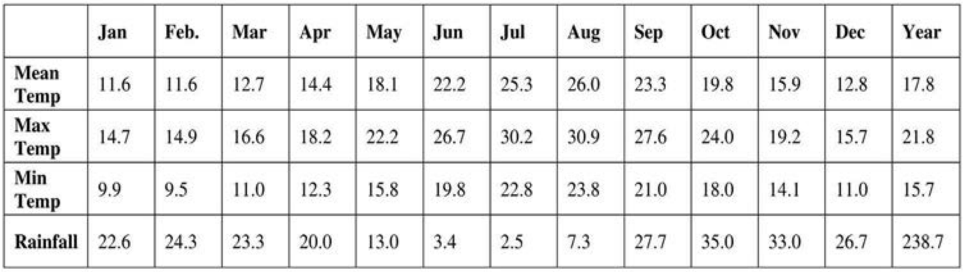


Fig. 1. Geographic position of the Marine Protected Area of Capo Carbonara (MPACC).

derive from granites and granodiorites subjected, during the alpine orogenesis, to tectonic movements that deformed then according to a NW-SE prevalent direction. The veins present the same orientation. They are mainly of a basic nature, dominated by lamprophyric and spessartitic lithologies which are important in shaping the coastal and submarine landscape, the coastline being formed by promontories with the same orientation as those of Capo Carbonara (Orrù & al. 1994). The oldest organogenic deposits are formed by fossiliferous beaches conglomerates known as Tyrrhenian Platform, which appear in various points of Capo Carbonara promontory. One of the most important outcrops is near Cava Usai, in the locality of Portu su Forru, which has a total extension of about 400 m. This formation is surmounted by sandstones of aeolic origin (paleodunes), a reddish paleosoil (palexeralf), and, in the submerged environment, by the sedimentation and cementation of beach-rocks. In the surrounding landscape, ancient shapes of smoothing such as “inselberg” and “tor” ornament the ridges and the plateaux at an elevation ranging from 400 to 500 m (Orrù & al. 1994).

Climate is typically Mediterranean; thermometric data (37 years of observations) from the climatic station of Capo Carbonara, show a strong seasonal trend in temperature, typical of the coast of Sardinia. Annual mean temperature is 21.8°C, mean maximum temperature of the hottest month 30.9°C (August) and mean minimum temperature of the coldest month 9.5°C (February). As for precipitation, the climatic station of Capo Carbonara recorded an annual mean of 238.7 mm, with higher values in autumn; October, with 35 mm on average, is the wettest month (Table 1).

Table 1. Mean monthly and annual temperature (°C) and rainfall (mm), Capo Carbonara station (Italian Air Force National Meteorological Service). Temperature observations: 1960-2007 (37 years); rainfall observations: 1954-2008 (54 years).



	Jan	Feb.	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean Temp	11.6	11.6	12.7	14.4	18.1	22.2	25.3	26.0	23.3	19.8	15.9	12.8	17.8
Max Temp	14.7	14.9	16.6	18.2	22.2	26.7	30.2	30.9	27.6	24.0	19.2	15.7	21.8
Min Temp	9.9	9.5	11.0	12.3	15.8	19.8	22.8	23.8	21.0	18.0	14.1	11.0	15.7
Rainfall	22.6	24.3	23.3	20.0	13.0	3.4	2.5	7.3	27.7	35.0	33.0	26.7	238.7

From a bioclimatic point of view, the study area has a Mediterranean Pluviseasonal Oceanic (MPO) bioclimate, a Thermo-Mediterranean (TME) thermotype and an ombrotype ranging from upper semiarid to lower dry (Bacchetta & al. 2009).

The superficial movable bottom is mainly colonized by beds of *Posidonia oceanica* Delile, being a part of the priority habitat 1120 “*Posidonia* beds (*Posidonion oceanicae*)” (Acunto & al. 2017).

The dune ecosystems are well preserved, hosting in different places the complete psammophilous geosigmataxa from the annual herbaceous vegetation to the micro-forest dominated by junipers of the priority habitat 2250 “Coastal dunes with *Juniperus* spp.” and pine of the priority habitat 2270 “Wooded dunes with *Pinus pinea* and/or *Pinus pinaster*” (Acunto & al. 2017). The populations of *Crucianella maritima* L. are of a great value. Even if fragmented, they occupy the back side of the dunes and belong to the habitat 2210 “*Crucianellion maritimae* fixed beach dunes”, as well as the formations of *Achillea maritima* (L.) Ehrend. & Y.P.Guo that can be found only in Cava Usai, Punta Molentis and a few other places along the south-eastern coast of Sardinia. The rocky surfaces and cliffs in front of the sea are occupied by the association *Crithmo maritimi-Limonietum retiramei corr.* (Mossa & Tamponi 1978) attributable to the habitat 1240 “Cliffs with the Mediterranean coastal vegetation with *Limonium* spp. endemic”. The Notteri pond occupies the back side of the dune area of the Porto Giunco beach. It occupies a surface of about 34 ha and hosts an interesting halophylous vegetation referred to the priority habitat 1510 “Mediterranean salt steppes (*Limonietalia*)”, while the muddy bottom is colonized by the association *Chaetomorpho-Ruppietum* Br.-Bl. 1952 being a part of the habitat 1150 “Coastal lagoons” (Mossa & al. 2000).

In the framework of the Italo-Tyrrhenian biogeographic superprovince (Ladero-Alvarez 1987; Bacchetta & al. 2013) and the Sardinian-Corsican biogeographic province (Bacchetta & al. 2012), based on the vascular endemic flora, the study area falls into the Campidanese-Turritano sector and Sarrabense subsector (Fenu & al. 2014).

Material and Methods

In order to perform the analysis of the vascular flora, floristic data retrieved from literature were implemented by a four years' work that included field investigation during the MATTM, LIFE PROVIDUNE and LIFE RES MARIS projects, and the revision of herbarium and bibliographic material.

The taxonomic treatment of plant species and subspecies follow the last checklists of the native and alien floras of Italy (Bartolucci & al. 2018; Galasso & al. 2018). Plant families have been validated according to the Angiosperm Phylogeny Group IV (APG 2016).

Life-forms were directly checked in the field and expressed according to the Raunkiaer's classification system (Raunkiaer 1934), using the abbreviations reported in Pignatti (1982). For the biogeographical types we used Pignatti's classification (Pignatti 1982), as modified by Brullo & al. (1996) for Mediterranean chorotypes. For endemic taxa, the categories proposed by Arrigoni & Di Tommaso (1991) were adopted, as modified by Bacchetta & Pontecorvo (2005).

The geographic origin of alien plants was based on Podda & al. (2012) and Puddu & al. (2016). The status of alien species was determined and ordered according to Richardson & al. (2000), Pyšek & al. (2004), and Richardson & al. (2011). Archaeophyte and neophyte taxa were differentiated depending on their introduction before or after the years 1492/1500, respectively.

Floristic checklist

Db = dubious reporting

Alien taxa: Neo = Neophytes; Arch = Archeophytes; Arch D = cryptogenic; Status alien taxa: Inv = invasive; Nat = naturalised; Cas = casual.

PTERIDOPHYTA

SELAGINELLACEAE

Selaginella denticulata (L.) Spring – Ch rept – Circum-Medit.

EQUISETACEAE

Equisetum ramosissimum Desf. – G rhiz – Circumbor.

DENNSTAEDTIACEAE

Pteridium aquilinum (L.) Kuhn subsp. ***aquilinum*** – G rhiz – Cosmop.

ASPLENIACEAE

Asplenium ceterach L. subsp. ***ceterach*** **–** H ros – Eurasiat.
Asplenium obovatum subsp. ***billotii*** **(**F.W.Schultz) O.Bolòs, Vigo, Masalles & Ninot – H ros – W-Medit.
Asplenium obovatum Viv. subsp. ***obovatum*** – H ros – Circum-Medit.

Pteridaceae

Anogramma leptophylla (L.) Link – T caesp – Subtrop.

Oeosporangium pteridioides (Reichard) Fraser-Jenk. & Pariyar – H ros – W-Medit.

Polypodiaceae

Polypodium cambricum L. – H ros – Euro-Medit.

PINOPHYTA

Cupressaceae

Cupressus sempervirens L. – P scap – E-Medit. (Arch – Cas)

Juniperus macrocarpa Sm. – P caesp – Circum-Medit.

Juniperus turbinata Guss. – P caesp – Euro-Medit.

Pinaceae

Pinus halepensis Mill. subsp. ***halepensis*** – P scap – Circum-Medit.

Pinus pinea L. – P scap – Euri-Medit. (Arch – Nat)

MAGNOLIOPHYTA

Magnolides

Aristolochiaceae

Aristolochia rotunda subsp. ***insularis*** (E. Nardi & Arrigoni) Gamisans – G rhiz – Endem. SA-CO

Aristolochia tyrrhena E.Nardi & Arrigoni – G rad – Endem. SA

Monocotyledones

Araceae

Ambrosina bassii L. – G rhiz – SW-Medit.

Arisarum vulgare O.Targ.-Tozz. subsp. ***vulgare*** – G rhiz – Circum-Medit.

Arum pictum L.f. subsp. ***pictum*** – G rhiz – Endem. SA-CO-AT

Helicodiceros muscivorus (L.f.) Engl. – G rhiz – Endem. SA-CO-BL

Lemna minor L. – I nat – Boreo-Trop.

Cymodoceaceae

Cymodocea nodosa (Ucria) Asch. – I rad – Medit.-Atl.

Potamogetonaceae

Posidonia oceanica (L.) Delile – I rad – Circum-Medit.

Ruppia maritima L. – I rad – Boreo-Trop.

Amaryrillidaceae

Acis autumnalis (L.) Sweet – G bulb – Circum-Medit.

Allium cepa L. – G bulb – Asia. (Arch – Cas)

Allium commutatum Guss. – G bulb – Circum-Medit.

Allium polyanthum Schult. & Schult.f. – G bulb – Euro-Medit.

Allium roseum L. subsp. ***roseum*** – G bulb – Circum-Medit.

Allium sativum L. – G bulb – Europ. (Arch – Cas)
Allium subhirsutum L. subsp. ***subhirsutum*** – G bulb – Circum-Medit.
Allium triquetrum L. – G bulb – Circum-Medit.
Narcissus miniatus Donn.-Morg., Koop. & Zonn. – G bulb – Circum -Medit.
Narcissus supramontanus subsp. ***cunicularium*** Arrigoni – G bulb – Endem. SA-CO
Pancratium maritimum L. – G bulb – Circum-Medit.

ASPARAGACEAE
Agave americana L. – P caesp – Neotrop. (Neo – Inv)
Agave attenuata Salm-Dyck subsp. ***attenuata*** – P caesp – Neotrop. (Neo – Cas)
Agave fourcroydes Lem. – P caesp – Neotrop. (Neo – Inv)
Agave ingens Brg. var. ***picta*** – P caesp – Neotrop. (Neo – Inv)
Agave salmiana Otto ex Salm-Dyck subsp. ***ferox*** (K.Koch) Hochstätter – P caesp – Neotrop. (Neo – Inv)
Asparagus acutifolius L. – G rhiz – Circum-Medit.
Asparagus albus L. – Ch frut – W-Medit.
Asparagus aphyllus L. – Ch frut – S-Medit.
Asparagus horridus L. – NP – S-Medit.
Charybdis pancration (Steinh.) Speta – G bulb – Circum-Medit.
Charybdis undulata (Desf.) Speta – G bulb – S-Medit.
Muscari comosum (L.) Mill. – G bulb – Euro-Medit.
Prospero corsicum (Boullu) J.-M.Tison – G bulb – Endem. SA-CO
Prospero obtusifolium subsp. ***intermedium*** (Guss.) Soldano & F.Conti – G bulb – SW-Medit.
Ruscus aculeatus L. – Ch frut – Euro-Medit.
Ruscus hypoglossum L. – G rhiz – Euro-Medit. (Neo – Cas)
Urginea fugax (Moris) Steinh. – G bulb – SW-Medit.
Yucca aloifolia L. – P caesp – Neotrop. (Neo – Cas)
Yucca gloriosa L. – P caesp – Neotrop. (Neo – Cas)

IRIDACEAE
Chamaeiris foetidissima (L.) Medik. – G rhiz – Euro-Medit.
Gladiolus byzantinus Mill. – G bulb – Circum-Medit. (Arch D – Nat)
Iris germanica L. – G rhiz – Europ. (Arch – Nat)
Limniris pseudacorus (L.) Fuss – G rhiz – Eurasiat.
Moraea sisyrinchium (L.) Ker Gawl. – G bulb – Circum-Medit.
Romulea columnae Sebast. & Mauri – G bulb – Circum-Medit.
Romulea ligustica Parl. – G bulb – SW-Medit.
Romulea ramiflora Ten. subsp. ***ramiflora*** – G bulb – Circum-Medit.
Romulea requienii Parl. – G bulb – Endem. SA-CO
Romulea rollii Parl. – G bulb – W-Medit.
Xiphion xiphium (L.) M.B. Crespo, Mart.Azorín & Mavrodie – G bulb – W-Medit. (Arch Db – Nat)

Orchidaceae

Anacamptis collina (Banks & Sol. ex Russell) R.M.Bateman, Pridgeon & M.W.Chase – G bulb – Circum-Medit.
Anacamptis laxiflora (Lam.) R.M. Bateman, Pridgeon & M.W. Chase – G bulb – Circum-Medit.
Anacamptis longicornu (Poir.) R.M. Bateman, Pridgeon & M.W. Chase – G bulb – W-Medit.
Anacamptis papilionacea (L.) R.M. Bateman, Pridgeon & M.W. Chase – G bulb – W-Medit.
Ophrys apifera Huds. – G bulb – Euro-Medit.
Ophrys bombyliflora Link – G bulb – Circum-Medit.
Ophrys conradiae Melki & Deschâtres – G bulb – Endem. SA-CO
Ophrys exaltata subsp. ***morisii*** (Martelli) Del Prete – G bulb – Endem. SA-CO
Ophrys incubacea Bianca – G bulb – W-Medit.
Ophrys speculum Link – G bulb – Circum-Medit.
Ophrys tenthredinifera Willd. subsp. ***neglecta*** (Parl.) E.G.Camus – G bulb – N-Medit.
Orchis* × *bornemanniae Asch. – G bulb – W-Medit.
Serapias lingua L. – G bulb – Medit.-Atl.
Serapias parviflora Parl. – G bulb – Medit.-Atl.
Spiranthes spiralis (L.) Chevall. – G rhiz – Europ.-Caucas.

Asphodelaceae

Aloe arborescens Mill. – NP – S-Africa (Neo – Cas)
Aloe ×caesia Salm-Dyck – NP – Africa (Neo – Cas)
Asphodelus fistulosus L. – H bien – Circum-Medit.
Asphodelus ramosus L. subsp. ***ramosus*** – G rhiz – Circum-Medit.

Dioscoreaceae

Dioscorea communis (L.) Caddick & Wilkin. – G rad – Euro-Medit.

Smilacaceae

Smilax aspera L. – P lian – Circum-Medit.

Arecaceae

Phoenix canariensis H.Wildpret – P scap – Macarones. (Neo – Cas)
Washingtonia filifera (Linden ex André) H.Wendl. ex de Bary – P scap – Neotrop. (Neo – Cas)

Cyperaceae

Carex distachya Desf. – H caesp – Circum-Medit.
Carex divisa Huds. – G rhiz – Medit.-Atl.
Carex flacca subsp. ***erythrostachys*** (Hoppe) Holub – G rhiz – Circum-Medit.
Carex halleriana Asso – H caesp – Euro-Medit.
Cyperus capitatus Vand. – G rhiz – Circum-Medit.
Cyperus rotundus L. – G rhiz – Medit-Trop. (Arch D – Nat)
Schoenus nigricans L. – H caesp – Subcosmop.
Scirpoides holoschoenus (L.) Sojàk – G rhiz – Euro-Medit.

JUNCACEAE

Juncus acutus L. subsp. ***acutus*** – H caesp – Euro-Medit.
Juncus bufonius L. – T caesp – Cosmop.
Juncus maritimus Lam. – G rhiz – Euro-Medit.
Juncus subulatus Forssk. – G rhiz – S-Medit.

JUNCAGINACEAE

Triglochin barrelieri Loisel. – G bulb – Circum-Medit.

POACEAE

Aira elegantissima Schur subsp. ***elegantissima*** – T scap – Euro-Medit.
Ampelodesmos mauritanicus (Poir.) T. Durand & Schinz – H caesp – SW-Medit.
Anisantha diandra (Roth) Tutin ex Tzvelev – T scap – Euro-Medit.
Anisantha madritensis (L.) Nevski subsp. ***madritensis*** – T scap – Medit-Atl.
Anisantha rubens (L.) Nevski – T scap – S-Medit.-Turan.
Anisantha sterilis (L.) Nevski – T scap – Paleotemp.
Arundo donax L. – G rhiz – Irano-Turan. (Arch – Inv)
Avena barbata Pott *ex* Link – T scap – Euro-Medit.-Turan.
Avena fatua L. – T scap – Irano-Turan. (Arch – Nat).
Avena sativa L. subsp. ***sativa*** – T scap – Irano-Turan. (Arch – Cas)
Avena sterilis L. – T scap – Circum-Medit. (Arch – Nat)
Brachypodium distachyon (L.) P. Beauv. – T scap – Medit.-Turan.
Brachypodium retusum (Pers.) P. Beauv. – H caesp – W-Medit.
Brachypodium sylvaticum (Huds.) P. Beauv. subsp. ***sylvaticum*** – H caesp – Paleotemp.
Briza maxima L. – T scap – Subtrop.
Briza minor L. – T scap – Subcosmop.
Bromus hordeaceus L. subsp. ***hordeaceus*** – T scap – Subcosmop.
Calamagrostis arenaria subsp. ***arundinacea*** (Husn.) Banfi, Galasso & Bartolucci – G rhiz – Circum-Medit.
Castellia tuberculosa (Moris) Bor – T scap – Medit.-Irano-Turan. (Db)
Catapodium balearicum (Willk.) H.Scholz – T scap – Medit.-Atl.
Catapodium rigidum (L.) C.E. Hubb. subsp. ***rigidum*** – T scap – Euro-Medit.
Cenchrus longisetus M.C. Johnst. – H caesp – S-Medit. (Neo – Nat)
Cortaderia selloana (Schult. & Schult. f.) Asch. & Graebn. – H caesp – S-Amer. (Neo – Cas)
Cutandia divaricata (Desf.) Barbey – T scap – Circum-Medit.
Cutandia maritima (L.) Benth. ex Barbey – T scap – Circum-Medit.
Cynodon dactylon (L.) Pers. – H rept – Subcosmop.
Cynosurus echinatus L. – T scap – Euro-Medit.
Dactylis glomerata subsp. ***hispanica*** (Roth) Nyman – H caesp – Circum-Medit.
Dasypyrum villosum (L.) P. Candargy – T scap – Euro-Medit.-Turan.
Elymus repens (L.) Gould subsp. ***repens*** – G rhiz – Paleotemp.
Festuca danthonii Asch. & Graebn. subsp. ***danthonii* –** T scap – Euro-Medit.
Festuca fasciculata Forssk. – T caesp – Circum-Medit.
Festuca geniculata (L.) Lag. & Rodr. subsp. ***geniculata*** – T caesp – W-Medit.
Festuca ligustica (All.) Bertol. – T caesp – Circum-Medit.

Gastridium ventricosum (Gouan) Schinz & Thell. – T scap – Medit.-Atl.
Holcus annuus subsp. ***setiglumis*** (Boiss. & Reut) M.Seq. & Castrov. – T scap – Circum-Medit.
Hordeum murinum subsp. ***leporinum*** (Link) Arcang. – T scap – Euro-Medit.
Hyparrhenia hirta (L.) Stapf subsp. ***hirta*** – H caesp – Paleotrop.
Imperata cylindrica (L.) Raeusch. – G rhiz – Cosmop.
Lagurus ovatus L. subsp. ***ovatus*** – T scap – Euro-Medit.
Lagurus ovatus L. subsp. ***vestitus*** (Messeri) Brullo – T scap – S-Medit.
Lamarckia aurea (L.) Moench – T scap – Medit.-Turan.
Lolium rigidum Gaudin – T scap – Paleo-Subtrop.
Lygeum spartum L. – H caesp – S-Medit.
Melica ciliata L. subsp. ***ciliata*** – H caesp – Euro-Medit.
Melica minuta L. – H caesp – Circum-Medit.
Oloptum thomasii (Duby) Banfi & Galasso – H caesp – Circum-Medit.
Parapholis incurva (L.) C.E.Hubb. subsp. ***incurva*** – T scap – Medit.-Atl.
Parapholis strigosa (Dumort.) C.E.Hubb. – T scap – Medit.-Atl.
Paspalum distichum L. – G rhiz – Neotrop. (Neo – Nat)
Phalaris brachystachys Link – T scap – Circum-Medit.
Phalaris coerulescens Desf. – H caesp – Medit.-Macarones.
Phalaris minor Retz. – T scap – Medit.-Irano-Turan.
Phleum arenarium subsp. ***caesium*** H.Scholz – T scap – Circum-Medit.
Phragmites australis (Cav.) Trin. ex Steud. – G rhiz – Subcosmop.
Piptatherum coerulescens (Desf.) P. Beauv. – H caesp – Circum-Medit.
Poa annua L. – T caesp – Cosmop.
Poa bulbosa L. subsp. ***bulbosa*** – G bulb – Paleotemp.
Polypogon monspeliensis (L.) Desf. – T scap – Subtrop.
Polypogon subspathaceus Req. – T scap – Circum-Medit.
Rostraria cristata (L.) Tzvelev – T scap – Medit.-Irano-Turan.
Rostraria pubescens (Lam.) Trin. – T scap – Circum-Medit.
Sporobolus pumilus (Roth) P.M.Peterson & Saarela – G rhiz – Anfiatl. (Neo – Nat)
Sporobolus virginicus (L.) Kunth – G rhiz – Circum-Medit.
Stipellula capensis (Thunb.) Röser & H.R.Hamasha – T scap – Circum-Medit.
Thinopyrum elongatum (Host) D.R.Dewey – H caesp – Euro-Medit.
Thinopyrum junceum (L.) Á.Löve – G rhiz – Circum-Medit.
Triticum neglectum (Req. ex Bertol.) Greuter – T scap – Medit.-Turan.
Triticum ventricosum (Tausch) Ces., Pass. & Gibelli – T scap – W-Medit. (Arch D – Nat)

TYPHACEAE
Typha angustifolia L. – G rhiz – Circumbor.

CANNACEAE
Canna indica L. – G rhiz – Neotrop. (Neo-Cas)

Eudicotyledones
PAPAVERACEAE

Fumaria capreolata L. subsp. ***capreolata*** – T scap – Euro-Medit.
Fumaria flabellata Gasp. – T scap – Circum-Medit.
Fumaria officinalis L. subsp. ***officinalis*** – T scap – Subcosmop.
Glaucium flavum Crantz – H scap – Circumbor.
Hypecoum procumbens L. subsp. ***procumbens*** – T scap – Paleotemp.
Papaver hybridum L. – T scap – Medit.-Turan.
Papaver rhoeas L. subsp. ***rhoeas*** – T scap – E-Medit. (Arch D – Nat)

RANUNCULACEAE
Anemone hortensis L. subsp. ***hortensis*** – G bulb – N-Medit.
Clematis cirrhosa L. – P lian – Medit.-Turan.
Clematis flammula L. – P lian – Euro-Medit.
Ficaria verna subsp. ***fertilis*** (Lawalrée ex Laegaard) Stace – G bulb – Euroasiat.
Nigella damascena L. – T scap – Euro-Medit.
Ranunculus bullatus L. – H ros – Circum-Medit.
Ranunculus paludosus Poir. – H scap – Medit.-Turan.

AMARANTHACEAE
Achyranthes sicula (L.) All. – Ch suffr – W-Medit.
Amaranthus albus L. – T scap – Neotrop. (Neo – Inv)
Amaranthus blitum L. subsp. ***blitum*** – T scap – Boreo-Trop.

CHENOPODIACEAE
Arthrocaulon macrostachyum (Moric.) Piirainen & G.Kadereit – Ch succ – Medit.-Irano-Turan. (Db)
Atriplex prostrata Boucher ex DC. – T scap – Circumbor.
Beta vulgaris L. subsp. ***maritima*** (L.) Arcang. – T scap – Euro-Medit.
Beta vulgaris L. subsp. ***vulgaris*** – H scap – Euro-Medit. (Arch – Cas)
Chenopodium album L. subsp. ***album*** – T scap – Subcosmop.
Chenopodiastrum murale (L.) S.Fuentes, Uotila & Borsch – T scap – Subcosmop.
Halimione portulacoides (L.) Aellen – Ch frut – Circumbor.
Oxybasis glauca (L.) S. Fuentes, Uotila & Borsch – T scap – Subcosmop. (Db)
Salicornia fruticosa (L.) L. – Ch succ – Boreo-Trop.
Salsola squarrosa subsp. ***controversa*** (Tod. ex Lojac.) Mosyakin – T scap – Circumbor.
Soda inermis Fourr. – T scap – Paleotemp.
Suaeda vera J.F.Gmel. – Ch suffr – Subcosmop.

AIZOACEAE
Carpobrotus acinaciformis (L.) L.Bolus – Ch suffr – S-Africa (Neo – Inv)
Carpobrotus edulis (L.) N.E.Br. – Ch suffr – S-Africa (Neo – Inv)
Drosanthemum floribundum (Haw.) Schwantes – H scand – S-Africa (Neo – Nat)
Malephora crocea (Jacq.) Schwantes – Ch scap – S-Africa (Neo – Inv)
Mesembryanthemum cordifolium L.f.– H rept – S-Africa (Neo – Inv)
Mesembryanthemum cristallinum L. – T scap – S-Africa (Neo – Nat)
Mesembryanthemum nodiflorum L. – T scap – S-Africa (Neo – Nat)

Cactaceae

Austrocylindropuntia subulata (Mühlenpf.) Backeb. – P succ – Neotrop. (Neo – Inv)
Nopalea dejecta Salm-Dick – P succ – Neotrop. (Neo – Cas)
Opuntia dillenii (Ker Gawl.) Haw. – P succ – Neotrop. (Neo – Nat)
Opuntia ficus-indica (L.) Mill. – P succ – Neotrop. (Neo – Inv)
Opuntia puberula Hort. Vindob. ex Pfeiff. – P succ – Neotrop. (Neo – Cas)
Opuntia monacantha Haw. – P succ – Neotrop. (Neo – Nat)

Caryophyllaceae

Arenaria leptoclados (Rchb.) Guss. subsp. ***leptoclados*** – T scap – Paleotemp.
Cerastium glomeratum Thuill. – T scap – Euro-Medit.
Cerastium pumilum Curtis – T scap – Euro-Medit.
Corrigiola telephiifolia Pourr. – H ros – W-Medit.
Eudianthe coeli-rosa (L.) Fenzl ex Endl. – T scap – W-Medit.
Paronychia argentea Lam. – H caesp – Circum-Medit.
Petrorhagia dubia (Raf.) G.López & Romo – T scap – S-Medit.
Petrorhagia nanteuilii (Burnat) P.W.Ball & Heywood – T scap – W-Medit.
Petrorhagia prolifera (L.) P.W.Ball & Heywood – T scap – Euro-Medit.
Polycarpon tetraphyllum subsp. ***alsinifolium*** (Biv.) Ball – T scap – S-Medit.
Polycarpon tetraphyllum subsp. ***diphyllum*** (Cav.) O. Bolòs & Font-Quer – T scap – Euro-Medit.
Rhodalsine geniculata (Poiret) F.N.Williams – Ch suffr – W-Medit.
Sagina apetala Ard. subsp. ***apetala*** – T scap – Euro-Medit.
Sagina maritima Don – T scap – Medit.-Atl.
Silene bellidifolia Jacq. – T scap – S-Medit.
Silene colorata Poir. – T scap – Circum-Medit.
Silene gallica L. – T scap – Euro-Medit.
Silene niceensis All. – T scap – Circum-Medit.
Silene succulenta subsp. ***corsica*** (DC.) Nyman – H caesp – Endem. SA-CO
Silene valsecchiae Bocchieri – T scap – Endem. SA
Silene vulgaris subsp. ***tenoreana*** (Colla) Soldano & F. Conti – H caesp – Circum-Medit.
Silene vulgaris (Moench) Garcke subsp. ***vulgaris*** – H caesp – Circum-Medit.
Spergularia marina (L.) Besser – T scap – Paleotemp.
Spergularia rubra (L.) J.Presl & C. Presl – Ch suffr – Subcosmop.
Stellaria media (L.) Vill. subsp. ***media*** – T rept – Cosmop.
Stellaria neglecta Weihe subsp. ***neglecta*** – T scap – Paleotemp.
Stellaria pallida (Dumort.) Crép. – T scap – Euro-Medit.
Velezia rigida L. – T scap – Medit.-Turan.

Frankeniaceae

Frankenia hirsuta L. – Ch suffr – Subcosmop.
Frankenia laevis L. subsp. ***laevis*** – Ch suffr – Subcosmop.

Nyctaginaceae

Mirabilis jalapa L. – T caesp – Neotrop. (Neo – Inv)

PHYTOLACCACEAE

Phytolacca americana L. – G rhiz – Neotrop. (Neo – Nat)

PLUMBAGINACEAE

Limonium dubium (Andrews ex Guss.) Litard. – Ch suffr – Endem. SA-CO-SI
Limonium narbonense Mill. – H ros – Circum-Medit.
Limonium retirameum Greuter & Burdet subsp. ***retirameum*** – Ch suffr – Endem. SA
Plumbago europaea L. – Ch frut – Circum-Medit.

POLYGONACEAE

Polygonum maritimum L. – Ch rept – Subcosmop.
Rumex bucephalophorus L. subsp. ***bucephalophorus*** – T scap – Medit.-Macarones.
Rumex crispus L. – H scap – Paleotemp.
Rumex pulcher L. subsp. ***pulcher*** – H scap – Euro-Medit.
Rumex spinosus L. – T scap – Circum-Medit.

PORTULACACEAE

Portulaca sardoa Danin, Bagella & Marrosu – T scap – Endem. SA-CO

TAMARICACEAE

Tamarix africana Poir. – P scap – W-Medit.
Tamarix gallica L. – P caesp – W-Medit.

SANTALACEAE

Osyris alba L. – NP – Euro-Medit.
Thesium humile Vahl – T scap – Medit.-Atl.

CRASSULACEAE

Aeonium haworthii (Webb & Berthel.) Webb & Berthel. – NP – Macarones. (Neo – Cas)
Bulliarda vaillantii (Willd.) DC. – T scap – Medit.-Trop.
Crassula tillaea Lest.-Garl. – T scap – Medit.-Atl.
Kalanchoë daigremontiana Raym.-Hamet & H. Perrier – Ch succ – Africa (Neo – Cas)
Petrosedum sediforme (Jacq.) Grulich subsp. ***sediforme*** – Ch succ – Circum-Medit.
Phedimus stellatus (L.) Raf. – T scap – Circum-Medit.
Sedum album subsp. ***micranthum*** (Bast. ex DC.) Syme – Ch succ – Euro-Medit.
Sedum caeruleum L. – T scap – SW-Medit.
Sedum litoreum Guss. – T scap – Circum-Medit.
Sedum rubens L. – T scap – Euro-Medit.
Umbilicus horizontalis (Guss.) DC. – G bulb – Circum-Medit.
Umbilicus rupestris (Salisb.) Dandy – G rhiz – Medit.-Atl.

GERANIACEAE
Erodium chium (L.) Willd. – T scap – Circum-Medit.
Erodium ciconium (L.) L’Hér. – H bien – Euro-Medit.
Erodium cicutarium (L.) L’Hér. – H ros – Subcosmop.
Erodium malacoides (L.) L’Hér. subsp. ***malacoides*** – T scap – Medit.-Macarones.
Erodium moschatum (L.) L’Hér. – T scap – Circum-Medit.
Geranium molle L. – T scap – Subcosmop.
Geranium purpureum Vill. – T scap – Euro-Medit.
Geranium rotundifolium L. – T scap – Paleotemp.

LYTHRACEAE
Punica granatum L. – P caesp – E-Medit.-Turan. (Arch – Cas)

MYRTACEAE
Eucalyptus camaldulensis Dehnh. – P scap – Australia (Neo – Nat)
Eucalyptus globulus Labill. – P scap – Australia (Neo – Cas)
Myrtus communis L. – P caesp – Circum-Medit.

ZYGOPHYLLACEAE
Tribulus terrestris L. – T rept – Asiat. (Arch – Nat)

CELASTRACEAE
Euonymus japonicus Thunb. – P caesp – Asiat. (Neo – Cas)

CUCURBITACEAE
Bryonia marmorata E. Petit – G rhiz – Endem. SA-CO
Cucumis melo L. – T scap – Paleotrop. (Arch – Cas)
Cucumis sativus L. – T scap – Paleotrop. (Arch – Cas)
Cucurbita maxima Duchesne subsp. ***maxima*** – T scap – Neotrop. (Neo – Cas)
Cucurbita pepo L. subsp. ***pepo*** – T scap – Neotrop. (Neo – Cas)
Ecballium elaterium (L.) A.Rich. – G bulb – Euro-Medit.

FABACEAE
Acacia saligna (Labill.) H.L.Wendl. – P caesp – Australia (Neo – Inv)
Anagyris foetida L. – P caesp – S-Medit.
Astragalus hamosus L. – T scap – Medit.-Turan.
Astragalus pelecinus (L.) Barneby subsp. ***pelecinus*** – T scap – Circum-Medit.
Bituminaria bituminosa (L.) C.H.Stirt. – H scap – Euro-Medit.
Cytisus laniger DC. – P caesp – Circum-Medit.
Ceratonia siliqua L. – P scap – E-Medit. (Arch – Nat)
Ervilia hirsuta (L.) Opiz – T scap – Paleotemp.
Ervum gracile DC. – T scap – Euro-Medit.
Ervum pubescens DC. – T scap – Euro-Medit.
Genista corsica (Loisel.) DC. – NP – Endem. SA-CO
Lathyrus annuus L. – T scap – Euro-Medit.
Lathyrus cicera L. – T scap – Euro-Medit.

Lathyrus clymenum L. (sensu Gallego 1999) – T scap – Circum-Medit.
Lathyrus oleraceus subsp. ***biflorus*** (Raf.) H. Schaef., Coulot & Rabaute – T scap – Medit.-Turan.
Lathyrus oleraceus Lam. subsp. ***oleraceus*** – T scand – Circum-Medit. (Arch – Cas)
Lotus angustissimus L. – T scap – Euro-Medit.
Lotus cytisoides subsp. ***conradiae*** Gamisans – Ch suffr – Endem. SA-CO
Lotus edulis L. – T scap – Circum-Medit.
Lotus ornithopodioides L. – T scap – Circum-Medit.
Lotus parviflorus Desf. – T scap – Circum-Medit.
Lupinus angustifolius L. – T scap – Circum-Medit.
Lupinus gussoneanus J.Agardh. – T scap – Circum-Medit.
Medicago italica (Mill.) – T scap – W-Medit.
Medicago littoralis Loisel. – T scap – Euro-Medit.
Medicago marina L. – Ch rept – Medit.-Atl.
Medicago minima (L.) L. – T scap – Eurasiat.
Medicago orbicularis (L.) Bartal. – T scap – Euro-Medit.
Medicago polymorpha L. – T scap – Subcosmop.
Medicago praecox DC. – T scap – Circum-Medit.
Medicago rugosa Desr. – T scap – W-Medit.
Medicago truncatula Gaertn. – T scap – Circum-Medit.
Medicago turbinata (L.) All. – T scap – Circum-Medit.
Trigonella elegans (Salzm. ex Ser.) Coulot & Rabaute – T scap – S-Medit.
Trigonella italica (L.) Coulot & Rabaute – T scap – N-Medit.
Trigonella officinalis (L.) Coulot & Rabaute – H bien – Subcosmop.
Trigonella sicula (Turra) Coulot & Rabaute – T scap – S-Medit. (Arch – Inv)
Trigonella smalii Coulot & Rabaute – T scap – Subcosmop.
Trigonella sulcata (Desf.) Coulot & Rabaute – T scap – Circum-Medit.
Ononis diffusa Ten. – T scap – Circum-Medit.
Ononis natrix subsp. ***ramosissima*** (Desf.) Batt. – H suffr – Circum-Medit.
Ononis reclinata L. – T scap – Circum-Medit.
Ononis variegata L. – T scap – Circum-Medit.
Ornithopus compressus L. – T scap – Euro-Medit.
Ornithopus pinnatus (Mill.) Druce – T scap – Medit.-Atl.
Robinia pseudacacia L. – P caesp – Neotrop. (Neo – Nat)
Scorpiurus muricatus L. – T scap – Euro-Medit.
Spartium junceum L. – P caesp – Euro-Medit. (Arch – Cas)
Sulla coronaria (L.) Medik. – H scap – W-Medit. (Arch – Nat)
Trifolium angustifolium L. subsp. ***angustifolium*** – T scap – Euro-Medit.
Trifolium arvense L. subsp. ***arvense*** – T scap – Euro-Medit.-Irano-Turan.
Trifolium campestre Schreb. – T scap – W-Paleotemp.
Trifolium cherleri L. – T scap – Euro-Medit.
Trifolium glomeratum L. – T scap – Euro-Medit.
Trifolium scabrum L. – T scap – Euro-Medit.
Trifolium spumosum L. – T scap – Circum-Medit.
Trifolium stellatum L. – T scap – Euro-Medit.

Trifolium subterraneum L. subsp. ***subterraneum*** – T rept – Euro-Medit.
Trifolium suffocatum L. – T scap – Circum-Medit.
Trifolium tomentosum L. – T rept – W-Paleotemp.
Tripodion tetraphyllum (L.) Fourr. – T scap – Circum-Medit.
Vachellia karroo (Hayne) Banfi & Galasso – P caesp – S-Africa (Neo – Inv)
Vicia bithynica (L.) L. – T scap – Euro-Medit.
Vicia angustifolia L. – T scap – Subcosmop.
Vicia faba L. – T scap – S-Medit. (Arch – Cas)
Vicia pseudocracca Bertol. – T scap – Circum-Medit.
Vicia sativa L. – T scap – Medit.-Turan.
Vicia villosa Roth – T scap – Euro-medit.

CYTINACEAE
Cytinus hypocistis (L.) L. – G rad – Medit.-Macarones.

EUPHORBIACEAE
Euphorbia characias L. – NP – Circum-Medit.
Euphorbia dendroides L. – NP – C-Medit.
Euphorbia exigua L. subsp. ***exigua*** – T scap – Euro-Medit.
Euphorbia helioscopia L. subsp. ***helioscopia*** **–** T scap – Cosmop.
Euphorbia paralias L. – Ch frut – Medit.-Atl.
Euphorbia peplis L. – T rept – Euro-Medit.
Euphorbia peplus L. – T scap – Cosmop.
Euphorbia pithyusa L. subsp. ***pithyusa*** – Ch suffr – W-Medit.
Euphorbia pterococca Brot. – T scap – W-Medit.-Macarones.
Euphorbia segetalis L. – Ch suffr – W-Medit.
Euphorbia terracina L. – H scap – Circum-Medit.
Mercurialis annua L. – T scap – Paleotemp.
Ricinus communis L. – P scap – Paleotrop. (Arch – Inv)

LINACEAE
Linum usitatissimum subsp. ***angustifolium*** (Huds.) Thell. – H bienn – Euro-Medit.-Atl.
Linum corymbulosum Rchb. – T scap – Circum-Medit.
Linum strictum L. – T scap – Circum-Medit.
Linum tenuifolium L. – Ch suffr – S-Medit.
Linum trigynum L. – T scap – Euro-Medit.

SALICACEAE
Populus alba L. – P scap – Paleotemp.

OXALIDACEAE
Oxalis corniculata L. – H rept – Cosmop. (Arch D – Nat)
Oxalis pes-caprae L. – G bulb – S-Africa (Neo – Inv)
Oxalis articulata Savigny – G bulb – Neotrop. (Neo – Nat)

Moraceae

Ficus carica L. – P scap – Medit.-Turan. (Arch D – Nat)

Rhamnaceae

Rhamnus alaternus L. subsp. ***alaternus*** – P caesp – Circum-Medit.

Rosaceae

Aphanes australis Rydb. – T scap – W-Medit. (Db)
Malus domestica (Borkh.) Borkh. – P scap – Euroasiat. (Arch – Cas)
Poterium sanguisorba subsp. ***balearicum*** (Bourg. ex Nyman) Stace – H scap – Medit.
Prunus dulcis (Mill.) D.A. Webb – P scap – Medit.-Turan. (Arch – Cas)
Pyrus spinosa Forssk. – P caesp – Circum-Medit.
Rubus ulmifolius Schott – NP – Euro-Medit.

Urticaceae

Parietaria judaica L. – H scap – Euro-Medit.
Parietaria lusitanica L. subsp. ***lusitanica*** – T rept – Circum-Medit.
Urtica membranacea Poir. – T scap – S-Medit.
Urtica pilulifera L. – T scap – S-Medit.
Urtica urens L. – T scap – Boreo-Trop.

Brassicaceae

Arabidopsis thaliana (L.) Heynh. – T scap – Cosmop.
Biscutella morisiana Raffaelli – T scap – Endem. SA-CO
Brassica insularis Moris – Ch suffr – Endem. SA-CO-SI-TN
Brassica napus L. – H scap – Asiat. (Arch – Nat)
Brassica nigra (L.) W.D.J.Koch – T scap – Euro-Medit. (Arch D – Nat)
Brassica rapa subsp. ***campestris*** (L.) A.R.Clapham – H scap – Euro-Medit. (Arch – Cas)
Brassica tournefortii Gouan – T scap – S-Medit.
Bunias erucago L. – T scap – Euro-Medit.
Cakile maritima Scop. subsp. ***maritima*** – T scap – Circum-Medit.
Capsella bursa-pastoris (L.) Medik. subsp. ***bursa-pastoris*** – H bienn – Cosmop.
Cardamine hirsuta L. – T scap – Cosmop.
Diplotaxis viminea (L) DC. – T scap – W-Medit.-Atl.
Eruca vesicaria (L.) Cav. – T scap – Euro-Medit.-Irano-Turan. (Arch D – Nat)
Erysimum cheiri (L.) Crantz – Ch suffr – Euro-Medit. (Arch – Cas)
Hirschfeldia incana (L.) Lagr.-Foss. subsp. ***incana*** – H scap – W-Medit.
Lepidium graminifolium L. subsp. ***graminifolium* –** Ch suffr – W-Medit.
Lobularia maritima (L.) Desv. – H scap – Circum-Medit.
Marcus-kochia ramosissima (Desf.) Al-Shehbaz – T scap – W-Medit.
Matthiola tricuspidata (L.) R.Br. – T scap – Circum-Medit.
Raphanus raphanistrum L. subsp. ***raphanistrum*** – T scap – Euro- Medit.
Rapistrum rugosum (L.) All. – T scap – Euro-Medit.
Sinapis alba L. subsp. ***alba*** – T scap – E-Medit. (Arch – Nat)
Sinapis arvensis L. subsp. ***arvensis*** – T scap – Circum-Medit.

Sisymbrium erysimoides Desf. – T scap – S-Medit.
Sisymbrium officinale (L.) Scop. – T scap – Subcosmop.
Succowia balearica (L.) Medik. – T scap – W-Medit.
Teesdalia coronopifolia (J.P. Bergeret) Thell. – T scap – Euro-Medit.

RESEDACEAE
Reseda alba L. – H scap – Circum-Medit.
Reseda luteola L. – H scap – Circumbor.

CISTACEAE
Cistus creticus subsp. **_eriocephalus_** (Viv.) Greuter & Burdet – NP – Circum-Medit.
Cistus monspeliensis L. – NP – Medit.-Macarones.
Cistus salviifolius L. – NP – Circum-Medit.
Fumana thymifolia (L.) Spach. ex Webb – Ch suffr – Circum-Medit.
Helianthemum salicifolium (L.) Mill. – T scap – Euro-Medit.
Tuberaria guttata (L.) Fourr. – T scap – Euro-Medit.

MALVACEAE
Alcea rosea L. – H scap – E-Medit. (Arch – Cas).
Malva arborea (L.) Webb & Berthel. – H bienn – Euro-Medit.
Malva multiflora (Cav.) Soldano, Banfi & Galasso – T scap – Circum-Medit.
Malva nicaeensis All. – T scap – Circum-Medit.
Malva olbia (L.) Alef. – P caesp – Circum-Medit.
Malva parviflora L. – T scap – Euro-Medit.
Malva sylvestris L. – H scap – Subcosmop.

THYMELAEACEAE
Daphne gnidium L. – P caesp – Medit.-Macarones.
Thymelaea hirsuta (L.) Endl. – NP – Circum-Medit.
Thymelaea tartonraira (L.) All. subsp. **_tartonraira_** – NP – Circum-Medit.

ANACARDIACEAE
Pistacia lentiscus L. – P caesp – Circum-Medit.
Schinus molle L. – P scap – Neotrop. (Neo – Cas).

RUTACEAE
Ruta chalepensis L. – Ch suffr – S-Medit.

SIMAROUBACEAE
Ailanthus altissima Mill. – P scap – Asiat. (Neo – Cas).

ERICACEAE
Erica arborea L. – P caesp – Circum-Medit.
Erica scoparia L. subsp. **_scoparia_** – P caesp – Circum-Medit.

Primulaceae

Lysimachia arvensis subsp. **latifolia** (L.) Peruzzi – T rept – Euro-Medit.
Lysimachia foemina (Mill.) U. Manns & Anderb. – T rept – Subcosmop.
Lysimachia linum-stellatum L. – T scap – Circum-Medit.
Lysimachia nardii Arrigoni – T rept – Circum-Medit. (Arch – Nat).
Samolus valerandi L. – H scap – Subcosmop.

Boraginaceae

Borago officinalis L. – T scap – Euro-Medit.
Cynoglossum creticum Mill. – H bienn – Euro-Medit.
Echium creticum L. subsp. **creticum** – H bien – W-Medit.
Echium italicum L. – H bienn – Euro-Medit.
Echium plantagineum L. – H bienn – Euro-Medit.
Echium vulgare L. – H bienn – Europ.
Heliotropium europaeum L. – T scap – Euro-Medit.-Turan.
Myosotis arvensis (L.) Hill subsp. **arvensis** – T scap – Euroasiat.
Myosotis ramosissima Rochel *ex* Schult. subsp. **ramosissima** – T scap – Euroasiat.

Apocynaceae

Nerium oleander L. subsp. **oleander** – P caesp – S-Medit.
Vincetoxicum hirundinaria Medik. subsp. **hirundinaria** – H scap – Euroasiat.

Gentianaceae

Centaurium erythraea Raf. subsp. **erythraea** – T scap – Paleotemp.
Centaurium maritimum (L.) Fritsch – T scap – W-Medit.
Centaurium tenuiflorum (Hoffmanns. & Link) Fritsch subsp. **tenuiflorum –** T scap – Medit.-Atl.
Schenkia spicata (L.) G.Mans. – T scap – Euro-Medit.

Rubiaceae

Crucianella maritima L. – Ch suffr – Circum-Medit.
Galium aparine L. – T scap – Eurasiat.
Galium murale (L.) All. – T scap – Circum-Medit.
Galium spurium L. – T scap – Euro-Medit.-Irano-Turan.
Galium verrucosum Huds. subsp. **verrucosum** – T scap – Circum-Medit.
Rubia peregrina L. – P lian – Circum-Medit.
Sherardia arvensis L. – T scap – Subcosmop.
Thelygonum cynocrambe L. – T scap – Circum-Medit.
Valantia muralis L. – T scap – Circum-Medit.

Acanthaceae

Acanthus mollis L. subsp. **mollis** – H scap – W-Medit. (Arch – Cas).

Bignoniaceae

Tecomaria capensis (Thunb.) Spach – T scap – S-Africa (Neo – Cas).

LAMIACEAE
Ajuga iva (L.) Schreber subsp. iva – Ch suffr – Circum-Medit.
Clinopodium vulgare subsp. ***arundanum*** (Boiss.) Nyman – H scap – Circumbor.
Lamium amplexicaule L. – T scap – Paleotemp.
Lavandula stoechas L. subsp. ***stoechas*** – NP – Circum-Medit.
Marrubium vulgare L. – H scap – Subcosmop.
Melissa officinalis subsp. ***altissima*** (Sm.) Arcang. – H scap – Euro-Medit.
Mentha pulegium L. subsp. ***pulegium*** – H scap – Subcosmop.
Micromeria graeca (L.) Benth. ex Rchb. subsp. ***graeca*** – Ch suffr – Circum-Medit.
Salvia rosmarinus Spenn. – NP – Circum-Medit.
Salvia verbenaca L. – H scap – Medit.-Atl.
Stachys major (L.) Bartolucci & Peruzzi – Ch frut – Circum-Medit.
Stachys romana (L.) E.H.L. Krause – T scap – Circum-Medit.
Teucrium marum L. – Ch suffr – Endem. SA-CO-BL-AT-H
Vitex agnus-castus L. – P caesp – Circum-Medit.

OLEACEAE
Olea europaea var. ***sylvestris*** Brot. – P scap – Circum-Medit.
Phillyrea angustifolia L. – P caesp – W-Medit.
Phillyrea latifolia L. – P scap – Circum-Medit.
Phillyrea latifolia var. ***media*** L. C.K. Schneid – P scap – Circum-Medit.

OROBANCHACEAE
Bellardia trixago (L.) All. – T scap – Euro-Medit.
Bellardia viscosa (L.) Fisch. & C.A. Mey. – T scap – Medit.-Atl.
Orobanche amethystea Thuill. – T par – Euro-Medit.
Orobanche minor Sm. – T par – Subcosmop.
Phelipanche ramosa (L.) Pomel – T par – Circum-Medit.

PLANTAGINACEAE
Callitriche palustris L. – I rad – Circumbor.
Cymbalaria aequitriloba (Viv.) A.Chev. subsp. ***aequitriloba*** – Ch rept – Endem. SA-CO-BL-AT
Linaria arvensis (L.) Desf. – T scap – Medit-Atl.
Linaria pelisseriana (L.) Mill. – T scap – Medit.-Atl.
Linaria simplex (Willd.) Desf. – T scap – Euro-Medit.
Misopates orontium (L.) Raf. – T scap – Paleotemp.
Plantago afra L. – T scap – Euro-Medit.
Plantago bellardii All. subsp. ***bellardii*** – T scap – S-Medit.
Plantago coronopus L. – T scap – Euro-Medit.
Plantago crassifolia Forssk. – H ros – Circum-Medit.
Plantago lagopus L. – T scap – Circum-Medit.
Plantago lanceolata L. – H ros – Cosmop.
Plantago macrorrhiza Poir. – H ros – W-Medit.
Plantago major L. – H ros – Euroasiat.

Plantago weldenii Rchb. – T scap – Euro-Medit.
Veronica cymbalaria Bodard subsp. ***cymbalaria*** – T scap – Euro-Medit.
Veronica persica Poir. – T scap – Irano-Turan. (Neo – Nat).

SCROPHULARIACEAE
Myoporum insulare R. Br. – P caesp – Australia (Neo – Nat).
Myoporum tetrandrum (Labill.) Domin – P caesp – Australia (Neo – Nat).
Scrophularia trifoliata L. – H scap – Endem. SA-CO-AT
Verbascum conocarpum Moris subsp. ***conocarpum*** – H bienn – Endem. SA-CO-AT
Verbascum sinuatum L. – H bienn – Euro-Medit.

VERBENACEAE
Lantana camara L. – NP – Neotrop. (Neo – Cas).
Verbena officinalis L. – H scap – Neotrop.

CONVOLVULACEAE
Convolvulus althaeoides L. – H scand – W-Medit.
Convolvulus arvensis L. – G rhiz – Cosmop.
Convolvulus sepium L. – H scand – Paleotemp.
Convolvulus siculus subsp. ***elongatus*** Batt. – T scap – S-Medit.
Convolvulus soldanella L. – G rhiz – Cosmop.
Cuscuta epithymum (L.) L. subsp. ***kotschyi*** (Des Moul.) Arcang. – T par – Circum-Medit.

SOLANACEAE
Datura innoxia Mill. – T scap – Neotrop. (Neo – Nat)
Datura stramonium L. – T scap – Neotrop. (Neo – Nat)
Datura wrightii Regel – T scap – Neotrop. (Neo – Nat)
Hyoscyamus albus L. – H bienn – Euro-Medit.
Nicotiana glauca Graham – NP – Neotrop. (Neo – Inv)
Solanum dulcamara L. – NP – Paleotemp.
Solanum linnaeanum Hepper & P.-M. L. Jaeger – NP – S-Africa (Neo – Nat)
Solanum lycopersicum L. – T scap – Neotrop. (Neo – Cas)
Solanum nigrum L. – T scap – Cosmop.

APIACEAE
Ammi majus L. – T scap – Euro-Medit.-Irano-Turan.
Ammoides pusilla (Brot.) Breistr. – T scap – Circum-Medit.
Bupleurum odontites L. – T scap – Medit.-Irano-Turan.
Bupleurum semicompositum L. – T scap – Circum-Medit.
Bupleurum tenuissimum L. – T scap – Euro-Medit.-Irano-Turan.
Crithmum maritimum L. – Ch suffr – Euro-Medit.
Daucus carota L. subsp. ***carota*** – H scap – Cosmop.
Daucus carota subsp. ***hispanicus*** (Gouan) Thell. – H bien – W-Medit.
Daucus carota subsp. ***maritimus*** (Lam.) Batt. – H bien – W-Medit.
Daucus carota subsp. ***maximus*** (Desf.) Ball – H bien – Euro-Medit.

Daucus pumilus (L.) Hoffmanns. & Link – T scap – Circum-Medit.
Echinophora spinosa L. – H scap – Euro-Medit.
Eryngium campestre L. – H scap – Euro-Medit.
Eryngium maritimum L. – G rhiz – Medit.-Atl.
Ferula arrigonii Bocchieri – H scap – Endem. SA-CO
Ferula communis L. subsp. ***communis*** – H scap – S-Medit.
Foeniculum vulgare Mill. – H scap – S-Medit.
Scandix pecten-veneris L. subsp. ***pecten-veneris*** – T scap – Subcosmop.
Smyrnium olusatrum L. – H bienn – Medit.-Atl.
Thapsia garganica L. subsp. ***garganica*** – H scap – S-Medit.
Tordylium apulum L. – T scap – Circum-Medit.
Torilis nodosa (L.) Gaertn. subsp. ***nodosa*** – T scap – Euro-Medit.-Turan.

ASTERACEAE

Achillea maritima (L.) Ehrend. & Y.P.Guo subsp. ***maritima*** – Ch suffr – Medit.-Atl.
Andryala integrifolia L. – T scap – Euro-Medit.
Anthemis arvensis L. – T scap – Subcosmop.
Artemisia arborescens (Vaill.) L. – NP – SW-Medit.
Bellis annua L. subsp. ***annua*** – T scap – Medit.-Macarones.
Bellis perennis L. – H ros – Circumbor.
Calendula arvensis (Vaill.) L. – T scap – Euro-Medit.
Calendula officinalis L. – T scap – Medit.-Turan. (Arch – Cas)
Carduus fasciculiflorus Viv. – H bien – Endem. SA-CO-AT
Carduus pycnocephalus L. subsp. ***pycnocephalus*** – H bienn – Euro-Medit.-Turan.
Carlina corymbosa L. – H scap – Circum-Medit.
Carlina gummifera (L.) Less. – H ros – S-Medit.
Carlina lanata L. – T scap – Circum-Medit.
Carthamus lanatus L. – T scap – Euro-Medit.
Centaurea calcitrapa L. – H bien – Medit.-Atl.
Centaurea napifolia L. – T scap – SW-Medit.
Centaurea sphaerocephala L. subsp. ***sphaerocephala*** – H scap – Circum-Medit.
Chamaemelum fuscatum (Brot.) Vasc. – T scap – W-Medit.
Chondrilla juncea L. – H scap – Euro-Medit.
Cichorium intybus L. – H scap – Cosmop.
Cirsium vulgare (Savi) Ten. subsp. ***sylvaticum*** (Tausch) Arènes – H bien – Subcosmop.
Cladanthus mixtus (L.) Chevall. – T scap – Circum-Medit.
Crepis bellidifolia Loisel. – T scap – W-Medit.
Crepis hyemalis (Biv.) Ces., Pass. & Gibelli – T scap – Endem. SA-SI
Crepis vesicaria L. subsp. ***vesicaria*** – T scap – Medit.-Atl.
Crupina crupinastrum (Moris) Vis. – T scap – Circum-Medit.
Cynara cardunculus L. subsp. ***cardunculus*** – H scap – Circum-Medit.

Dimorphotheca ecklonis DC. – Ch scap – S-Africa (Neo – Cas)
Dittrichia graveolens (L.) Greuter – T scap – Medit.-Turan.
Dittrichia viscosa (L.) Greuter subsp. ***viscosa*** – H scap – Euro-Medit.
Erigeron bonariensis L. – T scap – Neotrop. (Neo – Inv)
Erigeron canadensis L. – T scap – Neotrop. (Neo – Inv)
Erigeron sumatrensis Retz. – T scap – Neotrop. (Neo – Inv)
Eriocephalus africanus L. – P – S Africa (Neo – Cas).
Filago asterisciflora (Lam.) Sweet – T rept – Circum-Medit.
Filago germanica (L.) Huds. – T scap – Paleotemp.
Filago pygmaea L. – T rept – Circum-Medit.
Filago pyramidata L. – T scap – Euro-Medit.
Galactites tomentosus Moench – H bienn – Circum-Medit.
Galatella pannonica (Jacq.) Galasso, Bartolucci & Ardenghi – H bien – Euro-Medit.-Irano-Turan.
Glebionis coronaria (L.) Spach. – T scap – Circum-Medit. (Arch – Inv)
Hedypnois rhagadioloides (L.) F.W.Schmidt – T scap – Circum-Medit.
Helianthus annuus L. subsp. ***annuus*** – T scap – Neotrop. (Neo – Cas)
Helichrysum italicum subsp. ***tyrrhenicum*** (Bacch., Brullo & Giusso) Herrando, J.M.Blanco, L.Sáez & Galbany – Ch suffr – Endem. SA-CO
Helminthotheca echioides (L.) Holub – T scap – Euro-Medit.
Hyoseris scabra L. – T ros – Circum-Medit.
Hypochaeris achyrophorus L. – T scap – Circum-Medit.
Hypochaeris glabra L. – T scap – Euro-Medit.
Hypochaeris radicata L. – T scap – Circum-Medit.
Lactuca sativa L. subsp. ***sativa*** – H bienn – Medit. (Arch – Cas)
Lactuca sativa subsp. ***serriola*** (L.) Galasso, Banfi, Bartolucci & Ardenghi – T scap – Euro-Medit.
Leontodon tuberosus L. – H ros – Circum-Medit.
Limbarda crithmoides subsp. ***longifolia*** (Arcang.) Greuter – Ch suffr – Circum-Medit.
Logfia gallica (L.) Cosson & Germ. – T scap – Euro-Medit.
Onopordum illyricum L. – H bien – NE-Medit.
Pallenis spinosa (L.) Cass. subsp. ***spinosa*** – H bienn – Euro-Medit.
Phagnalon rupestre subsp. ***illyricum*** (H.Lindb.) Ginzb. – Ch suffr – W-Medit.
Phagnalon saxatile (L.) Cass. – Ch suffr – W-Medit.
Pulicaria odora (L.) Rchb. – H scap – Euro-Medit.
Pulicaria sicula (L.) Moris – T scap – Circum-Medit.
Reichardia picroides (L.) Roth – H scap – Circum-Medit.
Rhagadiolus stellatus (L.) Gaertn. – T scap – Euro-Medit.
Scolymus hispanicus L. – H bienn – Euro-Medit.
Scolymus maculatus L. – T scap – S-Medit.
Senecio leucanthemifolius Poir. subsp. ***leucanthemifolius*** – T scap – Circum-Medit.
Senecio lividus L. – T scap – Circum-Medit.
Senecio transiens (Rouy) Jeanm. – T scap – Endem. SA-CO
Senecio vulgaris L. subsp. ***vulgaris*** – T scap – Cosmop.
Silybum marianum (L.) Gaertn. – H bienn – Medit.-Turan.

Sonchus asper (L.) Hill subsp. ***asper*** – T scap – Subcosmop.
Sonchus bulbosus (L.) N. Kilian & Greuter subsp. ***bulbosus*** – G bulb – Circum-Medit.
Sonchus oleraceus L. – T scap – Subcosmop.
Sonchus tenerrimus L. – T scap – Circum-Medit.
Symphyotrichum squamatum (Spreng.) G.L.Nesom – T scap – Neotrop. (Neo – Inv).
Tolpis umbellata Bertol. – T scap – Circum-Medit.
Tolpis virgata (Desf.) Bertol. subsp. ***virgata*** – H scap – Circum-Medit.
Urospermum dalechampii (L.) F.W. Schmidt – H scap – Euro-Medit.
Urospermum picroides (L.) Scop. ex F.W. Schmidt – T scap – Euro-Medit.
Xanthium italicum Moretti – T scap – Neotrop. (Neo – Nat).
Xanthium spinosum L. – T scap – Neotrop. (Neo – Inv).

CAMPANULACEAE
Campanula erinus L. – T scap – Circum-Medit.
Jasione montana L. **–** H bienn – Euro-Medit.

DIPSACACEAE
Dipsacus ferox Loisel. – H bienn – Endem. SA-CO
Lomelosia rutifolia (Vahl) Avino & P.Caputo – H scap – W-Medit.
Sixalis atropurpurea (L.) Greuter & Burdet – H bien – Circum-Medit.

VALERIANACEAE
Centranthus calcitrapae (L.) Dufr. subsp. ***calcitrapae*** – T scap – Circum-Medit.
Valerianella dentata (L.) Pollich – T scap – Medit.-Atl.
Valerianella microcarpa Loisel. – T scap – Circum-Medit.

FAGACEAE
Quercus calliprinos Webb. – P scap – E-Medit.
Quercus ilex L. – P scap – Circum-Medit.
Quercus suber L. – P scap – Circum-Medit.

Results

The inventory of the vascular flora consists of 653 taxa, 84% of which are native (5% of them being endemic) and 16% non-native (10% neophytes, 6% archaeophytes) (Fig. 2), including 500 species, 148 subspecies, three varieties and two hybrids, from 89 families and 374 genera.

The native component includes 406 species, 135 subspecies, two variety and one hybrid, belonging to 75 families and 313 genera. The best represented phylum (Table 2) is *Magnoliophyta* (532 taxa), in which *Eudicotyledones* represent the largest systematic group, with 402 taxa, followed by 128 *Monocotyledones* taxa. The phylum *Pteridophyta* is represented by nine taxa, *Pinophyta* only by three taxa.

Among alien taxa, the best represented phylum (Table 2) is *Magnoliophyta* (107 taxa), in which *Eudicotyledones* represent the largest systematic group with 79 taxa, followed by *Monocotyledones* (28 taxa) and *Pinophyta* (two taxa).

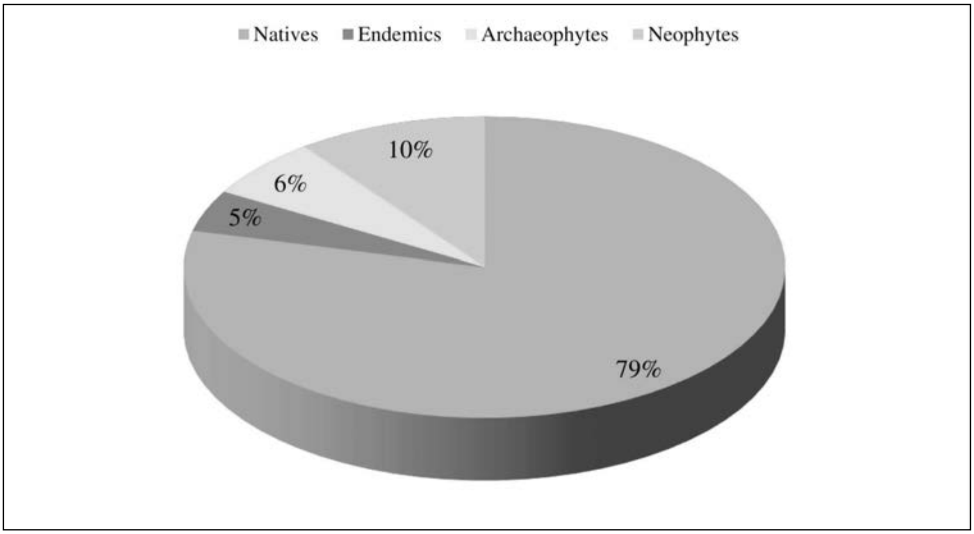


Fig. 2. The total vascular flora of the MPACC.

Among the native flora, the best represented family is *Asteraceae* (68 taxa) followed by *Poaceae* (60 taxa) and *Fabaceae* (59 taxa; Fig. 3).

Life-form analysis (Fig. 4) of native species revealed dominance of therophytes (49%) followed by hemicryptophytes (21%), geophytes (14%) and chamaephytes (7%). Phanerophytes are 5%, nano-phanerophytes 3%, hydrophytes only 1%.

As concerns chorology of native taxa (Fig. 5), the Mediterranean element is largely prevailing (81%, 440 taxa), followed by the Subcosmopolitan (6%, 33 taxa), Paleotemperate (4%, 22 taxa) and Cosmopolitan (3%, 17 taxa) elements.

In the chorological spectrum of the native Mediterranean species (Fig. 6a) most represented are the Circum-Mediterranean (37%, 162 taxa) and Euro-Mediterranean (27%, 119 taxa), followed by W-Mediterranean (9%, 40 taxa) and Endemic (6%, 29 taxa).

Table 2. Taxa numbers and percentages per phylum in the native and alien vascular flora of the MPACC.

Phylum	**Native**	**Alien**	**Native**	**Alien**
	N°	N°	%	%
Magnoliophyta - Eudicotyledones	402	79	73,90	72,48
Magnoliophyta - Monocotyledones	128	28	23,53	25,69
Magnoliophyta - Magnolides	2	0	0,37	0
Pinophyta	3	2	0,55	1,83
Pteridophyta	9	0	1,65	0
Total	**544**	**109**	**100**	**100**

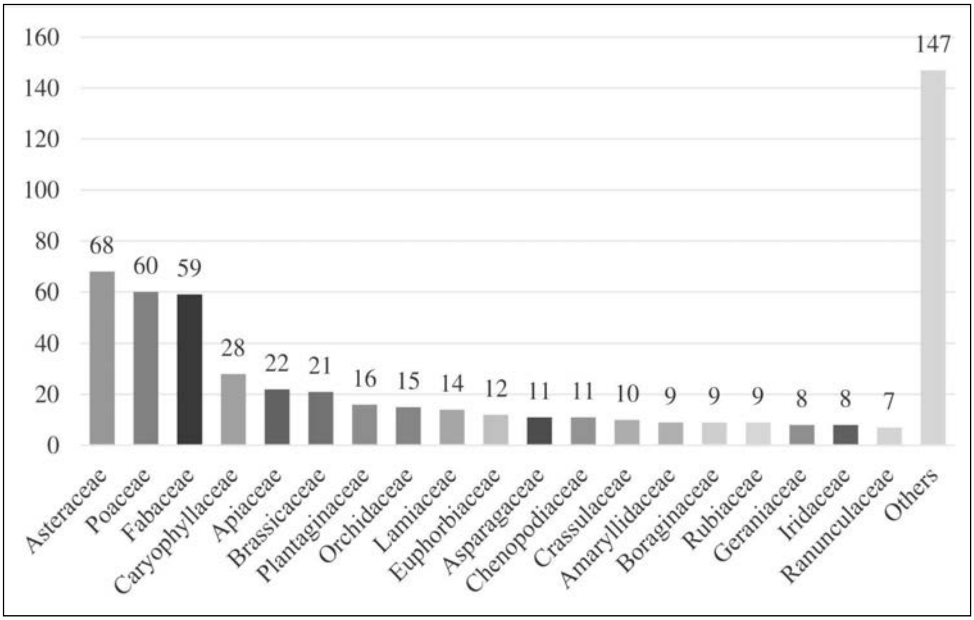
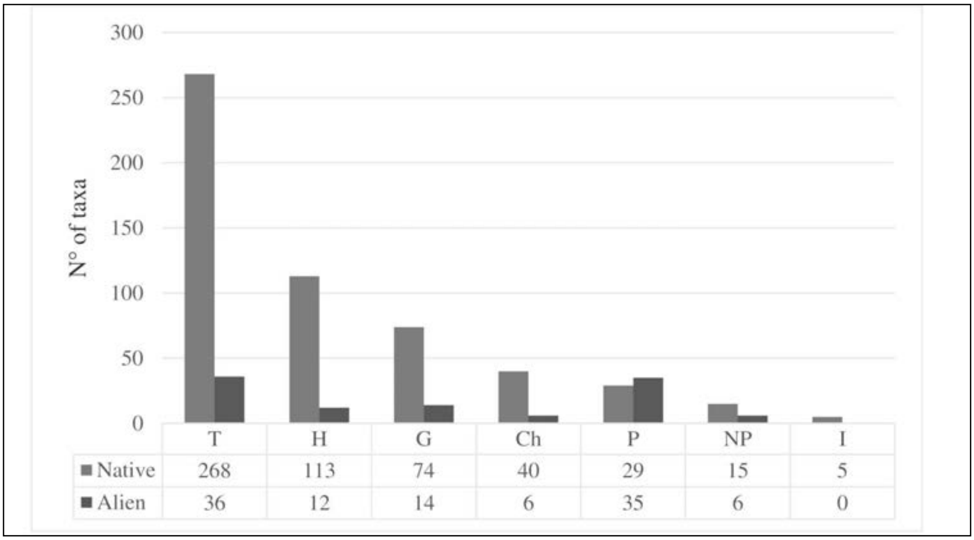


Fig. 3. Taxa numbers in the main families of the native vascular flora of the MPACC.



	T	H	G	Ch	P	NP	I
■ Native	268	113	74	40	29	15	5
■ Alien	36	12	14	6	35	6	0

Fig. 4. Comparison of taxa numbers per life-form in the native and alien vascular flora of the MPACC.

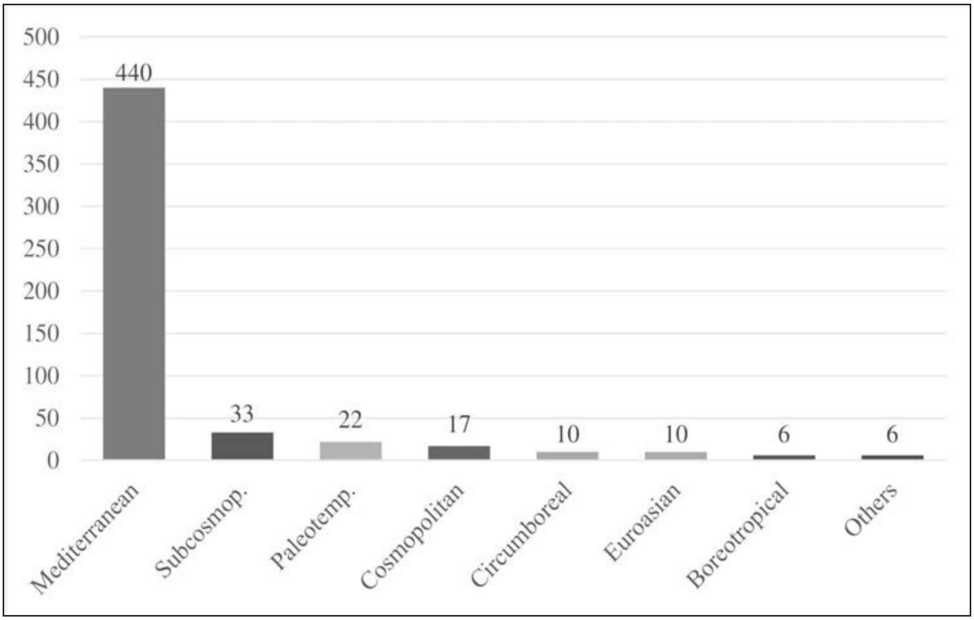


Fig. 5. Taxa numbers in the chorological types of the native vascular flora of the MPACC.

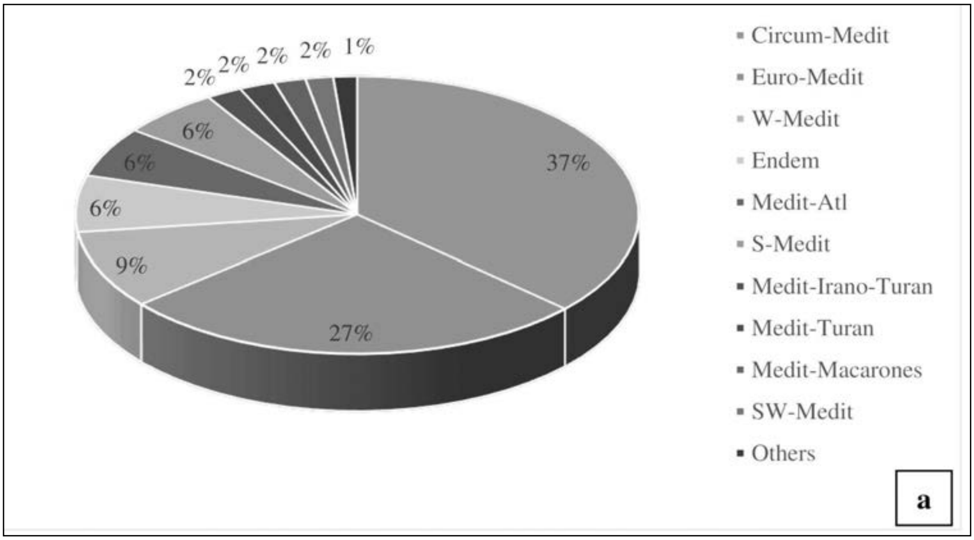
Among endemic plants (Fig. 6b), Sardo-Corsican taxa are predominant (55%, 16 taxa), followed by Sardo-Corsican-Tuscan Archipelago (14%, four taxa) and Sardinian taxa (10%, three taxa).

The non-native component includes 94 species, 13 subspecies, one variety and one hybrid, belonging to 40 families and 81 genera. Of the 109 alien taxa (Fig. 7), 25 (23%) are invasive, 40 (37%) naturalized and 44 (40%) casual. Among neophytes (67 taxa) the number of invasive taxa is 21 (19%), naturalized taxa are 20 (18%) and casual 26 (24%). Archaeophytes (42 taxa) have four invasive taxa (4%), 20 naturalized (19%) and 18 casual taxa (16%).

In the alien flora, the most represented family is *Asteraceae* (12 taxa) followed by *Fabaceae* (nine taxa) and *Poaceae* (nine taxa) (Fig. 8).

The best represented life-forms (Fig. 4) among alien taxa are therophytes (33%) and phanerophytes (32%), followed by geophytes (13%), hemicryptophytes (11%), chamaephytes (6%) and nano-phanerophytes (5%). There are no alien hydrophytes.

As concerns the geographic origin of alien species (Fig. 9), the American element (35%, 38 taxa) prevails, followed by the Mediterranean (27%, 30 taxa), the South African (13%, 14 taxa) and Asian (9%, 10 taxa) elements.



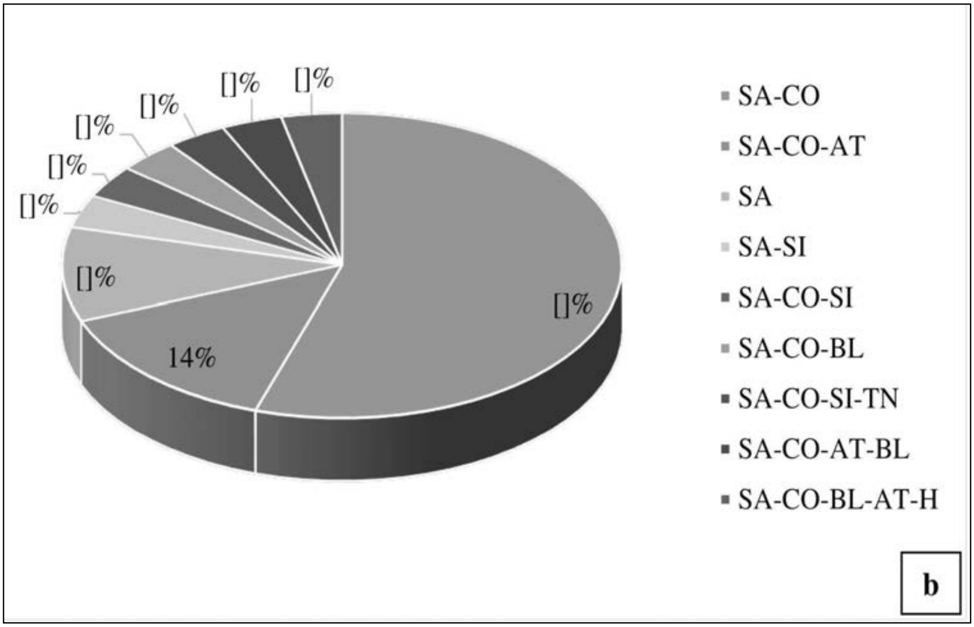


Fig. 6. Chorological spectrum of the Mediterranean (a) and Endemic (b) component of the native vascular flora of the MPACC.

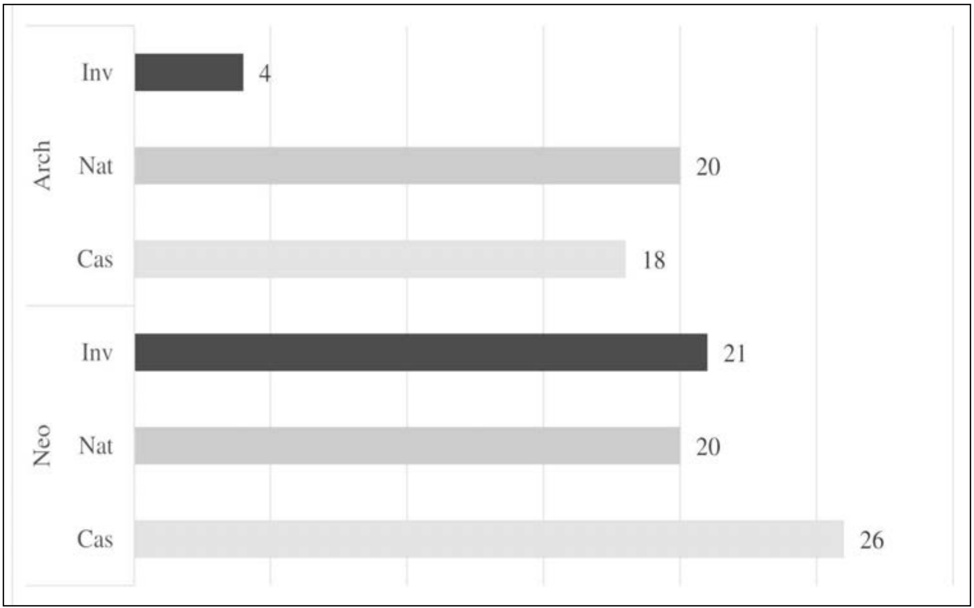


Fig. 7. Number of taxa per diffusion status among archaeophytes (Arch) and neophytes (Neo) of the MPACC.

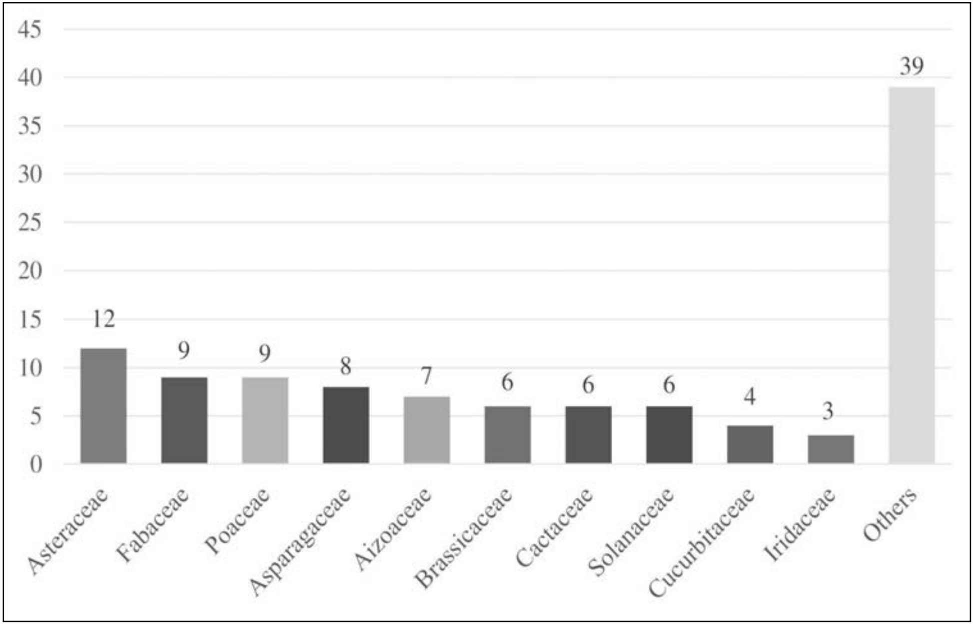


Fig. 8. Taxa numbers in the main families of the alien vascular flora of the MPACC.

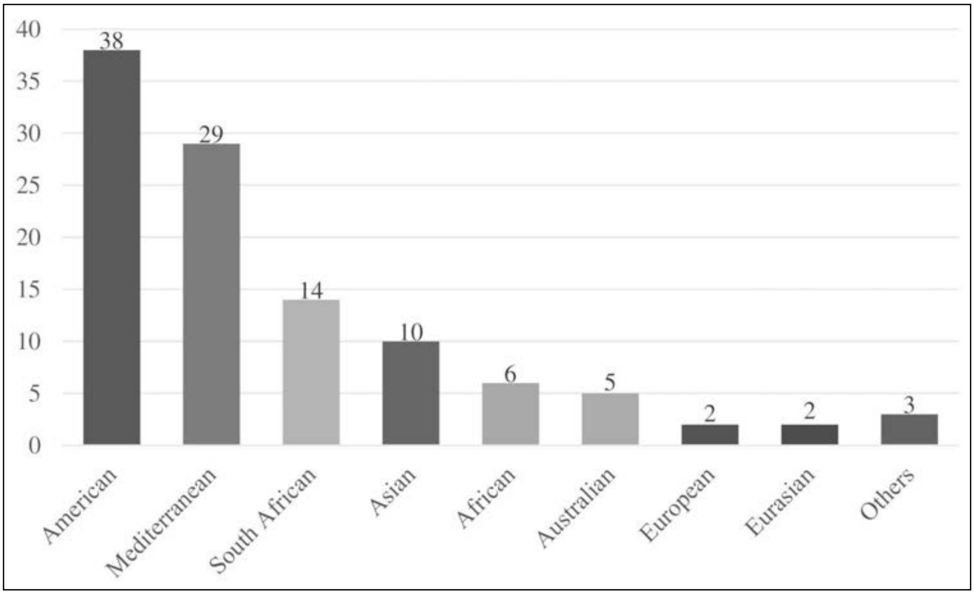


Fig. 9. Number of alien vascular taxa of the MPACC grouped by geographic origin.

Discussion

The floristic composition of the territory is similar to that of other Sardinian territories, especially as regards native families (e.g. Bacchetta 2006). Predominant are *Asteraceae*, *Poaceae* and *Fabaceae* which make up more than a third (34%) of the species in the MPACC’s flora (together with *Caryophyllaceae*, *Apiaceae* and *Brassicaceae* almost 50%). As regards the alien component, after the three families that have the greatest number of taxa (*Asteraceae*, *Poaceae* and *Fabaceae*), there are also families such as *Aizoaceae* and *Cactaceae* that are exclusively represented by alien species.

The life-form spectrum of the MPACC’s flora is consistent with those of other floras of neighbouring territories and highlights the Mediterranean nature of the climate in which therophytes (49%) and hemicryptophytes (21%) have a clear dominance over perennial biological forms (Bocchieri & al. 2008). The high percentage of geophytes (14%) appears to be linked to the anthropogenic use of the territory, in particular to the practice of fires and to agro-pastoral activities, but also proves the abundance of psammophilous habitats in which geophytes are important for the creation of dunes. The low percentage of phanerophytes (5%) and nano-phanerophytes (3%) reflects the low degree of woody cover.

The low percentage of hydrophytes is related to the almost absence of freshwater habitats, the five species present being related to sea, or pond water. As regards the alien component, the greater percentage of phanerophytes (32%) is emphasized, which, together with nano-phanerophytes (5%) become the prevalent biological form, testifying the use of species mainly introduced for reforestation, forestation and ornamental use, as already found for the alien vascular flora of Sardinia (Puddu & al. 2016).

Our analyses highlight the high floristic diversity of the investigated area, as testified by the presence of plants of high phytogeographical value, including 29 endemic species mainly confined in the two islands. Among the endemics, three species are exclusive to Sardinia: *Aristolochia tyrrhena* E. Nardi & Arrigoni, *Limonium retirameum* Greuter & Burdet subsp. *retirameum* and *Silene valsecchiae* Bocchieri. The latter two are also exclusive to eastern Sardinia. Most of the endemics (16 taxa) consist of Sardo-Corsican elements: *Aristolochia rotunda* subsp. *insularis* (E.Nardi & Arrigoni) Gamisans; *Biscutella morisiana* Raffaelli; *Bryonia marmorata* E. Petit; *Dipsacus ferox* Loisel.; *Ferula arrigonii* Bocchieri; *Genista corsica* (Loisel) DC.; *Helichrysum italicum* subsp. *tyrrhenicum* (Bacch., Brullo & Giusso) Herrando, J. M. Blanco, L. Sáez & Galbany; *Lotus cytisoides* subsp. *conradiae* Gamisans; *Narcissus supramontanus* Arrigoni subsp. *cunicularium* Arrigoni; *Ophrys conradiae* Melki & Deschâtres; *O. exaltata* Ten. subsp. *morisii* (Martelli) Del Prete; *Portulaca sardoa* Danin, Bagella & Marrosu; *Prospero corsicum* (Boullu) J.-M. Tison; *Romulea requienii* Parl.; *Senecio transiens* (Rouy) Jeanm.; *Silene succulenta* subsp. *corsica* (DC.) Nyman. *S. valsecchiae* and *F. arrigonii* have the *locus classicus* on the island of Serpentara. The endemics shared with Corsica and the Tuscan Archipelago are *Arum pictum* L. f. subsp. *pictum*, *Carduus fasciculiflorus* Viv., *Scrophularia trifoliata* L. and *Verbascum conocarpum* Moris subsp. *conocarpum*. Noteworthy is the abundance of the endemic *Brassica insularis* Moris, listed in Annexes II and IV of the Habitats Directive 92/43/EEC. This species, considered a Tyrrhenian endemic, is found only on the island of Cavoli, where one of the most important populations of Sardinia is present, the island taking its name from this species. The island of Serpentara is also probably a phytotoponym, which seems to take its name from *Helicodiceros muscivorus* (L. f.) Engl. (Biondi & al. 1993), endemic to Sardinia, Corsica, and the Balearic Islands.

Like most of the coastal territories of the Mediterranean area, also the study area is not immune from the spread of alien plant species, which make up 17% of the total flora. In particular, the high presence of invasive species is alarming, above all because they are a threat to the biodiversity of the most sensitive habitats, such as those of coastal dunes (Podda & al. 2018; Mayoral & al. 2020). In fact, among the 25 invasive species, the most common are neophytes introduced in gardens and public greenery as ornamental species, which escaped cultivation and become invasive in coastal habitats, such as *Carpobrotus acinaciformis* (L.) L. Bolus, *Carpobrotus edulis* (L.) N. E. Br., *Malephora crocea* (Jacq.) Schwantes and *Mesembryanthemum cordifolium* L.f., all belonging to the South African family *Aizoaceae*. In addition, several American plant species belonging to the *Agave* genus [*Agave americana* L., *Agave fourcroydes* Lem., *Agave ingens* Brg. var. *picta* (Salm.) Bgr., *Agave salmiana* subsp. *ferox* (K.Koch) Hochstätter], two *Fabaceae* [*Acacia saligna* (Labill.) H. L. Wendl. and *Vachellia karroo* (Hayne) Banfi & Galasso] and two *Cactaceae* [*Opuntia ficus-indica* (L.) Mill. e *Austrocylindropuntia subulata* (Mühlenpf.) Backeb] occur. There are also other species which are considered invasive in other territories, that have not yet shown their potential, but which could become so in the future such as *Ailanthus altissima* (Mill.) Swingle, *Cortaderia selloana* (Schult.) Asch. & Graebn. and *Cenchrus longisetus* M.C. Johnst. Differently, the archaeophytes of the study area are naturalized species, integrated with the flora, that show very little invasiveness since only four taxa [*Arundo donax* L., *Glebionis coronaria* (L.) Spach, *Ricinus communis* L., *Trigonella sicula* (Turra) Coulot & Rabaute] can be considered as invasive, especially in wetlands and synanthropic habitats.

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References

AA.VV. 2014: Layman’s Report PROVIDUNE. Conservazione e ripristino di habitat dunali nei siti delle Province di Cagliari, Caserta e Matera. – LIFE07NAT/IT/000519 PROVIDUNE.

Acunto, S., Bacchetta, G., Bordigoni, A., Cadoni, N., Cinti, M. F., Duràn Navarro, M., Frau, F., Lentini, L., Liggi, M. G., Masala, V., Meloni, F., Pinna, R., Podda, L. & Sanna, A. 2017: The LIFE+ project “RES MARIS - Recovering Endangered habitatS in the Capo Carbonara MARIne area, Sardinia”: first results. – Pl. Sociol. **54:** 85-95.

Angiosperm Phylogeny Group 2016: An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG IV. – Bot. J. Linn. Soc. **181:** 1-20. https://doi.org/10.1111/boj.12385

Arrigoni, P. V. 2006 - 2015: Flora dell’Isola di Sardegna, **1-6**. – Sassari.

— & Bocchieri, E. 1995: Caratteri fitogeografici della flora delle piccole isole circumsarde. – Biogeographia **18:** 63-90.

— & Di Tommaso, P. L. 1991: La vegetazione delle montagne calcaree della Sardegna centro-orientale. – Boll. Soc. Sarda Sci. Nat. **28:** 201-310.

Bacchetta, G. 2006: Flora vascolare del Sulcis (Sardegna Sud-Occidentale, Italia). – Guineana **12:** 1-369.

— & Pontecorvo, C. 2005: Contribution to the knowledge of the endemic vascular flora of Iglesiente (SW Sardinia-Italy). – Candollea **60:** 481-501.

—, Farris, E. & Pontecorvo, C. 2012: A new method to set conservation priorities in biodiversity hotspots. – Pl. Biosyst. **146:** 638-648. https://doi.org/10.1080/11263504.2011.642417

—, Iiriti, G. & Mossa, L. 2005: La flora endemica del Sarrabus-Gerrei: un patrimonio da tutelare e gestire. Atti del Convegno “Analisi e sistemi di gestione del territorio (Sarrabus-Gerrei)”. – Sinnai 30/31.1.2004: 105-112.

—, Fenu, G., Mattana, E., Meloni, F. & Podda, L. 2007: Conservazione *ex situ* e *in situ* della biodiversità vegetale dell’Area Marina Protetta di Capo Carbonara (Sardegna sud-orientale). – Fitosociologia **44:** 157-164.

—, Bagella, S., Biondi, E., Farris, E., Filigheddu, R. & Mossa, L. 2009: Vegetazione forestale e serie di vegetazione della Sardegna (con rappresentazione cartografica alla scala 1:350.000). – Fitosociologia **46:** 3-82.

—, Duràn Navarro, M., Fenu, G., Iiriti, G., Meloni, F. & Podda, L. 2015: Contribution to the knowledge of the vascular flora of the Marine Protected Area Capo Carbonara (South East Sardinia). — In: Peruzzi, L. & Domina, G. (eds) Approfondimenti floristici e sistematici sulla flora d’Italia. Comunicazioni. Società Botanica Italiana, Gruppo per la Floristica, Sistematica ed Evoluzione. – Orto botanico di Roma, La Sapienza Università di Roma, 20-21 novembre 2015.

—, Fenu, G., Iiriti, G., Mattana, E., Meloni, F., Mulè, P. & Podda, L. 2006: Territory defence throughout conservation of the plant diversity: the project of the Protected Sea Area of Capo Carbonara (South Eastern Sardinia). – Pp. 302-307 in Acts of the 1st International Symposium on Environment, Identities and Mediterranean area (ISEIM 2006). – Corte, Ajaccio (France).

—, —, Guarino, R., Mandis, G., Mattana, E., Nieddu, G. & Scudu, C. 2013: Floristic traits and biogeographic characterization of the Gennargentu massif (Sardinia). – Candollea **68:** 209-220.

—, Bordigoni, A., Cinti, M. F., Frau, F., Lentini, L., Liggi, M. G., Meloni, F., Orrù, M., Podda, L. & Sanna, A. 2018: Manuale di buone pratiche e linee guida per la corretta fruizione e gestione degli habitat naturali del sistema spiaggia. Progetto LIFE+ RES MARIS. – Cagliari.

Ballero, M. 1982: Etnoiatria nella zona di Villasimìus (Sardegna sud-orientale). – Rend. Sem. Fac. Sci. Univ. Cagliari **52:** 115-125.

Bartolucci, F., Peruzzi, L., Galasso, G., Albano, A., Alessandrini, A., Ardenghi, N. M. G., Astuti, G., Bacchetta, G., Ballelli, S., Banfi, E., Barberis, G., Bernardo, L., Bouvet, D., Bovio, M., Cecchi, L., Di Pietro, R., Domina, G., Fascetti, S., Fenu, G., Festi, F., Foggi, B., Gallo, L., Gottschlich, G., Gubellini, L., Iamonico, D., Iberite, M., Jiménez-Mejías, P., Lattanzi, E., Marchetti, D., Martinetto, E., Masin, R. R., Medagli, P., Passalacqua, N. G., Peccenini, S., Pennesi, R., Pierini, B., Poldini, L., Prosser, F., Raimondo, F. M., Roma-Marzio, F., Rosati, L., Santangelo, A., Scoppola, A., Scortegagna, S., Selvaggi, A., Selvi, F., Soldano, A., Stinca, A., Wagensommer, R. P., Wilhalm, T. & Conti, F. 2018: An updated checklist of the vascular flora native to Italy. – Pl. Biosyst. **152:** 179-303. https://doi.org/10.1080/11263504.2017.1419996

Biondi, E., Bocchieri, E., Brugiapaglia, E. & Mulas, B. 1993: La vegetazione dell'isola di Serpentara (Sardegna sud-orientale). – Boll. Soc. Sarda Sci. Nat. **29:** 115-130.

Bocchieri, E. 1988: *Silene valsecchiae* e *Ferula arrigonii*, due specie nuove della Sardegna. – Boll. Soc. Sarda Sci. Nat. **26:** 305-310.

— 1989: The flora of Serpentara island (Southern Sardinia): phytogeographic relevance and conservational requirements. – Coll. Phytosoc. **29:** 233-250.

— 2001: Endemismi e rarità tra la flora delle piccole isole della provincia di Cagliari (Sardegna). – Biogeographia **22:** 139-168.

— & Iiriti, G. 2007a: L'esplorazione botanica nei territori del Sarrabus-Gerrei (Sardegna sud orientale). – Rend. Sem. Fac. Sci. Nat. Univ. Cagliari **77:** 85-99.

— & — 2007b: Nuovi dati sulla presenza di habitat e specie vegetali di interesse comunitario in alcuni Siti d'Importanza Comunitaria del Sarrabus-Gerrei (Sardegna sud orientale). – Fitosociologia **44:** 207-211.

— & — 2008: Valutazione dello stato di conservazione e monitoraggio dei principali sistemi psammofili del settore sud orientale della Sardegna. – Pp. 177-184 in: Atti Secondo Simposio Internazionale "Il monitoraggio costiero mediterraneo: problematiche e tecniche di misura". – Napoli.

—, —, & Pontecorvo, C. 2008: Flora vascolare del Capo di Monte Santu (Sardegna centro orientale). – Webbia **63:** 1-24.

Brullo, S., Grillo, M. & Guglielmo, A. 1996: Considerazioni fitogeografiche sulla flora iblea. – Boll. Acc. Gioenia Sci. Nat. **29:** 45-111.

Camarda, I. & Ballero, M. 1981: Studi sulla flora e la vegetazione di Capo Carbonara (Sardegna meridionale). I: La Flora. – Boll. Soc. Sarda Sci. Nat. **20:** 157-185.

Carmignani, L., Cocozza, T., Ghezzo, C., Pertusati, P. C. & Ricci, A. C. 1982: Lineamenti del basamento sardo. Guida alla geologia del Paleozoico sardo. Mem. Soc. Geol. It. – Pp. 11-23 in: Guide Geologiche Regionali. – Cagliari.

Chiappini, M. & Diana, G. 1978: Distribuzione geografica ed ecologica dell'endemismo sardo-corso *Brassica insularis* Moris in Sardegna. – Morisia **4:** 55-62.

Corsi, G. 1963: Citologia, embriologia e distribuzione geografica di *Brassica insularis* Moris, endemismo sardo-corso. – Ann. Bot. (Roma) **27:** 419-430.

Durán, M., Pinna, M. S., Orrù, M., Sanna, A., Fenu, G., Cogoni, D., Nebot, A. & Bacchetta, G. 2016: Conservación y restauración de los hábitats de dunas costeras en Cerdeña: la experiencia del proyecto LIFE+ PROVIDUNE. – In: Xavier Roig-Munar, F. (ed.) Restauración y gestión de sistemas dunares Estudios de casos. Recerca i Territori, **8.** – Torroella de Montgrí.

Fenu, G., Fois, M., Cañadas, E. M. & Bacchetta, G. 2014: Using endemic-plant distribution, geology and geo-morphology in biogeography: the case of Sardinia (Mediterranean Basin). – Syst. Biodivers. **12:** 181-193.

Galasso, G., Conti, F., Peruzzi, L., Ardenghi, N. M. G., Banfi, E., Celesti-Grapow, L., Albano, A., Alessandrini, A., Bacchetta, G., Ballelli, S., Bandini Mazzanti, M., Barberis, G., Bernardo, L., Blasi, C., Bouvet, D., Bovio, M., Cecchi, L., Del Guacchio, E., Domina, G., Fascetti, S., Gallo, L., Gubellini, L., Guiggi, A., Iamonico, D., Iberite, M., Jiménez-Mejías, P., Lattanzi, E., Marchetti, D., Martinetto, E., Masin, R. R., Medagli, P., Passalacqua, N. G., Peccenini, S., Pennesi, R., Pierini, B., Podda, L., Poldini, L., Prosser, F., Raimondo, F. M., Roma-Marzio, F., Rosati, L., Santangelo, A., Scoppola, A., Scortegagna, S., Selvaggi, A., Selvi, F., Soldano, A., Stinca, A., Wagensommer, R. P., Wilhalm, T. & Bartolucci, F. 2018: An updated checklist of the vascular flora alien to Italy. – Pl. Biosyst. **152:** 556-592. https://doi.org/10.1080/11263504.2018.1441197

Iiriti, G. 2006: Flora e paesaggio vegetale del Sarrabus-Gerrei (Sardegna sud orientale). – Tesi di Dottorato in Botanica Ambientale ed Applicata (XIX ciclo). – Cagliari.

Ladero Alvarez, M., Díaz González, T. E., Penas Merino, A., Rivas-Martínez, S. & Valle Gutiérrez, C. 1987: Datos sobre la vegetación de las Cordilleras Central y Cantábrica. – Itinera Geobot. **1:** 3-147.

Mayer, A. 1995: Comparative study of the coastal vegetation of Sardinia (Italy) and Crete (Greece) with respect to the effects of human influence. – Libri Botanici **15.** – München.

Mayoral, O., Podda, L. & Porceddu, M. 2020: Invasive alien flora on coastal Mediterranean habitats. – In: Grigore, MN. (eds) Handbook of Halophytes. – Cham. https://doi.org/10.1007/978-3-030-17854-3_18-1.

Moris, G. G. 1827: Stirpium Sardoarum Elenchus. – Carali.

— 1837-1859: Flora Sardoa, **1-3.** – Taurini.

Mossa, L. & Fogu, M. C. 1987: La vegetazione dell’Isola dei Cavoli. – Ann. Bot. (Roma) **45:** 133-144.

— & Tamponi, G. 1978: La flora e la vegetazione dell’Isola dei Cavoli (Sardegna sud-orientale). – Rend. Sem. Fac. Sci. Nat. Univ. Cagliari **48:** 433-463.

—, Curreli, F. & Fogu, M. C. 2000: La vegetazione degli habitats terrestri della riserva marina protetta di Capo Carbonara (Sardegna sud-orientale). – Rend. Sem. Fac. Sci. Univ. Cagliari **70:** 163-185.

—, Guarino, R. & Fogu, M. C. 2003: Contributo alla conoscenza della flora terofitica della Sardegna. – Rend. Sem. Fac. Sci. Univ. Cagliari **73:** 1-209.

Orrù, P., Cocco, A. & Panizza, V. 1994: Rilevamento geomorfologico subacqueo del settore compreso tra Capo Boi e Punta Is Cappuccinus (Sardegna Sud-Occidentale). – Mem. Descr. Carta Geol. d’It. **52:** 163-176.

Palmese, M. T., Uncini Manganelli, R. & Tomei, P. E. 2001: An ethno-pharmacobotanical survey in thè Sarrabus district (south east Sardinia). – Fitoterapia **72:** 619-643.

Pignatti, S. 1982: Flora d’Italia **1-3**. – Edagricole, Bologna.

Pinna, M. S., Cañadas, E. M., Fenu, G. & Bacchetta, G. 2015: The European *Juniperus* habitat in the Sardinian coastal dunes: Implication for conservation. – Estuar. Coast. Shelf S. **164:** 214-220.

—, Bacchetta, G., Orrù, M., Cogoni, D., Sanna, A. & Fenu, G. 2017: Results of the Providune project: restoration of the “Coastal dunes with *Juniperus* spp” priority habitat in Sardinia. – Pl. Sociol. **54:** 73-84.

Podda, L., Lazzeri, V., Mascia, F., Mayoral García Berlanga, O. & Bacchetta, G. 2012: The Checklist of the Sardinian Exotic Flora: an Update. – Not. Bot. Horti Agrobo. **40:** 14-21, + Annex I checklist, 1-11.

—, Santo, A., Mattana, M., Mayoral, O. & Bacchetta, G. 2018: Inter- and intra-variability of seed germination traits of *Carpobrotus edulis* N. E. Br. and its hybrid *C.* affine *acinaciformis*. – Pl. Biol. **20:** 1059-1067. https://doi.org/10.1111/plb.12867

Puddu, S., Podda, L., Mayoral, O., Delage, A., Hugot, L., Petit, Y. & Bacchetta, G. 2016: Comparative analysis of the alien vascular flora of Sardinia and Corsica. – Not. Bot. Horti Agrobo. **44:** 337-346.

Pyšek, P., Richardson, D. M., Rejmánek, M., Webster, G. L., Williamson, M. & Kirschner, J. 2004: Alien plants in checklist and floras: towards better communication between taxonomist and ecologists. – Taxon **53:** 131-143.

Raunkiaer, C. 1934: The life forms of plants and statistical plant geography. – Oxford.

Richardson, D. M., Pyšek, P. & Carlton, J. T. 2011: A compendium of essential concepts and terminology in biological invasions. – Pp. 409-420 in: Richardson, D. M. (ed), Fifty years of invasion ecology: the legacy of Charles Elton. – Oxford.

—, —, Rejmánek, M., Barbour, M. G., Panetta, F. D. & West, C. J. 2000: Naturalization and invasion of alien plants: Concepts and definitions. – Divers. Distrib. **6:** 93-107.

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Contribution to the knowledge of the flora of Italy

edited by Fabio Garbari

Abstract

Garbari, F. (ed.): Contribution to the knowledge of the flora of Italy. — Fl. Medit. 31 (Special Issue): 451. 2022. — ISSN: 1120-4052 printed, 2240-4538 online.

In this series of short notes dedicated to the knowledge of some aspects of Italian vascular flora, 10 contributions were put together and presented. They are dedicated to floristic, chorological and/or taxonomic topics relating to both native or endemic and exotic plants in three Italian regions (Campania, Sicily and Trentino).

Presentation

This review brings together short articles of a floristic, chorological and/or taxonomic topics concerning unpublished data for the further knowledge of the vascular flora of Italy. These are the following 10 contributions: one of this regarding the flora of Trento Province (NE-Italy); one the flora of Campania (CS-Italy) and eight the flora of Sicily. From this island, five species (*Aloe brachystachis* [*Aloaceae*], *Araucaria columnaris* [*Araucariaceae*], *Megathyrsus maximus* var. *maximus* [*Poaceae*], *Muehlembeckia sagittifolia* [*Polygonaceae*] and *Wedelia glauca* [*Asteraceae*]) are reported as new for the alien flora of Italy. The case of *Araucaria columnaris* is also new for Europe.

1. E. Banfi, E. Bajona & F. M. Raimondo: *Megathyrsus maximus* var. *maximus* (*Poaceae*), a new naturalised grass alien to Italy.
2. E. Bajona & V. Spadaro: Chorological notes on the Sicilian endemic *Euphorbia papillaris* (*Euphorbiaceae*).
3. E. Del Guacchio, P. Cennamo, L. Paino & P. Caputo: Further remarks on the narrow endemic *Centaurea pandataria* (*Asteraceae, Cardueae*).
4. E. Di Gristina & F. M. Raimondo: *Muehlenbeckia sagittifolia* (*Polygonaceae*), a new alien for the Italian flora.
5. G. Domina & P. Mazzola: *Wedelia glauca* (*Asteraceae*) a new naturalized alien to Italy.
6. P. Pavone, F. M. Raimondo & V. Spadaro: New Aloes casual aliens in Sicily.
7. F. Pedrotti: *Juncus fontanesii* (*Juncaceae*), a new species for Trentino (Central Alps, northern Italy).
8. V. Piccione & V. Malacrinò: *Anredera cordifolia* (*Basellaceae*) invasive in the river vegetation of North-Eastern Sicily.
9. F. M. Raimondo & G. Venturella: A critical form of *Celtis* tree (*Ulmaceae*) occurring in Sicily.
10. G. Venturella & M. L. Gargano: *Araucaria columnaris* (*Araucariaceae*) casual alien in Sicily.

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E. Banfi, E. Bajona & F. M. Raimondo

Megathyrsus maximus var. *maximus* (*Poaceae*), a new naturalised grass alien to Italy

Abstract

Banfi, E., Bajona, E. & Raimondo, F. M.: *Megathyrsus maximus* var. *maximus* (*Poaceae*), a new naturalised grass alien to Italy. — Fl. Medit. 31 (Special Issue): 453-462. 2022. — ISSN: 1120-4052 printed, 2240-4538 online.

Megathyrsus maximus var. *maximus* is reported for the first time in Italy. This grass native to South-Saharan East Africa, the Arabian Peninsula and Madagascar, now widespread in vast areas including Mauritania, Mali, Egypt, Spain, Middle East, Pakistan, India, Southeast Asia, Indonesia, Australia and the Americas from the southern United States to Argentina, has been found widely and with invasive character along almost all the Tyrrhenian coast of Sicily. Data on its distribution in the island are given, in addition to some taxonomic considerations with reference to the correspondence of *M. maximus* var. *pubiglumis* with *Panicum compressum (= Megathyrsus bivonanus*).

Key words: alien flora, *Poaceae*, *Megathyrsus bivonanus*, Sicily.

Introduction

In the scenario of the bio-globalization marking the current historical period, the appearance and affirmation of alien species in different floristic contexts is now a fact of daily relevance. The easiest way to do this seems to be from tropical to temperate areas, since the human causes of this phenomenon act in synergy with global climate warming.

On this background the knowledge of the exotic vascular flora in Italy has recently found a synthesis in Galasso & al. (2018). In this regard, the framework provided by the important work carried out within the Working Group for Floristics, Systematics and Evolution of the Italian Botanical Society continues to grow thanks to the “Notulae to the Italian alien vascular flora” periodically published in Italian Botanist. However, contributions on this subject have also found their way into other periodicals. Some notes were in fact hosted in some volumes of Flora Mediterranea (Raimondo & Spadaro 2017; Scafidi & Raimondo 2018; Campisi & al. 2019) and in this same vol. 31 (Special Issue), where, in addition to this note, there are contributions by Di Gristina & Raimondo 2021; Domina & Mazzola (2021); Pavone & al. (2021) and Venturella & Gargano (2021).

Here we would like to point out the recent spread in Sicily and possibly elsewhere in Mediterranean Italy of *Megathyrsus maximus* (Jacq.) B. K. Simon & S. W. L. Jacobs var. *maximus*, a tropical species native to South-Saharan East Africa, the Arabian Peninsula and Madagascar, now present throughout the tropics due to its use as a pabular plant and yet endowed with invasive capabilities.

The secondary range of the species includes Mauritania, Mali, Egypt, Spain, Middle East, Pakistan, India, Southeast Asia, Indonesia, Australia and the Americas from the southern United States to Argentina (Kew Backbone Distributions, The International Plant Names Index and World Checklist of Selected Plant Families 2021. Published on the Internet at http://www.ipni.org and http://apps.kew.org/wcsp/).

As for Europe, the species was reported twice in Spain, first as the nominal variety of the species (var. *maximus*; Verloove 2005) which quickly became extinct as a result of environmental changes, and second as var. *pubiglumis* (K. Schum.) B. K. Simon & S. W. L. Jacobs (Verloove 2006), later quoted by Crespo & al. (2013), which is of close interest to us as we shall see below.

The genus *Megathyrsus* (Pilg.) B. K. Simon & S. W. L. Jacobs includes two formally accepted species: *M. infestus* (Andersson) B. K. Simon & S. W. L. Jacobs (East Africa) and *M. maximus*. It has been shown by Giussani & al. (2001), Gomez-Martínez & Culham (2000), Aliscioni & al. (2003) that *Megathyrsus* is phylogenetically sister to *Urochloa* P. Beauv. within a clade represented by the subtribe *Melinidinae* Stapf, thus distant from *Panicum* (Soreng & al. 2017) to which it was previously ascribed to sectional rank; in fact *Megathyrsus* is soon distinguished from *Panicum* by the lemma of the fertile floret which bears transverse wrinkles instead of being smooth.

Materials and Methods

The spontaneous population of a species of *Poaceae* observed for some years in Sicily along the coastal strip of the island and its representative specimens have been studied. The species identity was confirmed by several collections with the help mainly of the treatments of Bor (1960), Clayton & Renvoize (1982), Chen & al. (2006), Barkworth (in Barkworth & al. 2007). Specimens of different origins have been compared; the material examined is kept at the Herbaria PAL-Gr, PAL, FI, and at the Museum of Natural History of Milan (Herbarium MSNM).

Results

On the basis of the findings and the phenotypic characters examined, the material studied is attributed to *Megathyrsus maximus* var. *maximus*, a taxonomic unit previously unpublished in the Italian flora.

Taxonomy and classification

Megathyrsus maximus (Jacq.) B. K. Simon & S. W. L. Jacobs, Austrobaileya 6(3): 572 (2003).

[Bas. *Panicum maximum* Jacq.; Syn. *Panicum mananarense* A. Camus, *Panicum mahafalense* A. Camus; *Urochloa maxima* (Jacq.) R. D. Webster]

Poaceae, *Panicoideae*, *Paniceae*, *Melinidinae.*

Discovery site and ecology in Sicily

M. maximus var. *maximus* is found along the whole coastline between Capo d'Orlando (Messina) and Villa Grazia di Carini (Palermo) (Fig. 1). In the Messina area it can also be found inland,in the valleys of the Naso, Fitalia and Furiano streams (Figs. 2a, 2b). In the Palermo area, it is also found upstream of Termini Imerese on the edge of the carriageway towards the town of Caccamo, Trabia and Villabate (Fig. 2c). In the city of Palermo, although not reported in the census of Domina & al. (2019), the taxon is widespread not only along and at the margins of the road (Figs. 2d, 2e) but also at the margins and in the roadbeds of Vergine Maria (Figs. 3a, 3b) and of the Parco della Favorita (Figs. 3c, 3e), going up from the coast to about 350 m a.s.l.

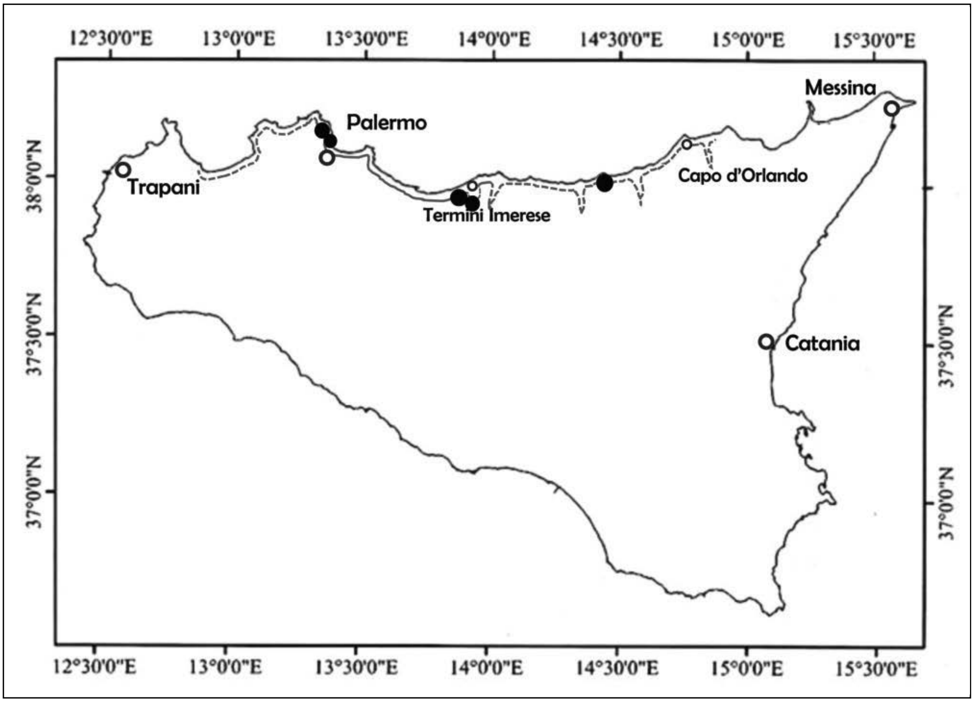

Fig. 1. Distribution of the sites of *Megathyrsus maximus* var. *maximus* in Sicily: ● location of the collection sites of the material studied. The line represent the coastal stretch of the island where the species has been observed in continuity or discontinuity.

Commonly, in the cited Sicilian localities, *M. maximus* var. *maximus* is found associated with other invasive plants, mostly alien or thermocosmopolite, such as *Boerhavia repens* L. subsp. *viscosa* (Choisy) Maire (Fig. 2d), *Bidens bipinnata* L., *B. pilosa* L., *B. subalternans* DC., *Cenchrus setaceus* (Forssk.) Morrone (= *Pennisetum setaceum* (Forssk.) Chiov.) (Fig. 2c), *Cynodon dactylon* (L.) Pers., *Digitaria sanguinalis* (L.) Scop.*, Echinochloa crus-galli* (L.) P. Beauv., *Erigeron bonariensis* L., *E. canadensis* L., *Paspalum dilatatum* Poir., *Oloptum miliaceum* complex, *Ricinus communis* L. (Fig. 2c), *Senecio vulgaris* L., *Setaria* sp.pl., *Solanum nigrum* L., *S. villosum* Mill., *Sonchus tenerrimus* L., *Sorghum halepense* (L.) Pers., and some native taxa, among these mainly *Hyparrhenia hirta* (L.) Stapf.

Discussion and Conclusion

The genus *Megathyrsus* (Pilg.) B. K. Simon & S. W. L. Jacobs includes two formally accepted species: *M. infestus* (Andersson) B. K. Simon & S. W. L. Jacobs (East Africa) and *M. maximus*. It has been shown by Gomez-Martínez & Culham (2000), Giussani & al. (2001), Aliscioni & al. (2003) that *Megathyrsus* is phylogenetically sister to *Urochloa* P. Beauv. within a clade represented by the subtribe *Melinidinae* Stapf, thus distant from *Panicum* (Soreng & al. 2017) to which it was previously ascribed to sectional rank; in fact *Megathyrsus* is soon distinguished from *Panicum* by the lemma of the fertile floret which bears transverse wrinkles instead of being smooth.

As mentioned above, *Megathyrsus maximus* is a variable species of which in particular two morphotypes are known, one corresponding to the nominal variety (var. *maximus*) with completely glabrous lemmas, the other with lemmas provided to varying degrees with hairs which are however always present, corresponding to var. *pubiglumis*. *Panicum compressum* Biv., currently a heterotypic synonym of *M. maximus* var. *pubiglumis*, was described in Sicily from Monte Pellegrino and it was later recognised and cited for other Sicilian localities as recalled in Giardina & al. (2007): «*Megathyrsus bivonanus* (Brullo, P. Minissale, F. Scelsi & Spamp.) Verloove (original spelling "*bivonianus*", but see footnote 1, Willdenowia 35: 63 (2005) [*Panicum bivonianum* Brullo, P. Minissale, F. Scelsi & Spamp., Giorn. Bot. Ital., Nov. ser., 129: 173 (1995); *Panicum maximum* auct. europ. non Jacq.; *Panicum compressum* Biv. non Forssk.]. Limestone cliffs. - Monte Pellegrino (Bivona Bernardi 1816); Palermo at Mt. Pellegrino, Mt. Gallo, Carini, Cinisi, Partinico, Cefalù (Gussone 1827); Messina (Parlatore) (Gussone 1843); Termini (Laresche) (Gussone 1845: 785); Mt. Pellegrino (Ross 1899); Mt. Pellegrino (Ross 1899: 785). Pellegrino (Ross 1899); Messina al Faro and Tremonti (Seguenza) (Nicotra & Campagna 1908); Mt. Turcisi in the Catania Plain (Borruso 1960); Piana di Catania (Tomaselli 1962). - R.»

Megathyrsus bivonanus[1] has been typified by Brullo & al. (2011); this taxon is officially reported in PoWO (Plants of the World Online. Facilitated by the Royal Botanic Gardens, Kew. Published on the Internet; http://www.plantsoftheworldonline.org/ Retrieved 11 / 2021) where it is not accepted by Clayton & al. (2006) and Govaerts & al. (2021). In fact *M. bivonanus* is essen-

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[1] Art. 60.8 of the ICN (Turland & al. 2018) inexplicably states that epithets dedicated to a person in the adjectival Latin form should not keep the thematic "i" as traditional Latin provides. The correction of this 'error' applies retroactively, so that *bivon-ianus* must become *bivon-anus*.

tially identical to *M. maximus* var. *pubiglumis* (Figs. 3d, 3f, 4b) having both pubescent spikelets as the only detectable difference from *M. maximus* var. *maximus* (Fig. 4a), which has completely glabrous spikelets. Keeping a taxonomic independence for *M. bivonanus* does not seem to be no longer sustainable and it is therefore better acceptable as a synonym of *M. maximus* var. *pubiglumis*. The taxonomic consistence of var. *pubiglumis* itself is under discussion and official sources such as PoWO do not hesitate to include it among the synonyms of *M. maximus*.

The Sicilian localities mentioned above partly coincide with those that today host the nominal variety which appears much more competitive and invasive than var. *pubiglumis*. With respect to the meeting of the old lineage (var. *pubiglumis*) with the new one (var. *maximus*), although in *M. maximus* apomixis is regulated by a gene pool whose implementation seems to be related to ploidy level ($2n$ = 16, 32, 40, 44, 48, 64) (Benabderrahim & Elfalleh 2021; Thamiris & al. 2020), gene flow among population segments is not necessarily precluded and there is a possibility that this exchange also will occur between Sicilian populations. One consequence could be that over time the diacritical reliability of the spikelet indumentum, which today enables the separation of the old Mt. Pellegrino inheritance from the new Sicilian settlement, will be weakened. Such a possibility together with the necessity of monitoring the coexistence of the two varieties in the same station and confirming the classical stations of *Panicum compressum* will be a matter of investigation for a future contribution.

Specimina visa

1) Megathyrsus maximus var. *maximus*

Sicily: Palermo, Monte Pellegrino, base of limestone wall, east side, 10.09.2018, *F. M. Raimondo* (PAL-Gr); Palermo at the Parco della Favorita, at the edge of Viale Diana, 20.10.2020, *F. M. Raimondo*; Palermo, shoreline of Vergine Maria, 28.09.2018, *F. M. Raimondo* (PAL-Gr); Caronia Marina, at the edge of the SS: 113, 18.09.2016, *F. M. Raimondo* (PAL-Gr); Caronia Marina, at the edge of the SS 113 at the junction for Caronia, 20.10.2020, *F. M. Raimondo* (PAL-Gr); Palermo, *culta* (from Trabia), 10.07.2021, *E. Bajona* (MSNM); Palermo, Parco della Favorita, uncultivated land near the road, 12.10.2021, *E. Bajona* (FI); Trabia (Palermo), roadside, next to the sea, 07.11.2021, *E. Bajona* (PAL); Trabia (Palermo), locality Speciale, country road border, 07.11.2021, *E. Bajona* (PAL); Palermo, Parco della Favorita, uncultivated land near the road, 13.11.2021, *E. Bajona* (PAL).

Other provenances: Sři Lanka, Northern Province, Mannar District, Mannar, roadside, 8° 58’ 51.61”N, 79° 54’ 15.87”E, 8 m a.s.l., 24.2.2019, *E. Banfi* (MSNM50090, 50091); Sři Lanka, Uva Province, Moneregala District, Udawalawe Elephants Park, rocky emergence in herbaceous monsoon savannah, 6° 26’ 20.52”N, 80° 53’ 30.59”E, 105 m a.s.l., 27.2.2019, *E. Banfi* (MSNM50130); Mauritius, La Pointe aux Canonniers, grass verge, 20° 00’ 36.52”S, 57° 33’ 37.73”E, 7 m a.s.l., 25.2.2013, *E. Banfi* (MSNM).

2) Megathyrsus maximus var. *pubiglumis*

Sicily: Palermo, Mt. Pellegrino slopes, seafront C. Colombo, , 38° 02’ 55.78”N, 13° 00’ 24.26”E, 52 m a.s.l., 27.9.2007, *G. Galasso & E. Banfi* (MSNM44166, 44167); Palermo, Mt. Pellegrino, roadside and rocky slopes S/SW oriented, 09.10.2021, *E. Bajona* (MSNM); Palermo, Mt. Pellegrino, roadside and rocky slopes E oriented, 12.10.2021, *E. Bajona* (FI); Palermo, Mt. Pellegrino, roadside and rocky slopes E oriented, 12.10.2021, *E. Bajona* (PAL).

Fig. 2. *Megathyrsus maximus* var. *maximus* in the various collection sites from Capo d'Orlando (East) to Palermo (West).

Fig. 3. a, b, c, e) *Megathyrsus maximus* var. *maximus* in the various collection sites of Palermo; d, f) *M. maximus* var. *pubiglumis* in Monte Pellegrino (Palermo).

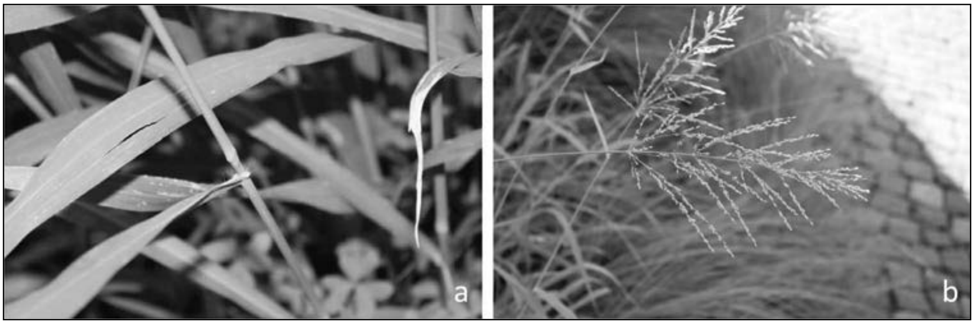

Fig. 4. Details of: a) *Megathyrsus maximus* var. *maximus* and b) *M. maximus* var. *pubiglumis*.

References

Aliscioni, S. S., Giussani, L. M., Zuloaga, F. O. & Kellogg, E. A. 2003: A molecular phylogeny of *Panicum* (*Poaceae: Paniceae*): Tests of monophyly and phylogenetic placement within the Paniceae – Amer. J. Bot. **90:** 796-821.

Barkworth, M. E. 2007: in Barkworth, M. E., Anderton, L. K., Capels, K. M., Long, S. & Piep, M. B.: Manual of Grasses for North America – Logan.

Benabderrahim, M. A. & Elfalleh, W. 2021: Forage potential of non-native Guinea grass in North African agroecosystems: genetic, agronomic and adaptive traits – Agronomy **11(6):** 1071. https://doi.org/10.3390/agronomy11061071

Bor, N. L. 1960: The grasses of Burma, Ceylon, India and Pakistan (excluding *Bambuseae*) – Oxford.

Brullo, C., Brullo, S. & Giusso Del Galdo, S. 2011: Lectotipificazione e *loci classici* di alcuni endemismi della flora sicula. – In: *Loci classici*, taxa critici e monumenti arborei della flora italiana – In: Peruzzi, L. & Domina, G., Contributi alla Ricerca floristica in Italia. – Roma.

Campisi, P., Raimondo, F. M. & Spadaro, V. 2019: New floristic data of alien vascular plants from Sicily. – Flora Medit. **29:** 263-267. https://doi.org/10.7320/FlMedit29.263

Chen, S.-L., Phillips, S. M. & Renvoize, S. A. 2006: *Panicum maximum* Jacq. – P. 506 in: Wu, Z. Y., Raven, P. H. & Hong, D. Y. (eds), Flora of China, **22.** –St. Louis & Beijing.

Clayton, W. D. & Renvoize, S. A. 1982: *Gramineae* (Part 3). – In: Polhill, R. M. (ed.), Flora of Tropical East Africa – Rotterdam.

—, Harman, K. T. & Williamson, H. 2006: World Grass Species - Synonymy database The Board of Trustees of the Royal Botanic Gardens – Kew.

Crespo, M. B., Martínez Azorín, M. & Camuñas E. 2013: Novedades corológicas para la flora valenciana – Fl. Montiberica **55:** 118-127.

Di Gristina, E. & Raimondo, F. M. 2021: *Muehlembeckia sagittifolia* (*Polygonaceae*), a new alien for the Italian flora. [In: Garbari, F. (ed.), Contributions to the knowledge of the flora of Italy]. – Fl. Medit. **31(Special Issue):** 477-481. https://doi.org/10.7320/FlMedit31SI.477

Domina, G. & Mazzola, P. 2021: *Wedelia glauca* (*Asteraceae*) a new naturalized alien to Italy. [In: Garbari, F. (ed.), Contributions to the knowledge of the flora of Italy]. – Fl. Medit. **31** (Special Issue): 483-488. https://doi.org/10.7320/FlMedit31SI.483

—, Di Gristina, E., Scafidi, F., Calvo, R., Venturella, G. & Gargano, M. L. 2019: The urban vascular flora of Palermo (Sicily, Italy). – Pl. Biosyst. **154(5):** 627-634. https://doi.org/10.1080/11263504.2019.1651787

Galasso, G., Conti, F., Peruzzi, L., Ardenghi, N. M. G., Banfi, E., Celesti-Grapow, L., Albano, A., Alessandrini, A., Bacchetta, G., Ballelli, S., Bandini Mazzanti, M., Barberis, G., Bernardo, L., Blasi, C., Bouvet, D., Bovio, M., Cecchi, L., Del Guacchio, E., Domina, G., Fascetti, S., Gallo, L., Gubellini, L., Guiggi, A., Iamonico, D., Iberite, M., Jimenez-Mejias, P., Lattanzi, E., Marchetti, D., Martinetto, E., Masin, R. R., Medagli, P., Passalacqua, N. G., Peccenini, S., Pennei, R., Pierini, B., Podda, L., Poldini, L., Prosser, F., Raimondo, F. M., Roma Marzio, F., Rosati, L., Santangelo, A., Scoppola, A., Scortegagna, S., Selvaggi, A., Selvi, F., Soldano, A., Stinca, A., Wagensommer, R. P., Wilhalm, T. & Bartolucci, F. 2018: An updated checklist of the vascular flora alien to Italy. – Pl Biosyst. **152:** 556-592. https://doi.org/10.1080/11263504.2018.1441197

Giardina, G., Raimondo, F. M. & Spadaro, V. 2007: A catalogue of the plants growing in Sicily. – Bocconea **20:** 5-558.

Giussani, L. M., Cota-Sanchez, H., Zuloaga, F. O. & Kellogg, E. A. 2001: A molecular phylogeny of the subfamily *Panicoideae* (*Poaceae*) shows multiple origins of C4 photosynthesis – Amer. J. Bot. **88:** 1993-2012. https://doi.org/10.2307/3558427

Gomez-Martinez, R. & Culham, A. 2000: Phytogeny of the subfamily Panicoideae with emphasis on the tribe Paniceae: Evidence from the trnh-V cpDNA region. – Pp. 136-140 in: Jacobs, S. W. L. & Everett, J. (eds), Grasses: Systematics and Evolution. International Symposium on Grass Systematics and Evolution (3rd:1998). – Collingwood.

Govaerts, R., Nic Lughadha, E., Black, N., Turner, R. & Paton, A. 2021: The World Checklist of Vascular Plants, a continuously updated resource for exploring global plant diversity. https://doi.org/10.1038/s41597-021-00997-6.

Pavone, P., Raimondo, F. M. & Spadaro, V. 2021: New Aloes casual aliens in Sicily. [In: Garbari, F.(ed.), Contributions to the knowledge of the flora of Italy]. – Fl. Medit. **31**(Special Issue): 489-493. https://doi.org/10.7320/FlMedit31SI.489

Raimondo, F. M. & Spadaro, V. 2017: First finding in Sicily of *Bidens subalternans* (*Asteraceae*). – Fl. Medit. **27:** 267-273. https://doi.org/10.7320/FlMedit27.267

Scafidi, F. & Raimondo, F. M. 2018: First record of *Pilea microphylla* (*Urticaceae*) in Sicily. – Fl. Medit. **28:** 79-84. https://doi.org/10.7320/FlMedit28.079

Soreng, R. J., Peterson, P. M., Romaschenko, K., Davidse, G., Teisher, J. K., Clark, L. G., Barberá, P., Gillespie, L. J. & Zuloaga, F. O. 2017: A worldwide phylogenetic classification of the *Poaceae* (*Gramineae*) II: an update and a comparison of two 2015 classifications – J. Syst. Evol. **55(4):** 259-290. Appendix 2.

Thamiris, G. D., Ferreira, R. C. U., Lara, L. A. C., Moraes, A. C. L., Alves-Pereira, A., de Oliveira, F. A., Garcia, A. A. F., Santos, M. F., Jank, L. & de Souza, A. P. 2020: High-resolution linkage map with allele dosage allows the identification of regions governing complex traits and apospory in Guinea grass (*Megathyrsus maximus*) – Front. Pl. Sci. **11:** 15. https://doi.org/10.3389/fpls.2020.00015

Turland, N. J., Wiersema, J. H., Barrie, F. R., Greuter, W., Hawksworth, D. L., Herendeen, P. S., Knapp, S., Kusber, W.-H., Li, D.-Z., Marhold, K., May, T. W., McNeill, J., Monro, A. M., Prado, J., Price, M. J. & Smith, G. F. (eds) 2018: International Code of Nomenclature for algae, fungi, and plants (Shenzhen Code) adopted by the Nineteenth International Botanical Congress Shenzhen, China, July 2017. – Regnum Vegetabile **159.** Glashütten: Koeltz Botanical Books. https://doi.org/10.12705/Code.2018

Venturella, G. & Gargano M. L. 2021: *Araucaria columnaris* (*Araucariaceae*) casual alien in Sicily. [In: Garbari, F. (ed.), Contributions to the knowledge of the flora of Italy]. – Fl. Medit. **31(Special Issue):** 509-513. https://doi.org/10.7320/FlMedit31SI.509

Verloove, F. 2005: New records of interesting xenophytes in Spain. – Lazaroa **26:** 141-148.

— 2006: Exotic grasses running wild: *Megathyrsus maximus* var. *pubiglumis* (*Poaceae*, *Paniceae*) new to Spain. – Bouteloua **1:** 55-60.

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Enrico Bajona & Vivienne Spadaro

Chorological notes on the Sicilian endemic *Euphorbia papillaris* (*Euphorbiaceae*)

Abstract

Bajona, E. & Spadaro, V.: Chorological notes on the Sicilian endemic *Euphorbia papillaris* (*Euphorbiaceae*). — Fl. Medit. 31 (Special Issue): 463-468. 2022. — ISSN: 1120-4052 printed, 2240-4538 online.

Thanks to the discovery of a new important site in the Trapani Mountains, the distribution of *Euphorbia papillaris*, a rare plant endemic to N-W Sicily, is revised. On the basis of the unpublished record, one of the two hypotheses on the discovery of the species in Sicily, previously advanced, is here confirmed. Floristic and ecological information on the new locality are also provided.

Key words: vascular flora, endemic plants, chorology, Italy.

Introduction

Euphorbia papillaris (Boiss.) Raffaelli & Ricceri is a species endemic to Sicily. Morphologically similar to *E. bivonae* Steud., for a long time it was identified with this taxon or it was considered as a mere variety. Raffaelli and Ricceri (1988) detected sufficient diagnostic differences to consider the population of the Egadi Islands as a separate species: precisely *E. papillaris*. It differs from *E. bivonae*, not only for the shape and density of the papillae of the coccarium but also for its modest size and pulvinate habit. It is close to *E. melitensis* Parl., endemic plant to the Maltese Islands, and it has some similarities with *E. spinosa* L., stenomediterranean element, in Italy found mostly in all the peninsular regions and in Sardinia (Bartolucci & al. 2018).

The species was originally described by Boissier (1862) as a variety of *E. bivonae* based on materials from the Egadi Islands, west of the Trapani coast (N-W Sicily). It was later found on the nearby Sicilian coast, within the Zingaro Nature Reserve (Spadaro 2006).

According to the description given by Brullo & Brullo (2020), *E. papillaris* is a glabrous suffrutex, 30-70 cm hight, with a shrubby or pulvinate habit (Figs. 1b, 1f), with branched root and enlarged stem segments, with a moniliform appearance. The old branches are woody, twisted and shortened; those dead sometimes thorny; the new ones are elongated, leafy, ending in the inflorescence. It has elliptical leaves, (11)14-20(30) × (4)5-6(9) mm, with obtuse apex, mucronate. The flowers are grouped in compound umbels. Each umbel has 3-5 rays; the umbellets, 2-3 rays. The bracts conform to the leaves (the

Fig. 1a-f. Pulvinate habit of *Euphorbia papillaris* and its habitat in the Sicilian new site of Mt Erice (Erice, Trapani).

upper ones are sometimes obovato-lanceolate), while the bracts are obovate, with a rounded apex. The cyathium, 1.5-2 mm long, has a pedicel of 0.5-1 mm and semielliptic glands. The interglandular lobes are rounded, with the indented margin and internally hairy. The fruit is a globose capsule, 4-4.5 mm, with flattened external cylindrical warts, externally puberulous (Figs. 1c, 1d). The seed, of brown colour, is smooth and has an helmet-like caruncle, wavy at the margin.

E. papillaris grows generally on limestone slopes, from 10 to 300 m a.s.l., in communities referable to the *Dianthion rupicolae* Brullo & Marcenò 1979 alliance or on lithosol in communities related to the *Oleo-Ceratonion siliquae* Br.-Bl. ex Guinochet & Drouineau 1944 em. Rivas-Mart. 1975. Considered schizoendemic ($2n = 14$), it is regarded as vulnerable species in the Red List of Italy. Reported from Marettimo, Favignana and Levanzo (Egadi Islands), it was subsequently indicated in the nearby northern coast of Sicily, near S. Vito lo Capo (Spadaro 2006).

Recent floristic collections on the northern slopes of Mount Erice have allowed to find a large population, the subject of this note (Fig. 1a).

New site and ecology

The new and large population was found on the northern slopes of Mount Erice (Fig. 3), in front of the coast where the site of the Zingaro is located (Spadaro 2006).

In the new site, the population of *E. papillaris* – in our opinion the most extensive and therefore significant – is accompanied by several species of the garrigue and the Mediterranean scrub. Among them occur: *Ampelodesmos mauritanicus* (Poir.) T. Durand & Schinz (Figs. 1a, 1b), *Anthyllis vulneraria* subsp. *maura* (Beck) Maire, *Arisarum vulgare* O. Targ. Tozz. subsp. *vulgare, Asparagus acutifolius* L., *A. pastorianus* Webb & Berthel. (Fig. 1e), *Asphodelus ramosus* L. subsp. *ramosus*, *Biscutella maritima* Ten., *Bituminaria bituminosa* (L.) C. H. Stirt., *Brachypodium retusum* (Pers.) P. Beauv., *Carlina sicula* Ten., *Chamaerops humilis* L. (Figs. 1a, 1e), *Charybdis maritima* (L.) Speta, *Convolvulus cantabrica* L., *Cytisus spinosus* (L.) Lam., *Dianthus siculus* C. Presl, *Erica multiflora* L., *Foeniculum vulgare* Mill. subsp. *vulgare, Gladiolus* aff. *segetum* Ker Gawl. (*Gladiolus italicus* Mill.), *Hyparrhenia hirta* (L.) Stapf subsp. *hirta, Iris planifolia* (Mill.) Asch., *Klasea flavescens* (l.) Holub subsp. *mucronata* (Desf.) Cantó & Rivas Mart., *Lonicera implexa* Aiton subsp. *implexa, Micromeria graeca* subsp. *fruticulosa* (Bertol.) Guinea, *Ophrys lutea* Cav., *O. speculum* Link., *Orchis brancifortii* Biv*., O. papilionacea* L., *Petrosedum sediforme* (Jacq.) Grulich subsp. *sediforme, Phagnalon rupestre* (L.) DC., *Quercus calliprinos* Webb. (Fig. 2b), *Quercus ilex* L., *Reichardia picroides* (L.) Roth, *Rhamnus lycioides* subsp. *oleoides* (L.) Jahand. & Maire, *Ruta chalepensis* L., *Senecio* sp., *Silene fruticosa* L., *Stachys major* (L.) Bartolucci & Peruzzi, *Teucrium fruticans* L., *Thapsia garganica* L. subsp. *garganica,* etc.

It is, therefore, a community clearly related to aspects of vegetation not strictly rocky and thus of the *Dianthion rupicolae*, but of calcareous lithosol and therefore to be assigned to the *Oleo-Ceratonion siliquae*.

Fig. 2. *Asparagus pastorianus* (a) and the rare *Quercus calliprinos* (b) in the new site of *Euphorbia papillaris* on the limestone slopes of Mt Erice (Trapani).

Conclusions

In the current state of knowledge, *E. papillaris* is present not only in the Egadi Islands but also in the context of the little mountains next to the east and south-east of Trapani (respectively Zingaro and Mount Erice), representing a characteristic element of the Drepano-Panormitano floristic district (*sensu* Brullo & al 1995).

In the new and more internal Sicilian locality of *Euphorbia papillaris*, the presence of some rare or endemic species on the island assumes phytogeographic importance. Among these are *Asparagus pastorianus* (Fig. 2a), *Klasea flavescens* (L.) Holub subsp. *mucronata* (Desf.) Cantó & Rivas Mart., and *Quercus calliprinos* (Fig. 2b). In particular, *A. pastorianus* is a rare species of the genus, new for the flora of Mt Erice (Spadaro & al. 2020); *Q. calliprinos* – rare in Sicily but present in other territories of the Province of Trapani – is instead new for the same area of Mt Erice.

The locality of Erice (Trapani), the highest in altitude (300-400 m a.s.l.), is very extensive and should be interpreted as a primary site from where the species, probably, has pushed down on the coast (Zingaro) and then in the Egadi (Fig. 4). Based on this further discovery, we consider grounded the two hypotheses formulated previously (Spadaro 2006) that the species has passed from the Sicilian coast – as observed just from Erice – to the Egadi Islands, or that it is instead a fragmentation of an ancient areal including the Tyrrhenian coastal reliefs of Trapani and all the Egadi Islands (Marettimo, Favignana and Levanzo) (Pignatti 2017).

Fig. 3. The area of Mt Erice (N-W Sicily) with the localization of the new site of *Euphorbia papillaris* (prepared by Google Earth Pro).

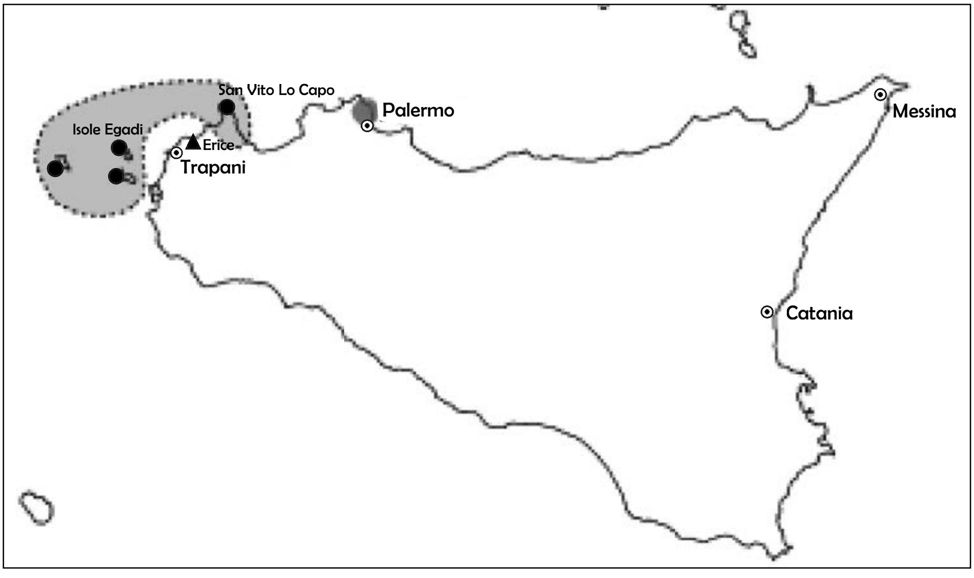

Fig. 4. Distribution sites of the Sicilian endemic *Euphorbia papillaris*: from literature (●) and from the new record (Erice, Trapani) (▲).

Exsiccata

Sicily – Erice (Trapani), limestone slopes of North-West of Mt Erice, on the rock, 370 m a.s.l., 8°2'37.31"N - 12°34'3.27"E, 7 June 2020, *Bajona* & *Raimondo* (PAL, PAL-Gr and FI); Erice (Trapani), limestone slopes of North West of Mt Erice, in the garrigue on litosol, 365 m a.s.l., 8°2'37.31"N - 12°34'3.27"E, 12 June 2020, *Raimondo* (PAL-Gr and FI).

References

Brullo, C. & Brullo, S. 2020: Flora endemica illustrata della Sicilia. – Reggio Calabria.

Brullo, S., Minissale, P. & Spampinato, G. 1995: Considerazioni fitogeografiche sulla flora della Sicilia. – Ecol. Medit. **21(1):** 99-117.

Bartolucci, F., Peruzzi, L., Galasso, G., Albano, A., Alessandrini, A., Ardenghi, N. M. G., Astuti, G., Bacchetta, G., Ballelli, S., Banfi, E., Barberis, G., Bernardo, L., Bouvet, D., Bovio, M., Cecchi, L., Di Pietro, R., Domina, G., Fascetti, S., Fenu, G., Festi, F., Foggi, B., Gallo, L., Gottschlich, G., Gubellini, L., Iamonico, D., Iberite, M., Jimenez-Mejias, P., Lattanzi, E., Marchetti, D., Martinetto, E., Masin, R. R., Medagli, P., Passalacqua, N. G., Peccenini, S., Pennesi, R., Pierini, B., Poldini, L., Prosser, F., Raimondo, F. M., Roma-Marzio, F., Rosati, L., Santangelo, A., Scoppola, A., Scortegagna, S., Selvaggi, A., Selvi, F., Soldano, A., Stinca, A., Wagensommer, R. P., Wilhalm, T. & Conti, F. 2018: An updated checklist of the vascular flora native to Italy. – Pl. Biosyst. **52(2):** 179-303. https://doi.org/10.1080/11263504.2017.1419996.

Fiori, A. 1926: *Euphorbia*. – Pp. 168-187 in: Nuova Flora Analitica d'Italia, **2.** – Firenze.

Giardina, G., Raimondo, F. M. & Spadaro, V. 2007: A catalogue of the plants growing in Sicily. – Bocconea **20:** 5-584.

Pignatti, S. 2017: *Euphorbia* – Pp. 321-353 in: Pignatti, S., Guarino, R. & La Rosa, M. (eds), Flora d'Italia 2° ed, & Flora Digitale, **2.** – Milano.

Raffaelli, M. & Ricceri, C. 1988: Su alcune specie mediterranee del genere *Euphorbia* L.: *E. bivonae* Steud., *E. papillaris* (Boiss.) Raffaelli et Ricceri, *stat. nov*., *E. melitensis* Parl. – Webbia **42(1):** 1-13. https://doi.org/10.1080/00837792.1988.10670423

Spadaro, V. 2006: Segnalazione di *Euphorbia papillaris* (*Euphorbiaceae, Magnoliophyta*) nella costa nord-occidentale della Sicilia. – Naturalista Sicil. **30(1):** 131-135.

—, Di Gristina, E. & Raimondo, F. M. 2020: Osservazioni sulla distribuzione ed ecologia in Sicilia di *Asparagus pastorianus* (*Asparagaceae*). – Pp. 142 in: Abstracts, 115° Congresso Società Botanica Italiana, Online 9–11 settembre 2020. – Firenze.

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E. Del Guacchio, P. Cennamo, L. Paino & P. Caputo

Further remarks on the narrow endemic *Centaurea pandataria* (*Asteraceae, Cardueae*)

Abstract

Del Guacchio, E., Cennamo, P., Paino, L. & Caputo, P.: Further remarks on the narrow endemic *Centaurea pandataria* (*Asteraceae, Cardueae*). — Fl. Medit. 31 (Special Issue): 469-475. 2022. — ISSN: 1120-4052 printed, 2240-4538 online.

Centaurea pandataria is a very narrow endemic with unclear taxonomy and some uncertainness even about its nomenclature. In this contribution, the correct authorship of the basionym *C. cineraria* var. *pandataria* Bég. & Fiori ex Fiori is clarified and, as a consequence, the recent lectotypification of the name is re-examined, resulting fully acceptable. Founding on the review of bibliographic data and on herbarium and field observations, a treatment at species-level is deemed the most consistent. Authors also report the first chromosome count of *C. pandataria*, which is diploid ($2n = 18$), as the close *C. aeolica*.

Key words: Mediterranean flora, Tyrrhenian islands, taxonomy.

Introduction

In the framework of our researches about the flora of the Tyrrhenian islands (e.g., Cennamo & al. 2013; De Castro & al. 2013; Vallariello & al. 2016; Iamonico & al. 2017; Del Guacchio & al. 2020), we refer here some issues on the controversial nomenclature and taxonomy of *Centaurea pandataria* (Bég. & Fiori ex Fiori) Bég., endemic to Ventotene island, anciently named Pandataria (Pontine archipelago, Latium, central Italy).

Béguinot (1902) first wrote about this plant, enlightening its peculiar morphological features by reporting it as "*Centaurea aplolepa* var.". Despite his opinion (Béguinot 1905: 443), however, he was not the first collector, as the plant had been already gathered on the island by G. Gussone (Fig. 1) in 1834 (Grande 1924: 115-116). This population was described as a new variety of *C. cineraria* L., i.e., *C. cineraria* var. *pandataria* Bég. & Fiori ex Fiori (1904a: 334), even if raising some doubts (Fiori 1904b). However, Béguinot (1905) himself raised it to the species rank and interpreted *C. pandataria* (Fiori) Bég. as a microspecies of the fragmented *C. cineraria* group. Later, Fiori (1927) fully included *C. cineraria* var. *pandataria* in *C. cineraria* var. *aeolica* (Guss. ex Lojac.) Fiori. Also Grande (1925), Béguinot (1931) himself and Zangheri (1976) included *C. cineraria* var. *pandataria* in *C. aeolica* Lojac., without recognizing any taxonomic distinction. The same opinion was expressed by Cela Renzoni & Viegi (1982) and Anzalone (1984: 126), while Dostál (1976) regarded the taxon as one of the several subspecies of *C. aplolepa* Moretti

Fig. 1. A specimen of the first gathering of *C. pandataria* (NAP-“Gussone Generale” collection).

(1826: 154). Anzalone (in Anzalone & Caputo 1976: 82-83) and Pignatti & Lausi (1982: 193) re-proposed the first treatment by Fiori (1904a). Nevertheless, later Anzalone (1995) preferred to employ the subspecific rank, but under *C. aeolica*. In the last years, his proposal has prevailed (Conti & al. 2005; Greuter 2006; Hilpold & al. 2011; Anzalone & al. 2010; Peruzzi & al. 2015; Pignatti 2018; WCSP 2021). However, Arrigoni (2003), Del Guacchio & al. (2019), and Brullo & al. (2021) treated again *C. pandataria* at the specific level. Therefore, the status remains uncertain; indeed, recent molecular analyses were not able to clarify the phylogenetic relationships of this taxon (Hilpold 2014). For this reason, we re-examined the question including further considerations from literature, clarifying the correct citation of the name and reporting the first chromosome count for this taxon.

Material and Methods

The present contribution is based on both analysis of the relevant literature (including protologues) and examination of specimens at CAT, FI, GDOR, GE, NAP, P, and PAD (herbarium codes according to Thiers 2021 onwards) and in field during 2017–2019. The articles cited throughout the text follow the *Shenzhen Code* (Turland *& al.* 2018, hereafter ICN).

The chromosomal observations were made on root tips obtained from the cypselae by germination. The root tips were pre-treated with 0.4% colchicine for 4 hours and then fixed in Carnoy fixative solution for 1 hour. After hydrolysis in 1N HCl at 60 ° C for 7 mins, the tips were stained with leukobasic fuchsin. Root tips were then soaked in 45% acetic acid, macerated and squashed. Metaphasic plates were observed for 3 different individuals, using a Nikon Eclipse Ci-L microscope.

Results and Discussion

Nomenclature and considerations on the lectotype

Despite the most widespread opinion (e.g., Greuter 2006; PFI 2021; Brullo & al. 2021), the name *C. cineraria* var. *pandataria* is to be attributed only to Fiori, who cured the treatment of *Compositae* in *Flora Analitica d'Italia* (Fiori 1904a: 193). In fact, even if Fiori (1904a) reports "Fiori et Bég." in the protologue, there is no evidence that the description of the variety was provided by others than Fiori himself. This statement is further supported by Fiori and Béguinot themselves in herbarium cards (FI, see below). Therefore, according to Art. 46.5 of ICN, the correct citation for the authorship is "Fiori & Bég. ex Fiori" or simply "Fiori", as already proposed for similar cases (e.g., Del Guacchio & al. 2021). The name has been recently typified (Brullo & al. 2021). Fiori (1904a) explicitly alluded in the protologue to the "Bég. hb.", i.e. the private herbarium of Augusto Béguinot. At PAD, where the main part of the collection by Béguinot is preserved, two pertinent sheets are kept. Other pertinent specimens of the Béguinot's herbarium were found at FI, and are filed with the following codes (the specimens in braces were attached on a single sheet when incorporated into the herbarium of Stéphen Sommier): {FI-051937, FI-051938}, FI-051939, {FI-051940, FI-051941}. The above-indicated specimens at PAD and FI (no other specimens were located at GE or GDOR), although belonging to different gatherings (between May 20, 1900 and September 20, 1901), and even if cited in the protologue only by a generic reference to the herbarium of Béguinot, are syntypes according to Art. 9.5 of ICN. However, there is no proof that the specimens at PAD were ever examined by Fiori, whereas the label on FI-051938 adds a relevant detail: Fiori revised FI-051937, FI-051938, FI-051940, and FI-051941 only in 1912. On the contrary, FI-051939 was incorporated into the personal herbarium of Adriano Fiori. On the original label, Béguinot wrote "*Centaurea aplolepa* var. *meridionalis* Nobis?" (evidently an unpublished varietal name, not found elsewhere); while Fiori barred the word "*meridionalis*" and wrote "*pandataria*". Brullo & al. (2021) chosen FI-051939 as the lectotype. After the clarification about the authorship of the name, this is a very agreeable choice. In fact, even if Art. 9.4 (c) does not impose that the author had seen the lectotype, FI-051939 is the only specimen personally revised by Fiori before the publication of the protologue and moreover it includes representative material (a complete fruiting individual, a basal rosette, and a small plant with some flowers and cypselae).

Chromosome number

According to our results (Fig. 2), counts of three different individuals indicate that *C. pandataria* is diploid (2*n* = 18), as the other representatives of *C. cineraria* group, among which *C. aeolica* Guss. ex Lojac. (Cela-Renzoni & Viegi 1982; Bedini & Peruzzi 2021).

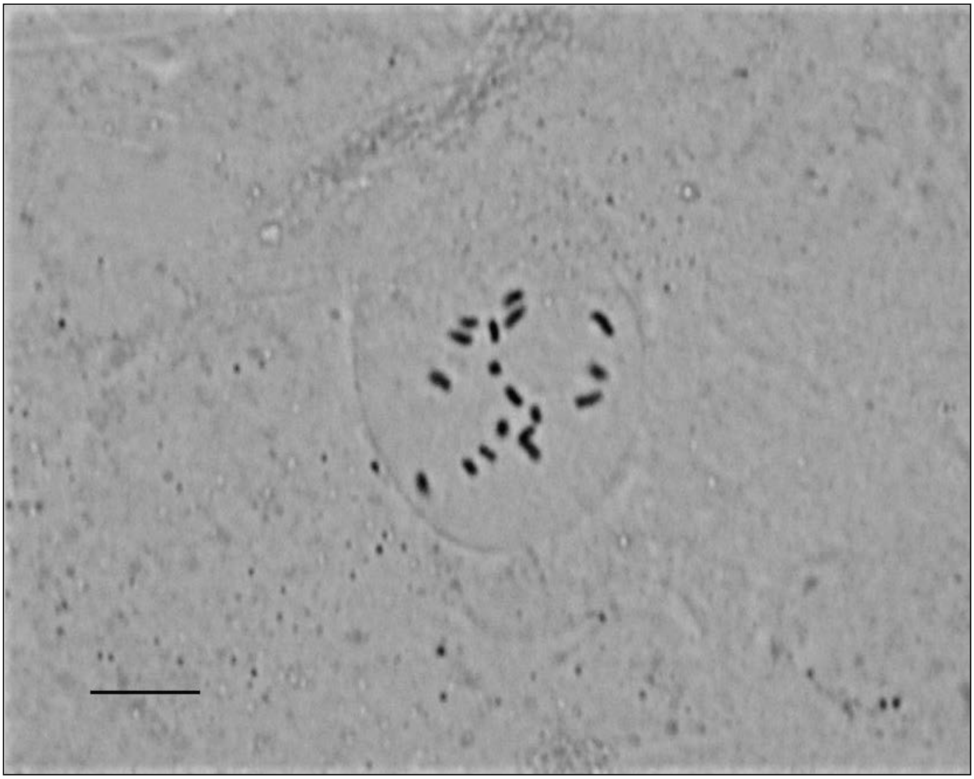

Fig. 2. Metaphase plate representative of three counts on three different individuals of *C. pandataria*. The bar equals 10 µm.

Phylogenetic hypotheses

As the indications of *C. aeolica* for Ischia island (Gulf of Naples, Campania, southern Italy) (e.g., Pignatti & Lausi 1982; Hilpold & al. 2011; Peruzzi & al. 2015; cf. Ricciardi & al. 2004) are to be referred to escaped plants (cf. Gussone 1855 sub *C. aplolepa*) (Del Guacchio & al. 2019), the geographical separation between the very local *C. pandataria* and the other taxa of the *C. aeolica* group is remarkable (Brullo & al. 2021). The most likely explanation for this fragmentation is probably a single long-distance dispersal event. It is to be noted that, within the southern Tyrrhenian Sea, the emerged portion of the earliest Aeolian islands appeared around 450,000-400,000 ya (Branca 2014), and Ventotene is even more ancient (Bergomi & al. 1967); while the volcanic Phlegrean Islands (which are geographically intermediate between the two archipelagos) are much more recent (Aiello & al. 2007).

In any case, *C. aeolica* is the closest relative of *C. pandataria*. According to a first and simpler hypothesis, *C. pandataria* could have originated as a local differentiation by dispersal from *C. aeolica* or its ancestor. However, as already noted for another controversial group in *Centaurea* (e.g., Santangelo & al. 2017), possibly hybridization may have played a role in differentiating local morphs. Also according to our molecular data (not shown), *C. aeolica* and *C. pandataria* are very close, in agreement with Hilpold (2011), and represent an outgroup to a clade including *C. cineraria*.

Conclusions and taxonomic treatment

Several considerations convinced us that, at the present status of knowledge, the specific rank for this taxon is probably the most correct: (1) a remarkable separation between the native ranges of the Aeolian and the Ventotene populations; (2) a trend towards geographical fragmentation of the genus along the Mediterranean coasts (e.g., Hilpold & al. 2014); (3) the perfect separation of the two taxa according to AFLP analysis (Hilpold 2011); (4) the constancy of differential characters which allow to discriminate between them (Anzalone 1995; Brullo & al. 2021).

References

Aiello, G., Barra, D., De Pippo, T., Donadio, C., & Petrosino, C. 2007: Geomorphological evolution of Phlegrean volcanic islands near Naples, southern Italy. – Z. Geomorph. **51(2):** 165-190. https://doi.org/10.1127/0372-8854/2007/0051-0165

Anzalone, B. 1984: Prodromo della Flora Romana (Elenco preliminare delle piante vascolari del Lazio). – Roma.

— 1995: A proposito di una *Centaurea* L. dell'Isola di Ventotene (Isole Ponziane - Lazio). – Boll. Soc. Sarda Sci. Nat. **30:** 511-515.

— & Caputo, G. 1976: Flora e Vegetazione delle Isole Ponziane (Golfo di Gaeta). – Delpinoa n. s. **16-17:** 3-185.

—, Iberite, M. & Lattanzi, E. 2010: La Flora vascolare del Lazio. – Inform. Bot. Ital. **42:** 187-137.

Arrigoni, P. V. 2003: Le Centauree Italiane del gruppo "*Centaurea paniculata* L.". – Parlatorea **6:** 49-78.

Bedini, G. & Peruzzi, L. (eds) 2021 onwards: Chrobase.it - Chromosome numbers for the Italian flora v. 2.0. – Available from: http://www.biologia.unipi.it/chrobase/ [Last accessed 18 December 2021].

Béguinot, A. 1902: L'Arcipelago Ponziano e la sua flora. Appunti di geografia storica e di topografia botanica. – Boll. Soc. Geogr. Ital. **39:** 214-243, 339-370, 408-438.

— 1905: La vegetazione delle isole ponziane e napoletane. – Ann. Bot. (Rome) **3:** 181-453.

— 1931: Uno sguardo sintetico alle minori isole italiane. – Nuovo Giorn. Bot. Ital. *n. s.* **38:** 558-559.

Bergomi, C., Catenacci, V., Cestari, G., Manfredini, M. & Manganelli, V. 1967: Note illustrative della Carta Geologica d'Italia alla Scala 1: 100.000 – Foglio 171: Gaeta e Roccamonfina. – Ercolano (Napoli).

Branca, S. 2014: IV - Vulcanismo. – Pp. 323-349 in: Lentini, F. & Carbone, S. (eds), Geologia della Sicilia. – Memorie descrittive della Carta Geologica d'Italia **95**.

Brullo, S., Cambria, S., Crisafulli, A., Tavilla, G. & Scialandrello, S. 2021: Taxonomic remarks on the *Centaurea aeolica* (Asteraceae) species complex. – Phytotaxa **483:** 9-24. https://doi.org/10.11646/phytotaxa.483.1.2

Cela-Renzoni, G. & Viegi, L. 1982: *Centaurea cineraria* s.l. (*Asteraceae*) in Italia: Revisione citotassonomica. – Atti Soc. Tosc. Sci. Nat. Pisa, Mem., Ser. B, **39:** 99-144.

Cennamo, P., Del Guacchio, E., Paino, L., De Castro, O., Menale, B., Vazquez-Torres, M. & Caputo, P. 2013: Genetic structure of *Ipomoea imperati* (Convolvulaceae) in the Mediterranean region and implications for its conservation. – Phytotaxa **141:** 40-54. http://dx.doi.org/10.11646/phytotaxa.141.1.3

Conti, F., Abbate, G., Alessandrini, A. & Blasi, C. (eds) 2005: An annotated checklist of the Italian vascular flora. – Roma.

De Castro, O., Vallariello, R. & Del Guacchio, E. 2013: Integration of morphology, genetics, historical and ethnobotanical data: a case of an enigmatic *Genista* (Fabaceae) from Ischia Island (southern Italy). – Phytotaxa **82:** 64-68. http://dx.doi.org/10.11646/phytotaxa.82.2.2

Del Guacchio, E., Cambria, S. & Brullo, S. 2021: Typification of the name *Ephedra nebrodensis* (*Ephedraceae*). – Phytotaxa **496:** 90-92. https://doi.org/10.11646/phytotaxa.496.1.5

—, Cennamo, P. & Caputo, P. 2019: Sulla presenza di *Centaurea aeolica* e *C. aplolepa* (*Asteraceae*) in Campania. – Notiz. Soc. Bot. Ital. **3:** 11-12.

—, Innangi, M., Giacò, A., Peruzzi, L. & Caputo, P. 2020. Taxa endemic to Campania (southern Italy): nomenclatural and taxonomic notes. – Phytotaxa **449:** 217-231. https://doi.org/10.11646/phytotaxa.449.3.2

Dostál, J. 1976: New nomenclatural combinations and taxa of the Compositae subtribe Centaureinae in Europe. – In: Heywood V. H. (ed.), Notulae Systematicae ad Flora Europaeam spectantes, No. 18. – Bot. J. Linn. Soc. **71:** 191-210.

Fiori, A. 1904a: *Centaurea* L. – Pp. 321-349 in: Fiori, A. & Paoletti, G. (eds), Flora analitica d'Italia, **3.** – Padova.

— 1904b: Entità nuove di composite italiane descritte nella "Flora Analitica d'Italia". Nota II^{a}. – Boll. Soc. Bot. Ital. **Anno 1904:** 96-108.

— 1927: Nuova Flora analitica d'Italia, **2(5).** – Firenze.

Grande, L. 1924: Note di floristica. – Nuovo Giorn. Bot. Ital., n. s., **31(2):** 105-160.

Greuter, W. 2006+: Compositae (pro parte majore). – In: Greuter, W. & Raab-Straube, E. von (eds), Compositae. Euro+Med Plantbase]. – http://ww2.bgbm.org/EuroPlusMed/PTaxonDetail.asp?NameId=135137&PTRefFk=7000000 [Last accessed 07/04/2021].

Gussone, G. 1855 ["1854"]: Enumeratio plantarum vascularium in insula Inarime. – Neapoli.

Hilpold, A., Schönswetter, P., Susanna, A., Garcia-Jacas, N. & Vilatersana, R. 2011: Evolution of the central Mediterranean *Centaurea cineraria* group (Asteraceae): Evidence for relatively recent, allopatric diversification following transoceanic seed dispersal. – Taxon **60:** 528-538.

—, Vilatersana, R., Susanna, A., Meseguer, A. S., Boršić, I., Constantinidis, T., Filigheddu, R., Romaschenko, K., Suárez-Santiago, V. N., Tugay, O., Uysal, T., Pfeil, B. E., Garcia-Jacas, N. 2014: Phylogeny of the *Centaurea* group (*Centaurea*, Compositae) - geography is a better predictor than morphology. – Mol. Phylogenetics Evol. **77:** 195-215. http://dx.doi.org/10.1016/j.ympev.2014.04.022

Iamonico, D., Vallariello, R. & Del Guacchio, E. 2017: Nomenclatural and distributional remarks on *Limonium tenoreanum* (Plumbaginaceae), a narrow endemic from southern Italy. – Nord. J. Bot. **35:** 445-448. http://dx.doi.org/ 10.1111/njb.01313

Peruzzi, L., Domina, G., Bartolucci, F., Galasso, G., Peccenini, S., Raimondo, F. M., Albano, A., Alessandrini, A., Banfi, E., Barberis, G., Bernardo, L., Bovio, M., Brullo, S., Brundu, G., Brundu, A., Camarda, I., Carta, L., Conti, F., Croce, A., Iamonico, D., Iberite, M., Iiriti, G., Longo, D., Marsili, S., Medagli, P., Pistarino, A., Salmeri, C., Santangelo, A., Scassellati, E., Selvi, F., Soldano, A., Stinca, A., Villani, M., Wagensommer, R. P. & Passalacqua, N. G. 2015: An inventory of the names of vascular plants endemic to Italy, their loci classici and types. – Phytotaxa **196:** 1-217. http://dx.doi.org/10.11646/phytotaxa.196.1.1

PFI. 2021: Portal to the Flora of Italy. – http:/dryades.units.it/floritaly [Last accessed 19/03/2021]

Pignatti, S. 2018: Flora d'Italia, ed. 2, **3.** – Milano.

— & Lausi, D. 1982: *Centaurea* L. – Pp. 173-209 in*:* Pignatti, S. (ed.), Flora d'Italia, **3.** – Bologna.

Santangelo, A., Del Guacchio, E., Cennamo, P. & Caputo, P. 2017. Reassembling the *Centaurea tenorei* group (*Asteraceae*) puzzle: typification of the names. – Phytotaxa **298:** 119-133. https://doi.org/10.11646/phytotaxa.298.2.2

Thiers, B. 2021 onwards: Index Herbariorum: A global directory of public herbaria and associated staff. New York Botanical Garden's Virtual Herbarium. – http://sweetgum.nybg.org/ih/ [Last accessed 8 March 2021].

Turland, N. J., Wiersema, J. H., Barrie, F. R., Greuter, W., Hawksworth, D. L., Herendeen, P. S., Knapp, S., Kusber, W.-H., Li, D.-Z., Marhold, K., May, T. W., McNeill, J., Monro, A. M., Prado, J., Price, M. J. & Smith, G. F. (eds) 2018: International Code of Nomenclature for algae, fungi, and plants (Shenzhen Code) adopted by the Nineteenth International Botanical Congress Shenzhen, China, July 2017. – Regnum Veg. **159:** 1-254. https://doi.org/10.12705/Code.2018

Vallariello, R., Iamonico, D. & Del Guacchio, E. 2016: Typification of three accepted names in *Limonium* (*Plumbaginaceae*). – Phytotaxa **263:** 131-138. http://dx.doi.org/10.11646/phytotaxa.263.2.5

WCSP 2021 onwards: World Checklist of Selected Plant Families. – http://wcsp.science.kew.org/ [Last accessed 8/03/2021].

Zangheri, P. 1976: Flora Italica, **1.** – Padova.

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Emilio Di Gristina & Francesco M. Raimondo

Muehlenbeckia sagittifolia (*Polygonaceae*), a new alien for the Italian flora

Abstract

Di Gristina, E. & Raimondo, F. M.: *Muehlenbeckia sagittifolia* (*Polygonaceae*), a new alien for the Italian flora. — Fl. Medit. 31 (Special Issue): 477-481. 2022. — ISSN: 1120-4052 printed, 2240-4538 online.

Muehlenbeckia sagittifolia, native plant from South America, is reported for the first time as naturalized in Italy. The Italian site is located in Palermo (CN-Sicily), within the Parco della Favorita where the species occurs climbing partly exotic trees and shrubs. Taxonomic, biological and chorological information on the species together with the characters of the Sicilian site are provided.

Key words: xenophytes, vascular flora, alien plants, Sicily.

Introduction

In the exotic flora of Italy, the *Polygonaceae* family is currently present with the only genus *Fallopia* Adans. There are three species of this genus present in various regions, including Sicily (Galasso & al. 2008): *F. baldschuanica* (Regel) Holub, *F. convolvulus* (L.) Á. Löve and *F. dumetorum* (L.) Holub. In Palermo, during the inspection activities aimed at the restoration of the Favorita Park, the opportunity arose to observe a different *Polygonacea*, apparently similar to *Fallopia* but lacking the floral elements necessary for its identification. Finally, the opportunity has arisen to return to the same site and to grasp the plant in full bloom that had been well preserved from the first observation. It was thus possible to identify and attribute it to *Muehlenbeckia sagittifolia* (Ortega) Meisn., a new entity for the alien flora of Italy.

Materials and Methods

The present contribution is based on field surveys and analysis of relevant literature. The plants were photographed, collected and then identified using the reference floras (Akeroyd & Webb 1993; Jankowski & al. 2000). New herbarium specimens are housed in PAL, PAL-Gr and FI.

Results and Conclusions

Taxonomy

***Muehlenbeckia sagittifolia* (Ortega) Meisn.** in Pl. Vasc. Gen. 1: 227 (1839) [*Polygonaceae*]

Basonym: *Coccoloba sagittifolia* Ortega. Synonyms: *Menispermum sagittatum* (Ortega) Spreng., *Calacinum sagittifolium* (Ortega) J. F. Macbr., *Coccoloba dioica* Steud., *Coccoloba sagittata* Poir., *Karkinetron hastatum* Raf., *Polygonum acetosifolium* Vent., *Polygonum ribesioides* C. Huber, *Polygonum sagittifolium* (Ortega) Kuntze, *Sarcogonum sagittifolium* (Ortega) Samp.

For the taxon, Jankowski & al. (2000) provides the following general informations:

Description: Climbing plant, perennial, glabrous, with lignified rhizome from which twining, thin, reddish aerial stems emerge, up to 3 m long. Alternate leaves with 5-15 mm long petiole, little evident hyaline ocher and oblong-deltoid lamina with acute apex, the entire margin and sagittate base from 40 to 70 mm in length and 10 to 20 mm in width. Flowers in glomeruli arranged in spiciform clusters, lax, with a greenish-white perigonium of 5 1.5 mm long tepals, which turn reddish when ripe and finally fleshy and white in the fruit. Achene trine, partially surrounded by the fleshy perigonum. Seeds ovoid, longitudinally three-furrowed.

Biology

Climbing perennial plant with spring emergence and sprouting, summer vegetation and summer-autumnal flowering. Dioecious or polygamous-dioecious species with entomophilous pollination, it has anemocora and zoocora dissemination. In the native range, the propagation occurs trough the regrowth of its rhizomes and the dispersion of its seeds by the wind and by animals.

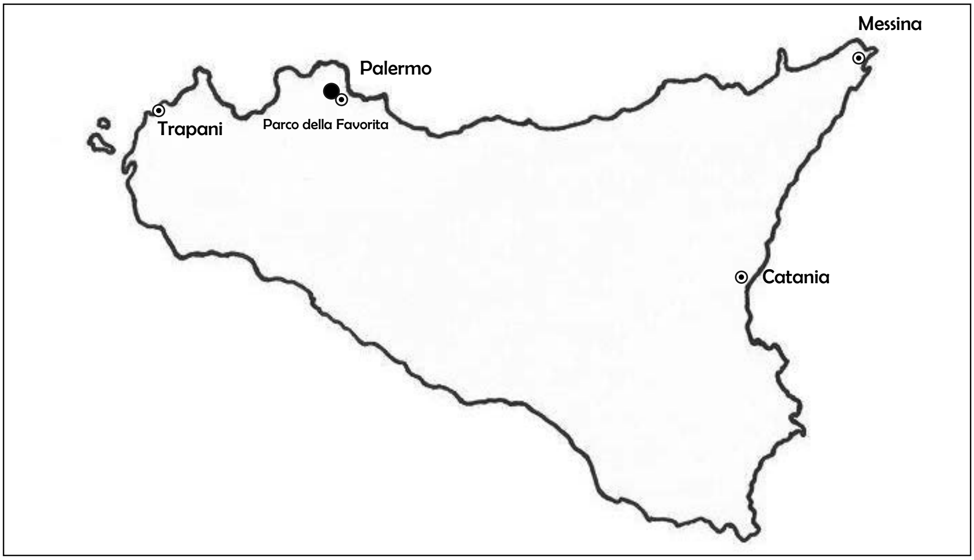

Fig. 1. Geographical localization of the first record of *Muelehnbeckia sagittifolia* in Sicily (Italy).

Chorology

Origin and native range: South American species that goes as far as the north and north-east of Argentina. Its distribution includes Bolivia, central and southern Brasil, Paraguay, Uruguay and Argentina (Jankowski & al. 2000; POWO 2019).

European distribution: Azores, Madeira and Portugal (Akeroyd & Webb 1993; POWO 2019).

Notes: *Muehlenbeckia sagittifolia* is reported also from Morocco (Dobignard & Chatelain 2013).

Ecology and uses

In South America, the species grows in coastal woodlands, forest edges, roadsides and fences. Ruderal and weeds of orchards and gardens, is sometimes cultivated for ornamental and medicinal use.

Italian record

Muehlenbeckia sagittifolia is recorded in Sicily to Palermo (Fig. 1), inside the historic urban park "La Favorita". In this first Italian site, the small spontaneous population occupies an area of about 100 m^2 on the edge of a path very popular with people who practice jogging, near Case Rocca (Fig. 2).

In this place, the species is found on red Mediterranean soil, climbing on trees and shrubs, among which *Celtis australis* L., *Parkinsonia aculeata* L., *Ulmus* aff. *canescens* Melville*, Asparagus acutifolius* L. and *Rubus ulmifolius* Schott (Figs. 3a-d).

Fig. 2. The area and the site of the new record in the area of Parco della Favorita (Palermo, Sicily) (prepared by Google Earth Pro).

The herbaceous layer is characterized by *Achyranthes sicula* (L.) All., *Arisarum vulgare* O. Targ.Tozz., *Arum italicum* Mill., *Bromus sterilis* L., *Geranium dissectum* L., *Lobularia maritima* (L.) Desv., *Lotus biflorus* Desr., *Mercurialis annua* L., *Oxalis pes-caprae* L., *Smilax aspera* L., *Smyrnium olusatrum* L., *Solanum nigrum* L., *Trifolium campestre* Schreb., *Urtica membranacea* Poir., etc. (Figs. 3e-f).

Fig. 3. Some expressions of the Sicilian population of *Muelhembeckia sagittifolia.*

Exsiccata

Sicily: Palermo, Parco della Favorita, at the edge of a path near Case Rocca, on Mediterranean red soil, 50 m a.s.l. (38°09’28” N – 13°20’26”), 7 Juli 2015, *Raimondo* (PAL); Palermo, Parco della Favorita, in bloom at the edge of a path near Case Rocca, on red Mediterranean soil, 50 m a.s.l. (38°09’28” N – 13°20’26”), 15 October 2020, *Raimondo & Di Gristina,* (PAL, PAL-Gr, FI).

References

Akeroyd, J. R. & Webb, D. A. 1993: *Muehlenbeckia*. – Pp. 107-108 in: Tutin, T. G., Burges, N. A., Chater, A. O., Edmondson, J. R., Heywood, V. H., Moore, D. M., Valentine, D. H., Walters, S. M. & Webb, D. A. (eds), Flora Europaea, **1.** – Cambridge.

Galasso, G., Conti, F., Peruzzi, L., Ardenghi, N. M. G., Banfi, E., Celesti-Grapow, L., Albano, A., Alessandrini, A., Bacchetta, G., Ballelli, S., Bandini Mazzanti, M., Barberis, G., Bernardo, L., Blasi, C., Bouvet, D., Bovio, M., Cecchi, L., Del Guacchio, E., Domina, G., Fascetti, S., Gallo, L., Gubellini, L., Guiggi, A., Iamonico, D., Iberite, M., Jimenez-Mejias, P., Lattanzi, E., Marchetti, D., Martinetto, E., Masin, R. R., Medagli, P., Passalacqua, N. G., Peccenini, S., Pennei, R., Pierini, B., Podda, L., Poldini, L., Prosser, F., Raimondo, F. M., Roma-Marzio, F., Rosati, L., Santangelo, A., Scoppola, A., Scortegagna, S., Selvaggi, A., Selvi, F., Soldano, A., Stinca, A., Wagensommer, R. P., Wilhalm, T. & Bartolucci, F. 2018: An updated checklist of the vascular flora alien to Italy. – Pl. Biosyst. **152:** 556-592. https://doi.org/10.1080/11263504.2018.1441197

Dobignard, A. & Chatelain, C. 2013: Index Synonymique de la Flore d’Afrique du Nord [Synonym Index of the Flora of North Africa], **5.** – Genève.

Jankowski, L., Bazzano, D., Sáenz, A., Tourn, M. & Roitman, G. 2000: Planta trepadoras Nativa y exóticas. Collección Biota Rioplatense V. – Buenos Aires.

POWO 2019: Plants of the World Online. Facilitated by the Royal Botanic Gardens, Kew. – https://powo.science.kew.org/taxon/urn:lsid:ipni.org:names:1155902-2 [Last accessed 15/12/2021].

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Gianniantonio Domina & Pietro Mazzola

Wedelia glauca (*Asteraceae*) a new naturalized alien to Italy

Abstract

Domina, G. & Mazzola, P.: *Wedelia glauca* (*Asteraceae*) a new naturalized alien to Italy. — Fl. Medit. 31 (Special Issue): 483-488. 2022. — ISSN: 1120-4052 printed, 2240-4538 online.

Wedelia glauca (Ortega) Blake (*Asteraceae*), perennial herb native to the tropical regions of South America, was found naturalized in the suburbs of Palermo (Sicily). This is the first report to Italy. In Europe this plant is known from Spain and Portugal.

Key words: Alien Flora, Sicily, *Wedelia*.

Introduction

Interest on alien flora in Italy has always been high, but in recent decades it has grown considerably. The recent dedicated checklist (Galasso & al. 2018) and its six months updates (Galasso & al. 2021) are the result of the studies coordinated by the group for Floristics, Systematics and Evolution of the Italian Botanical Society. In addition, several independent contributions that are published annually (e.g. Del Guacchio & al. 2020; Mugnai & al. 2021).

In the course of floristic investigations in Sicily a new perennial herbaceous species of *Asteraceae*, was found in the suburbs of the city of Palermo. It occupies a large area among the agricultural lands surrounding the city and is characterized by a rich luxuriance and a high dispersal capability by seeds and vegetatively.

This plant has been identified as *Wedelia glauca* (Ortega) Blake, a species native to the tropical regions South America, and widespread especially in Argentina, Chile, Paraguay, Southern Brazil and Uruguay (Martínez-Sagarra & al. 2016). It has a great adaptive capacity; as obtained from herbarium specimens housed in L, MA, P, SI (Herbarium acronyms according to Thiers 2021) in the area of origin it grows in farmlands and pastures from the sea level to 2600 m a.s.l. It is reported as naturalized in the southeastern US, Alaska, India, SE Australia, New Zealand and South Africa in wastelands, farmlands and pastures. *W. glauca* is considered as a very dangerous invasive weed, given the ease with which it spreads over wastelands, croplands and pastures, and the difficulty in eradicating it (Burkart & Carera 1953). In addition, it is very toxic for livestock (Micheloud & Odriozola 2012; Giannitti & al. 2013) and has been reported as having allelopathic potential against irrigated herbaceous crops (Sobrero & al. 2004; Mujawar 2017).

In Europe it is known only from Spain and Portugal in the Iberian Peninsula (Greuter 2006; Roy & al. 2020). Curiously, the species has been described on material grown in the botanical garden of Madrid (Gómez Ortega 1797) (Fig. 1) but its naturalization in Spain has been reported only recently (Carretero 1988).

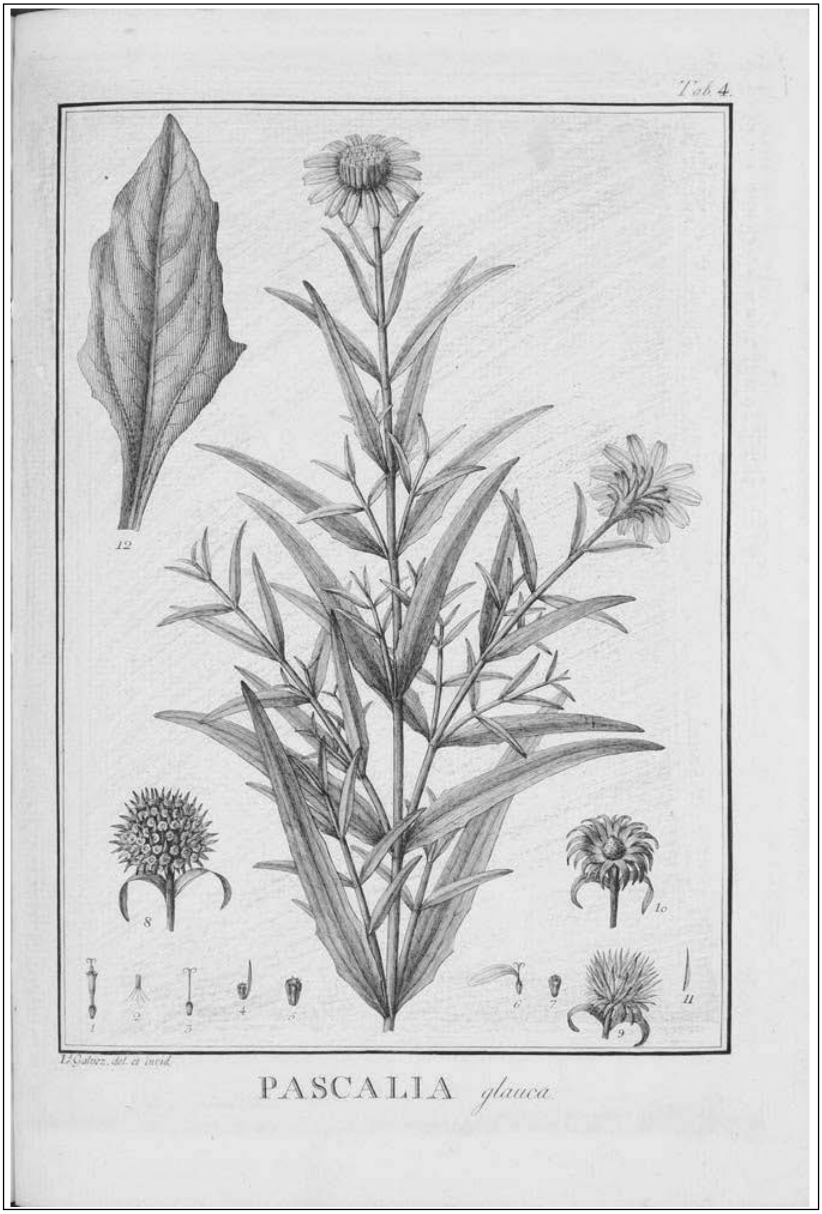

Fig. 1. Original iconography of *Wedelia glauca* in Gómez Ortega (1797).

Materials and Methods

The description below is based on material collected in Sicily. The illustration and photos are offered as an aid to identification. Exsiccata are housed in the *Herbarium Mediterraneum Panormitanum* (PAL) and in the Herbarium of Department of Agricultural and Forest Sciences of Palermo (SAF). The main and most updated floristic surveys of Italy (Pignatti 2018; Galasso & al. 2018, 2021), Europe and the Mediterranean (Greuter 2006; Roy & al. 2020) were consulted to check the occurrence of this taxon and trace its distribution.

Description

Erect perennial rhizomatose herb to 70 cm high. Scapes glabrous. Leaves opposite, narrow-lanceolate, 5–15 cm long, 5–3 mm wide, sessile, usually entire, rarely with remote teeth near the base, glabrous to finely pubescent (Fig. 2a). Capitula solitary, 10–15 mm diam.; peduncles 2–6 cm long; involucral bracts lanceolate, 6–15 × 1.5-2.5 mm; receptacle scales lanceolate. Ray florets bright yellow, 10–15 × 2.2-3 mm; ligulate oblanceolate, 3-toothed. Disc florets numerous, yellow (Fig. 2b). Cypselae angled, 4–6 mm long (Fig. 2 c); pappus scales 2 mm long.

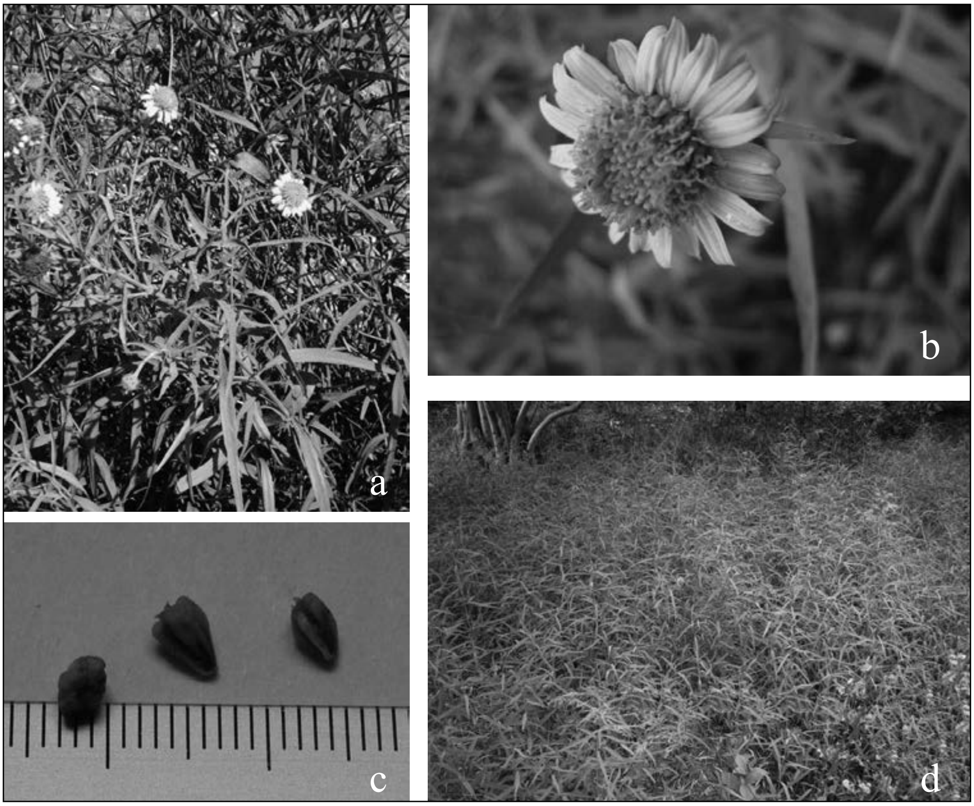

Fig. 2. *Wedelia glauca* in Sicily: a) habit; b) detail of the capitulum; c) detail of the cypselae.

Results and Discussion

The species was found in a residential area in the suburbs of the city of Palermo where it discontinuously occupies an area of about 10 ha on gardens, citrus orchards and uncultivated lands on clay and sandy soils on carbonate substratum between 100 and 150 m a.s.l. (Fig. 3). It has been recorded for the first time in 2009 and monitored for 12 years during which it expanded its area of a couple of hectares. This species is not mentioned in the recent contribution on the urban vascular flora of Palermo (Domina & al. 2020) because the place of discovery falls outside the perimeter of the area examined in that contribution.

Wedelia glauca makes a dense and continuous lawn almost monospecific. The population found in Sicily is characterized by a rich luxuriance and a high dispersal capability. The milling of the soil facilitates its diffusion by fragmenting the rhizomes. Given the high invasive capacities, shown since the first observations, and its toxicity to livestock, the expansion of this plant in Sicily needs to be monitored. In summer, when the plant has bloomed, it is also evident when driving through the area, in winter the vegetative part merges with native vegetation making it less easy to recognize. The monitoring of this species through aerial photos or Google Street View panoramas (Barone & al. 2021) would, therefore, be conducted using photos taken in the summer.

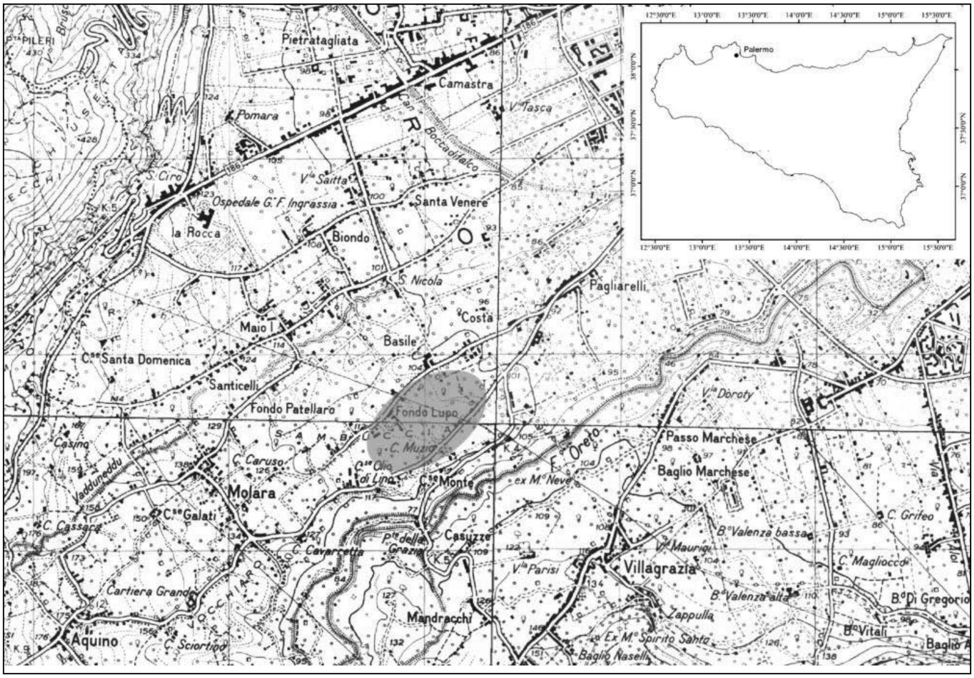

Fig. 3. Distribution of *Wedelia glauca* in Sicily.

Exsiccata: Wedelia glauca (Ortega) Blake**,** Palermo, via Olio di Lino, 8.6.2009, *P. Mazzola* (PAL); Palermo, via Olio di Lino, waste land and citrus orchards, 38° 08' 14,97"N 13° 32' 10,66"E, 120 m a.s.l., 23.7.2013, *P. Mazzola & G. Domina* (PAL99981, 99982); *ibidem*, 3.7.2021, *G. Domina* (PAL, SAF).

References

Barone, G., Domina, G. & Di Gristina, E. 2021: Comparison of different methods to assess the distribution of alien plants along the road network and use of Google Street View panoramas interpretation in Sicily (Italy) as a case study. – Biodiv. Data J. **9:** e66013. https://doi.org/10.3897/BDJ.9.e66013.

Burkart, A. & Carera, M. N. 1953: Estudios sobre malezas. Morfología vegetativa y germinación del sunchillo (*Wedelia glauca*). – Darwiniana **10(2):** 113-144.

Carretero, J. L. 1988: *Wedelia glauca* (Ortega) O. Hoffm. ex Hicken en España. – Anales Jard. Bot. Madrid **45:** 346-347.

Del Guacchio, E., De Natale, A. & Stinca, A. 2020: Notes to the non-native flora of Campania (southern Italy). – Atti Soc. Tosc. Sci. Nat., Mem-, Serie B **127:** 39-49. https://doi.org/10.2424/ASTSN.M.2020.07

Domina, G., Di Gristina, E., Scafidi, F., Calvo, R. Venturella, G. & Gargano, M. L. 2020: The urban vascular flora of Palermo (Sicily, Italy). – Pl. Biosyst. **154(5):** 627-634. https://doi.org/10.1080/11263504.2019.1651787

Galasso, G., Conti, F., Peruzzi, L., Ardenghi, N. M. G., Banfi, E., Celesti-Grapow, L., Albano, A., Alessandrini, A., Bacchetta, G., Ballelli, S., Bandini Mazzanti, M., Barberis, G., Bernardo, L., Blasi, C., Bouvet, D., Bovio, M., Cecchi, L., Del Guacchio, E., Domina, G., Fascetti, S., Gallo, L., Gubellini, L., Guiggi, A., Iamonico, D., Iberite, M., Jimenez-Mejias, P., Lattanzi, E., Marchetti, D., Martinetto, E., Masin, R.R., Medagli, P., Passalacqua, N. G., Peccenini, S., Pennei, R., Pierini, B., Podda, L., Poldini, L., Prosser, F., Raimondo, F. M., Roma-Marzio, F., Rosati, L., Santangelo, A., Scoppola, A., Scortegagna, S., Selvaggi, A., Selvi, F., Soldano, A., Stinca, A., Wagensommer, R. P., Wilhalm, T. & Bartolucci, F. 2018: An updated checklist of the vascular flora alien to Italy. — Pl. Biosyst. **152:** 556-592. https://doi.org/10.1080/11263504.2018.1441197

—, Domina, G., Andreatta, S., Argenti, E., Bacchetta, G., Bagella, S., Banfi, E., Barberis, D., Bardi, S., Barone, G., Bartolucci, F., Bertolli, A., Biscotti, N., Bonali, F., Bonini, F., Bonsanto, D., Brundu, G., Buono, S., Caldarella, O., Calvia, G., Cambria, S., Campus, G., Caria, M. C., Conti, F., Coppi, A., Dagnino, D., Del Guacchio, E., Di Gristina, E., Farris, E., Ferretti, G., Festi, F., Fois, M., Furlani, F., Gigante, D., Guarino, R., Gubellini, L., Hofmann, N., Iamonico, D., Jiménez-Mejias, P., La Rosa, A., Laface, V. L. A., Lallai, A., Lazzaro, L., Lonati, M., Lozano, V., Luchino, F., Lupoletti, J., Magrini, S., Mainetti, A., Marchetti, D., Marenzi, P., Marignani, M., Martignoni, M., Mei, G., Menini, F., Merli, M., Mugnai, M., Musarella, C. M., Nicolella, G., Noor Hussain, A., Olivieri, N., Orlandini, S., Peccenini, S., Peruzzi, L., Pica, A., Pilon, N., Pinzani, L., Pittarello, M., Podda, L., Probo, M., Prosser, F., Raffaelli, C., Ravetto Enri S., Rivieccio, G., Rosati, L., Sarmati, S., Scafidi, F., Selvi, F., Sennikov, A. N., Sotgiu Cocco, G., Spampinato, G, Stinca, A., Tavilla, G., Tomaselli, V., Tomasi, D., Tomasi, G., Trenchi, M., Turcato, C., Verloove, F., Viciani, D., Villa, M., Wagensommer, R. P. & Lastrucci, L. 2021: Notulae to the Italian alien vascular flora: 11. – Ital. Bot. **11:** 93-119. https://doi.org/10.3897/italianbotanist.11.68063

Giannitti, F., Margineda, C. A., Cid, M. S., Montobbio, C., Soteras, C. I., Caffarena, R. D. & Diab, S. S. 2013: Fatal *Wedelia glauca* intoxication in calves following natural exposure. – Vet. Pathol. **50(3):** 530-533.

Gómez Ortega, C. 1797: Novarum, aut rariorum plantarum Horti Reg. Botan. Matrit. descriptionum decades, **1.** – Madrid.

Greuter, W. (2006+): *Compositae* (pro parte majore). — In: Greuter, W. & Raab-Straube, E. von (ed.): *Compositae*. Euro+Med Plantbase - the information resource for Euro-Mediterranean plant diversity. http://ww2.bgbm.org/EuroPlusMed/ [Last accessed 1/5/2021].

Martínez-Sagarra, G., Devesa, J. A., Crespo, M. B. 2016: 204. *Pascalia glauca* Ortega (*Asteraceae*), nueva para la flora de Andalucía Occidental. – Acta Bot. Malacitana **41:** 317-318.

Micheloud, J. F. & Odriozola, E. 2012: Actualización sobre la intoxicación por *Wedelia glauca* (Ort.) Hoffm. ex Hicken, *Asteraceae*. – Revista FAVE-Ci. Veterin. **11:** 31-42.

Mugnai, M., Lazzaro, L., Di Nuzzo, L., Foggi, B., Viciani, D. & Ferretti, G. 2021: Synopsis of *Euphorbia* section *Anisophyllum* (*Euphorbiaceae*) in Italy, with an insight on variation of distribution over time in Tuscany. – Phytotaxa **485(1):** 1-65. https://doi.org/10.11646/phytotaxa.485.1.1

Mujawar, I., Kanade, M. & Murumkar, C. 2017: Allelopathic potential of *Pascalia Glauca* Ortega aqueous extract against seed germination and seedling growth of groundnut. – Biosci. Disc. **8(1):** 35-39.

Pignatti S. 2018: Flora d'Italia, 2° ed, **3.** – Milano.

Roy, D., Alderman, D., Anastasiu, P., Arianoutsou, M., Augustin, S., Bacher, S., Başnou, C., Beisel, J., Bertolino, S., Bonesi, L., Bretagnolle, F., Chapuis, J. L., Chauvel, B., Chiron, F., Clergeau, P., Cooper, J., Cunha, T., Delipetrou, P., Desprez-Loustau, M., Détaint, M., Devin, S., Didžiulis, V., Essl, F., Galil, B. S., Genovesi, P., Gherardi, F., Gollasch, S., Hejda, M., Hulme, P. E., Josefsson, M., Kark, S., Kauhala, K., Kenis, M., Klotz, S., Kobelt, M., Kühn, I., Lambdon, P. W., Larsson, T., Lopez-Vaamonde, C., Lorvelec, O., Marchante, H., Minchin, D., Nentwig, W., Occhipinti-Ambrogi, A., Olenin, S., Olenina, I., Ovcharenko, I., Panov, V. E., Pascal, M., Pergl, J., Perglová, I., Pino, J., Pyšek, P., Rabitsch, W., Rasplus, J., Rathod, B., Roques, A., Roy, H., Sauvard, D., Scalera, R., Shiganova, T. A., Shirley, S., Shwartz, A., Solarz, W., Vilà, M., Winter, M., Yésou, P., Zaiko, A., Adriaens, T., Desmet, P. & Reyserhove, L. 2020: DAISIE - Inventory of alien invasive species in Europe. Version 1.7. – Research Institute for Nature and Forest (INBO). Checklist dataset https://doi.org/10.15468/ybwd3x [Last accessed 10/5/2021]

Sobrero, M. T., Ochoa, M. C. & Chaila, S. 2004: Potencial alelopático de *Wedelia glauca*: efecto sobre especies hortícolas. – Planta Daninha, Viçosa-MG **22(1):** 71-75.

Thiers, B. 2021 [continuously updated]: Index Herbariorum: A global directory of public herbaria and associated staff. New York Botanical Garden's Virtual Herbarium. – http://sweetgum.nybg.org/ih/ [Last accessed 10/5/2021]

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P. Pavone, F. M. Raimondo & V. Spadaro

New Aloes casual aliens in Sicily

Abstract

Pavone, P., Raimondo, F. M. & Spadaro, V.: New Aloes casual aliens in Sicily. — Fl. Medit. 31 (Special Issue): 489-493. 2022. — ISSN: 1120-4052 printed, 2240-4538 online.

Aloë arborescens, A. brachystachys and *A. maculata* (*Asphodelaceae*) are reported for the first time as casual aliens in Sicily. *A. brachystachys* is new also for the alien flora of Italy.

Key words: alien plants, succulents, Italian flora, Sicily.

Introduction

Aloë L. is a genus of the *Asphodelaceae* family (*Liliaceae* p.p.) represented by a very rich number of infraspecific species and taxa (Carter & al. 2011). Among them, there are many species introduced and cultivated in various regions of the world and then in part naturalized.

According to Galasso & al. (2018), the following nine taxa belong to the Italian alien flora: *Aloë arborescens* Mill., *A. humilis* (L.) Mill., *A. maculata* All., *A. perfoliata* L., *A. reynoldsii* Letty, *A. striata* Haw. subsp. *striata*, *A. striatula* Haw., *A. vera* (L.) Burm.f., and *A.* ×*caesia* Salm-Dyck. For Sicily are reported only *A.* ×*caesia* and *A. vera*, both naturalized (P A NAT). Recent explorations, in particular in western Sicily, have allowed the discovery in the spontaneous state of some of the above reported taxa hitherto unpublished for the alien flora of Sicily. These are *A. arborescens* and *A. maculata*. In addition *A. brachystachys* Baker was also found, a species that is still unknown to date due to the alien flora of Italy.

Review of the records

Aloë arborescens L. (Fig. 1).

Plant widely cultivated in all the coastal Italian regions, both in gardens and in flower beds and terraces - in the ground and in pots - it is indicated as naturalized in many Italian regions with the exception of Lombardy and Trentino-Alto Adige (Galasso & al. 2018). It has recently been reported as naturalized in Puglia (Oliveri in Galasso & al. 2019). It is a winter flowering plant (Carter & al. 2011) of which several varieties are grown in Italy. Spontaneous populations of *A. arborescens* are also found in Sicily where they have been recorded in Taormina, Capo d'Orlando, Cefalù, Palermo, Scopello, Valderice and S. Vito Lo Capo (Trapani). In these localities the species occurs on rocky substrates, slopes and uncultivated areas, therefore also in semi-natural environments. However, these localities are close to residential centers distributed along the coast, or plants that have escaped from cultivation sites or from landfills located on the outskirts of inhabited centers.

Fig. 1. *Aloë arborescens* in Taormina, Messina.

Aloë brachystachys Backer (Fig. 2)

It is a plant native to South Africa (Cape Provinces). Also known as *Aloë lastii* L., it is cultivated both in gardens and in pots (Carter & al. 2011). To date, the species is not known as naturalized or casual in any of the Italian regions (cfr. Galasso & al. 2018). In Sicily, a casual population was recently found in Capo Rama, near Terrasini (Palermo), on the outer edges of the homonymous nature reserve. In this locality *A. brachystachys* coexists with *Opuntia stricta* L. and other succulents such as *Agave americana* L., *Aeonium arboreum* (L.) Webb & Berth., *Carpobrothus edulis* (L.) L. Bolus, and *Cylindropuntia* sp. (cfr. Raimondo & al. 2021).

Fig. 2. *Aloë brachystachys* in Capo Rama, Palermo.

Aloë maculata All. (Fig. 3)

Widely cultivated species in flowerbeds and in pots, in Italy it is given as an alien plant (P A CAS) in Lazio, Campania, Puglia and Sardinia (Galasso & al. 2018). In Sicily, although widely cultivated, it has not been reported as naturalized or casual so far. Two small groups, located a few meters from each other, along the rocky coast - between the outcrop-

Fig. 3. *Aloë maculata* in Sferracavallo (Palermo), with other alien species naturalized in Sicily.

ping limestones and the clayey-sandy soil - were recently found to Punta Matese (Sferracavallo, Palermo). This species can be considered a casual alien in Sicily.

Discussion and Conclusion

The alien flora of Sicily is enriched by three additional taxa, two of which (*A. brachystachys* and *A. maculata*) to be considered as casual alien species (P A CAS, *sensu* Galasso & al. 2018). Instead, the spontaneous presence of *A. arborescens*, a plant that has long been widely cultivated not only in Sicily, offers the opportunity for some considerations, given the well-known medicinal properties of the leaves which have been widely disclosed in the last three decades. On the island, in fact, the plants of this species were used for the supply of leaves which were then used in the preparation of syrups to also be used as a therapeutic. This has resulted in the reduction of cultivated populations, helping to contain the potential spread of this species not only in urban green areas and in poorly cared public gardens but also naturalized in partly accessible sites. *A. arborescens* very decorative and also rustic, is given in all the Italian regions where it is present as a naturalized alien plant (P A NAT, *sensu* Galasso & al. 2018). In Puglia (Oliveri in Galasso & al. 2019) and, on what has been reported above, in Sicily it is to be considered, instead, as a causal alien (P A CAS *sensu* Galasso & al. 2018). The localization in Sicily of the taxa retrieval sites, reported here, is shown in the following Fig. 4.

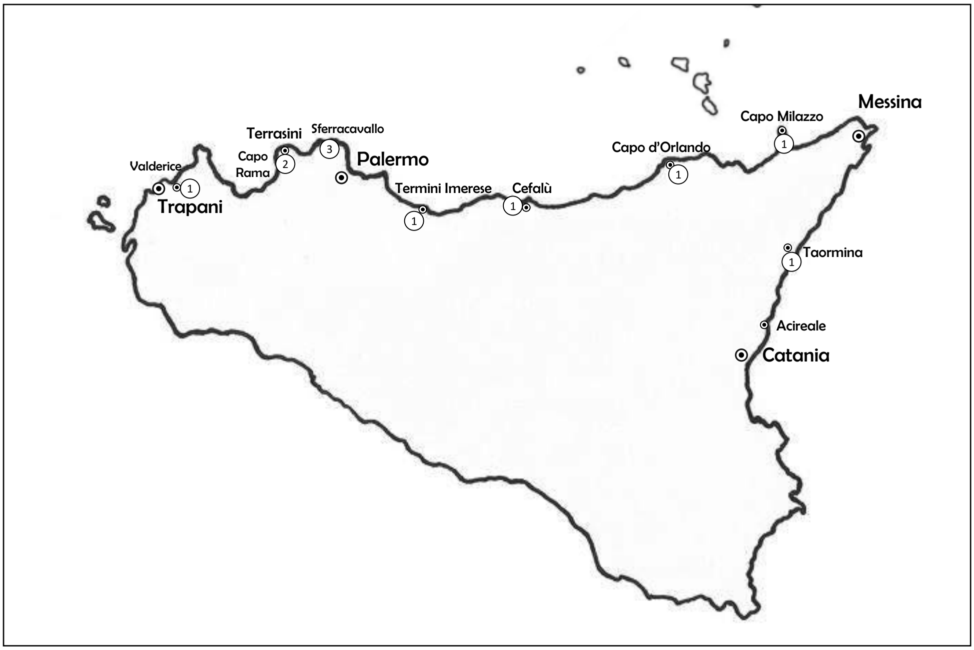

Fig. 4. Location in Sicily of the discovery sites of the three species of *Aloë* reported: 1 = *A. arborescens*; 2 = *A. brachystachys*; 3 = *A. maculata*.

Finally, the report of *A. brachystachys* as a casual alien species, in this contribution, has greater importance both because it is the first case observed in the entire Italian territory, and because it can affect other Italian regions where its spontaneous occurrence has probably been hitherto underestimated or, in any case, overlooked.

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References

Carter, S., Lavranos, J. J., Newton, L. E. & Walker, C. C. 2011: Aloes. The definitive Guide. – Kew.

Galasso, G, Conti, F., Peruzzi, L., Ardenghi, N. M. G., Banfi, E., Celesti-Grapow, L., Albano, A., Alessandrini, A., Bacchetta, G., Ballelli, S., Bandini Mazzanti, M., Barberis, G., Bernardo, L., Blasi, C., Bouvet, D., Bovio, M., Cecchi, L., Del Guacchio, E., Domina, G., Fascetti, S., Gallo, L., Gubellini, L., Guiggi, A., Iamonico, D., Iberite, M., Jimenez-Mejias, P., Lattanzi, E., Marchetti, D., Martinetto, E., Masin, R.R., Medagli, P., Passalacqua, N. G., Peccenini, S., Pennei, R., Pierini, B., Podda, L., Poldini, L., Prosser, F., Raimondo, F. M., Roma-Marzio, F., Rosati, L., Santangelo, A., Scoppola, A., Scortegagna, S., Selvaggi, A., Selvi, F., Soldano, A., Stinca, A., Wagensommer, R. P., Wilhalm, T. & Bartolucci, F. 2018: An updated checklist of the vascular flora alien to Italy. – Pl. Biosyst. **152:** 556-592. https://doi.org/10.1080/11263504.2018.1441197

Oliveri, N. 2019: *Aloe arborescens* L. – In: Galasso, G., Domina, G., Ardenghi, N. M. G., Aristarchi, C., Bacchetta, G., Bartolucci, F., Bonari, G., Bouvet, D., Brundu, G., Buono, S., Caldarella, O., Calvia, G., Cano-Ortiz, A., Corti, E., D'Amico, F. S., D'Antraccoli, M., Di Turi, A., Dutto, M., Fanfarillo, E., Ferretti, G., Fiaschi, T., Ganz, C., Guarino, R., Iberite, M., Laface, V. L. A., La Rosa, A., Lastrucci, L., Latini, M., Lazzaro, L., Lonati, M., Lozano, V., Luchino, F., Magrini, S., Mainetti, A., Manca, M., Mugnai, M., Musarella, C. M., Nicolella, G., Olivieri, N., Orrù, I., Pazienza, G., Peruzzi, L., Podda, L., Prosser, F., Ravetto Enri, S., Restivo, S., Roma-Marzio, F., Ruggero, A., Scoppola, A., Selvi, F., Spampinato, G., Stinca, A., Terzi, M., Tiburtin, M., Tornatore, E., Vetromile, R. & Nepi, C.: Notulae to the Italian alien vascular flora: 7. – Italian Botanist **7:** 157-182. https://doi.org/10.3897/italianbotanist.7.36386

Raimondo, F. M., Bajona, E., Di Gristina, E. & Domina, G. 2021: Xenophytes and anthropogenic vegetation in Sicily: the case of *Opuntia stricta* (*Cactaceae*) in the protected area of Capo Rama (Terrasini, Palermo). – P. XXI in: Abstracts IV International conference. Online, S.B.I., September 8-10, 2021. – Firenze.

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Franco Pedrotti

Juncus fontanesii (*Juncaceae*), a new species for Trentino (Central Alps, northern Italy)

Abstract

Pedrotti, F.: *Juncus fontanesii* (*Juncaceae*), a new species for Trentino (Central Alps, northern Italy). — Fl. Medit. 31 (Special Issue): 495-500. 2022. — ISSN: 1120-4052 printed, 2240-4538 online.

The presence of *Juncus fontanesii* subsp. *fontanesii* is reported for the first time for Trentino (Province of Trento, Central Alps, Northern Italy). In addition to the distinctive features of the taxon, the author recalls the stationary characteristics of the new record followed by some brief phytogeographic considerations.

Key words: vascular flora, *Juncus* , chorology, Alps, N. Italy.

Introduction

The purpose of this note is to report the first finding of *Juncus fontanesii* subsp. *fontanesii* in Trentino, Central Alps (Northern Italy), the flora of which has been explored and treated extensively. Many specific and infraspecific taxa in the genus *Juncus* occur in Italy, 17 of which are also present in Trentino (Prosser & al. 2019).

Taxonomy

Juncus fontanesii J. Gay ex Laharpe in Mem. Soc. Hist. Nat. Paris 3: 130 (1827)

Juncus fontanesii is a rhizomatous geophyte, perennial, with long sterile stems snaking on the ground and rooting at the nodes, 3-5, rarely 20 decimeters long ; the fertile stems are short and ascending; leaves with evident transverse septa, up to 10 centimeters long and more; large inflorescence, with about ten flower heads with 6-20 flowers (Pignatti 2017). This taxon is well distinguished from other species of the genus, due to the prostrate stem, floating in shallow water or lying on humid soil. Another very evident characteristic is stems rooting at the nodes, as is well illustrated in the iconography of the species by Arrigoni (2015) and shown in Fig. 1. *Juncus fontanesii* is divided into two subspecies (Snogerup 1980; Bartolucci & al. 2018), namely *J. fontanesii* subsp. f*ontanesii* and *J. fontanesii* subsp. *pyramidatus* (Laharpe) Snogerup. In Trentino only the nominal subspecies is present.

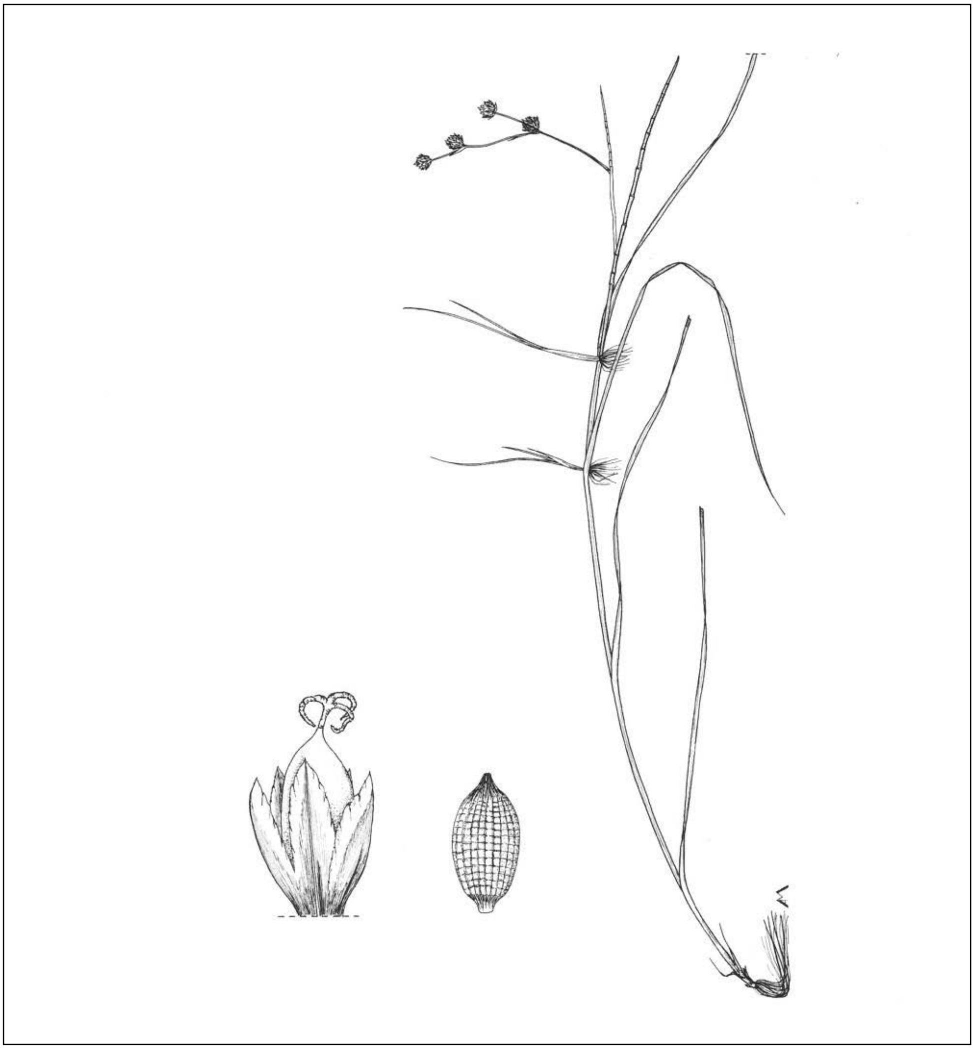

Fig. 1. Iconographic plate of *Juncus fontanesii* subsp. *fontanesii* (from Arrigoni 2015).

The new record

Juncus fontanesii was found in a bog in Maderlina, Dossone Cembra, on the right bank of the Val di Cembra (Trentino, Central Alps), at 900-1000 m [25.VIII. 2020, Pedrotti (CAME)]. It is a rhizomatous geophyte and its stems, at Maderlina, are always prostrate on soil and 70-80 cm long (Fig. 2). *Juncus fontanesii* forms a mono-specific population, with a cover degree of 100%, and occupies the entire central part of the swamp.

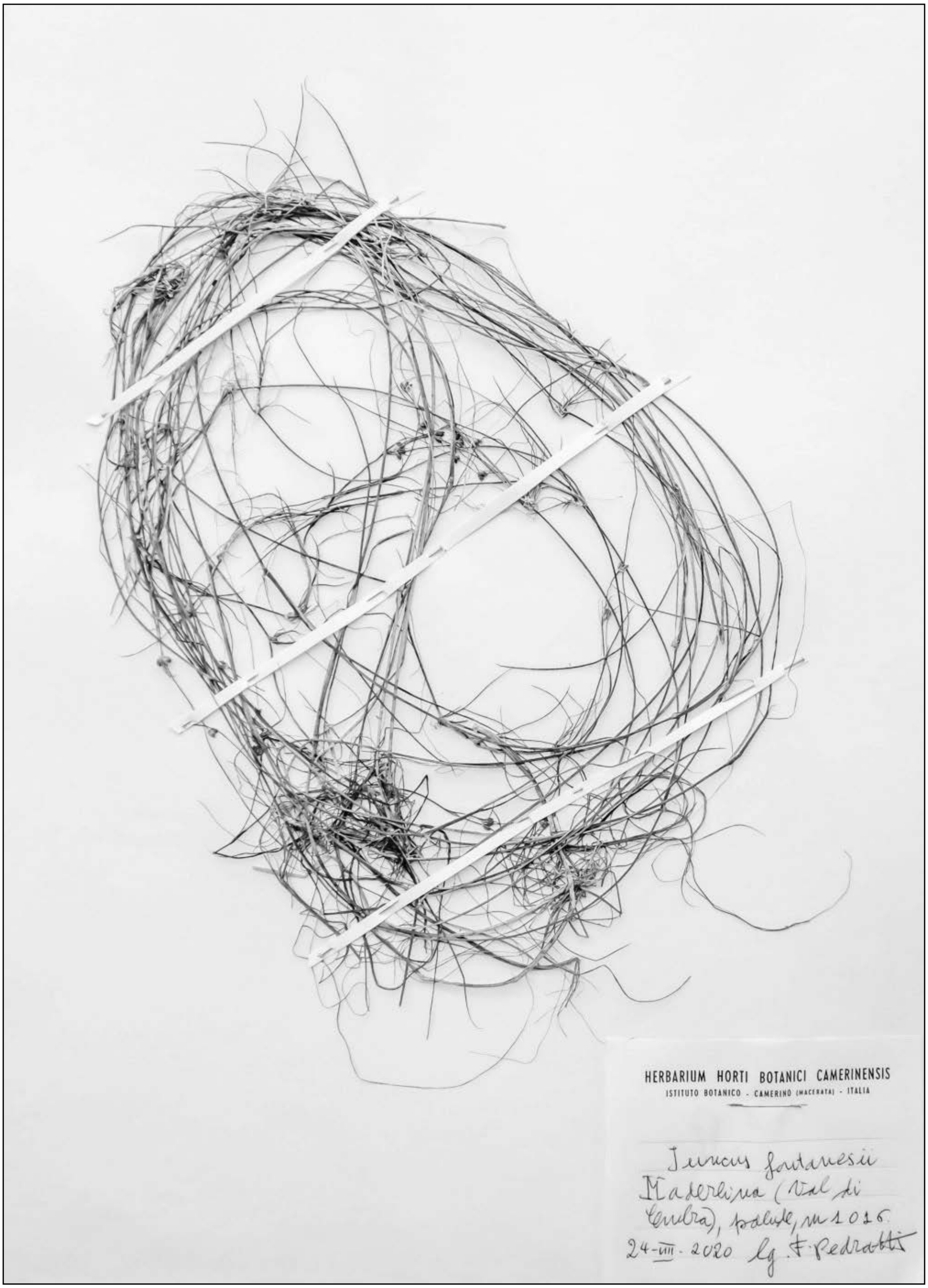

Fig. 2. Herbarium sheath of a specimen of *Juncus fontanesii* subsp. *fontanesii* collected in the Maderlina swamp (Val di Cembra, Trentino), 2020, and housed in the *Herbarium Horti Botanici Camerinensis* (CAME).

The environment where *Juncus fontanesii* grows is the marshes of Maderlina, an area located on a not very marked plateau, completely covered by forests, between 900-1000 m of altitude, in the lower humid pre-alpine supra-temperate (Gafta & Pedrotti 1996) or montane belt. The vegetation on the plateau consists of an acidophilic beech forest (*Luzulo-Fagetum)* plus Scots pine (*Vaccinio vitis-idaeae-Pinetum sylvestris*). On the slopes of the plateau the forest is represented by the *Luzulo niveae-Quercetum petraeae*. There is a group of 9 marshes occurring in hollows not far from each other, all surrounded by woods, on an irregular plateau inclined slightly towards the northeast.

The swamps are all small (the largest 80 × 5 m), round or elongated, and 1.50-2.0 m deep. None of these marshes is mapped on the Trentino Technical Map (Autonomous Province of Trento). *Juncus fontanesii* was found in a single swamp, during inspections at the end of August 2020, when the swamp itself was devoid of water.

The plateau is made up of volcanites (porphyry) of the Atesina porphyry platform, on which there are more or less vast moraine deposits (Venzo 1962-1963). The basins with the marshes can be considered of glacial origin, partly inter-moraine and partly of glacial excavation. The water of the marshes derives from snow and rain, coming especially in the spring and autumn months. At the Cembra station (662 m) the rainfall is 902 mm per year, and on the Maderlina Plateau (900-1000 m) is around 1000 mm per year. No springs were observed in the area. In August, the marshes are dry, but the mud at the bottom remains very moist.

The banks of the marshes are bordered by a belt of marshy vegetation (*Caricetum vesicariae*), common to all the marshes. The *Caricetum elatae* and the *Caricetum gracilis* appear more irregularly and in smaller areas. Outside the associations of large sedges (listed above), the marshes are surrounded by an irregular strip of *Molinia caerulea* (*Succiso-Molinietum*). At the center of the marshes, the stretch of water is almost always invaded by *Potametum natantis*; between the large sedge associations and *Potametum natantis* it is possible to find some groups of *Glycerietum notatae*.

Chorological Note and Conclusions

Juncus fontanesii is a Mediterranean-Iranian-Turanian species (Arrigoni 2015). In Italy it is present in the Peninsula, Sicily and Sardinia. In Lombardy it has been reported for Valcamonica in Campolungo (Cedegolo), at 450 m) (Martini & al. 2012). The taxon does not appear in Aeschimann & al. (2004); the stations of Valcamonica and Val di Cembra (Trentino) are the only two known for the entire chain of the Alps (Fig. 3).

The discovery of *Juncus fontanesii* subsp. *fontanesii* in Trentino assumes considerable significance, both floristically and phytogeographically. In the first case it is a kind of new signal for Trentino, which increases - in particular - the biodiversity of wetlands.

With regard to the second aspect, *Juncus fontanesii* is a Mediterranean-Iranian-Turanian species that, like other taxa of the Mediterranean contingent (primarily *Quercus ilex*), penetrates the Alpine region and reaches the northern limit of its range. The Trentino location is very disconnected from its main distribution

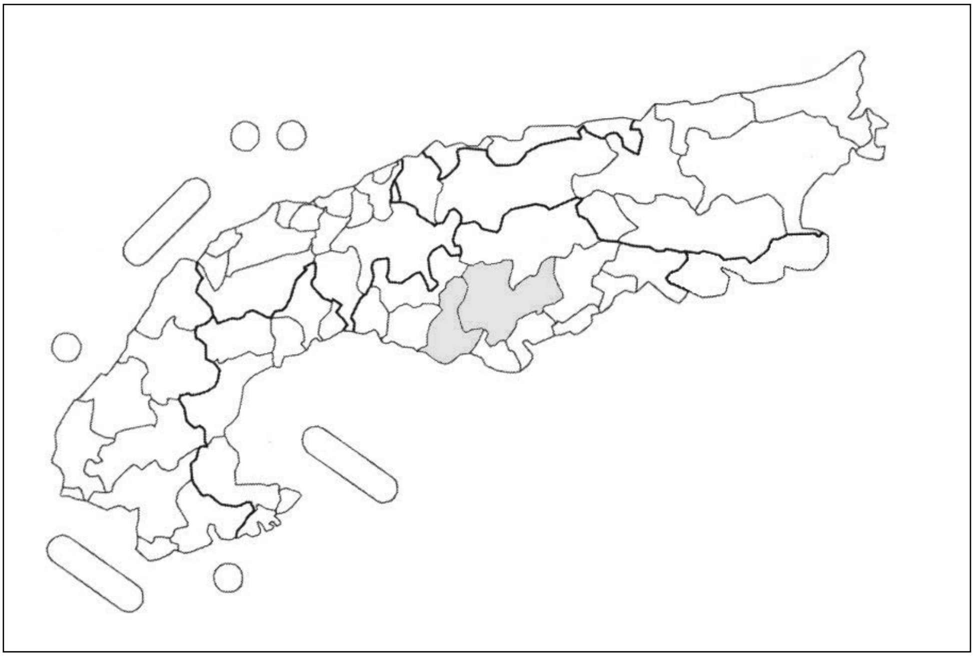

Fig. 3. Distribution of *Juncus fontanesii* subsp. *fontanesii* in the chain of the Alps, Provinces of Brescia and Trento. The reference map is that of Aeschimann & al. (2004).

area, as is the Lombardy location. Normally this species is reported for humid places in hilly plains with a Mediterranean or sub-Mediterranean climate. In Trentino, however, it occurs at an altitude of 900-1000 m, in vegetation of the beech forest and the Scots pine forest, which are typical of the lower montane belt (lower pre-alpine humid supra-temperate).

References

Aeschimann, D., Lauber, K., Moser, D. M. & Theurillat, J.-P. 2004: Flora alpina. — Bologna.

Arrigoni, P. V. 2015: Flora dell'Isola di Sardegna. **6.** — Sassari.

Bartolucci, F., Peruzzi, L., Galasso, G., Albano, A., Alessandrini, A., Ardenghi, N. M. G., Astuti, G., Bacchetta, G., Ballelli, S., Banfi, E., Barberis, G., Bernardo, L., Bouvet, D., Bovio, M., Cecchi, L., Di Pietro, R., Domina, G., Fascetti, S., Fenu, G., Festi, F., Foggi, B., Gallo, L., Gottschlich, G., Gubellini, L., Iamonico, D., Iberite, M., Jiménez-Mejías, P., Lattanzi, E., Marchetti, D., Martinetto, E., Masin, R. R., Medagli, P., Passalacqua, N. G., Peccenini, S., Pennesi, R., Pierini, B., Poldini, L., Prosser, F., Raimondo, F. M., Roma-Marzio, F., Rosati, L., Santangelo, A., Scoppola, A., Scortegagna, S., Selvaggi, A., Selvi, F., Soldano, A., Stinca, A., Wagensommer, R. P., Wilhalm, T. & Conti, F. 2018: An updated checklist of the vascular flora native to Italy. — Pl. Biosyst. **152(2):** 179-303. https://doi.org/10.1080/11263504.2017.1419996

Gafta, D. & Pedrotti, F. 1996: Fitoclima del Trentino-Alto Adige. — Studi Trent. Sc. Nat. **73:** 55-111.

Martini, F., Bona, E., Federici, G., Fenaroli, F. & Perico, G. 2012: Flora vascolare della Lombardia centro-orientale. vol. 1, Parte generale. — Trieste.

Pignatti S., 2017: *Juncus* L. — Pp. 390-407 in: Flora d'Italia, 2ª ed., **1.** — Milano.

Prosser, F., Bertolli, A., Festi, F. & Perazza, G., 2019: Flora del Trentino — Rovereto.

Snogerup, S. 1980: *Juncus* L. – Pp. 102-112 in: Tutin, T. G., Heywood, V. H., Burges, N. A., Valentine, D. H., Walters, S. M. & Webb, D. A. (eds), Flora Europaea, **5.** –Cambridge.

Venzo, G. A. 1962-1963: Geologia della regione dalla confluenza Val di Cembra-Val d'Adige all'altipiano di Lavazè (Trentino-Alto Adige). — Mem. Mus. Storia Nat. Venezia Tridentina **14(1A):** 1-227.

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Vincenzo Piccione & Vincenzo Malacrinò

Anredera cordifolia **(*Basellaceae*) invasive in the river vegetation of North-Eastern Sicily**

Abstract

Piccione, V. & Malacrinò, V.: *Anredera cordifolia* (*Basellaceae*) invasive in the river vegetation of North-Eastern Sicily. — Fl. Medit. 31 (Special Issue): 501-507. 2022. — ISSN: 1120-4052 printed, 2240-4538 online.

The occurrence of *Anredera cordifolia* as invasive element of the vegetation of the watercourses of the Tyrrhenian East coast of Sicily is reported. The species - indicated in Sicily as alien and then as a rapidly spreading plant in the Western sector of the island - had already been reported for some generic localities in the province of Messina. Here it is reported its abundant presence, within hygrophilous forest phytocoenoses where the species ends up physiognomizing the woody vegetation of a stream. In this vegetation, *A. cordifolia* exerts an indisputable synecological role and, at the same time, has an impact that deserves to be monitored.

Key words: alien flora, *Salici-Populetea nigrae*, *Nerio-Tamaricetea*, synecological impact.

Introduction

Anredera cordifolia (Ten.) Steenis (= *Boussingaultia cordifolia* Ten.), native to South America, is reported to Italy as a naturalized alien (Celesti Grapow 2009). In the last 20 years, its diffusion has affected many coastal areas of various regions, from north to south (Pasta & al. 2016). This species had been reported as a casual alien in Sardinia (Galasso & al. 2018) and in a few years became naturalized (Manca & Brundu 2020). This latter status is also recognized in Calabria, the extreme region of the Peninsula close to Sicily (Musarella & al. 2020).

A. cordifolia is therefore an alien species now widespread in almost all the Italian regions including, as mentioned, also Sicily (Galasso & al. 2018). For this island, recent data demonstrate its widespread occurrence in the Western part (Pasta & al. 2016), as well as in the Aeolian Islands and in the Messina area, along the coastal stretch between Milazzo and S. Agata di Militello (Rossitto & Ilardi 1998). Recently, the species has landed even further south, on the small island of Linosa (Pasta & al. 2017). On the other hand, there are recent reports for Calabria (Musarella & al. 2020) and - outside the Italian territory - in the nearby North African coast, specifically in Algeria (Sakhraoui & al. 2019).

In the Messina area the species was reported very generically. Recent observations on the vegetation of the watercourses of the Tyrrhenian side of the Nebrodi Mountains, have allowed us to observe a widespread occurrence along the Naso stream, downstream of the homonymous inhabited center in the province of Messina, near the most famous town of Capo d'Orlando.

The site in question – as it is located between Milazzo and S. Agata di Militello – therefore falls within the coastal stretch reported by Rossitto & Ilardi (1998), but more than the coastal strip it concerns the fluvial branch of the aforementioned stream, in North-South direction, or from the valley towards the mountain, up to the inhabited area of Sinagra, a small town of the Nebrodi at 260 m (a.s.l.) [latitude 38°5'0"N - longitude 14°51'0" E].

The object of this contribution is therefore reporting the particular Sicilian settlement of *Arendera cordifolia*, a plant with a marked invasive character on the native river vegetation. It has evident environmental and synecological as well as landscape effects (Fig. 1).

Fig. 1. Arendera *cordifolia* in the riverbed of the Naso stream (NE-Sicily): the impact on woody vegetation and the landscape is evident.

For these aspects, its further diffusion in Sicily and in the fluvial habitats deserves to be controlled and monitored over time.

Materials and Methods

The presence along the Naso stream, in the province of Messina, of the alien *Anredera cordifolia* is examined with reference to its impact on the vegetation of the watercourse. The population of this species is located along the riverbed of the Naso stream, falling within the territory of the Province of Messina, between Capo d'Orlando and Brolo (Fig. 2). The torrential course examined flows between 50-250 m (a.s.l.), for a length of about 3 km, involving the potential space pertaining to the associations referable to the class *Quercetea Ilicis* Br.-Bl. ex A. & O. Bolos 1950. The phytocoenosis in which the species occurs was analyzed on the basis of 5 surveys carried out in October 2020, following the phytosociological method of the Zurich-Montpellier School, limited to the coverage index only. The relevés carried out at 50, 100, 150, 200 and 250 m (a.s.l.) are reported in Table 1. The nomenclature of taxa listed therein follows Bartolucci & al. (2018) for the native taxa; Galasso & al. (2018) for the alien ones.

Fig. 2. a) The lianosus character of *Arendera cordifolia* in the Nebrodi site ensures that the plant covers the entire canopy of the trees that support it; b) Aspect of vegetation physiognomized by *Tamarix gallica* invaded by *Arendera cordifolia*.

Table 1. Aspects of hygrophilous woody vegetation with *Anredera cordifolia* along the Naso stream (N-E Sicily).

Biological form	Relevé (n°)	1	2	3	4	5	FREQUENCY
	Altitude (m a.s.l.)	50	100	150	200	250	
	Exposure	N	N	N	N	N	
	Slope (°)	3	5	3	4	5	
	Total cover (%)	90	95	100	95	100	
	Woody layer average height (m)	5,0	5,5	6,0	6,0	6,5	
	Area (m^2)	70	90	80	80	70	
	Invasive species						
NP	*Anredera cordifolia*	1	3	5	4	1.	V
	Salici-Populetea nigrae *Contingent*						
P	*Salix alba*	1	1	2	2	2	V
P	*Salix pedicellata*	1	2	1	2	2	V
P	*Populus nigrae*		2	2	2	2	IV
P	*Salix purpurea* ssp. *lambertiana*		1	1	1	2	IV
P	*Ulmus canescens*		1	1	1	1	IV
P	*Alnus glutinosa*			1	1	1	III
P	*Fraxinus angustifolia*	1	1		1		III
P	*Salix ×rubens*			1	1	1	III
P	*Sambucus nigra*			1	1	1	III
H	*Carex pendula*		1	1		1	III
NP	*Hypericum hircinum* ssp. *majus*				1	1	II
NP	*Solanum dulcamara*			1	1		II
H	*Saponaria officinalis*		1	1			II
H	*Angelica arcangelica*			1			I
	Nerio Tamaricetea *Contingent*						
NP	*Rubus ulmifolius*	1	1	1		1	IV
P	*Tamarix gallica*	1	1	1			III
P	*Spartium junceum*	1	1		1		III
P	*Tamarix africana*	1	1				II
P	*Nerium oleander*		1				I
	Other species						
NP	*Rubus ulmifolius*	1	1.	1	1	1	V
H	*Juncus inflexus* ssp. *inflexus*	1	1	1	1		IV
H	*Mentha pulegium* ssp. *pulegium*	1	1	2		1	IV
P	*Pyrus spinosa*		1	1		1	III
P	*Prunus spinosa* ssp. *spinosa*			1	1	1	III
H	*Prunella vulgaris* ssp. *vulgaris*		1		1	1	III
H	*Cirsium creticum* ssp. *triumfettii*		1	1		1	III
H	*Typha latifolia*	1	1		1		III
P	*Crataegus monogyna*				1	1	II
P	*Ricinus communis*	1	1				II
P	*Clematis vitalba*				1	1	II
NP	*Smilax aspera*	1		1			II
H	*Juncus articulatus* ssp. *articulatus*			1		1	II
H	*Rumex conglomeratus*	1			1		II
G	*Equisetum telmateia*				1	1	II
H	*Juncus conglomeratus*			1		1	II
Ch	*Dittrichia visosa*	1	1				II
G	*Tussilago farfara*		1		1		II
H	*Mentha aquatica* s.l.				1	1	II
H	*Heracleum sphondylium* ssp. *elegans*				1	1	II
H	*Mentha spicata*			1	1		II
H	*Calystegia sepium*			1	1		II

Table 1. continued.

G	*Phragmites australis*	1			1		II
G	*Arundo plinii*	1	1				II
H	*Scirpoides holoschoenus*	1	1				II
H	*Urtica dioica*				1	1	II
H	*Hyparrhenia hirta*	1	1				II
T	*Symphyotrichum squamatum*	1	1				II
H	*Oloptum miliaceum* s.l.	1		1			II
H	*Cyperus alternifolius*		1		1		II
T	*Xanthium italicum*	1		1			II
P	*Malus sylvestris*				1		I
P	*Rhamnus alaternus*		1				I
Ch	*Dorycnium rectum*	1	1				I
H	*Plantago major*	1					I
H	*Lolium arundinaceum*	1					I
T	*Persicaria lapathifolia*		1				I
H	*Epilobium montanum*				1		I
H	*Carex distans*					1	I
G	*Arundo donax*	1					I
H	*Epilobium hirsutum*				1		I
T	*Datura stramonium*		1				I

Results and Conclusion

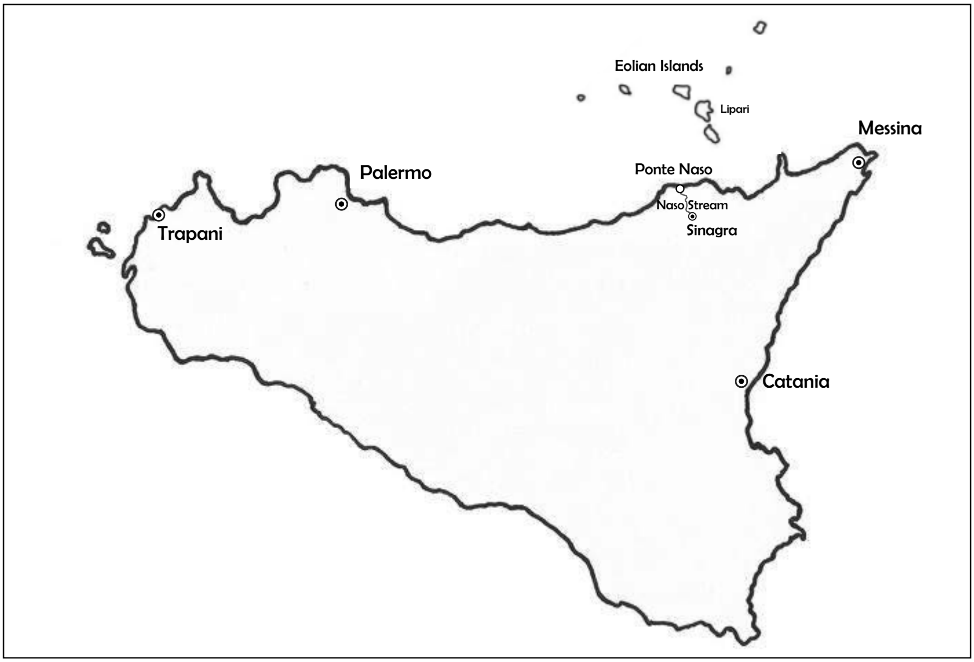
The Sicilian site examined falls along the river course of the Naso stream, on the northern side of the Nebrodi area, of which unpublished mesophilic aspects of woody vegetation have also been presented (Raimondo & al. 2021). The greatest diffusion *of Anredera cordifolia* is observed along a significant part of the Naso Torrent, a watercourse descending from the northern slopes of the wooded mountain system of the province of Messina, with seasonal variable flows, but nevertheless sufficient even in summer to feed in addition to the woody phytocoenoses hygrophilous of the class *Salici purpureae-Populetalia nigrae* Rivas Mart. & Canto ex Rivas Mart. & al. 1991, and hydrophilic herbaceous phytocenoses of the *Nasturtio officinalis-Glycerietalia fluitantis* Pignatti 1953.

The South American alien is a fickle suffruticosa; due to this character it climbs both shrubs and trees, forming a characteristic facies, particularly evident during the flowering period with creamy-white tones, spectacular for the recurrence of the plant on the vegetal landscape of the watercourse (Fig. 3).

From the phytosociological point of view – as can be seen from Table 1 – it is an unusual facies of natural hygrophilous forest vegetation, to refer to both mesophilic aspects of the class *Salici-Populetea nigrae*, and more thermophilic aspects of the class *Nerio-Tamaricetea* Br.-Bl. & O. Bolos 1958.

In relation to its diffusion and known data in Sicily, the Messina province site represents the area of largest diffusion of the species in Sicily, affecting a long stretch of the bed of a watercourse. Due to the density and extent that the population of the Messina area has so far assumed, today it is not possible to hypothesize the impact that the species may have on the occupied phytocoenosis. Probably – at least in the examined site – it already constitutes a differential element of the plant communities of the two classes mentioned above.

Fig.



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References

Bartolucci, F., Peruzzi, L., Galasso, G., Albano, A., Alessandrini, A., Ardenghi, N. M. G., Astuti, G., Bacchetta, G., Ballelli, S., Banfi, E., Barberis, G., Bernardo, L., Bouvet, D., Bovio, M., Cecchi, L., Di Pietro, R., Domina, G., Fascetti, S., Fenu, G., Festi, F., Foggi, B., Gallo, L.,Gottschlich, G., Gubellini, L., Iamonico, D., Iberite, M., Jimenez-Mejias, P., Lattanzi, E., Marchetti, D., Martinetto, E., Masin, R. R., Medagli, P., Passalacqua, N. G., Peccenini, S., Pennesi, R., Pierini, B., Poldini, L., Prosser, F., Raimondo, F. M., Roma-Marzio, F., Rosati, L., Santangelo, A., Scoppola, A., Scortegagna, S., Selvaggi, A., Selvi, F., Soldano, A., Stinca, A.,Wagensommer, R. P., Wilhalm, T. & Conti, F. 2018: An updated checklist of the vascular flora native to Italy. – Pl. Biosyst. **52(2):** 179-303. https://doi.org/10.1080/11263504.2017.1419996

Celesti-Grapow L., Alessandrini A., Arrigoni P. V., Banfi, E., Bovio, M., Brundu, G., Cagiotti, M., Camarda, I., Bernardo, L., Conti, F., Fascetti, S., Galasso, G., Gubellini, L., La Valva, V., Lucchese, F., Marchiori, S., Mazzola, P., Peccenini, S., Pretto, F., Poldini, L., Prosser, F., Siniscalco, C., Villani, M. C., Viegi, L., Wilhalm, T. & Blasi, C. 2008: The inventory of the non-native flora of Italy. – Pl. Biosyst. **143(2):** 386-430. https://doi.org/10.1080/11263500902722824

Galasso, G., Conti, F., Peruzzi, L., Ardenghi, N. M. G., Banfi, E., Celesti-Grapow, L., Albano, A., Alessandrini, A., Bacchetta, G., Ballelli, S., Bandini Mazzanti, M., Barberis, G., Bernardo, L., Blasi, C., Bouvet, D., Bovio, M., Cecchi, L., Del Guacchio, E., Domina, G., Fascetti, S., Gallo, L., Gubellini, L., Guiggi, A., Iamonico, D., Iberite, M., Jimenez-Mejias, P., Lattanzi, E., Marchetti, D., Martinetto, E., Masin, R. R., Medagli, P., Passalacqua, N. G., Peccenini, S., Pennei, R., Pierini, B., Podda, L., Poldini, L., Prosser, F., Raimondo, F. M., Roma-Marzio, F., Rosati, L., Santangelo, A., Scoppola, A., Scortegagna, S., Selvaggi, A., Selvi, F., Soldano, A., Stinca, A., Wagensommer, R. P., Wilhalm, T. & Bartolucci, F. 2018: An updated checklist of the vascular flora alien to Italy. – Pl. Biosyst. **152:** 556-592. doi:org: 10.1080/11263504.2018.1441197

Manca, M. & Brundu, G. 2020: *Anredera cordifolia* (Ten.) Steenis (*Basellaceae*). – In: Galasso, G., Domina, G., Ardenghi, N. M. G., Aristarchi, C., Bacchetta, G., Bartolucci, F., Bonari, G., Bouvet, D., Brundu, G., Buono, S., Caldarella, O., Calvia, Cano-Ortiz, Corti, E., D'Amico, F. S., D'Antroccoli, M., Di Turi, A., Dutto, M., Fanfarillo, E., Ferretti, G., Fiaschi, T., Ganzi, C., Guarino, R., Iberite, M., Laface, V. L. A., La Rosa, A., Lastrucci, L., Latini, M., Lazzaro, L., Lonati, M., Lozano, V., Luchino, F., Magrini, S., Mainetti, A., Manca, M., Mugnai, M., Musarella, C. M., Nicolella, G., Olivieri, N., Orru, I., Pazienza, G., Peruzzi, L., Podda, L. Prosser, F., Ravetto Enri, S., Restivo, S., Roma-Marzio, F., Ruggero, A., Scoppola, A., Selvi, F., Spampinato, G., Stinca A., Terzi, M., Tiburtini, M., Tornatore, E., Vetromile, R. & Nepi, C. 2020: Notulae to the Italian alien vascular flora: 1. – Italian Botanist **7:** 157-182 (2019) 17-37.

Musarella, C. M., Stinca, A., Cano-Ortíz, A., Laface, V. L. A., Petrilli, R., Esposito, A. &, Spampinato, G. 2020: New data on the alien vascular flora of Calabria (Southern Italy). – Ann. Bot. (Roma) **10:** 55-66.

Pasta, S., La Rosa, A., La Mantia, T., Badalamenti, E. 2016: *Anredera cordifolia* (Ten.) Steenis (*Basellaceae*): status in Italia e sua espansione in Sicilia occidentale. – Il Naturalista Siciliano s. 4, **40(1):** 145-149.

—, Ardenghi, N. M. G., Badalamenti, E., La Mantia, T., Livreri Console, S. & Parolo, G. 2017: The alien vascular flora of Linosa (Pelagie Islands, Strait of Sicily): update and management proposals. – Willdenowia **47(2):** 135-144. https://doi.org/10.3372/wi.47.47205

Raimondo, F. M., Domina, G. & Di Gristina, E. 2021: Unpublished aspects of hygrophilous wood vegetation from Nebrodi Mountains (N-E Sicily). – Fl. Medit. **31(Special Issue):** 145-167.

Rossitto, M. & Ilardi, V. 2000: Note tassonomiche e distributive su *Buossingaultia cordifolia* (*Basellaceae*, *Magnoliophyta*). – Quad. Bot. Amb. Appl. **9(1998):** 207-209.

Sakhraoui, N., Metallaooui, S. & Chefrour, A. 2019: Naturalisation d'*Anredera cordifolia* (*Basellaceae*) en Algérie. – Fl. Medit. **29:** 159-162. https://doi.org/10.7320/FlMedit29.159

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Francesco M. Raimondo & Giuseppe Venturella

A critical form of *Celtis* tree (*Ulmaceae*) occurring in Sicily

Abstract

Raimondo, F. M. & Venturella, G.: A critical form of *Celtis* tree (*Ulmaceae*) occurring in Sicily. — Fl. Medit. 31 (Special Issue): 509-513. 2022. — ISSN: 1120-4052 printed, 2240-4538 online.

The morphological variability of the Sicilian population of *Celtis australis* is examined. On the basis of leaf and branching characters, recurrent in various trees growing both in natural and urban environment, a new variety is recognized and described, indicated as *Celtis australis* var. *panormitana*. The most significant differential characters and the ecology of the new taxon are reported. Finally, the taxonomic affinities with the two other conspecific taxa are recalled. At the current state of knowledge the new variety is endemic to Sicily.

Key words: Taxonomy, dendrological flora, new variety, endemism, Italy.

Introduction

According to Giardina & al. (2007), and in agreement with other authors studying the Italian flora (Pignatti 2017; Bartolucci & al. 2018), to date, the genus *Celtis* in Sicily is represented by only two species: *Celtis australis* L. and *C. tournefortii* DC. The former is reported with only the nominal subspecies; the latter with two different subspecies: respectively *C. tournefortii* subsp. *aetnensis* (Guss.) Raimondo & Schicchi and *C. tournefortii* subsp. *asperrima* (Lojac.) Raimondo & Schicchi.

C. australis, in the European flora is represented both by *C. asutralis* subsp. *australis* and *C. australis* subsp. *caucasica* (Willd.) C. C. Towns., often treated at specific level sub *C. caucasica* Willd. (Tutin 1964). Recent observations of this subspecies have revealed very close similarities of the Caucasian population with forms of *C. australis* growing in Sicily and so far recognized with the same binomial.These specimens are widely distributed in the plain of Palermo, where they can be found both in semi-natural and cultivated environments (citrus groves and city green spaces created after the building activity that developed at the expense of the citrus gardens that surrounded the old town of Palermo, after the last world war).

The studies on the urban and peri-urban green of this city, which in the same period of time has tripled the built space, allowed to appreciate a widespread presence of this form of *Celtis* considered similar to *C. australis* subsp. *caucasica*. However, due to its presence in the urban and peri-urban area of Palermo, together with the typical form of the species, it is taxonomically distinguished from *C. australis* subsp. *caucasica*, giving it the varietal rank better defined below.

Materials and Methods

The variability of the population of *Celtis australis* occurring in the central-western Tyrrhenian sector of Sicily, between Messina and Trapani (Caronia, Polizzi, Palermo, Segesta, Erice, Trapani) is analyzed.

The critical materials - collected both in Palermo, in anthropized and semi-natural environments, as well as in natural environments in the nearby Caronie – were compared with the authors' personal collections partly kept at the SAF herbarium of the Department of Agricultural, Food and Forestry Sciences (SAAF) and partly at PAL-Gr. These materials come both from natural habitat in the Boschi di Caronia (Nebrodi Mountains), where the species occurs widely, taking part in the forest structure of the extensive cork oak woods (*Quercus suber* L.) among the most important in Sicily, and in urban and peri-urban areas.

The material, taxonomically critical and related to *C. australis* subsp. *caucasica*, was compared with material from the South Caucasus (Raimondo in PAL-Gr).

Results and Discussion

The taxonomic analysis of the Sicilian population of *Celtis australis* subsp. *australis* allows to distinguish and describe the following variety.

Celtis australis var. ***panormitana*** Raimondo & Venturella **var. nov.**

Diagnosis: differs from the nominal variety by the globular, regular, drooping foliage, smaller and narrower leaves, elongated, gradually attenuated and acuminated.

Type – Holotypus: Sicilia, Palermo, nel giardino di Villa Mary adiacente il Parco della Favorita, su suolo rosso mediterraneo, ca. 40 m (s.l.m), 20.11.2020, *Raimondo* (PAL-Gr) – *Isotypi* in FI and PAL.

Description: Tree 8-10 m tall, with globular, regular crown. Branches dense, slender, drooping (Fig. 1a-b). Leaves with variable asymmetrical, acuminate lanceolate lamina, 3-6 cm long, 2.5-3.5 cm wide (Fig. 1e).

Distribution and Ecology: Piana di Palermo (Fig. 2), on clayey-loamy soils (Mediterranean red soils), both in Mediterranean forest scrub and in urban spaces spared by building constructions, as well as in the surviving citrus groves, almost always together with the nominal variety (*C. australis* var. *australis*).

Taxonomic remarks

From a taxonomic point of view the new variety is similar to *C. australis* subsp. *caucasica* (Fig. 3) from which, however, differs in the shape of the leaf blade. Compared to the other Sicilian population of *C. australis* var. *australis* and with the Linnean type materials of the species for the leave morphology, the new variety besides the regular and globular shape of the crown, is distinguished by the thicker and thinner branching, the drooping branches, the smaller leaves and the narrower and longer acuminate lamina. Almost similar

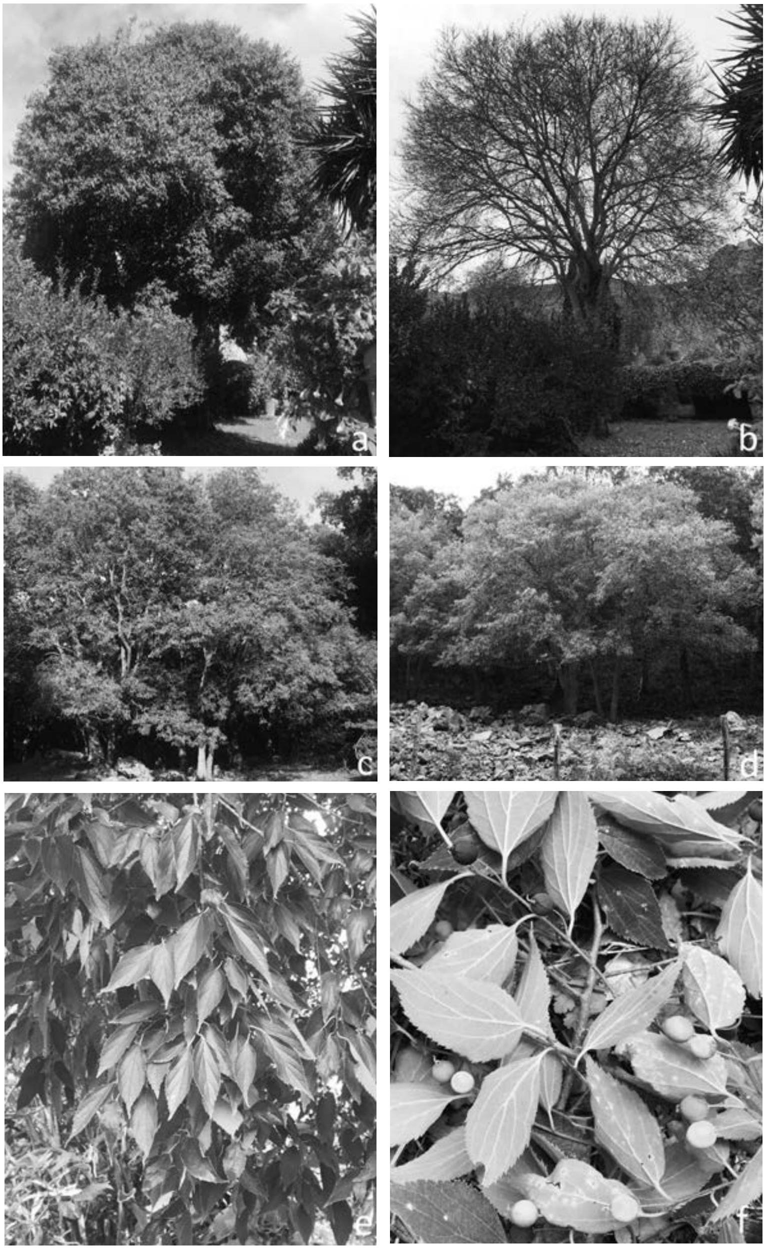

Fig. 1. a) Type tree of *Celtis australis* var. *panormitana* resumed in full vegetative activity; b) The same tree in winter version; c) Typical habitus of *C. australis* var. *australis* in Bosco di Caronia; d) Trees related to the new var. *panormitana*, present together with the typical form of the species in the same Bosco di Caronia; e) Detail of a branch showing the leaf shape of the new variety; f) Detail of the leaves and fruits of plants related to var. *panormitana* found in Bosco di Caronia.

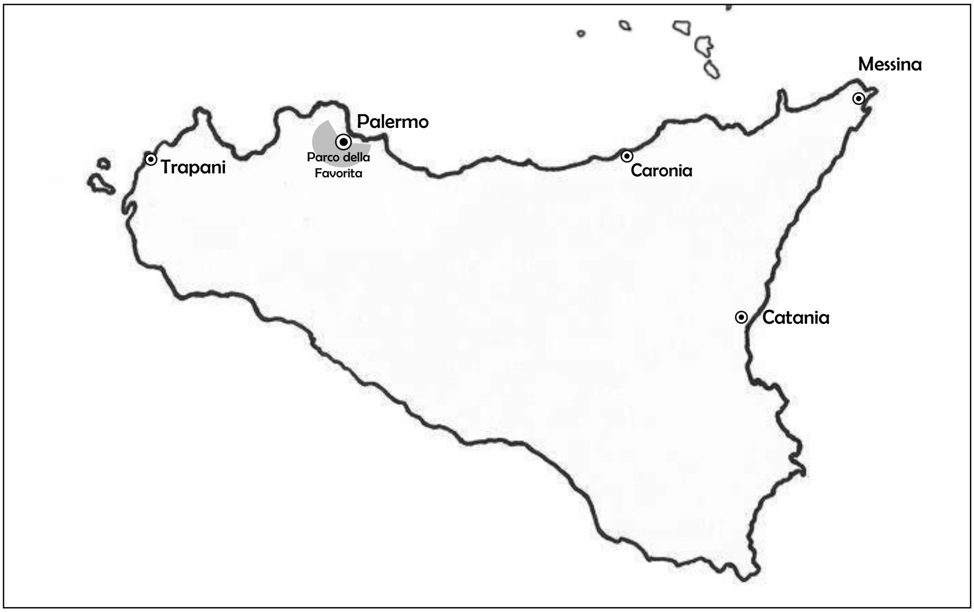

Fig. 2. Localization in Sicily of the area where the *locus classicus* of *Celtis australis* var. *panormitana* occurs.

Fig. 3. *Celtis australis* subsp. *caucasica* in Tbilisi.

characters present some plants found in nature in the Bosco di Caronia (Fig. 1d, f). Here, too, these plants coexist with trees of the same species with assurgent canopy (Fig. 1c), a character more adherent to the usual shape of the typical species.

Exsiccata

Sicily – *C. australis* var. *panormitana* Raimondo & Venturella, Nebrodi: Bosco di Caronia, versante settentrionale di Monte Pagano, 480 m (s.l.m.) ai margini della sughereta, 18.09.2019, *Raimondo* (PAL-Gr); Palermo: Parco della Favorita, su terra rossa mediterranea, 40 m (s.l.m.), 18.10.2020, *Venturella* (Herb. Dep.to SAAF); Monreale: incolti ai margini della circonvallazione, su litosuolo calcareo, 300 m (s.l.m.), 10.11.2020, *Raimondo & Venturella* (PAL-Gr).

Georgia – *C. australis* subsp. *caucasica* (Willd.) C. C. Towns, Tbilisi: nel parco del Museo Etnografico, 30.10.2017, *Raimondo* (PAL-Gr).

Acknowledgements

The authors are grateful to Tiziana Siciliano and Silvio Coco for facilitating the study of the plant type of the new variety in their garden (Villa Mary, Palermo); to G. Nakhutsrishvili and N. Lachashvili, from the Ila University of Tblisi (Georgia) for their suggestions; to Gianniantonio Domina for the reading of the text.

References

Bartolucci, F., Peruzzi, L., Galasso, G., Albano, A., Alessandrini, A., Ardenghi, N. M. G., Astuti, G., Bacchetta, G., Ballelli, S., Banfi, E., Barberis, G., Bernardo, L., Bouvet, D., Bovio, M., Cecchi, L., Di Pietro, R., Domina, G., Fascetti, S., Fenu, G., Festi, F., Foggi, B., Gallo, L., Gottschlich, G., Gubellini, L., Iamonico, D., Iberite, M., Jimenez-Mejias, P., Lattanzi, E., Marchetti, D., Martinetto, E., Masin, R. R., Medagli, P., Passalacqua, N. G., Peccenini, S., Pennesi, R., Pierini, B., Poldini, L., Prosser, F., Raimondo, F. M., Roma-Marzio, F., Rosati, L., Santangelo, A., Scoppola, A., Scortegagna, S., Selvaggi, A., Selvi, F., Soldano, A., Stinca, A.,Wagensommer, R. P., Wilhalm, T. & Conti, F. 2018: An updated checklist of the vascular flora native to Italy. – Pl. Biosyst. **52(2):** 179-303. https://doi.org/10.1080/11263504.2017.1419996

Giardina, G., Raimondo, F. M. & Spadaro, V. 2007: A catalogue of the plants growing in Sicily. – Bocconea **20:** 5-582.

Pignatti, S. 2017: Flora d'Italia, **2.** – Milano.

Tutin, T. G. 1964: *Celtis* L. – In: Tutin T. G.,·Heywood, V. H., Burges, N. A., Valentine, D. H., Walters, S. M. & Webb, D. A. (eds), Flora Europaea, **1.** – Cambridge.

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Giuseppe Venturella & Maria Letizia Gargano

Araucaria columnaris (*Araucariaceae*) casual alien in Sicily

Abstract

Venturella, G. & Gargano, M. L.: *Araucaria columnaris* (*Araucariaceae*) casual alien in Sicily. — Fl. Medit. 31 (Special Issue): 515-519. 2022. — ISSN: 1120-4052 printed, 2240-4538 online.

The first case of spontaneous regeneration of *Araucaria columnaris* in Europe is reported. Data are given on the taxon and on the Sicilian site where *A. columnaris* - native to New Caledonia (Australia) - tends to spread autonomously.

Key words: Dendrological flora, urban green, alien trees, Mediterranean area, Palermo.

Introduction

New Caledonia hosts almost half of the world's species of *Araucariaceae* (19 out of 45 species) (Earle 2021). In Italy, fewer than ten specific taxa are included in the genus *Araucaria* Juss. Most of them are of Australian origin. In the Italian territory *Aracuaria bidwillii* Hook., *A. columnaris* (G. Forst.) Hook. (= *A.cookii* R.Br. ex Endl.), *A. heterophylla* (Salisb.) Franco, *A. cunninghamii* Sweet ex Courtois are widely cultivated. Localized in the Insubric region and scattered at a few sites in other regions, it is also *A. araucana* (Molina) K. Koch (= *A. imbricata* Pav.) from Cile (Traverso 1915).

Individual specimens of *A. luxurians* (Brogn. & Gris) de Laub. (Fig. 1*a*) and *A. rulei* F. Muel. ex Lindl. are known in two gardens of the city of Palermo: Villa Malfitano and the Giardino Inglese respectively (Raimondo 2019; Schicchi & Speciale 2020). In the literature, none of the *Araucaria* species are listed among the alien plants of the Italian flora (Galasso & al. 2018), nor are there any cases of naturalization of species of this genus in Europe. In this study, the first case of naturalization found in the city of Palermo is reported.

Araucaria columnaris, casual alien in Sicily

A. columnaris is an Australian species of great ornamental value, native to New Caledonia. It can reach a height of more than 40 meters and has an erect trunk, gray and flaky bark, which is detached by rings, with short branches and branched, verticillate, starting from the base of the tree. It has persistent, spiraled, lesiniform, narrow leaves at the apex of the twigs. The female cones, ovoid in shape, are composed of numerous scales, each bearing a seed.

It is one of the most remarkable trees of the historical gardens of the city of Palermo where the species has been introduced in the second half of the nineteenth century (Schicchi & Speciale 2020). Magnificent and numerous are the specimens present in the Giardino Inglese, two of which are truly remarkable (Fig. 1*a*), slightly younger than the oldest and tallest specimen cultivated inside the Botanical Garden, and coeval with a second group of soaring specimens that in Palermo embellish the garden of the family Tasca d'Almerita.

First report of spontaneous renewal of *Araucaria columnaris*

The tree from which the spontaneous renewals of *A. columnaris*, is about 60 years old. It is located within a small private garden, situated in Via Armida (Fig. 1*b*), in the residential area of Mondello (Figs. 1*b,* 2). A number of seedlings between 1 and 8 years old can be found spontaneously in the flowerbeds near the mother plant, or in disused pots stored nearby to be repurposed (Fig. 3).

Fig. 1. *a*) The English Garden in the city of Palermo: in the foreground - in the center - the only plant known in Italy of *Araucaria luxurians*, behind - on both sides - two centuries-old *A. columnaris*, one of them - to the right - with forked top); *b*) The fertile tree of *A. columnaris* in the site of Via Armida (Mondello, Palermo).

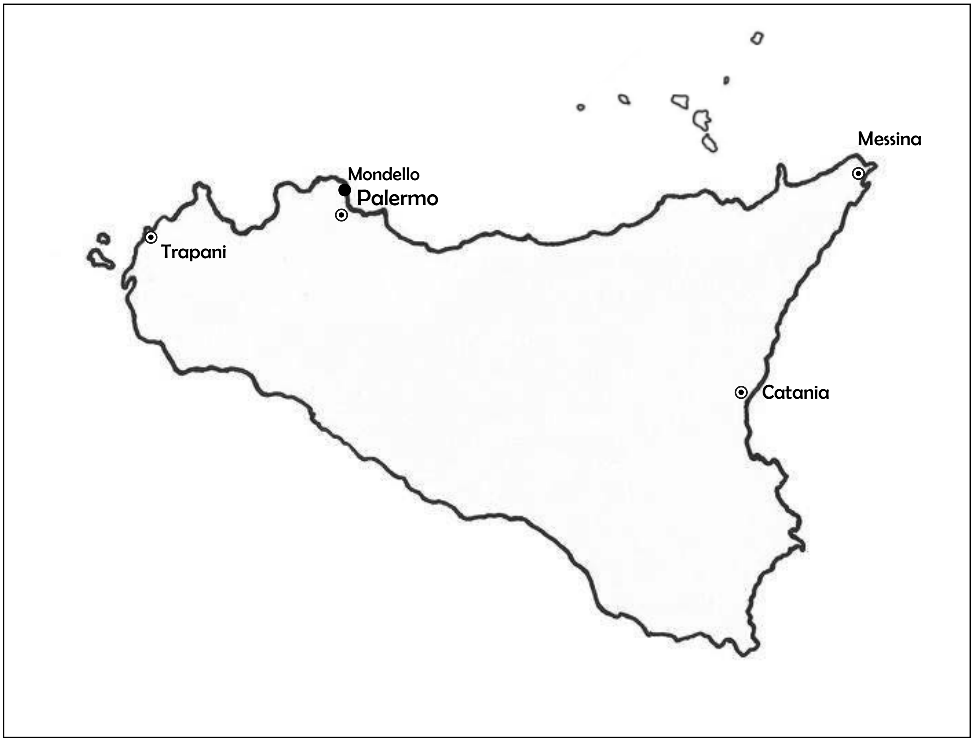

Fig. 2. Localization in Sicily of the Mondello site (Palermo), where the first case of spontaneous renewal of *Araucaria columnaris* in Europe was recorded.

Discussion and Conclusion

Compared to the *Araucaria* species cultivated in Italy and in the European territory, excluding botanical gardens and arboreta, Sicily is the Italian region with the highest number of taxa of the genus, introduced in urban green areas. In this Mediterranean island with climatic conditions almost similar to those recorded in particular in some sectors of the Australian Continent - from which most of the species originates - 6 specific taxa are known, all cultivated. Among these species, *A. columnaris* is very important and it is particularly widespread in the city of Palermo. Moreover, the Palermo area is the place where all the species present in the parks and gardens of the whole Italy occur, with the only exception of *A. araucana,* the only American species cultivated in Sicily which grows in few humid hilly sites, exposed to the sea, among which Ucria (Messina), a small center of Nebrodi Mountains (Fig. 4).

As already mentioned, the species is native to New Caledonia (Australia) from where also originate *Araucaria rulei* and *A. luxurians* present inside, respectively, even if with only one specimen, in the two extraordinary gardens of Palermo.

Fig. 3. Seedlings of *Araucaria columnaris* in two pots (*a* and *b*) from the private garden of Via Armida (Mondello), near the fertile tree of the species in Fig. 1*b*.

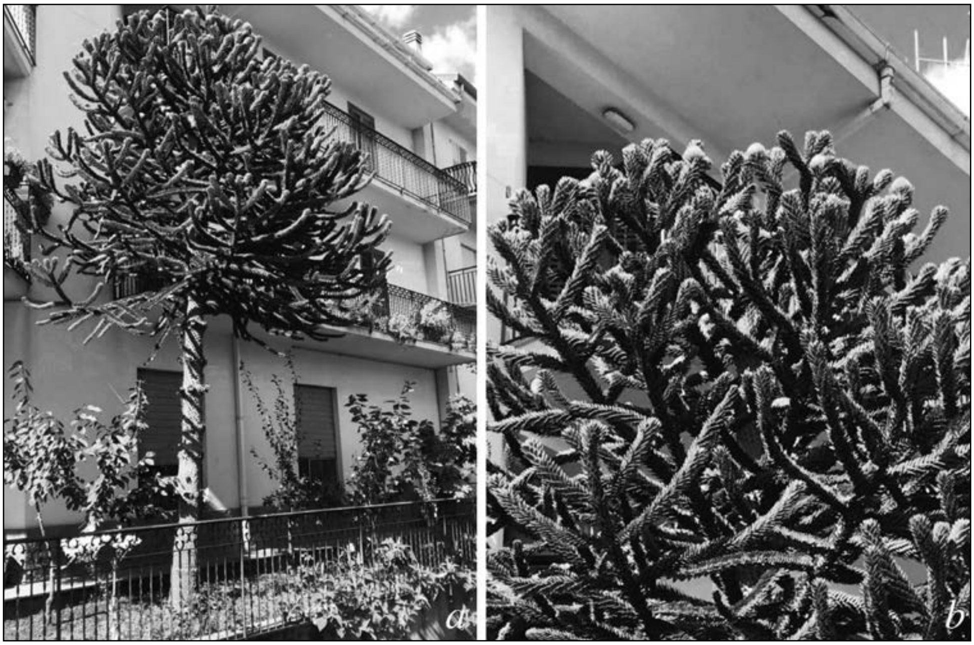

Fig. 4. *a*) *Araucaria auracana* cultivated in a private site of Ucria (Nebrodi, Messina); *b*) Detail of the branches and the leaves.

Acknowledgements

The authors wish to thank: Dr. Anna Gelardi of Palermo, owner of the garden in Via Armida in Mondello, for having allowed access to her garden for the collection of data useful for the writing of this short note; *PLANTA*/Center for Research, Documentation and Training (Palermo) for the photos in Fig. 4.

References

Earle, C. J. 2021: The Gymnosperm database. – https://www.conifers.org/ [Last accessed 10/12/2021]

Galasso, G, Conti, F., Peruzzi, L., Ardenghi, N. M. G., Banfi, E., Celesti-Grapow, L., Albano, A., Alessandrini, A., Bacchetta, G., Ballelli, S., Bandini Mazzanti, M., Barberis, G., Bernardo, L., Blasi, C., Bouvet, D., Bovio, M., Cecchi, L., Del Guacchio, E., Domina, G., Fascetti, S., Gallo, L., Gubellini, L., Guiggi, A., Iamonico, D., Iberite, M., Jimenez-Mejias, P., Lattanzi, E., Marchetti, D., Martinetto, E., Masin, R.R., Medagli, P., Passalacqua, N. G., Peccenini, S., Pennei, R., Pierini, B., Podda, L., Poldini, L., Prosser, F., Raimondo, F. M., Roma-Marzio, F., Rosati, L., Santangelo, A., Scoppola, A., Scortegagna, S., Selvaggi, A., Selvi, F., Soldano, A., Stinca, A., Wagensommer, R. P., Wilhalm, T. & Bartolucci, F. 2018: An updated checklist of the vascular flora alien to Italy. – Pl. Biosyst. **152:** 556-592. https://doi.org/10.1080/11263504.2018.1441197

IPNI 2021: The International Plant Names Index and World Checklist of Selected Plant Families – http://www.ipni.org and http://apps.kew.org/wcsp [Last accessed 10/12/2021]

Raimondo, F. M. 2019: Nuove acquisizioni per la dendroflora urbana di Palermo (Sicilia). – Quad. Bot. Amb. Appl. **27(2016):** 51-53.

Schicchi, R. & Speciale, M. 2020: Alberi di Palermo. – Palermo.

Traverso, O. 1926: Botanica Orticola. – Pavia.

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Epilogue: Tribute to Sandro and Erika

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Cesare Lasen

Biodiversité végétale, valeurs naturelles et sauvegarde du paysage dans le domaine dolomitique

Abstract

Lasen, C.: Biodiversité végétale, valeurs naturelles et sauvegarde du paysage dans le domaine dolomitique. — Fl. Medit. 31 (Special Issue): 521-544. 2022. — ISSN: 1120-4052 printed, 2240-4538 online.

This contribution summarizes the state of the geobotanical knowledge of the Dolomite area starting with the excursions made in the early 1970s with Erika and Sandro Pignatti. The references are limited to the main titles and a meaningful increase in knowledge has been detected, especially at floristic level, also with the discovery of new taxa. The Dolomites were recognized as a World Heritage Site in 2009 by UNESCO on the basis of geological and landscape criteria. The conservation and protection of the Dolomite landscape therefore assumes priority in a historical period in which the natural resources of the planet are increasingly threatened by interventions and projects based on further exploitation initiatives, called "enhancement" for touristic purposes. The article refers to the centrality of geobotanical knowledge and the priority to be attributed to biodiversity, also considering the current evolutionary dynamics. Adequate protection of naturalistic values, as well as landscape values, should be guaranteed by the existence of a large network of national, regional protected areas and/or belonging to the Natura 2000 network.

Key words: Dolomites, plant biodiversity, protected areas, nature conservation, evolution dynamics.

Introduction

Les excursions dans le territoire dolomitique avec Erika et Sandro Pignatti, pendant les années ‘70-80, ont profondément marqué la mémoire et le coeur. Les exemplaires de l’herbier, aujourd’hui conservés au Musée Naturalistique du Parco Nazionale Dolomiti Bellunesi, en sont le témoignage. C’est justement avec eux et avec le maître Armando Scopel qu’on a publié (Lasen & al. 1977) la “Guida Botanica des Dolomiti di Feltre e Belluno” dans la précise intention de pousser à la réalisation, au niveau de données scientifiques, du Parco Nazionale, depuis longtemps imaginé et désiré. Cet espoir s’est concrétisé une douzaine d’années plus tard par le D.M. du 20-04-1990 qui en établissait les limites avec la dénomination de Parco Nazionale delle Dolomiti Bellunesi et avec il DPR du 12-07-1993 qui instituait l’Ente Parco siégé à Feltre et dont je fus nommé Président.

Après avoir résumé les éléments d'importance cardinale, même pour ceux qui ne connaissent pas ce territoire, en rajoutant les connaissances sur la flore et la faune, cette prémisse est nécessaire pour comprendre le point de vue de cette contribution avec laquelle on veut concentrer l'attention sur le thème, toujours actuel et souvent mal compris, de la conservation de la Nature dans le sens plus exhaustif du terme, conjuguant les valeurs scientifiques, par chance, encore solides et sans la nécessité de contrainte pour être mises en évidence, avec le réalisme de la gestion qui impose des solutions d'équilibre et de courage, imprévues et non passives. Je suis sûr que Sandro, collègue dans la première Consulta Nazionale pour les Aree Protette, présidée par le Maître Gianluigi Ceruti, l'un des pères de la loi-cadre 394/91, partagera ce choix qui s'adresse, ici, à un milieu territorial local, encore que les Dolomites soient célèbres dans tous les continents. Mais ce choix veut se projeter sur un scénario global qui voit la planète en grave souffrance. Même le Pape François l'a mis en évidence avec un appel plein de tristesse dans l'encyclique "Laudato sì", publiée le 18 juin 2015.

L'état des connaissances

Le territoire dolomitique a fait l'objet (et encore actuellement) de nombreuses publications sur l'aspect naturel, en particulier géologique et du paysage. Au niveau botanique, en ce qui concerne les plantes vasculaires, les contributions scientifiques sont, elles aussi, importantes pour le nombre et la qualité. Pour des raisons d'espace, évidemment, on se limitera à considérer les textes les plus récents et moins localisés, vu que quelques-uns de ces textes contiennent de précises références bibliographiques qui permettent de puiser aux sources de l'exploration de la flore.

La panoramique la plus exhaustive sur la flore et la végétation du territoire dolomitique, c'est précisément celle publiée, en trois volumes, entre 2014 et 2017 par Erika et Sandro Pignatti.

Ils ont commencé à étudier les Dolomites vers la fin des années '60 et début des années '70. Nombre de données et de reliefs remontent à cette période, entretemps les connaissances de la flore ont évolué. Essentiellement la position écologique et sur la végétation n'a pas changé, tandis que la syntaxonomie ressent de différentes approches et elle rend difficiles les comparaisons. Pendant cette période on a eu de nombreuses occasions de collaboration qui ont abouti, même, à quelques publications. Outre la "Guida Botanica" (Lasen & al. 1977), ci-dessus mentionnée et rapidement épuisée, qui a représenté un fort élan pour la promotion de l'institution du Parco Nazionale, il faut considérer le volume de Studia Geobotanica (n°3, 1984a, soigné par les deux), dédié exprès, avec de différentes contributions, à la flore et à la végétation des Vette Feltrine, mais qui, en réalité, rapporte aussi des reliefs effectués sur les montagnes aux alentours de Belluno. Toujours à propos du milieu dolomitique, ensuite on a publié une étude sur les groupements à *Matteuccia* (Lasen & Pignatti 1992) et en 2002 (Lasen & Pignatti) une tentative pour typer les sapinières. A partir de 1960 (sur la végétation casmophile à *Physoplexis comosa* et *Asplenium seelosii)*, il y a déjà de nombreuses contributions sur la végétation avec la description de nouvelles communautés végétales ou dans le but de les ajouter. Après la "Guida Botanica alla Val di

Fassa" (Pignatti E. & Pignatti S. 1974), pendant une excursion de la Società Botanica, Erika et Sandro recommencèrent à étudier la végétation des parois rocheuses en décrivant le *Campanuletum morettianae* (1978) et, en 1985, le *Caricetum rupestri*s des milieux herbeux-rupestres, fouettés par le vent. En 1981 ils anticipèrent les nouveautés de leurs recherches par la descriptions de nouvelles communautés. En 1983 ils typèrent un *Danthonio-Nardetum*, écologiquement très clair, même si aujourd'hui il n'est pas reconnu avec ce nom. En 1984 (b) ils s'occupèrent de la syntaxonomie des éboulis de faille et, en 1988 (b) des prairies semi-grasses à *Trifolium pratense* subsp. *nivale,* (*Knautio-Trifolietum,* terme tombé en désuétude, mais lui aussi écologiquement explicite). Ce n'est qu'en 1995 que l'on publiera une première liste des unités végétales. On peut relever l'évolution syntaxonomique, en comparant le prodrome italien (Biondi & al. 2014), mais il existe des synthèses à niveau européen qu'il faut considérer. Datée 1981 (œuvre de Sandro), très importante au niveau méthodologique, il y a la publication d'un plan des ensembles de végétation pour la Conca Ampezzana. Dommage, par la suite l'idée de relever les ensembles de végétation, pour décrire le paysage, n'a pas eu le succès qu'elle aurait mérité. Les articles du 1988 (Pignatti & Pignatti 1988a), du 2003 et celui signé par Sandro en 1998 ont une position surtout sur le paysage. Pour la flore, comme l'on sait, il a été, pour longtemps, le promoteur du relèvement cartographique par quadrants et l'on commençait à penser aux archives informatisés (Pignatti & al. 1966). A partir de la seconde moitié des années '70, grâce aux nombreuses excursions ensemble, on a exploré d'autres domaines et l'on a approfondi les connaissances sur les territoires de particulière valeur naturelle. Avec les pharmaciens Thea Saffaro et Italico Boiti, résidants à Predazzo, on a publié une monographie sur la Val Venegia (Boiti & al. 1989) après avoir anticipé (Boiti & al. 1988) une contribution sur les alluvions des torrents glaciaux avec le relèvement sur *Caricion maritimae*. Aujourd'hui encore, les terrasses sur le fond de la vallée du Travignolo, depuis les sources jusqu'à Malga Venegia, abritent des espèces d'une valeur naturelle extraordinaire telles que *Carex microglochin, Carex bicolor, Juncus arcticus*, outre à des briophytes, *Kobresia simpliciuscula, Juncus triglumis* et d'autres. Dans la même vallée, les groupes de saules aussi sont remarquables (Lasen 1989b). Avec Marcello Tomaselli et Italico Boiti on a traité de la végétation des plateaux glacio-karstiques. Avant la reconnaissance formelle des Dolomites comme patrimoine sériel naturel de l'humanité (en 2009, si cfr. Lasen 2012; Viola & al. 2005), il semblait important de proposer des synthèses de vulgarisation (Lasen 2000, 2001). Une fois fondé le Parco Nazionale des Dolomiti Bellunesi en 1990 (l'Ente de gestion en 1993), il y eut de nouvelles raisons pour approfondir les recherches. La première ceck-list du Parco et des aires limitrophes, avec 1700 espèces, date de 2001 (Argenti & Lasen). Les mêmes auteurs en 2004 publièrent la ceck-list de toute la province avec la liste rouge (pour le Trentino, elle avait été rédigée par Prosser en 2001) qui fut rajoutée, après, pour la totalité du territoire provincial dans la volumineuse œuvre de Prosser & al. en 2019. Des ajoutés à la liste rouge du territoire de Belluno ont été publiés en Buffa & al. (2016). Indépendamment de chaque contribution aux ajoutés, souvent publiée dans la revue Gredleriana pour la Provincia Autonoma de Bolzano, la référence de base reste le «Katalog» (Wilhalm & al. 2006). Il y a aussi plusieurs contributions publiées pour les territoires du Friuli entre lesquelles l'atlas chorologique de Poldini (2002) qui est une référence valable. Les contributions, concernant surtout la végétation, sont également nombreuses. Pour le territoire du Parco Nazionale (Lasen 2004) et pour le territoire provincial (Lasen 2008, dans les "Tesori Naturalistici" qui traite aussi le thème du paysage, 2020a). En ce qui concerne l'autre parc de la province, celui régional des Dolomiti d'Ampezzo, les études publiées sont remarquables, à partir des recherches bien localisées sur quelque biotope (Tomaselli & al. 2006; Da Pozzo & Lasen 2010), à d'autres notes de synthèse (Lasen & Da Pozzo 2011; Da Pozzo & al. 2016), à la découverte d'une rareté, *Carex maritima* (Lasen & Da Pozzo 2017). Il serait interminable de citer toutes les contributions intéressantes soit sur la flore, soit sur la végétation ou les paysages (les nombreuses brochures des cours de géographie organisés par la Fondazione Angelini rentrent dans cette catégorie) concernant chaque site, biotope, vallée.On peut citer, par exemple, une note de synthèse sur les Dolomites de Sinistra Piave (Lasen 2009) et un volume dédié à la Forêt de Somadida (Del Favero & Lasen 2016). Après l'événement de Vaia, on a publié plusieurs contributions (Lasen 2020b), mais celles à position écologique et de la végétation sont limitées et parfois, encore en cours d'imprimerie. Grâce aux banques des données de la flore (Musée de Rovereto et de Bolzano), les niveaux de connaissance pour les provinces autonomes sont avancés. Pour Belluno aussi, la couverture est importante, malgré l'absence d'organisme institutionnel préposé, mais grâce au travail des volontaires. Il en va de même pour le domaine dolomitique plus oriental, sachant que pour le FVG un nouveau atlas, fondé sur des quadrants à l'échelle 1:25.000 au lieu de 1:50.000 (Martini ex verbis), devrait être publié. Pour les données sur la végétation, la situation est plus complexe. Il y a de nombreuses contributions à l'échelle locale. La synthèse des Pignatti est certainement remarquable à l'échelle écologique générale, tandis qu'il manque encore une vraie et propre liste de chaque phytocénose qui tienne edonnée.sn compte les acquisitions syntaxonomiques les plus récentes. Le paysage a été l'objet de plusieurs études, mais les changements en action nous rappellent que tous les détails ne sont pas éclaircis et, en particulier, les successions écologiques du post-Vaia démontrent que nos connaissances sont encore limitées et incomplètes.

Valeurs naturelles et du paysage

Pour ce qui concerne la flore, il est relativement simple de définir qualitativement les indicateurs qui contribuent à tracer un tableau de valeurs. Le composant de la quantité, fondé essentiellement sur la richesse des espèces (par exemple la flore vasculaire qui est plus facile à évaluer), fournit moins d'informations puisque un élément de dérangement ou causant quand même hétérogénéité (un sentier qui traverse le bois, des passages ou lieux de repos des animaux sauvages) provoque une augmentation des espèces pour la plupart banales et qui ne représentent sûrement pas un indice de qualité. Dans la littérature on trouve nombre d'études et de modèles qui ont cherché à offrir un tableau avec des points attribués à de différents paramètres dont la somme permet, enfin, de trouver des valeurs utilisables pour des confrontations, soit dans le champ de l'application (pâturages, forêts), soit pour des évaluations d'impact. Parmi les premières études, suivant plus une école naturelle plutôt que d'écologie appliquée, on rappelle celle de Poldini & Pertot (1991) sur le Karst de Trieste. L'utilisation d'organismes comme bio-indicateurs du milieu a été examinée avec beaucoup de contributions et, entre autres, on rappelle le volume par soin de Gasparo & Zappa, en 1994, toujours publié à Trieste. Ce thème a vu fleurir des articles et des rencontres, précisément dans les années à cheval sur les deux siècles et, entres autres, on cite Tomaselli & Gualmini (2000) qui ont mis au point le problème au niveau, surtout, des communautés végétales. Pour ses articulations et ses variétés des thèmes le volume soigné par Pirola (2000) reste intéressant.

Le travail de Melzer (1999) sur le macrophytes aquatiques que l'on considère comme des indicateurs du niveau de nourrissants, est historique et assez utilisé (Lasen & Scariot 2007). Pour les cours fluviaux, assez connu est le travail de Lippert & al. (1995), d'où il apparaissait la remarquable qualité du milieu des biocénoses le long du fleuve Tagliamento. Sur les indicateurs de valeur dans les différents types forestiers, on rappelle une approche, non analytique et assez pragmatique, dans le volume de Del Favero & al. (2000), le dernier de la série publiée sur les types forestiers du Veneto et certainement encore utile pour la région dolomitique. Bonomi & Buffa (2000) ont fournit des indications sur l'évaluation de la qualité de la végétation dans les aires de tourbière. A ce propos, aujourd'hui, il serait plus facile d'individualiser les indicateurs les plus idoines, après la publication des listes rouges nationales, régionales et provinciales. Scotton & al. (1996) et Rodaro & al. (1998) ont travaillé surtout à l'attribution d'une valeur agronomique aux pâturages (dans les deux cas, dans l'Ampezzano). Ferrari & al. (2000) proposent une approche quantitative pour évaluer la qualité naturelle et la diversité de la végétation. Comparable, avec l'application à toute la Province de Varese sur une base cartographique, c'est la proposition de Cerabolini & al. (2007). Toujours pendant les mêmes années (Mazzocchi & al. 1999), c'est l'ENEA qui publie une étude où l'on évalue la qualité ambiante, en intégrant des données sur la flore et la végétation et cela est bien significatif. En considérant les données dont on dispose, pour la plupart des cas et, certes dans le domaine dolomitique, il serait intéressant de reformuler une vision intégrée qui pourrait fournir des résultats utiles à la prévention des projets d'infrastructures, en multiplication, dans la prévision de grands évènements sportifs. Indépendamment de l'importance quantitative que l'on décidera d'y attribuer, il faut tenir dans la plus grande considération les paramètres suivants:

- Rareté et insertion dans les listes rouges (avec les différents niveaux de menace);
- Importance locale d'espèces et de communautés végétales situées dans des stations séparées, à la limite de l'aire (extra-zonales au niveau de phytocénose);
- Observations récentes relatives à des situations de déclin (réduction de la population et/ou fragmentation de l'habitat);
- Présence d'endémismes de différents niveaux ou d'autres chorotypes d'intérêt phytogéographique
- Situations objectivement de péril, causées par de fortes possibilités que l'espèce et surtout l'habitat souffrent à cause du changement climatique et du dynamisme évolutif défavorable;
- Valeurs éventuelles de caractère historique-ethnographique.

Récentes acquisitions sur la flore et la végétation

Le territoire dolomitique s'étend sur des régions et des provinces autonomes, ayant chacune une banque des données qu'on pourrait définir institutionnelle (aux musées de Rovereto et Bolzano), exception faite pour le Veneto où des spécialistes individuels sont en activité, souvent sur base provinciale. En Friuli, on faisait référence à l'Université de Trieste, mais, à présent, on attend la publication d'un nouveau atlas par soin de Fabrizio Martini. Le classement aux archives des données de la végétation est plus compliqué, même si, en général, auprès des musées déjà cités, une banque bibliographique est disponible. Les données, donc, résultent pour la plupart subdivisées au niveau géographique. Comme déjà dans La Flora d'Italia, provocant aussi des critiques de la part de groupes qui se sont vus dépassés, seulement Pignatti a publié une monographie sur le territoire dolomitique, indépendamment des questions administratives. Dans ce paragraphe, d'autre part, on veut tout simplement souligner le progrès des connaissances, pleinement développé, pendant les dernières décennies. Il est vrai que les endémismes, reconnus pour les Dolomites, ne sont pas nombreux, et cela a pesé sur la reconnaissance ratée des critères IX et X pour l'insertion dans la liste du patrimoine de l'humanité par UNESCO. Mais, bien sûr, il faut souligner que la richesse globale, en termes de flore est plus que remarquable par la présence d'espèces rares, menacées, situées aux marges de l'aire et qui ne sont pas, d'autre part, exclusives. Celui-là c'est seulement l'un des critères. Il ne s'agit pas de nombres, mais de la qualité et des valeurs phytogéographiques, bien mis en évidence dans les nombreux travaux publiés. Un exemple: la richesse de la flore est en général plus grande dans les secteurs extérieurs (ésodolomitiques) plutôt que dans ceux intérieurs (endodolomitiques à climat continental). Les études ajoutées (et c'est seulement un exemple) sur le territoire du Parco delle Dolomiti d'Ampezzo (œuvres citées) semblent démentir, au moins au niveau de la quantité, ce présumé, né sur la présence du nombre d'espèces dans les différents quadrants de la Cartografia Floristica dell'Europa Centrale. En revenant aux endémismes (inclus quelques-uns avec peu de stations extérieures au territoire, il vaut la peine de les rappeler: *Sempervivum dolomiticum, Saxifraga facchinii, Saxifraga depressa, Draba dolomitica, Rhizobotrya alpina, Campanula morettiana, Prymula tyrolensis, Gentiana brentae* (la découverte la plus récente, Prosser & Bertolli 2008), *Nigritella buschmanniae* et *Festuca austrodolomitica.*

Evidemment on ne considère pas les espèces de genre apomictique, *Alchemilla, Hieracium, Rubus, Taraxacum* pour lesquels il faudrait formuler d'autres types d'observations. En tout cas, leur récolte systématique et les révisions spécialisées prouvent que l'échantillonnage n'est pas complet et que d'autres découvertes sont possibles. Après avoir rappelé que la synthèse de Pignatti n'est pas à considérer exhaustive au niveau d'association et qu'elle reste inspirée à la position écologique classique, il manque encore, au niveau de communautés, une ceck-liste complète, surtout pour les catégories de formes moins naturelles. Cela paraît évident aussi par de récentes listes publiées au niveau européen (Mucina & al. 2016). Parmi les découvertes les plus étonnantes de ces dernières années, une série d'excursions, en 2014, pour étudier la réserve naturelle de Somadida (gérée par CFS, Ufficio Territoriale pour la Biodiversità de Vittorio Veneto), ont permis de découvrir, dans une zone difficilement accessible, un bois résiduel qu'on pourrait définir primordial plutôt que vétuste, avec des mélèzes et des arolles pluriséculaires (non signalés auparavant dans ce territoire). Des recherches successives ont démontré qu'ils étaient âgés de plus de 500 ans. De cette découverte, objectivement aventureuse, on en a traité dans le volume par soin de Del Favero & Lasen (2016) et dans d'autres articles à caractère scientifique, concernant aussi la faune invertébré. Le bois de Col Nero, déjà clairsemé à cause de l'altitude et sub-rupestre, a subi d'autres espacements forcés à cause des évènements météo extrêmes. Malgré cela, il garde un charme sans pareil qui fait vraiment comprendre la force de la Nature. Au contraire, de nombreuses contributions de récente publication, sont disponibles et elles concernent soit les seuls milieux géographiques, soit des groupements de habitat tels que les forêts, les zones humides, d'intérêt agro-pastoral ou bien des catégories primitives. Ce qui manque, pour le moment, c'est une synthèse sur base régionale. On sait qu'en Alto Adige, on est à l'ouvrage pour des finalités d'application, par un groupe de travail, dans le but d'atteindre cet objectif.

La couverture forestière

Certes les Dolomites sont célébrées pour leurs paysages, pour les vastes prairies, pour les aiguilles et les crêtes, pour les spectaculaires conoïdes détritiques. Ce sont des milieux merveilleux pour leur noble flore et pour la présence de communautés végétales endémiques et rares. Toutefois, parmi les catégories d'habitat, le rôle prépondérant, non seulement au niveau quantitatif, c'est celui de la couverture forestière. Contrairement à d'autres milieux alpins, depuis n'importe quel sommet dolomitique important, il est toujours possible d'apercevoir la présence des arbres. On ne pourrait pas imaginer un paysage sans les extraordinaires couleurs qui, en automne spécialement, caractérisent les bois latifoliés mixtes ou simplement de conifères. Un court résumé des principaux types et formations contribue à décliner un étonnant tableau riche en variétés, soit en relation à la série d'altitude, soit aux principales différences entre les milieux extérieurs (éso-mésalpiques) et intérieurs (méso-endalpiques) bien plus articulés selon les différents substrats depuis les carbonatés purs jusqu'aux silicatés avec de différentes séries bien exprimées, même si sur une échelle peu détaillée (1:500.000), dans la publication sur les séries végétales (Blasi 2010) dont les textes et les références sur des bases phytosociologiques sont rédigés par de divers auteurs pour les différents territoires régionaux. Depuis les fonds de la vallée extérieurs, encore semblables à ceux préalpins (bois de charmes et chênaies-charmes-*Carpinion orientalis* et d'autres formations à dominance de *Quercus robur* dans la vallée du Piave à partir de 250 m), jusqu'à la limite supérieure de la forêt et des groupes d'arbres qui, dans les zones internes plus continentales, comprennent des mélèzes (*Larix decidua*) et des arolles (*Pinus cembra*) qui s'élèvent jusqu'à 2300-2400 m. Outre les végétations de type azonale (milieux riverains avec des saulaies-*Salix* sp. pl., parfois avec peuplier-*Populus* sp., aulnaies d'aulne blanc-*Alnetun incanae* s.l., avec de modestes coins d'aulne noir-*Alnus glutinosa* dans des zones marécageuses), ou liées à de particuliers substrats (par exemple des groupes de châtaigneraies à *Castanea sativa* parfois avec du rouvre-*Quercus petraea*, toujours bien localisés mais importants pour la biodiversité), on observe une série articulée avec d'étonnantes particularités jusqu'à présent approfondies seulement en partie. Et encore, on peut observer des tilleuls-érablières et des érables-frênaies (*Tilia platyphyllos, Tilia cordata, Acer pseudoplatanus, Acer platanoides, Fraxinus excelsior*, c'est à dire biocénose de *Tilio-Acerion* s.l.) dans des milieux de ravin ou de versants frais, des bois de *Carpinus betulus* riches en géophytes (complètement absents en Alto Adige) où le robinier-*Chelidonio-Robinietalia*, indicateur de bouleversement n'a pas pris le dessus. Sur les versants escarpés des zones inaccessibles, exposés à de fortes variations d'humidité du sol, toujours dans les secteurs externes, on trouve les formations à *Ostrya carpinifolia* et *Fraxinus ornus*, *Ostryo-Carpinenion orientalis* et *Erico-Fraxinion orni* avec des groupes peux nombreux mais intéressants de chêne pubescent (*Quercus pubescens-Quercion pubescenti-petraeae*). Dans le paysage dolomitique, toujours sur des sols drainants, capables de supporter l'aridité estivale, sont diffusées les pinèdes, de pin sylvestre (*Erico carneae-Pinion sylvestris*) pour la plupart, depuis les premiers versants jusqu'à environ 1700-1800 m. d'altitude, mais aussi celles de pin noir (*Pinus nigra*) dans les secteurs plus orientaux avec plus de précipitations ou d'humidité atmosphérique qui deviennent prédominantes, en alternance avec *Fagus sylvatica* selon l'évolution du sol, dans les Dolomites du Friuli.

Au-dessus de la zone des bois latifoliés mixtes, où l'on compte aussi des formations secondaires ou des stades sériels avec la prédominance de bouleaux-*Betula pendula*, de trembles-*Populus tremula* ou de noisetier-*Corylus avellana* (expressions de *Betulo pendulae-Populetalia tremulae*), dans le paysage dolomitique ce sont les hêtraies qui ont une importance remarquable et qui sont dominantes et pures dans les zones préalpines et dans les Dolomites extérieures à climat sub-océanique.

Les hêtraies comprennent de différentes associations de *Aremonio-Fagion*, depuis celles submontagneuses avec *Taxus baccata* et/ou *Ostrya carpinifolia*, jusqu'à celles haut-montagneuses-subalpines avec *Polystichum lonchitis*, d'autres fougères et abondance d'*Acer psueudoplatanus*. Bien plus rares sont les hêtraies acidophiles du *Luzulo-Fagion* (aux alentours de Gosaldo).

Les hêtraies deviennent mixtes avec le sapin blanc-*Abies alba*, en formant des bois spectaculaires (sapinières-hêtraie-*Abieti-Fagetum*) dans l'aire centrale des Dolomites. La sylviculture a favorisé (et on explique ainsi les lacunes de *Abies alba* dans le territoire de Agordo) le sapin rouge (épicéa, *Picea excelsa*) répandu partout, mais qui forme d'abord des associations de *Abieti-Piceenion* ou des *Calamagrostio variae-Abietenion* sur beaucoup de versants et dans les fonds de la vallée dolomitiques dans le secteur méso-endalpique. Seulement dans le secteur plus à l'intérieur, les bois purs de *Picea excelsa* prennent leur habit le plus typique et en syntonie avec la végétation potentielle, à partir de la zone montagneuse (900-1000 m.) et ensuite pour entrer en compétition avec les bois de *Larici-Pinetum cembrae* à partir de 1700-1800 m. Tandis que *Pinus cembra* (rare à cause du pâturage actuel et d'antan) s'établit seulement dans les secteurs plus continentaux en devenant un très bon indicateur du bioclimat, les bois pionniers de *Larix decidua* (*Rhodothamno-Laricetum*) ou plus mûrs aussi, sont répandus dans tout le territoire, même dans les secteurs les plus à l'extérieur, où il manque une vraie et propre zone de conifères et ils suivent en altitude les hêtraies. Il faut considérer que même les arbustes ont un rôle déterminant, non seulement dans le paysage, mais aussi pour la protection du sol. Le symbole dolomitique par excellence peut-être considéré le pin couché (*Pinus mugo*). On rappelle que les bois basophiles de pin couché à *Rhododendron hirsutum,* en acidifiant le sol, abritent aussi le *Rhododendron ferrugineum* et ils sont considérés l'habitat prioritaire dans l'Annexe I du Réseau Nature 2000 (avec le code 4070*). Outre les vastes brousses à *Pinus mugo*, objet de monographies spécifiques, se sont répandues les aulnaies de aune vert-*Alnus viridis*, *Alnetum viridis* s.l. (sub-hygrophiles qui couvrent les versants neigeux ou des couloirs exposés aux avalanches sur des terrains avec une bonne rétention hydrique), les étendues acidophiles de rhododendron à *Rhododendron ferrugineum*, exclusives dans les secteurs siliceux, parfois associées au genévrier nain (*Juniperus sibirica*) et, enfin, les saulaies avec de différents types (en particuier, dans l'aire dolomitique prévalent les aspects à prédominance de *Salix waldsteiniana, Salix glabra, Salix mielichhoferi, Salix myrsinifolia, Salix hastata*, avec *Salix glaucosericea, Salix caesia, Salix foetida* plus localisés et seulement dans les aires à l'intérieur) d'importante valeur naturelle, presque toujours des expressions pionnières et sub-hygrophiles. Moins connues et étudiées ce sont les formations à *Genista radiata* qui, après l'abandon des aires fauchées dans le passé, se sont diffusées dans les milieux herbu-rupestres au soleil, en contact avec les bois de *Ostrya carpinifolia*, et qui en altitude parviennent même à 1900 m. On peut faire égale considération pour les aspects à néflier des rochers (*Amelanchier ovalis*), que presque toujours on peut associer à des milieux de pinède potentielle et essentiellement azoneaux. Encore à étudier ce sont les formations, toujours dans des milieux ardus et bien au soleil, des substrats volcaniques (en Agordo en particulier) dominées par *Juniperus sabina*, qui posent aussi d'importants problèmes de syntaxonomie. Si la bruyère haute, à *Rhododendron ferrugineum*, c'est une formation zonale à la limite supérieure de la forêt, également spectaculaire c'est la bruyère basse à azalée naine - (*Loiseleuria procumbens*), au faux myrtille (*Vaccinium gaultherioides*) ou à *Empetro-Vaccinietum*, parfois associé à des sphaignes (*Sphagnum* sp.pl.). De toutes les formations forestières, décrites ou souvent seulement citées sans la publication des reliefs, c'est la pessière des alluvions à *Petasites paradoxus* dans les zones internes qui mérite un approfondissement ainsi que la pinède endalpique qui abrite aussi *Pinus cembra*. Sans comparaison, pour sa richesse, c'est la sapinière sub-montagneuse de ravin, riche en bois latifoliés nobles en particulier *Ulmus glabra*, étendue dans la Valle del Grisol et en moindre quantité dans d'autres vallées latérales dans la droite hydrographique du Maé. Ce sont encore les bois d'*Acer pseudoplatanus*, au début de la Vallée de San Lucano, qui méritent une mention. Ils sont presque purs mais, en altitude, ils sont remplacés par des formations à dominance de *Sorbus aucuparia,* avec la présence plus ou moins étendue d'*Alnus viridis*. En ce qui concerne la partie du territoire de Belluno, une synthèse récente sur la végétation, surtout forestière, est relatée en Lasen (2020a), tandis que sur les versants de Trento il y a de nombreuses études, même monographiques de Pedrotti ou de son école (sur les brousses à *Pinus mugo, Pinus sylvestris, Abies alba*). Par contre ce qui manque, ce sont des références récentes pour l'Alto Adige (l'étude typologique est difficilement rapportable à un tableau phytosociologique). Pour Trento et Bolzano, on peut encore utiliser les manuels, même si destinés aux objectifs d'application de Nature 2000, respectivement Lasen 2006 pour Trento; Lasen & Wilhalm, 2004 pour Bolzano. Pour la région du Friuli il y a beaucoup de travaux monographiques sur les seules catégories par l'oeuvre de Poldini et son école.

Systèmes de tutelle et patrimoine UNESCO

L’absolue qualité de la nature et du paysage des territoires dolomitiques est affirmée par le nombre et l’extension des aires sous tutelle pour de variées raisons: les parcs nationaux et régionaux, les réserves naturelles, les biotopes, les sites du Réseau Nature 2000, les aires de nature sauvage.

Même les Plans Territoriaux de coordination et les PRG de quelques communes contiennent des normes spécifiques pour la tutelle des aires de grande valeur pour la conservation. En 2009, enfin, le 26 juin à Séville, le site sériel « Dolomiti» est entré dans la liste du patrimoine naturel mondial de l’humanité pour les critères VII, le paysage, et VIII, la géologie. Les qualités d’unicité et surtout d’intégrité, requises pour entrer dans cette liste, ont déterminé une sélection des aires core et buffer (regroupées ensuite en 9 systèmes), en excluant, justement, les secteurs les plus exploités au niveau touristique. Ce n’est pas un cas si le 95% de l’aire comprise dans le site UNESCO rentre en parcs, aires protégées ou sites Nature 2000. Dans le domaine dolomitique se trouvent de différentes aires protégées qui, liées entre elles, constituent le principal réseau écologique du pays entier, digne d’être activé et qui devrait représenter une force de dissuasion contre de futurs projets d’exploitation et de consommation du sol.

Tableau 1. Parcs naturels et autres aires protégées établies dans les Dolomites.

Dans la province de Belluno
Parco Nazionale delle Dolomiti Bellunesi: 31512 hectares
Parco Regionale delle Dolomiti d’Ampezzo: 11200 hectares

Dans la region Friuli Venezia Giulia (Pordenone et Udine)
Parco Regionale delle Dolomiti Friulane: 36950 hectares

Dans la province autonome de Trento
Parco Naturale Adamello-Brenta: 62051 (il rentre aussi dans le réseau de Geoparchi)
Parco Naturale Paneveggio-Pale di San Martino: 19727 hectares

Dans la province autonome de Bolzano-Südtyrol
Parco Naturale delle Tre cime: 111892 hectares
Fanes-Senes-Braies: 25453 hectares
Puez-Odle: 10772 hectares
Sciliar-Catinaccio: 7291 hectares

Les nombres déjà indicatifs se réfèrent au domaine global du parc, indépendamment du fait que les aires soient insérées dans la «core» ou dans la «buffer» du périmètre du site sériel UNESCO et que les classifications officielles au niveau national ne tiennent pas en compte les territoires où l’activité de la chasse est permise.

L’existence d’aires protégées et de toutes façon renommées pour leur grande valeur naturelle, c’est le centre du système sériel qui a obtenu la reconnaissance internationale. Mais, en dehors de bien connues différences d'ordre administratif et de gestion entre les provinces autonomes et celles ordinaires (le FVG est autonome mais d'une façon assez différenciée de deux provinces du Trentino Alto Adige), l'essentiel c'est de rappeler, qu'en réalité, les directeurs des parcs naturels dans le périmètre sous la tutelle UNESCO avaient entrepris des formes de collaboration bien avant 2009 et, qu'à présent, une liste de bonnes pratiques, dérivée de variées expériences, est disponible.

Ce «réseau de fait», même où il n'a pas été reconnu et institutionnalisé, représente le point fort de l'un des réseaux fonctionnels où le travail de la Fondazione Dolomiti Unesco s'est articulé.

Avec la coordination des deux provinces du Friuli, il existe une table technique avec un groupe de travail qui, après la fusion, est dénommé Réseau du patrimoine du paysage et des aires protégées.

Ce réseau a produit beaucoup de documents et il suffit d'entrer dans le site de la Fondation pour les visionner en partie. Même s'il est vrai que les aspects concernant la tutelle de la biodiversité et du patrimoine naturel ne sont pas un devoir principal du Réseau, vu qu'il ne rentre pas dans les critères pour lesquels le territoire a obtenu la reconnaissance, on ne peut pas nier que la contribution de la qualité naturelle à la valeur du patrimoine du paysage reste un composant basilaire. Par conséquent, même les indicateurs individualisés et nécessaires pour la surveillance et le monitorage de la gestion du bien ont puisé abondamment aux facteurs qui caractérisent un patrimoine naturel, soit en termes d'espèces-parapluie très significatives et faciles au monitoring, soit sur les types d'habitat qui sont les plus emblématiques et caractérisants du paysage dolomitique.

Pressions et menaces

Les Dolomites sont une marque trop invitante pour penser que la concentration d'aires protégées et la bonne organisation d'ensemble de la gouvernance et des appareils administratifs, soient suffisants pour garantir une tutelle efficace du patrimoine de la nature. Les faits liés aux grands événements sportifs, le Championnat mondial de ski alpin, en février 2021, et les Olympiades d'hiver en 2026 (Milano-Cortina, mais avec des lieux de compétition même dans les provinces autonomes de Trento et Bolzano) témoignent que, malgré le «soutenable» affiché, des projets plus ou moins destructeurs ont surgit et ils ont causé encore des pertes du sol, le sacrifice de parties de bois, la construction d'oeuvres pour les chantiers, les transports, les remontées, l'approvisionnement hydrique.

Les dossiers présentés par des groupes d'associations environnementalistes, le CAI inclus, montrent l'entité des impacts sur le paysages. Les financements publics attirent beaucoup. Il y a de nombreux projets qui prévoient de nouvelles liaisons et des carrousels, menaçant des aires d'évidente valeur, encore intègres et qui rentrent aussi dans le Réseau Nature 2000. L'opposition des associations et des comités locaux, soutenus par quelques communes, ne peuvent pas s'opposer, semble-t-il, aux forts intérêts en jeu. Les gestions par commissaire, rapides dans l'exécution des procédures pour les autorisations, en réalité, portent à dépasser les obligations concernant le milieu qui sont les seules mesures de tutelle et garantie pour limiter les dommages. La monoculture du ski alpin qui cause des impacts évidents, a déjà contribué à corrompre le paysage, en laissant des signes de dégât et dénaturant l'étique de vivre à la montagne.

Une conception de développement qui implique une augmentation de consommation et favorise le tourisme de masse est incompatible souvent avec les fragiles équilibres écologiques.

Les faits liés à la pandémie ont fortement limité l'accès aux pistes et mis en évidence, que l'on ne peut pas soutenir dans le moyen et long terme le dessein de viser à de nouvelles remontées, de nouvelles pistes, des canons pour la neige artificielle, des routes de service, des lieux pour la restauration et tout l'induit. Même en relation au changement du climat en action, une rationalisation de ce qui existe, s'annonce comme la seule solution compatible pour la tutelle de la Nature restante. On sait bien que beaucoup de fonds de la vallée dolomitiques ont été occupés par des infrastructures, semblant ainsi à des secteurs de la plaine, et que le réseau écologique en est compromis. Les évènements répétitifs, liés aux précipitations intenses qui causent des éboulements et des alluvions, sont bien sûr naturels, mais certes favoris par des choix qui ont privilégié la réalisation des profits par rapport aux circonspections nécessaires à la tutelle des équilibres écologiques. En général tout le secteur touristique provoque des pressions de différente nature, concentrées dans quelques vallées et sites, tandis que dans d'autres les accès sont inférieurs à l'expectative et au seuil de la capacité accueillante. Les études coordonnées par la Fondazione Dolomiti Unesco ont mis en évidence que le nombre de touristes dans deux lieux symbole tels que le Lac de Braies et les Trois Cimes de Lavaredo dépasse largement la capacité d'accueil du système, avec des milliers de visiteurs pendant les mois d'été.

Dans l'attente des publications officielles à ce propos, on peut trouver des informations sur les sites de la Fondazione: https://www.dolomitiunesco.info/dolomiti-unesco-lo-studio-per-una-gestione-degli-accessi-nei-luoghi-piu affollati/ et de la Provincia Autonoma di Bolzano: http://www.provincia.bz.it/news/it/news.asp?news_action=4&news_article_id=645521

L'accès au Lac du Sorapiss est un autre point chaud qui a fait couler beaucoup d'encre et qui reste un thème central de la région dolomitique entière. Il faut limiter le trafic routier privé des automobiles et des motos à travers les cols dolomitiques. Ce n'est pas ici que l'on veut disserter profondément, ni faire une liste des situations critiques sur la réglementation et développement du tourisme dolomitique, mais, partout, il est évident que l'impact sur les dynamiques écologiques est important et il y faut des attentions et des circonspections. A ce propos on pourrait commencer des recherches avec des monitorages continuels et périodiques de quelques variantes, observant les indicateurs bien connus. Par exemple, les groupes des lichens près des cols les plus fréquentés, pour évaluer la pollution atmosphérique, la diffusion d'espèces allochtones, etc.). Mais les Dolomites n'auraient pas la renommée dont elles jouissent, justement, au niveau planétaire, si leur paysage ne fût pas rapportable à une gestion soignée des milieux qui traditionnellement sont le centre de toute économie de la montagne: la sylviculture et l'alpiculture. L'évolution socioéconomique à provoqué l'abandon de vastes aires à prairies à cause de la difficulté d'accès et des coûts. En bonne partie, cela est le résultat des choix politiques. Par exemple, en Alto Adige, la situation est bien différente par rapport aux territoires limitrophes. En plusieurs cas, en effet, le vrai problème c'est l'écoulement du purin et des excréments des animaux, pour répondre aussi à la directive européenne sur les déversements d'eaux sales zootechniques. Beaucoup de cabanes de bergers développent encore leur activité et comptent aussi sur les ressources apportées par les touristes de passage (restauration et vente des produits), d'autres ont été abandonnées, ou en phase de dégradation, ou bien elles ont été restructurées comme refuge pour le maintien du paysage. La vraie émergence n'est pas représentée par les pâturages, mais par les prés à faucher toujours plus rares qui, toutefois, en particulier pour la conservation de la biodiversité de la flore et de la végétation, ont un rôle fondamental.

Il reste les prairies alpines primaires avec leurs floraisons spectaculaires, mais elles aussi sont souvent menacées à cause du changement du climat qui favorise la remontée de la limite des espèces ligneuses. La délicatesse de la conservation des biotopes humides se heurte aux exigences pratiques et aux œuvres des chantiers qui, enfin, en déterminent la fragmentation et le déclin. Ce thème a été bien reconnu et il ne manque pas d'exemples édifiants. Pour ce qui concerne la gestion forestière, habituellement les bois en haute altitude sont classés de «protection» et non de «production», mais, la diffusion des routes forestières qui, en réalité, favorisent aussi les accès touristiques et la chasse, n'aide pas les politiques de réelle conservation et, en particulier, l'introduction de quelques parcelles laissées à l'évolution naturelle, sans utilisation, vers le bois vétuste plus proche-naturel. C'est un choix de fondamentale importance stratégique et capable d'élever encore plus la valeur ajoutée de ces territoires. On pourrait aussi réaliser de vrais laboratoires en plein air où l'on pourrait mesurer les effets des changements en action. Nombre de bois en haute altitude ont été dans le passé des pâturages et, aujourd'hui, on observe que la réduction de la charge baisse la pression et elle favorise l'arolle qui était pénalisé par rapport au mélèze. En automne, les étonnantes couleurs des mélèzes et des arolles sont l'un des éléments les plus caractéristiques du paysage dolomitique. Mais, la conservation de beaux bois de mélèzes est en péril sans des interventions appropriées, comme le démontrent les successions de bois de mélèzes et de sapinières que l'on peut souvent observer dans une vaste zone d'altitude et qui ne contribuent pas à améliorer la perception du paysage.

Perspectives et dynamiques évolutives

Si, faire le point sur l'état des connaissances, même dans une sélection partielle, il signifie de traiter essentiellement du passé, plus proche que lointain, il devient décisif de comprendre la direction du dynamisme naturel et d'imaginer le scénario du paysage dolomitique des décennies à venir. Les observations directes concernent la dernière moitié du siècle et elles ont subi une accélération dans les derniers temps, soit pour les effets du changement climatique, soit pour ceux dérivés des interventions de l'homme qui ont affaibli souvent la résistance de certains écosystèmes. Si, dans une certaine mesure, la fragmentation des phytocénoses et les interventions de l'homme peuvent provoquer une augmentation de la biodiversité (et cela ne signifie pas de qualité d'ensemble), déjà à moyen terme, il y aura des effets négatifs causés par des gestions agro-sylvo-pastorales irrespectueuses des principes de la conservation écologique. Dans certains cas, l'abandon ne cause pas des désastres écologiques, mais il conduit à des phases de transition bien moins spectaculaires et attractives. Les facteurs qui interagissent sont complexes et les situations articulées selon les différentes vallées et zones, mais quelques éléments à caractère général surgit clairement.

La limite de la forêt et des arbustes va grandir, comme prévu, par la suite de l'augmentation des températures moyennes. On peut le prouver par les comparaisons photographiques. Le fait qu'un nombre important d'espèces herbacées soit aujourd'hui repérable à des altitudes jamais observées auparavant, c'est une donnée bien documentée. Parmi les graminacées dominantes sur quelques pentes escarpées, exposées au sud, *Molinia arundinacea* a dépassé 1900 m. et *Brachypodium caespitosum* va au dessus de 2100 m.

Les études sur les petites vallées nivales des Alpi Feltrine démontrent un recul des espèces de *Salicetea herbaceae* et une entrée toujours plus grande d'espèces pabulaires de grande valeur écologique. (Tomaselli & al. 2005; Tomaselli ex verbis). On signale aussi le rapprochement de quelques entités thermophiles, en particulier des orchidées, vers l'aire dolomitique, même si le phénomène n'est pas encore éclatant.

Les événements extrêmes, comme celui de Vaia, comportent des bouleversements écologiques qui font paraître des successions sérielles imprévisibles ou, au moins, bien peu étudiées et jamais signalées auparavant. Des observations au mois de mai 2020 en Alto Agordino ont vérifié, auprès des souches arrachées par la violence du vent, une prolifération de *Corydalis capnoides*, espèce connue seulement dans une station avec peu d'exemplaires, au point d'être évaluée CR dans la liste rouge provinciale. Même la *Lappula squarrosa* s'est multipliée en abondance, parvenant à l'altitude de 1700 m. Dans le paysage dolomitique, les espèces allochtones trouvent peu d'opportunité pour leur diffusion, surtout en altitude. Parmi les exceptions il y a *Erigeron annuus*, espèce envahissante, même en montagne, dans des milieux proche-naturels. Dans les bois humides et non cultivés des fonds de la vallée *Impatiens glandulifera* est en expansion. La concentration d'entités allochtones est inversement proportionnelle à l'altitude et au niveau du bouleversement. Le long des cours fluviaux, le Piave en particulier, le nombre et la couverture de ces entités augmentent en procédant des sources jusqu'au débouché vers la haute plaine. En extrême synthèse, sans recours à des scores, surtout discutables, il peut être utile de formuler des indications sur la tendance évolutive telles qu'elles apparaissent après les 50 années d'observations sur le champ comme macro-catégorie de l'habitat.

- Milieux némoraux. Dans l'ensemble ils sont les moins critiques, excepté ceux humides dans les fonds de la vallée ou dans des stations où la compétition de *Robinia pseudacacia* et *Ailanthus altissima* (cette dernière encore marginale) est forte, à la suite d'utilisations peu adroites. Il ne manque pas d'aires qui bénéficient des dernières décennies de trêve et d'économie et où l'on observe une amélioration d'ensemble au niveau de la qualité de la nature, c'est à dire de rapprochement à des conditions plus voisines à celles de la végétation potentielle. Pour citer un exemple, la récupération du rouvre (*Quercus petraea*) dans le domaine de orne-ostryetum et la bonne tenue des communautés riches en bois latifoliés nobles (*Tilio-Acerion* s.l.) dans de milieux de ravin et non seulement. Parmi les conifères, *Abies alba* et *Pinus cembra* sont en récupération remarquable.

- Formations à arbustes. Soit celles thermophiles, soit surtout celles tempérées-boréales et subalpines paraissent en progrès appréciable et en bon état de santé. Leur expansion est en partie déterminée par la moindre pression du pâturage et en partie par les effets du changement du climat. La situation de quelques saulaies est plus délicate, soit parce qu'elles sont essentiellement rares, soit parce qu'elles gravitent dans des milieux humides à plus grand péril.

- Formations herbacées. Elles souffrent en général pour de variées raisons, les prés gras à cause de l'abandon ou des engrais excessifs et aussi pour des irrégularités de la gestion. A présent il est difficile d'observer de vastes zones à trisètes en très bonnes conditions. On trouve une meilleure situation pour les arrhenateraies, même si elles ont subi une remarquable réduction de leur aire. Les aires à pâturage où prédominent les aspects à *Poion alpi-*

nae, ressentent elles aussi de gestions alternes et rarement optimales. Il y a quelque exception dans les Dolomites d'Ampezzo. Pour des causes naturelles et pour l'absence de gestion, les prairies de type aride-steppique sont en forte diminution, déjà rares pour des raisons historico-climatiques. Elles mériteraient une attention spécifique avec des interventions appropriées. Enfin, il faut souligner que la biodiversité de quelques secteurs est protégée justement par des irrégularités de gestion qui gardent d'élevés niveaux de diversification, ralentissant ainsi la banalisation et la diffusion de communautés nitrophiles.

- Milieux humides. Même s'ils sont souvent recensés et individualisés comme des sites Nature 2000 ou des biotopes, les situations critiques de base, innées dans leur fragilité et leur sensibilité, restent bien présentes. Dans quelque cas ils nécessitent de protections spécifiques pour éviter l'abandon à la libre évolution ou aux effets négatifs causés par la proximité de routes, de pistes, de lignes de débardage. Il faudrait interdire de nouveaux drainages, parfois justifiés pour des raisons de sûreté. Dans d'autres cas, au contraire, il est convenable de les préserver du pâturage qui, au cours des saisons sèches, peut causer des effets délétères. En général, les sources, là où il n'y ait pas d'indications d'espèces rares et tous les milieux humides sont importants pour la biodiversité surtout animale, et donc ils exigent du respect. Pour les miroirs d'eau, en outre, il faut individualiser les mesures appropriées pour ralentir ou empêcher l'eutrophisation qui, néanmoins est un phénomène naturel, en partie. Enfin, on connaît les contrastes entre protectionnistes et hydrauliciens ou forestiers pour la gestion des communautés péri-fluviales. Sans entrer dans les détails de la diatribe, il faut distinguer les situations des cénoses des grèves, conditionnées par les prélèvements et par la réglementation du régime, de celles des milieux riverains plus mûrs qui développent des fonctions écologiques de primaire valeur.
- Les milieux typiquement dolomitiques représentés par les communautés pionnières des parois rocheuse et/ou des éboulis de faille, particulièrement ravissantes dans beaucoup de secteurs, jouissent généralement de bonne santé à l'exception de cas extrêmes ou très localisés, ils ne nécessitent pas d'intervention particulières.
- Pour les prairies primaires d'altitude, habituellement non fauchées et éventuellement exposées au pâturage extensif, les effets du changement du climat peuvent être négatifs. Ces effets se manifestent déjà, en toute évidence dans la réduction, qualitative et quantitative, des phytocénoses des petites vallées nivales.

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Bibliographie

AA.VV. (by Gasparo, D. & Zappa, L.), 1994: Organismi come bioindicatori ambientali. –Trieste.
AA.VV. (by Pirola, A.) 2000: Contributi alla valutazione dell'impatto ambientale con indicatori floristici e vegetazionali. – Archiv. Geobotanico **5(1-2)**, 1999.

Argenti, C. & Lasen, C. 2001: La flora. – P. 210 in: Studi e Ricerche del Parco Nazionale Dolomiti Bellunesi, **3.** – Castelfranco Veneto.

— & — 2004: Lista rossa della flora vascolare della Provincia di Belluno. – Vicenza.

Biondi, E., Blasi, C., Allegrezza, M., Anzellotti, I., Azzella, M. M., Carli, E., Casavecchia, S., Copiz, R., Del Vico, E., Facioni, L., Galdenzi, D., Gasparri, R., Lasen, C., Pesaresi, S., Poldini, L., Sburlino, G., Taffetani, F., Vagge, I., Zitti, S. & Zivkovic, L. 2014: Plant communities of Italy: The Vegetation Prodrome. – Pl. Biosyst. **148(4):** 728-814, https://doi.org/10.1080/11263504.2014.948527

Blasi, C. (ed.): La vegetazione d'Italia, con carta delle serie di vegetazione in scala 1:500.000. – Roma.

Boiti, I., Lasen, C. & Saffaro Boiti, T. 1988: Interessante Aspekte im Refugialgebiet des Venegia-Tales. – Sauteria **4:** 121-131.

—, — & — 1989: La vegetazione della Val Venegia. Provincia Autonoma di Trento. – Calliano.

Bonomi, C. & Buffa, G. 2000: Valutazione della qualità della vegetazione della torbiera delle Viote del Monte Bondone (TN) con lineamenti di corretta gestione ambientale. – Studi Trent. Sc. Nat. **74(1997):** 77-97.

Buffa, G., Carpenè, B., Casarotto, N., Da Pozzo, M., Filesi, L., Lasen, C., Marcucci, R., Masin, R., Prosser, F., Tasinazzo, S., Villani, M. & Zanatta, K. 2016. Lista rossa regionale delle piante vascolari. – Venezia.

Cerabolini, B., Raimondi, B., Cattaneo, M., Preatoni, D. & Brusa, G. 2007: I caratteri della vegetazione come descrittori della qualità ambientale: un'applicazione cartografica (provincia di Varese, Lombardia). – Inform. Bot. Ital. **39(1):** 155-165.

Da Pozzo, M. & Lasen, C. 2010: Le zone umide di interesse naturalistico nelle Dolomiti d'Ampezzo. – Frammenti **2:** 9-46.

Del Favero, R. (by), Abramo, E., Andrich, O., Corona, P., Cassol, M., Lasen, C., Marchetti, M., Carraro, G., Dissegna, M., Giaggio, C., Savio, D. & Zen, C. 2000: Biodiversità e Indicatori nei tipi forestali del Veneto. – Venezia.

Favero, P. & Lasen, C. (by) 2016: La Riserva Naturale Orientata di Somadida. Scrigno di biodiversità e luogo di boschi vetusti. – Corpo Forestale dello Stato – Rasai di Seren del Grappa.

Ferrari, C., Pezzi, G. & Dell'aquila, L. 2000: Diversità e naturalità della vegetazione. Elementi per un'analisi quantitativa integrata. – Inf. Bot. Ital. **32 (suppl. 1):** 31-34. Atti XIV Convegno G. Gadio.

Fondazione Dolomiti Unesco 2014: "Linee guida per il paesaggio" convenzione di ricerca tra l'Università degli Studi di Udine, la Provincia di Udine e la Fondazione Dolomiti-Dolomiten-Dolomites-Dolomitis UNESCO nell'ambito dei lavori della Rete funzionale del Patrimonio Paesaggistico e Aree Protette.

Lasen, C. 1982: Vegetazione nivale a *Luzula alpino-pilosa* nelle Alpi Feltrine. – Studi Trent. Sc. Nat. **59:** 31-40, Trento.

— 1989a: Varietà floristica e vegetazionale nel paesaggio dolomitico, una risorsa in pericolo da apprezzare e tutelare. – Pp. 121-131 in: "Dolomiti, risorsa dell'Europa". Atti del convegno di Cortina d'Ampezzo 7-8 aprile 1989.

— 1989b: Note floristiche, ecologiche e fitosociologiche sui salici della Val Venegia (Dolomiti sud-occidentali). – Studi Trent. Sc. Nat. **65:** 49-61.

— 2000: Paesaggio vegetale e flora. – Pp. 366-375 in: De Battaglia, F. & Marisaldi, L. (eds), Enciclopedia delle Dolomiti. – Bologna.

— 2001: Le Dolomiti. – Pp. 68-79 in: AA.VV.: Parchi Montani. – Forlì.

— 2004: Sintesi descrittiva e valori vegetazionali. – Pp. 153-176 in: Cason Angelini, E. (ed.), Un Parco per l'uomo. Dieci anni di vita del Parco Nazionale Dolomiti Bellunesi. – Belluno.

— 2006: Habitat Natura 2000 in Trentino. – Trento.

— 2008: Natura e paesaggi del territorio bellunese. – Pp. 25-139 in: Lasen, C. (ed.), Tesori naturalistici. Viaggio alla scoperta dei paesaggi e della biodiversità, dalla montagna al mare, nelle province di Belluno, Vicenza, Verona, Mantova, Ancona. – Verona.

— 2009: Paesaggio vegetale e valori floristico-vegetazionali in Centro Cadore e Dolomiti di Sinistra Piave. – Pp. 43-70 in: Begotti, Pc. & Majoni, E. (ed.), Dolomites. – Atti del LXXXVI Congresso della Società Filologica Friulana, Pieve di Cadore 20-09-2009. – Udine.

— 2012: Dolomiti. La promozione del bene Unesco. – Pp. 271-276 in: Varotto, M. & Castiglioni, B. (ed.), Di chi sono le Alpi? Appartenenze politiche, economiche e culturali nel mondo alpino contemporaneo. – Rete Montagna, Università di Padova. – Atti del VI Convegno internazionale di Rete montagna, Agordo 22-24 settembre 2011.

— 2016: Lineamenti vegetazionali. Pp. 244-251 in: Da Pozzo, M., Argenti, C. & Lasen, C.: Atlante floristico delle Dolomiti d'Ampezzo. Specie notevoli, valori ecologici e fitogeografici. – Cortina d'Ampezzo.

— 2020a: Lineamenti della vegetazione in provincia di Belluno. – Pp. 13-58 in: Padovan, F., Lorenzon, L., Campo, E., Floriani, M., Michelin, L., Brotzu, R., Bizio, E. & Magnozzi, M.: 1260 funghi della Provincia di Belluno. Atlante fotografico. – Belluno.

— 2020b: La Natura: tra vincoli, interessi contrapposti e opportunità di recupero. – Pp. 23-38 in: Viola, F. (ed.), Cause ed effetti della devastazione nell'area montana triveneta. Giornata di Studi 30 gennaio 2019. – Padova.

— & Da Pozzo, M. 2011: La flora e la vegetazione. – Pp. 94-145, with redlist pp. 322-327 and bibliography p. 331 in: Alberti, A., Cassol, M., Da Pozzo, M., Lasen, C. & Siorpaes, C. 2011: Dolomiti d'Ampezzo. Guida alla conoscenza delle meraviglie naturali di Cortina. – PCortina d'Ampezzo.

— & — 2017: *Carex maritima* Gunnerus (*Cyperaceae*) rara specie artico-alpina scoperta sulle Dolomiti d'Ampezzo. – Frammenti **7:** 95-99.

— & Pignatti, S. 2002: Spruce forests of the Dolomites and related areas of the South-Eastern Alps. Ecology, management and syntaxonomy. – Razprave IV. Razreda SAZU, **XLIII-3:** 267-282. – Ljubljana.

— & Scariot, A. 2007: Le macrofite. – Pp. 155-186 in: AA.VV. (by ARPAV, Belluno), 2007: Studio della qualità delle acque dei piccoli laghi alpini. – Venezia.

— & Wilhalm, T. 2004: Natura 2000. Habitat in Alto Adige. – Bolzano.

—, Pignatti, E. & Pignatti, S. 1992: Le comunità a *Matteuccia struthiopteris* nelle Dolomiti sudoccidentali. – Ann. Bot. (Roma) **48 suppl. 7(1990):** 155-162.

—, —, — & Scopel, A. 1977: Guida Botanica delle Dolomiti di Feltre e di Belluno. – Calliano (TN).

Lippert, W., Müller, N., Rossel, S., Schauer, T. & Vetter, G. 1995: Der Tagliamento- Flußmorphologie und Auenvegetation der größten Wildflußlandschaft in den Alpen. – Verein zum Schutz der Bergwelt e.V. München: 11-70.

Marchiori, S., Rizzo, F., Medagli, P., Albano, A. & Farenga, T. 2000: Indicatori e metodi per la valutazione della qualità ambientale nella pianificazione territoriale nel comune di Vergole (Lecce). – Inform. Bot. Ital. **32 suppl. 1:** 21-25.

Mazzocchi, F., Castorina, M. & De Mei, M. 1999: Rappresentazione sintetica della qualità ambientale attraverso l'integrazione di indici floristici e vegetazionali: il caso di Macchia Grande di Ponte Galeria (Roma). – Roma.

Melzer, A. 1999: Aquatic macrophytes as tools for lake management. – Hydrobiologia **395/396:** 181-190.

Mucina, L., Bültmann, H., Dierßen, K., Theurillat, J. P., Raus, T., Čarni, A., Šumberová, K., Willner, W., Dengler, J., Gavillán Garcia, L., Chytrỳ, M., Háyek, M., Di Pietro, R., Iakuschenko, D., Pallas, J., Danièls, F. J. A., Bergmeier, E., Santos Guerra, A., Ermakov, N., Valachovič, M., Schaminée, J. H. J., Lysenko, T., Didukh, Y. P., Pignatti, S., Rodwell, J. S., Capelo, J., Weber, H. E., Solomeshch, A., Dimopoulos, P., Aguiar, C., Hennekens, S. M. & Tichỳ, L. 2016: Vegetation of Europe: hierarchical floristic classification system of vascular plant, bryophyte, lichen and algal communities. – Appl. Veg. Sci. **19 supplement 1**: 3-265. http://dx.doi.org/10.1111/avsc.12257

Pignatti, E. & Pignatti, S. 1960: Un'associazione rupestre endemica nelle Dolomiti (*Phyteumateto - Asplenietum seelosii*) all'estremo orientale della sua area. – N. Giorn. Bot. Ital., n.s., **66 (4, 1959):** 1-5.

— & — 1974: Guida botanica alla Val di Fassa. – Inform. Bot. Ital. **6:** 116-130.

— & — 1978: Über die *Campanula morettiana*-Vegetation in den Dolomiten. – Mittl. Ostalp.-din. Ges. f. Vegetskde. **14:** 279 - 291.

— & — 1981: Su alcune nuove associazioni vegetali delle Dolomiti. – Giorn. Bot. Ital. **115:** 138-139.

— & — 1983: *Danthonio - Nardetum* eine neue Bürstlinggesellschaft aus dem Südrand der Ostalpen. Contributions, IV, 1 - 2 - Section of Biological and Medical Sciences. – Skopje.

— & — 1984a: La vegetazione delle Vette di Feltre al di sopra del limite degli alberi. – Studia Geobot. **3(1983):** 7-47. Trieste.

— & — 1984b. Zur Syntaxonomie der Kalkschuttgesellschaften der südlichen Ostalpen. – Acta Bot. Croatica **43:** 243-255.

— & — 1985: Das *Caricetum rupestris*, eine neue Assoziation der Südtiroler Dolomiten. – Tuexenia **5:** 175-179.

— & — 1988a: Introduzione al paesaggio vegetale delle Dolomiti. – Studi Trent. Sci. Nat. **64(suppl.):** 13-26.

— & — 1988b: Zur syntaxonomie der *Trifolium nivale*-reichen Almwiesen in den südlichen Ostalpen. Sauteria **4:** 55 - 69.

— & — 1995: Lista delle unità vegetazionali delle Dolomiti. – Atti dei Convegni Lincei 115, XI Giornata dell'Ambiente: La vegetazione Italiana (Roma, 5 giugno 1993): 175-188. – Roma.

— & — 2003: Le Dolomiti come modello di lettura del paesaggio montano e delle sue trasformazioni. – Inf. Bot. Ital. **35(2):** 371-372. – Atti del Convegno: Il patrimonio vegetale delle Montagne. Valori e problemi delle montagne europee ed extraeuropee, metodi di studio. Bergamo 31 maggio-1 giugno 2002.

— & — 2014-2017: Plant life of the Dolomites, **1-3.** – Heidelberg, New York, Dordrecht, London.

—, —, Pietrosanti, S. & Paglia, S. 1996: La flora delle Dolomiti come archivio informatizzato. – Atti 24° Simposio Soc. Estalpino-dinarica di Fitosociologia. Rovereto 2-6 luglio 1995. – Ann. Mus. Civ. Rovereto, suppl., **11 (1995):** 27-43.

Pignatti, S. 1981: Carta dei complessi di vegetazione di Cortina d'Ampezzo. – Roma.

— 1998 (1995): Die Dolomiten-Vegetation als System. – Acta Bot. Croat. **54:** 89-96.

Poldini, L. (with Oriolo, G. & Vidali, M.) 2002: Nuovo Atlante corologico delle piante vascolari nel Friuli Venezia Giulia. – Trieste.

— & Pertot, M. 1991: Criteri di indicizzazione del valore naturalistico sull'esempio del Carso Triestino - Goriziano. – Inform. Bot. Ital. **21(1-3):** 133-151.

Prosser, F. 2001: Lista Rossa della Flora del Trentino. Pteridofite e Fanerogame. – Rovereto.

— & Bertolli, A. 2008: A new species of *Gentiana* sect. *Calathianae* (*Gentianaceae*) from the Brenta Group. European Alps, Italy. – Willdenowia **38:** 423-431.

—, —, Festi, F. & Perazza, G. 2019: Flora del Trentino. – ERovereto.

Rodaro, P., Scotton, M., Ziliotto, U. & Cerantola, L. 1998: Studio vegetazionale e agronomico dei pascoli di Gotres (Cortina d'Ampezzo, BL, Italia). – Doc. Phytosoc. **18:** 73-95.

Rossi, G., Tomaselli, M. & Gualmini, M. 2000: Messa a punto metodologica sul problema dell'indicizzazione del valore naturalistico delle comunità vegetali. – Arch. Geobot. **5(1-2)**, 1999: 129-133.

Scotton, M., Rodaro, P. & Ziliotto, U. 1996: Analisi fitosociologica e valutazione agronomica di pascoli subalpini (Malga Padeon, Cortina d'Ampezzo, NE Italia). – Studia Geobot. **15:** 51-72.

Tomaselli, M. & Gualmini, M. 2000: Indicizzazione del valore naturalistico dei pascoli di altitudine nel Parco Regionale dell'Alto Appennino Modenese (Italia settentrionale). – Arch. Geobot. **5(1),** 1999: 135-144.

—, Lasen, C., Argenti, C., Gualmini, M., Petraglia, A. & Nascimbene, J. 2006: Studio Geobotanico di due Biotopi del Parco Naturale Regionale delle Dolomiti d'Ampezzo (Belluno – Italia Nordorientale). – Gredleriana **6:** 9-30.

—, — & Boiti, I. 1989: Zusammenhänge zwischen Vegetation und Oberflächen-karstformen in einigen Gletscherkare der italienischen Dolomiten. – Atti del simposio della Società Estalpinodinarica di fitosociologia, Feltre 29/6-3/7 1988: 127-133.

—, Petraglia, A. & Lasen, C. 2005: Flora briologica e vegetazione delle vallette nivali nelle Vette di Feltre (Parco Nazionale Dolomiti Bellunesi, Italia settentrionale). – Gortania **26:** 111-136.

Viola, F., Gianolla, P., Cassol, M. & Lasen, C. 2005: Perché le Dolomiti meritano molto di più. Per entrare a pieno titolo nella World Natural Heritage List. – Parchi **46:** 50-77.

Wilhalm, T., Niklfeld, H. & Gutermann, W. 2006: Katalog der Gefäßpflanzen Südtirols. – Ver. des Naturmuseums Südtirols **3:** 1-216.

Cet article comprend deux annexes: annexe 1, imprimée, avec les plaques photographiques de certains taxons mentionnés dans le texte; annexe 2, en numérique (ESF1), avec la liste des taxons et syntaxons cites dans le texte et dans les legendes des plaques photographiques.

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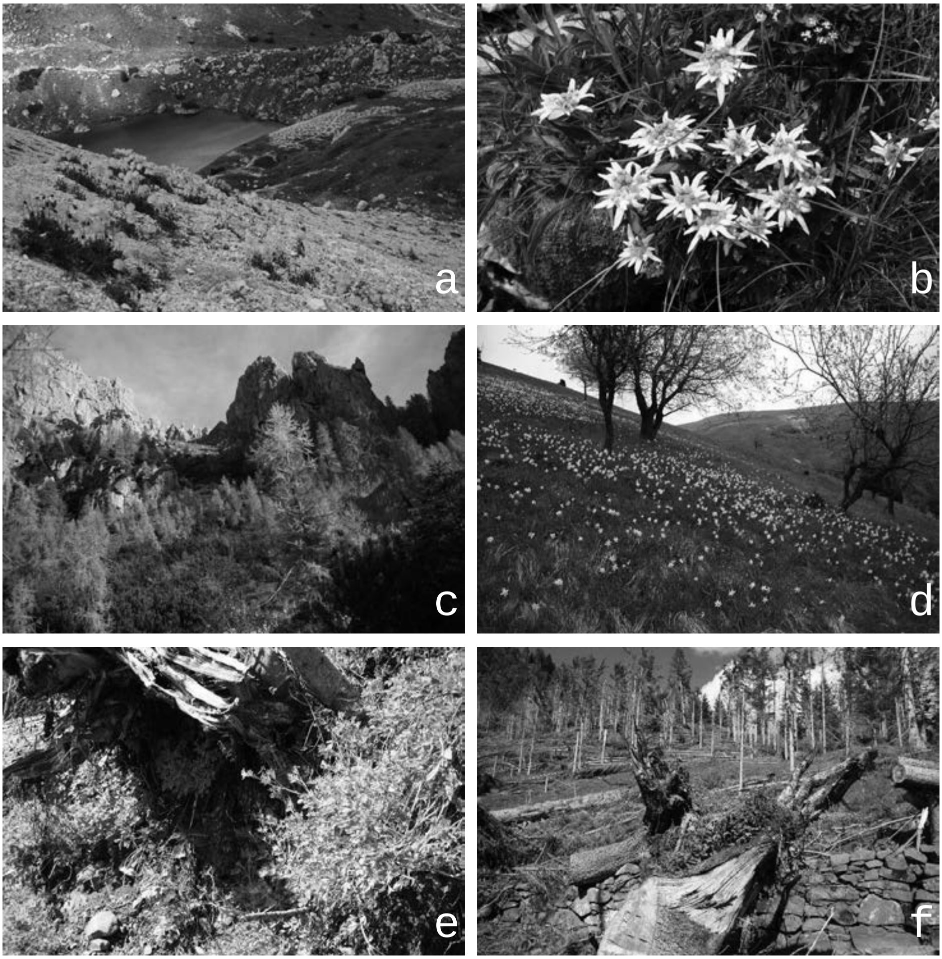
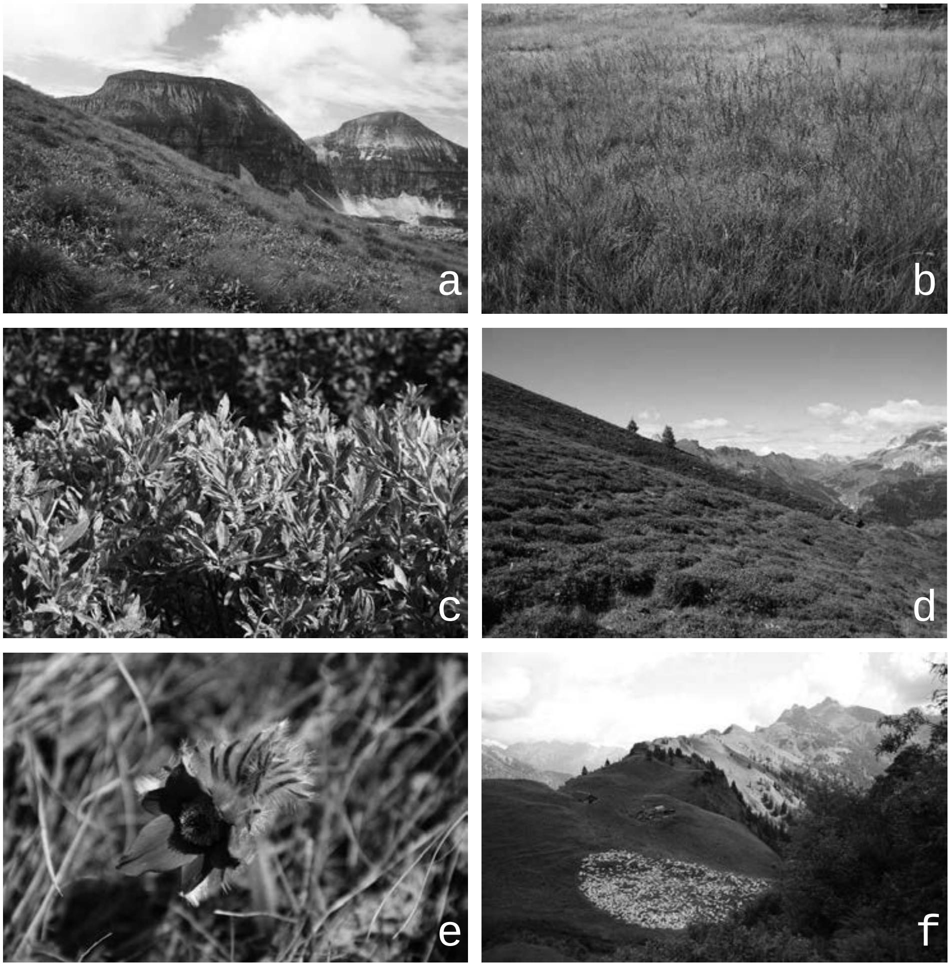
PREMIERE ANNEXE - PLAQUES PHOTOGRAPHIQUES

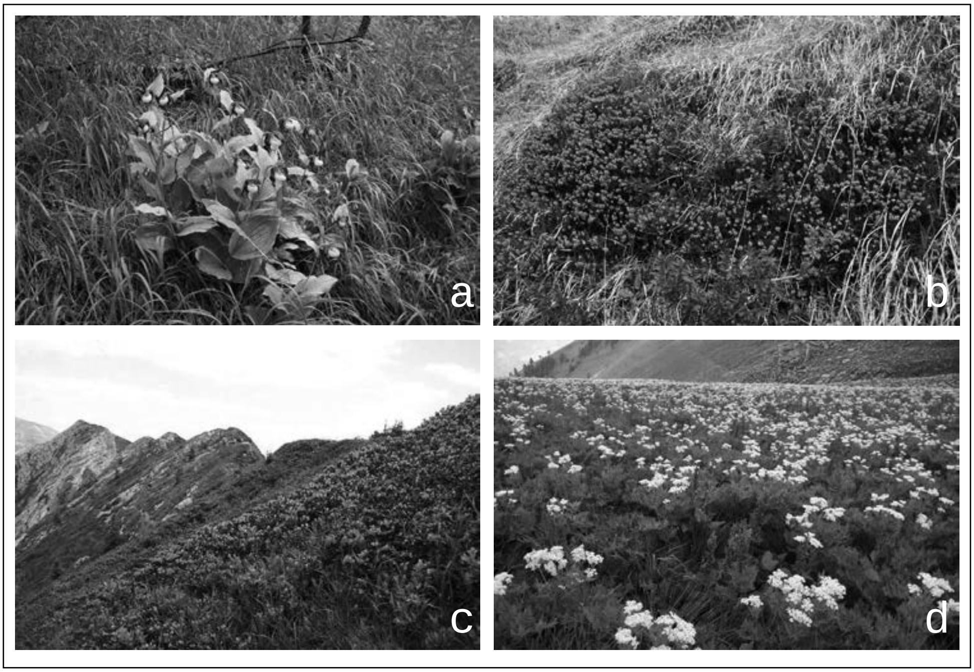


Plaque 1: a) Le paysage dolomitique est caractérisé par de vastes couvertures détritiques. Typique des stations enneigées de haute altitude, c'est le *Papaver rhaeticum*, espèce de l'association *Papaveretum rhaetici*; b) *Leontopodium nivale* subsp. *alpinum* est considéré le symbole de la montagne et autrefois il a été l'objet de cueillettes dans le seul but commercial qui ont réduit l'abondance de sa population; c) Aspects de végétation subalpine en Val Canali où l'on distingue des parcelles de brousses à pin couché qui colonisent les milieux détritiques et où, par la suite, s'installe le mélèze, en contribuant ainsi à caractériser les couleurs du paysage autumnal; d) Pendant la saison printanière les floraisons du narcisse, *Narcissus radiiflorus*, intéressent les prés de montagne frais et pas trop engraissés. A la suite du changement climatique, le niveau d'altitude va s'élever et, ici sur le Mont Castello (Vette Feltrine), les prés arrivent jusqu'à plus de 1800 mètres d'altitude; e) *Corydalis capnoides*; f) Le 29 octobre 2018 une tempête de vent et de pluie torrentielle, dénommée Vaia, a abattu de vastes parties de forêt en causant des dommages jamais observés dans la région dolomitique. Les dynamiques qui s'en succèdent ouvrent des séries inconnues. Sur les substrats du haut Agordino s'est vérifiée une explosion d'une espèce considérée très rare auparavant, la *Corydalis capnoides*. Elle a trouvé un micro-habitat idéal à la base des souches des arbres écroulés.

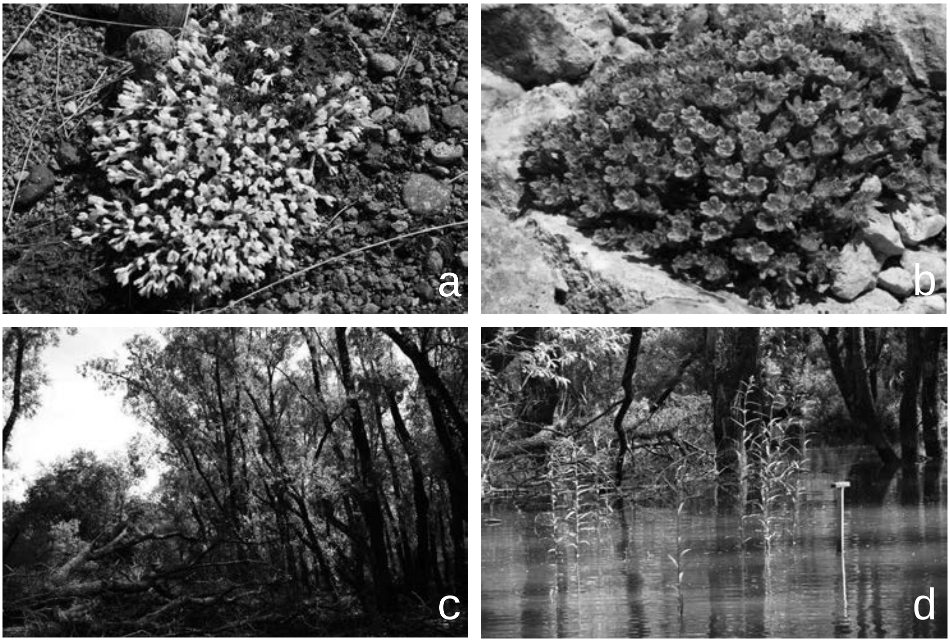
Plaque 2: a) *Primula tyrolensis* c'est l'un des endémismes le plus répandu du territoire dolomitique, en caractérisant les stations rocheuses fraîches et plutôt humides. Ici avec *Carex firma* qui est l'espèce colonisatrice prédominante sur les détritus et dans les prairies primaires sur sol primitif (*Gentiano terglouensis-Caricetum firmae*); b) *Geum reptans* caractérise la végétation des détritus siliceux et parfois même de ceux carbonatés terrigènes; c) Parmi les espèces les plus spectaculaires des rochers de haute altitude, on remarque *Eritrichium nanum*, ici sur détritus carbonaté, mais répandu aussi sur des substrates siliceux; d) La gestion pour la conservation des prairies alpines représente l'un des problèmes le plus urgents et de complexe solution. Les zones fauchées sont de plus en plus rares. Ici un aspect où l'on remarque une population de *Hieracium auriantiacum*; e) Les stations d'altitude élévée à substrat siliceux (ici porphyre) offrent souvent des milieux humides avec des sources, tourbières, mares, et petits lacs. Ici un aspect avec *Eriophoretum scheuchzeri* au-dessus du lac de Cavia; f) La végétation des prairies alpines des substrats acides (même si dérivant de sols d'origine carbonaté comme ici sur les Vette Feltrine, arête du Mont Vallazza) va rapidement s'évoluer et sur les crêtes et les zones venteuses s'impose une formation à dominance de *Juncus trifidus*.



Plaque 3: a) Voilà un autre aspect des versants nord des Vette avec des prairies carbonatées (série Rosso Ammonitico) et des sols acides avec aspects à *Gentiana punctata* et *Juncus trifidus*; b) Les zones humides sont toujours d'un grand intérêt pour la conservation. Ici, près de Forcelle Aurine, de moins en moins communes, on trouve des molinaies dans un biotope où l'on remarque aussi des aspects à *Rhynchospora alba* et *Drosera rotundifolia*; c) Parmi les espèces les plus importantes genres des territoires alpins, le genre *Salix* est l'un de plus caractérisant et intéressant. *Salix glaucosericea*, ici en floraison avec des chatons féminins, est rare dans le domaine dolomitique où il parvient à la partie plus orientale de sa distribution; d) En correspondance des substrats volcaniques ou carbonatés-terrigènes acidifiés aussi, l'abandon du pâturage a favorisé la reprise de la bruyère basse avec de différentes espèces de *Vaccinium*, *Loiseleuria procumbens, Empetrum hermaphroditum* et de nombreux lichens et bryophytes; e) *Pulsatilla montana* est une espèce assez rare et thermo-xérophile qui fleurit bien précocement sur les versants plus à l'extérieur du territoire considéré. Ici sur le Mont Avena dans le Feltrino; f) La gestion des ressources naturelles du territoire dolomitique est devenu un problème sérieux. Le pâturage, pratiqué depuis des siècles avec une surveillance et une alternance correctes, ne représente pas toujours la solution idéale pour la tutelle de la biodiversité. Ici un troupeau de moutons à Campigat avec l'arête de la Paladada.



Plaque 4: a) Même si l’espèce est insérée dans l’Annexe II de la directive Habitat 92/43 et sous la tutelle de l’UE, le *Cypripedium calceolus* est bien représenté dans quelques secteurs du domaine dolomitique et préalpin; b) Beaucoup de territoires dolomitiques sur des versants escarpés des substrats carbonatés sont caractérisés par des formations compétitives sur des sols à humidité alternante, exposés à ruissellement alterné à des périodes seches. Ici une spectaculaire floraison de *Erica carnea* avec *Rhododendron hirsutum*, espèce guide; c) Tandis que le *Rhododendron hirsutum* est exclusif des substrats carbonatés, le *Rhododendron ferrugineum* aime ceux siliceux, mais il forme de vastes populations aussi sur les substrats carbonatés acidifiés. Ici un aspect de *Rhododendron ferrugineum* sur l’arête du Mont Coppolo; d) Dans les paysages dolomitiques et préalpins aussi, la présence des cabanes de bergers et le pâturage des bovins et des ovins ont déterminé les communautés végétales dominantes dont l’effet dure longtemps, même après l’abandon. Ici une rare et vaste formation de *Myrrhis odorata* près de la Vallazza, l’élévation la plus occidentale des Vette Feltrine.



Plaque 5: a) Les substrats volcaniques du haut Agordino (ici la chaîne du Padon) sont vraiment intéressants pour la flore. Ici une floraison de *Vitaliana primulaeflora*. Aux alentours se trouve la seule station connue dans le territoire de Belluno de *Dianthus glacialis*; b) *Saxifraga facchinii* est l'un des endémismes dolomitiques le plus circonscrit. Elle végète seulement sur les crêtes et les parois rocheuses les plus élévées, en corrélation peut-être avec des sites épargnés par les glaciations du quaternaire; c) Aux marges du territoire dolomitique, sur les rives du lac artificiel de Santa Croce, s'est développé un bois ripicole à *Salix alba* d'une valeur naturelle extraordinaire qui offre surtout des habitats spéciaux pour de différentes espèces animales. Il abrite aussi une nombreuse population du rare *Senecio paludosus*, ici au début de sa floraison. L'importance du bois mort et des habitats forestiers intacts est ici particulièrement didactique et significative; d) *Senecio paludosus*.

Lasen, C.: Biodiversité végétale, valeurs naturelles et sauvegarde du paysage dans le domaine dolomitique. — Fl. Medit. 31 (Special Issue): 521-544. 2022. — ISSN: 1120-4052 printed, 2240-4538 online.
Electronic Supplementary File 1. https://doi.org/10.7320/FlMedit31SI.521.1
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DEUXIEME ANNEXE - LISTE DES TAXONS ET SYNTAXONS CITES DANS LE TEXTE ET DANS LES LEGENDES DES PLAQUES PHOTOGRAPHIQUES

Liste des taxons

Abies alba Mill.
Acer platanoides L.
Acer pseudoplatanus L.
Ailanthus altissima (Mill.) Swingle
Alchemilla L.
Alnus glutinosa (L.) Gaertn.
Alnus viridis (Chaix) DC.
Amelanchier ovalis Medik.
Asplenium seelosii Leyb.

Betula pendula Roth
Brachypodium caespitosum (Host) Roem. et Schult.

Campanula morettiana Rchb.
Carex bicolor All.
Carex firma Host
Carex maritima Gunnerus
Carex microglochin Wahlenb.
Carpinus betulus L.
Castanea sativa Mill.
Corydalis capnoides (L.) Pers.
Corylus avellana L.
Cypripedium calceolus L.

Dianthus glacialis Haenke
Draba dolomitica Buttler
Drosera rotundifolia L.

Empetrum hermaphroditum Hagerup
Erica carnea L.
Erigeron annuus (L.) Desf.
Eritrichium nanum (L.) Schrad. ex Gaudin

Fagus sylvatica L.
Festuca austrodolomitica Pils & Prosser
Fraxinus excelsior L.
Fraxinus ornus L.

Genista radiata (L.) Scop.
Gentiana brentae Prosser & Bertolli
Gentiana punctata L.
Geum reptans L.
Hieracium L.
Hieracium aurantiacum L.

Impatiens glandulifera Royle
Juncus arcticus Willd.
Juncus trifidus L.
Juncus triglumis L.
Juniperus sabina L.
Juniperus sibirica Burgsd.
Kobresia simpliciuscula (Wahlenb.) Mack.

Lappula squarrosa (Retz.) Dumort.
Larix decidua Mill.
Leontopodium nivale (Ten.) Huet ex Hand.-Mazz. subsp. *alpinum* (Cass.) Greuter
Loiseleuria procumbens (L.) Desv.
Luzula alpino-pilosa (Chaix) Breistr.

Matteuccia struthiopteris (L.) Tod.
Molinia arundinacea Schrank
Myrrhis odorata (L.) Scop.

Narcissus radiiflorus Salisb.
Nigritella buschmanniae Teppner & Ster

Ostrya carpinifolia Scop.

Papaver rhaeticum Leresche
Petasites paradoxus (Retz.) Baumg.
Physoplexis comosa (L.) Schur
Picea excelsa (Lam.) Link
Pinus cembra L.
Pinus mugo Turra
Pinus nigra J.F. Arnold
Pinus sylvestris L.
Polystichum lonchitis (L.) Roth

Populus L.
Populus tremula L.
Primula tyrolensis Schott
Pulsatilla montana (Hoppe) Rchb.

Quercus petraea (Matt.) Liebl.
Quercus pubescens Willd.)
Quercus robur L.
Rhizobotrya alpina Tausch
Rhododendron ferrugineum L.
Rhododendron hirsutum L.
Rhynchospora alba (L.) Vahl
Robinia pseudacacia L.
Rubus L.

Salix L.
Salix alba L.
Salix caesia Vill.
Salix foetida Schleich.
Salix glabra Scop.
Salix glaucosericea Flod.
Salix hastata L.
Salix mielichhoferi Saut.
Salix myrsinifolia Salisb.
Salix waldsteiniana Willd.
Saxifraga depressa Sternb.
Saxifraga facchinii Koch
Sempervivum dolomiticum Facchini
Senecio paludosus L.
Sorbus aucuparia L.

Sphagnum L.

Taraxacum F.H. Wigg.
Taxus baccata L.
Tilia cordata Mill.
Tilia platyphyllos Scop.
Trifolium pratense L. subsp. nivale (Koch) Ces.

Ulmus glabra Huds.

Vaccinium L.
Vaccinium gaultherioides Bigelow
Vitaliana primulaeflora Bertol.

Liste des syntaxons

Abieti-Fagetum auct.
Abieti-Piceenion Br.-Bl. in Br.-Bl. et al. 1939
Alnetum viridis Br-Bl. 1918
Aremonio-Fagion (Horvat 1950) Borhidi in Török et al. 1989
Betulo pendulae-Populetalia tremulae Rivas-Mart. et M. Costa 1998
Calamagrostio variae-Abietenion (Horvat 1962) Exner et Willner 2007
Campanuletum morettianae Pignatti E. et S. 1978
Caricetum rupestris Pignatti E. et S. 1985
Caricion maritimae Br.-Bl. in Volk 1940 *nom. mut. propos.*
Carpinion orientalis Horvat 1958
Chelidonio-Robinietalia Jurko ex Hadac et Sofron 1980
Danthonio-Nardetum Pignatti E. et S. 1986
Empetro-Vaccinietum Br.-Bl. in Br.-Bl. et Jenny 1926
Erico carneae-Pinion sylvestris Br.-Bl. in Br.-Bl., Sissingh et J. Vlieger 1939
Erico-Fraxinion orni Horvat 1959 *nom. invers. propos*
Eriophoretum scheuchzeri Rübel 1911
Gentiano terglouensis-Caricetum firmae T. Wraber 1970
Knautio-Trifolietum Pignatti E. et S. 1988
Larici-Pinetum cembrae [*sensu* Ellemberg]
Luzulo-Fagion Lohmeyer et Tüxen in Tüxen 1954
Ostryo-Carpinenion orientalis Poldini 1982
Quercion pubescenti-petraeae Br.-Bl. 1932 *nom. mut.*
Papaveretum rhaetici Wikus 1959
Poion alpinae Gams ex Oberdorfer 1950
Rhodothamno chamaecisti-Laricetum H. Mayer 1984
Tilio-Acerion Klika 1955

La Furtuna estate: storytelling of a Sicilian wonderland

by Pasquale Marino*

There is a farm in Corleone (Sicily) that makes high-quality extra virgin olive oil and botanicals – and beside that – it promotes research in a variety of sectors, implementing sustainability and preserving the environment; it aims to boost the local economy and welfare services, encouraging job creation and social activities.

We can't talk about this project without talking about when, at the beginning of the last century, little Rosalia moved with her mother and two sisters from Corleone to the United States. In 1901, after a long journey on a big ship, she landed in a new place whose inhabitants spoke a language she never heard before, and she had no other choice but to start working hard, despite her young age, to help her family make a new start. Picking strawberries in the fields of Louisiana, she kept Sicily in her heart with nostalgia while – on the other side of the ocean – the country house where she was born was given away. But eventually, the energies spent on rebuilding her life in the new country were paid off when America gave her a love called Cosimo, loving children and nephews, among whom is Steve Luczo (CEO and chairman of Seagate Technology, one of the largest technology companies in the world).

"*When I was quite young my grandmother used to tell me how beautiful her homeland was, and how deeply she missed it…,*" "*I made a pledge to myself then, when I was 10 years old, that one day I would find the land and buy it back for Nonna Rosalia and our family*."

In 2013, thirty five years later, Luczo fully embodied his childhood dream to find his property, he retrieved his much-coveted land and now manages it with his wife, Agatha. "*I found the property with the help of my great friend, the botanist Pasquale Marino (aka Mimmo), and we retrieved the much-coveted land.* "*The company is called Bona Furtuna because my grandfather would always say this to us whenever we said goodbye after our meetings, while he was kissing us on both cheeks, it meant 'all good things in life'* — more than just *'good fortune'* ".

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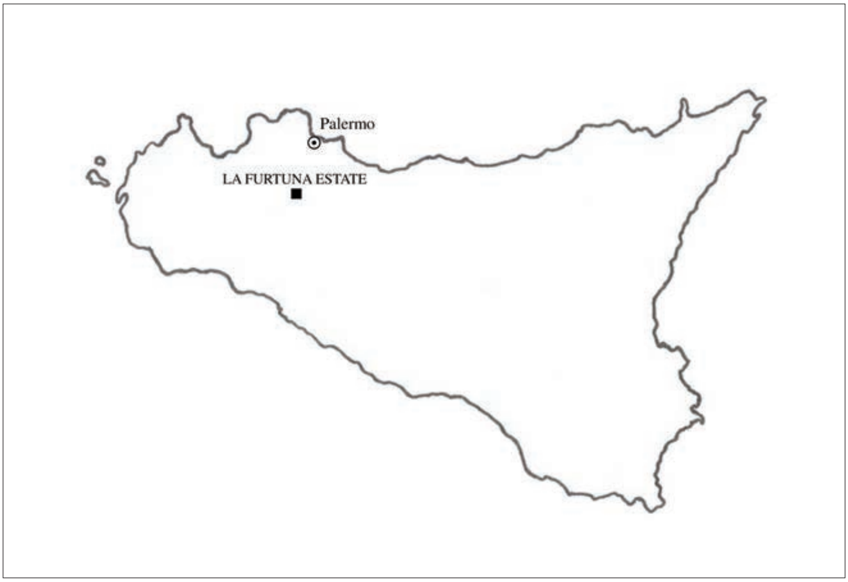
Over the years, much land was added to the original plot, as part of their effort to create a biodiverse organic farm and to generate employment opportunities in the territory of Corleone.

The property includes significant natural resources, as 70 percent of the 300 hectares fall into a special protection area which is part of the Natura 2000 network of Mt. Barraù. Over the past 9 years have been collected over 500 vascular species, focusing attention on about hundred medicinal and aromatic plants, among which *Anchusa azurea* Mill., featured by highest antioxidant activity of any wild Mediterranean plant, allowed to Furtuna Skin a new industrial patent for cosmetics Splendore Anchusa^{TM}.

In addition, wild plants and plants subjected to environmental stress have allowed to create other patents Wild Potent^{TM} and Extremophyte^{TM}.

As Steve argues "*at the heart of our mission is the welfare of the territory through employment creation. "It's been an amazing journey of my Family. It's really something to see the love that the workers have for what they are doing. To have a solid job brings such an important element to one's life. The workers are proud to be working the land. And, most importantly, what we are producing for the world is important and unique. I believe that Sicily's best chance for economic growth is related to tourism and organic farming, we are trying to provide a roadmap to build a sustainable business with these elements –Sicily is a magical place with a way of life that should be honored."*

Our goal is to leave the earth a better place than we found it. We love our land. We protect it. We preserve it. We nurture it, so it can flourish indefinitely.



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