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An updated overview of invasive *Caulerpa* taxa in Sicily and circum-Sicilian Islands, strategic zones within the NW Mediterranean Sea

Abstract

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The spread dynamics of invasive *Caulerpa* taxa (i.e. *Caulerpa cylindracea*, *C. taxifolia* var. *taxifolia* and *C. taxifolia* var. *distichophylla*) in Sicily and circum-Sicilian Islands, based on relevant publications, grey literature, unpublished data and *in situ* observations during the last 23 years, is presented here and discussed. Their known distribution is mapped. New records are also reported. Transport-stowaway is considered the most plausible vector of introduction of invasive *Caulerpa* in the area. The three invasive taxa showed different spread dynamics. *Caulerpa cylindracea* and *C. taxifolia* var. *distichophylla*, behaved as highly successful and fast-spreading taxa, i.e. as true invasive taxa. On the contrary, *C. taxifolia* var. *taxifolia* did not behave like the others, remaining limited to two small areas distant from each other. Due to their geographical position, Sicily and circum-Sicilian Islands are particularly vulnerable to biological invasions and therefore they could play an important role as receiver, transit and donor zone for alien species within the Mediterranean Sea. The creation of permanent observatories and alarm systems in this area might be an effective tool in the management of present and future introductions of alien species in the Mediterranean Sea.

Key words: *Caulerpa cylindracea, C. taxifolia,* invasive species, Mediterranean basin.

Introduction

The Mediterranean Sea is an important hotspot for alien species (Rilov & Galil 2009; Coll & al. 2010; Zenetos & al. 2012; Galil & al. 2015) which have almost reached a number of 1,000 (about 6% of the total flora and fauna) (Zenetos & al. 2012).

According to the definition adopted by the European Environmental Agency (2012), "an alien species is an organism introduced outside its natural past or present distribution range by human agency, either directly or indirectly." Whereas species which have expanded their range as a result of changing environmental conditions are not considered alien species.

Por (1978) coined the term "Lessepsian migration" to indicate the phenomenon of migration of Red Sea species into the Mediterranean Sea through the Suez Canal (opened in 1869).

But later, Galil (2000) replaced the term "Lessepsian migration" with the original term "Erythrean invasion" because she considered this inflow of tropical species an invasion more than a migration ("cyclical and predictable movement between two geographic areas that is related to the spatio-temporal distribution of resources or the reproductive cycle").

In recent decades a conspicuous increase of introductions, essentially due to escape from confinement, transport-stowaway and corridor (i.e. Suez Canal) entries (categories according to CBD 2014), was registered. The Suez Canal is considered to be one of the main vectors for the introduction of alien species into the Mediterranean Sea. However, some authors (e.g. Por 2009) considered the current high settlement of tropical species coming from the Suez Canal, mainly due to the ongoing sea-warming, as a re-colonization by Tethyans descendants more than an invasion of alien species. As far as marine macrophytes are concerned, a total of 133 species (23 belong to Chlorophyta, 79 to Rhodophyta, 30 to Ochrophyta, and 1 to Tracheophyta) have been recently listed as possible aliens in the Mediterranean Sea (Verlaque & al. 2015). This number is likely to increase as proved by the recent record of *Halimeda incrassata* (J. Ellis) J.V. Lamouroux in the waters off Mallorca Island (Alós & al. 2016).

Invasive Alien Species (IAS) are considered to be among the most serious threats, after habitat losses, to biodiversity and natural ecosystem functioning (Bax & al. 2003; Wallentinus & Nyberg 2007). Among the IAS recorded in the Mediterranean Sea, the following three *Caulerpa* taxa have raised serious concern due to their potential or ascertained impact on the native communities (Boudouresque & al. 1995; Klein & Verlaque 2008; Katsanevakis & al. 2014).

Caulerpa cylindracea Sonder: even though it was reported along the coast of Tunisia by Hamel (1926), the occurrence off the coasts of Libya in 1990 (Nizamuddin 1991) is generally accepted as the first record for the Mediterranean Sea. It was initially considered a "Lessepsian migrant" (Alongi & al. 1993; Giaccone & Di Martino 1995a), but, recently, Belton & al. (2014) concluded that this species has been introduced from Australia and New Caledonia. Until Belton & al. (2014) it was reported in the literature as *Caulerpa racemosa* var. *cylindracea* (Sonder) Verlaque, Huisman and Boudouresque, a new combination proposed by Verlaque & al. (2003).

Caulerpa taxifolia (M. Vahl) C. Agardh (invasive aquarium strain): this strain, first recorded in the Mediterranean in 1984 (Meinesz & Hesse 1991), is genetically identical to the strain cultivated in aquaria of western Europe (Jousson & al. 1998). According to Meusnier & al. (2001), the first strain introduced in the Mediterranean is native to South-Eastern Australia.

Caulerpa taxifolia (Vahl) C. Agardh var. *distichophylla* (Sonder) Verlaque, Huisman and Procaccini: this alga, native to South Western Australia, was first reported in the Mediterranean Sea as *C. taxifolia* from the coasts of South Turkey (2006, by Cevik & al. 2007).

Within the Mediterranean Sea, Sicily and circum-Sicilian Islands, as a consequence of their strategic position both from a geographical and a transport-stowaway point of view, including fisheries and recreational fleets, are particularly vulnerable and suitable to biological marine invasions (Occhipinti-Ambrogi & al. 2011a, b; Coll & al. 2012; Katsanevakis & al. 2014; Mannino & al. 2014, 2015, 2017; Celesti-Grapow & al. 2016). Since reliable and accessible information (literature, online inventories and databases) on the spread dynamics, the introduction pathways and the invasiveness of marine alien species is crucial for planning effective management and conservation strategies, the aim of the present paper is to offer an updated overview of the distribution of invasive *Caulerpa* specific and infraspecific taxa in Sicily and in circum-Sicilian Islands.

Materials and methods

All the relevant publications and reports dealing with invasive *Caulerpa* taxa in Sicily and in circum-Sicilian Islands, from their first record in the area and updated till 2016, were searched and analysed, using standard databases and available libraries at the University of Palermo and at the Institut Méditerranéen d'Océanologie (MIO) of Marseille. *In situ* observations provided by the authors of the present paper were included, as well as personal communications provided by skilled citizen scientists.

The successful establishment of each taxon was determined on the basis of published and unpublished data. We considered species as established when the species was either established in the wild with free-living, self-maintaining and self-perpetuating populations, or recorded at least twice and spread over time and space. The most plausible pathway of introduction was attributed according to the hierarchical classification pathway adopted by the CBD (2014).

Results

Caulerpa cylindracea

Distribution (Table 1 and Fig. 1): since 1993 (first Italian record at Baia di San Panagia and at the Island of Lampedusa), the number of Sicilian sites affected by *Caulerpa cylindracea* has regularly increased and the alga has been steadily spreading, as indicated by the numerous new sightings recently recorded, mainly on the eastern coast. In particular, the number of new colonized sites has increased significantly from 2000 to 2007. Currently, 90% of areas colonized by *C. cylindracea* are located along the eastern and north-western coasts of Sicily.

Colonisation level: the level of colonisation ranged from sparse individuals to patches (ranging from 1 to 25 mq) and meadows (ranging from 150 mq to 1 ha) whereas the substratum cover (%) ranged from 5 to 100%.

Habitat (Fig. 2A, 3A, 3B): *Caulerpa cylindracea* is thriving under wide environmental conditions: in marine and hyperaline habitats, from the surface down to 50 m depth (even though the areas which were highly colonized ranged mainly from 0 to 20 m depth), on sand, rock and mud (mainly on sand), on exposed and sheltered sites, under low and high light conditions, in areas characterized by secondary volcanism phenomena (i.e. fumaroles and hot springs, e.g. Aeolian Islands), in altered areas as well as in pristine and protected areas (e.g. Marine Protected Areas and Natural Reserves).

Caulerpa cylindracea was found as an epibiont on different habitat-building species like *Mytilus galloprovincialis* (Lamarck, 1819), the two reef-building species, the vermetid *Dendropoma cristatum* (Biondi, 1859) and the polychaete *Sabellaria alveolata* (Linnaeus, 1767), but also on calcareous algae, sponges and corals. It was associated to both indige-

Table 1. Known sites of occurrence of *Caulerpa cylindracea* in Sicily and in circum-Sicilian Islands. MPA: Marine Protected Area; ONR: Oriented Natural Reserve.

Locality (site codes)	References
WESTERN COAST	
TRAPANI	
Capo Feto (1)	Piazzi & al. (2005), Riggio & al. (2007)
Mazara del Vallo (2)	Gagliano & al. (2002), P. Gandolfo (present work)
Marsala (3)	Piazzi & al. (2005), A.M. Mannino (present work)
ONR Saline di Trapani e Paceco (4)	Mannino & al. (2008)
Trapani, Torre Ligny, Rombo, Ronciglio (5)	Piazzi & al. (2005), A.M. Mannino (present work)
ONR Zingaro (6)	Riggio & al. (2007)
Golfo di Castellammare (7)	Piazzi & al. (2005), Riggio & al. (2007)
EGADI ISLANDS MPA	
Favignana Island (8)	Piazzi & al. (2005), Riggio & al. (2007), Mannino & al. (2016), A.M. Mannino (present work)
Levanzo Island (9)	Riggio & al. (2007), Mannino & al. (2016), A.M. Mannino (present work)
Marettimo Island (10)	Mannino & al. (2014), A.M. Mannino (present work)
NORTHERN COAST	
PALERMO	
Balestrate (11)	Riggio & al. (2007)
Cinisi (12)	A.M. Mannino (present work)
Punta Raisi (13)	S. Calascibetta (present work)
Capo Gallo-Isola delle Femmine MPA (14)	Mannino & al. (2008)
Casteldaccia (15)	A.M. Mannino (present work)
Termini Imerese (16)	Piazzi & al. (2005), Mannino & Di Giovanni (2011)
Ustica Island (17)	Di Trapani & al. (2016)
EASTERN COAST	
MESSINA	
Patti (18)	V. Di Martino (present work)
Oliveri (19), Milazzo (20)	A. Ruggeri (present work)
Torre Faro (21)	Riggio & al. (2007)
Strait of Messina (22)	Profeta & al. (2004)
Taormina (23)	V. Di Martino (present work)

Table 1. continued.

Eolian Archipelago (24)	V. Di Martino (present work)
CATANIA	
Santa Maria La Scala (25)	Di Martino (2001)
Capo Mulini (26)	Famà & al. (2000)
Isole Ciclopi (27)	Cormaci & Furnari (2005)
Acitrezza (28)	Verlaque & al. (2000)
Catania (29)	Piazzi & al. (2005)
SIRACUSA	
Brucoli (30)	Serio & Pizzuto (1998)
Baia di San Panagia (31)	Alongi & al. (1993), Giaccone & Di Martino (1995b), Pandolfo & Chemello (1995), Cantone (1999), Gianguzza & al. (2001, 2002)
Siracusa (32)	Di Martino (2001), Piazzi & al. (2005)
Peninsola Maddalena (33)	Marino & al. (1999), Di Martino & al. (2006)
Plemmirio MPA (34)	Di Martino (2001), Vinceti (2006)
Avola (35)	E. Tiralongo (present work)
Calamosche (36)	R. Barone (present work)
Capo Passero (37)	Di Martino (2001), Piazzi & al. (2005)
Isola di Capo Passero (38)	Di Martino & Stancanelli (1998)
SOUTHERN COAST	
RAGUSA	
Pozzallo (39)	Di Martino (2001), Piazzi & al. (2005)
Punta Braccetto (40)	Jongma & al. (2013), Musco & al. (2014)
Scoglitti (41)	M. Toccaceli & M. Gristina (present work)
AGRIGENTO	
Licata (42)	Riggio & al. (2007)
Agrigento (43)	A.M. Mannino (present work)
PELAGIAN ARCHIPELAGO	
Lampedusa Island (44)	Alongi & al. (1993), Piazzi & al. (2005), Alomar & al. (2016)
Linosa Island (45)	Piazzi & al. (2005), Azzurro & al. (2004, 2007), Lodola & al. (2012), Lodola (2013)
Pantelleria Island (46)	Di Martino (2001), Piazzi & al. (2005)

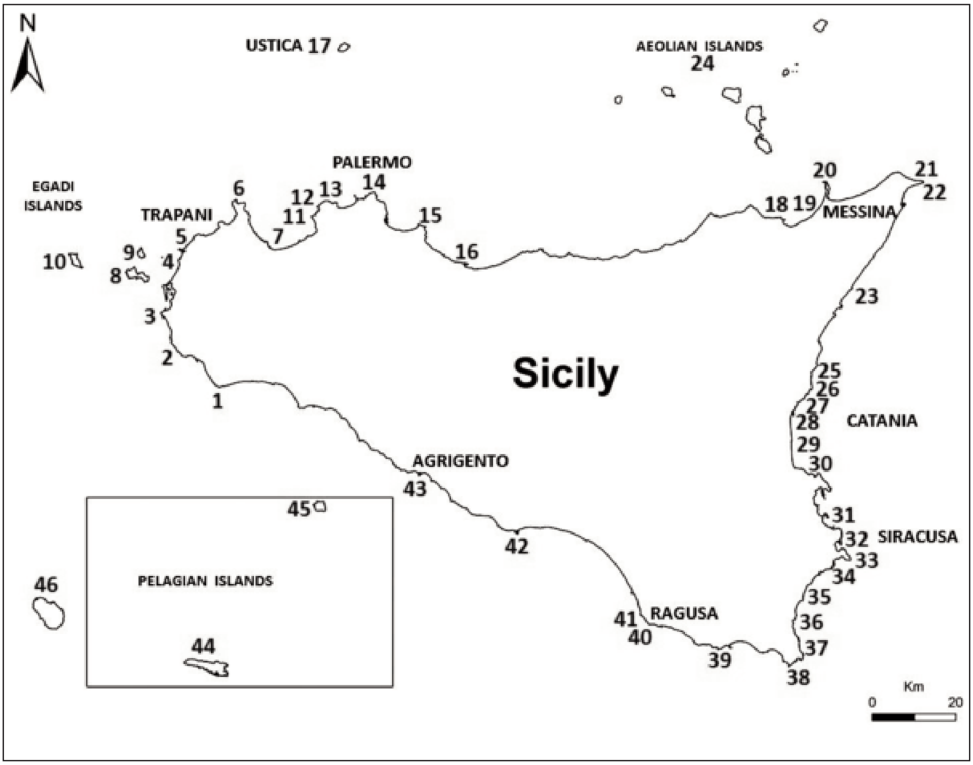

Fig. 1. Known sites of occurrence of *Caulerpa cylindracea* in Sicily and circum-Sicilian Islands (see Table 1 for the site codes).

nous and introduced macrophytes, such as *Posidonia oceanica* (L.) Delile (on *matte* as well as along the borders), *Cymodocea nodosa* (Ucria) Ascherson, *Ruppia cirrhosa* (Petagna) Grande, *Halophila stipulacea* (Forsskål) Ascherson, *Cystoseira* species, *Asparagopsis taxiformis* (Delile) Trevisan, *Ulva rigida* C. Agardh, *Dictyota spiralis* Montagne, *Caulerpa prolifera* (Forsskål) J.V. Lamouroux, *C. taxifolia* and *C. taxifolia* var. *distichophylla*.

Caulerpa taxifolia (invasive aquarium strain)

Distribution (Table 2 and Fig. 4): *Caulerpa taxifolia* was first observed in Sicily (off the coast of the Strait of Messina in 1993) ten years after its first Mediterranean record. In 2004 it was recorded along the coasts of Favignana Island. After that we have not had any further records till now.

Colonisation level: the level of colonisation ranged from patches to meadows (ranging from 0.5 mq to 1 ha).

Habitat (Fig. 2B, 3C): this alga was mainly found from 0 to 30 m depth, on rocky and sandy substrates, on dead matte of *P. oceanica,* intermingled with macroalgae or associated to *A. taxiformis, C. nodosa* and *C. cylindracea*.

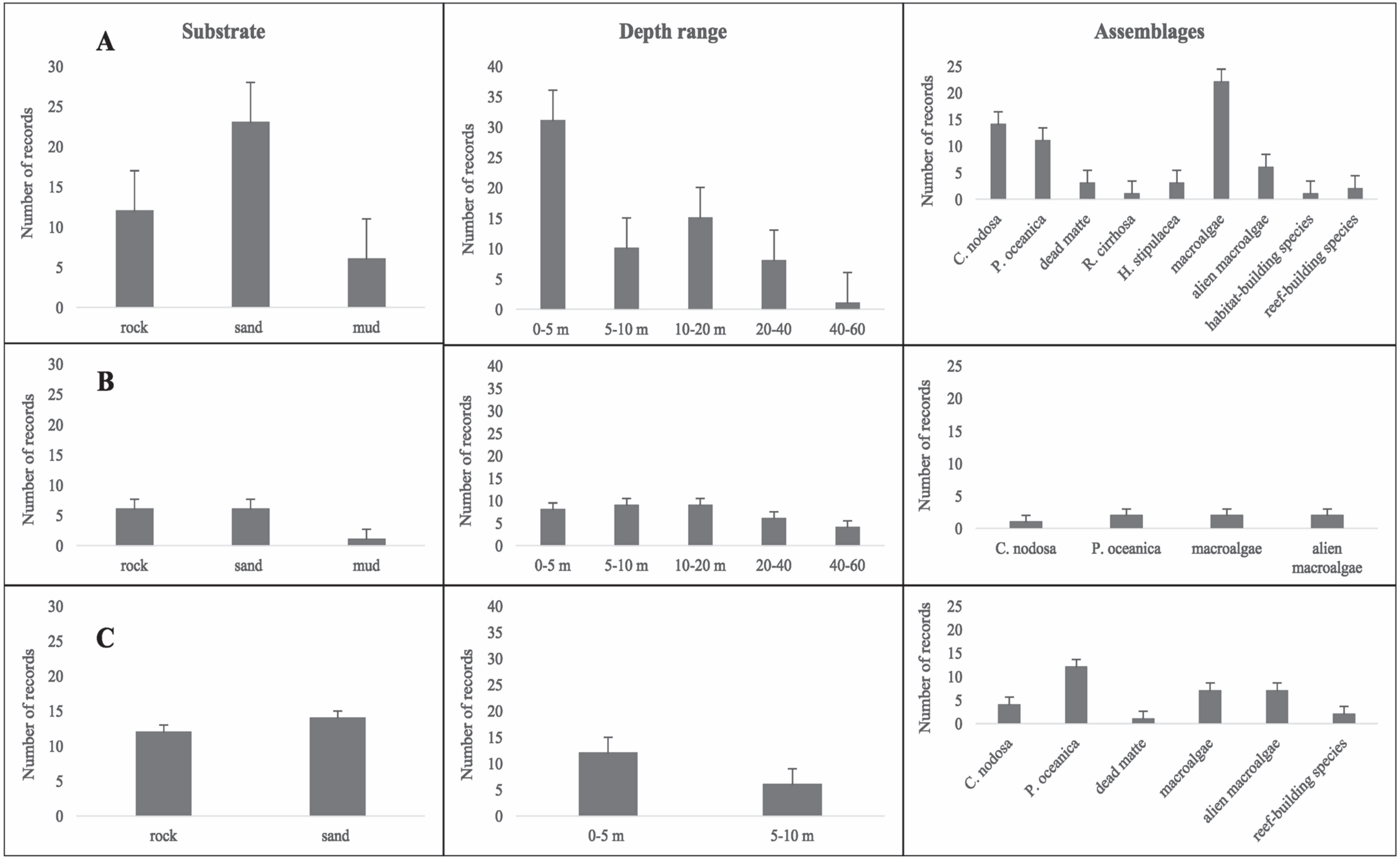

Fig. 2. Occurrences of *Caulerpa* taxa with respect to substrate typology, depth and native communities. A) *Caulerpa cylindracea*; B) *C. taxifolia*; C) *C. taxifolia* var. *distichophylla.*

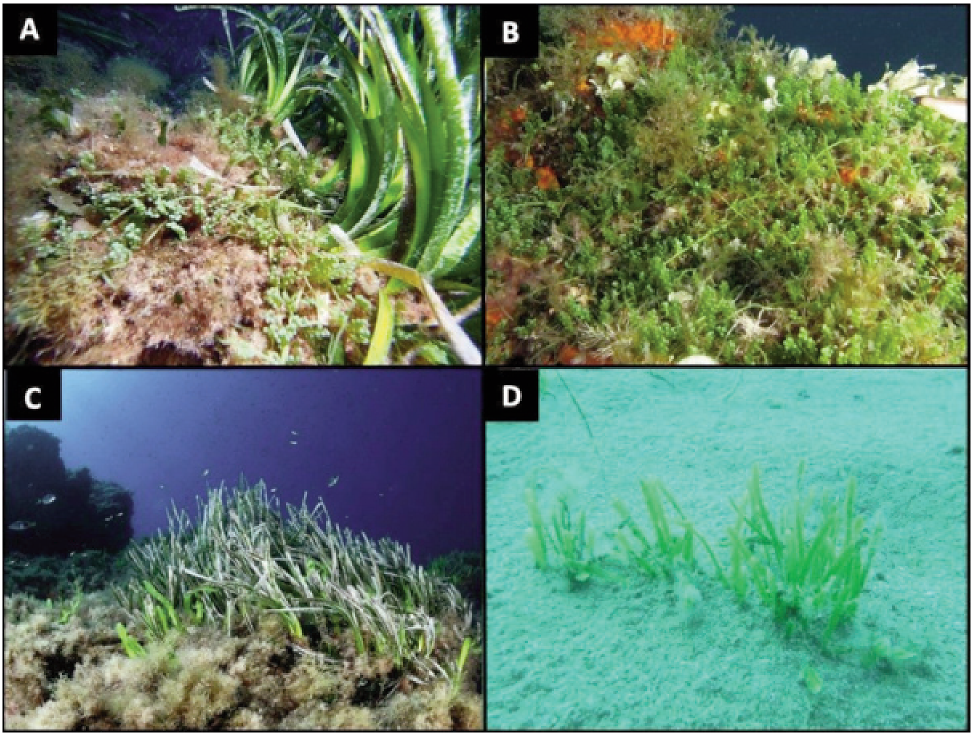

Fig. 3. *Caulerpa* species in different benthic assemblages along the coasts of Sicily and of circum-Sicilian Islands. A) *Caulerpa cylindracea* with *Posidonia oceanica* (Secca del Cammello - Marettimo, 28 m depth; photo Gianluca Neri); B) *Caulerpa cylindracea* with macroalgae and sponges (Secca del Toro – Favignana, 15 m depth; photo Sergio Zanoni); C) *Caulerpa taxifolia* in a *Posidonia oceanica* meadow (Strait of Messina, 12 m depth; photo Alessandro Pagano); D) *Caulerpa taxifolia* var. *distichophylla* in a *Cymodocea nodosa* meadow (Termini Imerese coast, 9-10 m depth; photo Marco Toccaceli).

Caulerpa taxifolia var. distichophylla

Distribution (Table 2 and Fig. 5): *Caulerpa taxifolia* var. *distichophylla* was first recorded on south-eastern coasts of Sicily in 2007 (as *C. distichophylla*, first Italian record). From then it spread rapidly along the southern coast and recently it was recorded along the northern and eastern coast. A new record (Termini Imerese) is here reported. From 2007 to 2009, 85 km of the south-eastern coast of Sicily (Isola delle Correnti, Capo Passero and Punta Braccetto) were already affected by *C. taxifolia* var. *distichophylla*.

Colonisation level: the level of colonisation ranged from sparse individuals to patches (about 100 cmq) whereas the substratum cover (%) mainly ranged from 8% to over 50%. In the southern coast its density showed an increasing gradient going from the west to the east.

Habitat (Fig. 2C, 3D): this alga occurs in shallow waters on sandy and rocky bottoms, mixed to *C. cylindracea*, on dead *matte* as well as along the borders of *P. oceanica* mead-

Table 2. Known sites of occurrence of *Caulerpa taxifolia* and *Caulerpa taxifolia* var. *distichophylla* from Sicily and circum-Sicilian Islands. MPA: Marine Protected Area.

Locality (site codes)	**References**
Caulerpa taxifolia	
WESTERN COAST	
EGADI ISLANDS MPA	
Favignana Island (8)	Gianguzza & al. (2006a, b), Riggio & al. (2007)
EASTERN COAST	
MESSINA	
Strait of Messina (22)	Di Martino (2001), Orestano & al. (2001), Profeta & al. (2004)
Torre Faro (21) – Ganzirri (47)	Fradà Orestano & al. (1994), Cantone (1999), Di Martino (2001), Orestano & al. (2001), Riggio & al. (2007)
Caulerpa taxifolia* var. *distichophylla	
NORTHERN COAST	
PALERMO	
Termini Imerese (16)	M. Toccaceli (present work)
Sant'Ambrogio (48)	Musco & al. (2014)
EASTERN COAST	
MESSINA	
Strait of Messina (22)	Picciotto & al. (2016)
SIRACUSA	
Isola delle Correnti (49)	Meinesz & al. (2010), Antoci & al. (2015)
Capo Passero (37)	Meinesz & al. (2010)
SOUTHERN COAST	
RAGUSA	
Punta Braccetto (40)	Meinesz & al. (2010), Jongma & al. (2013), Musco & al. (2014), Antoci & al. (2015)
Torre di Mezzo, Punta Secca, Marina di Ragusa, Donnalucata (50)	Musco & al. (2014)
Foce Fiume Irminio, Marina di Acate (51)	Antoci & al. (2015)
AGRIGENTO	
Malerba (52), Realmonte (53)	Antoci & al. (2015)
Torre Salsa (54)	Musco & al. (2014)

Fig. 4. Known sites of occurrence of *Caulerpa taxifolia* in Sicily and circum-Sicilian Islands (see Table 2 for the site codes).

ows, on the polychaete *Sabellaria* spp., and intermingled with macroalgae and *C. nodosa*. In the Strait of Messina, it occurs in habitats different to those occupied by *C. taxifolia*.

Discussion

Caulerpa cylindracea

Over the years, the level of colonization in the area has either decreased (A.M. Mannino, present work) or increased (Azzurro & al. 2004; Lodola & al. 2012).

Although Sicily and circum-Sicilian Islands have not been thoroughly investigated, the current data lead us to hypothesize that the entire coastline is affected by *C. cylindracea*.

Certainly, it is difficult to know the precise extent of the colonization in terms of area and coastline concerned, because mapping data are lacking and estimations of the reported colonized surfaces are not homogeneous and very often not accurate or completely lacking.

Although many colonized localities are touristic and/or fishing areas or are located in the vicinity of ports, non-urbanized areas (e.g. Marine Protected Areas and Natural Reserves) are also concerned.

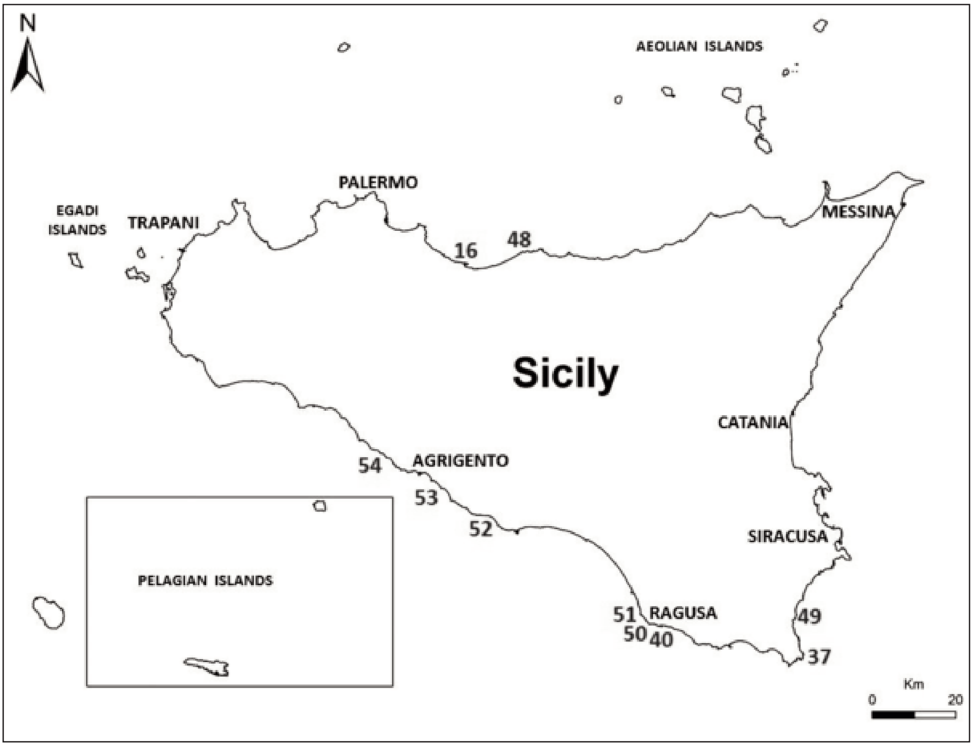

Fig. 5. Known sites of occurrence of *Caulerpa taxifolia* var. *distichophylla* in Sicily and circum-Sicilian Islands (see Table 2 for the site codes).

Similar rapid spreads were observed in other Mediterranean areas, e.g. along the French Mediterranean coasts and the south-eastern coast of Spain (Ruitton & al. 2005; Ruiz & al. 2011). However, even if *C. cylindracea* spread much faster and further than *C. taxifolia* it didn't generate the same public concern (Piazzi & al. 2005; Klein & Verlaque 2008; Boudouresque & al. 2009).

The spread of *C. cylindracea,* considered established in Sicily and in circum-Sicilian Islands, would probably result from the co-occurrence of extrinsic (i.e. current regime, temperate climate and presence of vectors of secondary dispersal) and intrinsic (i.e. the efficiency of its vegetative multiplication by cutting and propagules, the production of secondary metabolites) factors (Occhipinti-Ambrogi & al. 2011a, b; Gorbi & al. 2014). It has been suggested that the invasion of the Mediterranean region by *C. cylindracea* might have originated in the southern coast of Sicily (Papini & al. 2013). Transport-stowaway is considered the plausible pathway of introduction for local specimens but also the main vector of its spread.

The active mechanism of stolonisation allowed *C. cylindracea* to spread rapidly, forming compact multilayered mats which trap sediment creating a relevant decrease of redox potential underneath and negatively affecting the native assemblages (Piazzi & al. 2005;

Klein & Verlaque 2008; Holmer & al. 2009; Mannino & Di Giovanni 2011; Matijević & al. 2013). Therefore, it can be regarded as a "habitat modifier" (*sensu* Wallentinus & Nyberg 2007), ''ecosystem engineer'' (*sensu* Jones & al. 1994) and ''foundation species'' (*sensu* Bruno & al. 2003). Recently, it has been hypothesized that the bacterial community associated with *C. cylindracea* could have a potential role in its spread (Rizzo & al. 2016).

Fragmented or less structured habitats such as dead *mattes* of *P. oceanica*, sparse *P. oceanica* and *C. nodosa* meadows, algal turfs and annual photophilic macroalgal assemblages seem to be more vulnerable to invasion by *C. cylindracea* (Ceccherelli & al. 2000; Montefalcone & al. 2007; Katsanevakis & al. 2010). Recently, Bulleri & al. (2016) observed that the effects of *C. cylindracea* are more negative in well preserved sites.

Usually, *C. cylindracea* showed a marked seasonal cycle, with an alternation of a long growth period, from spring to autumn, and a withdrawal (resting period) in winter.

Gametogenesis has never been observed in Sicily and in circum-Sicilian Islands (Giaccone & Di Martino 1995; Di Martino & al. 2006; Mannino & Di Giovanni 2011).

Since gametogenesis has been locally observed (e.g. in the South Aegean Sea; Panayotidis & Žuljević 2001), it is likely that sexual reproduction may have contributed to its rapid spread in other parts of the Mediterranean Sea.

Caulerpa taxifolia (invasive aquarium strain)

Since it was officially reported exclusively for the coasts of the Strait of Messina and of Favignana Island so far (Fradà Orestano & al. 1994; Orestano & al. 2001; Profeta & al. 2004; Gianguzza & al. 2006a, b), its spread was very limited if compared to that of *C. cylindracea*. Its presence along the coast of Favignana Island is likely to be a consequence of a secondary anthropogenic introduction (Gianguzza & al. 2006a, 2006b).

According to Di Martino & Giaccone (1996) in the Strait of Messina the complex *C. taxifolia* - *Caulerpa mexicana* Sonder *ex* Kützing would be present. Chisholm & al. (1995) stated that the Mediterranean *C. taxifolia* and the Eastern Mediterranean *C. mexicana* would be conspecific, suggesting its occurrence in the Mediterranean as a result of a biogeographic dispersion instead of an accidental introduction. But later, Jousson & al. (1998) demonstrated that the aquarium-Mediterranean strain of *C. taxifolia* was not related to any specimens of *C. mexicana*, thus invalidating the hypothesis of Chisholm & al. (1995).

A combination of unfavourable intrinsic (e.g. lack of specialized propagules, low propagation speed and/or weakness of the population) and/or extrinsic factors (e.g. hydrodynamics conditions and lack of shipping-trade with the other parts of Sicily) could have stopped its northward and southward expansion and could be also responsible for the regression observed in the Strait of Messina between 2008 and 2009 (Meinesz & al. 2010). The regression and/or disappearance of *C. taxifolia* populations observed in other Mediterranean areas (Iveša & al. 2006; Montefalcone & al. 2015) has also been related to genetic degeneration of the Mediterranean clone and to the presence of parasites (Longepierre & al. 2005; Meinesz & al. 2010). As in other Mediterranean areas, sexual reproduction remains unknown. Transport-stowaway is considered the plausible pathway of introduction for local specimens.

Caulerpa taxifolia, which was also considered established in Sicily, did not behave as a highly successful and fast-spreading species as it did in other Mediterranean areas (Boudouresque & al. 1992; Meinesz & al. 2001; Balata & al. 2004) and as we would have expected from the "alga killer".

Caulerpa taxifolia var. *distichophylla*

As in other Mediterranean regions, it mainly occurs in shallow waters where it can be more easily ripped off and spread (Schembri & al. 2015). Even if it has been recently introduced, it is already established in the area and it is considered a potential threat for the indigenous communities but also for fishing activities, to such an extent that it is considered a real pest (Musco & al. 2014). It has been observed that winter water temperatures might limit its spread to the northern and western parts of the Mediterranean Sea (Jongma & al. 2013).

The occurrence of this alga in association with phanerogams and green algae of tropical-subtropical origin (e.g. *H. stipulacea* and *Penicillus capitatus* Lamarck) would suggest a reorganisation of Mediterranean benthic communities as a consequence of global change (Picciotto & al. 2016). Fertile thalli have not been observed in Sicily so far. Also for *C. taxifolia* var. *distichophylla* the Sicilian coast would be the start of an invasion in the Mediterranean Sea (Musco & al. 2014). Transport-stowaway is considered the plausible pathway of introduction for local specimens.

Sicily, representing the western and northern limit of this taxon (Jongma & al. 2013; Musco & al. 2014), would have been the source of the Maltese populations of *C. taxifolia* var. *distichophylla*. Since the traffic of recreational and/or commercial vessels is very intense between the two islands, shipping is the most likely vector (Schembri & al. 2015). As hydrodynamics conditions do not facilitate the westward and northward spread, secondary shipping could be the vector of its spread along the northern coast of Sicily.

Conclusions

In the Mediterranean Sea, maritime traffic plays an important role in the introduction and spread of alien species, and the Pacific Ocean is the main donor of alien species due to climatic affinities. Since the Suez Canal is considered to be one of the main pathways for the introduction of marine alien species, the creation of a second canal, increasing the number of introductions, will certainly have a strong impact on the Mediterranean ecosystems (Galil & al. 2015). Sicily and circum-Sicilian Islands, at the crossroads between the western and eastern Mediterranean and interested by intense maritime traffic, are particularly vulnerable to biological marine invasions. The fact that many colonized areas were located in the vicinity of harbours, and exposed to human activities (e.g. shipping, tourism, fishing), would support this hypothesis.

Indeed, maritime traffic can produce a constant spillover of new invaders into surrounding areas, making this area an important transit zone and a source for secondary dispersal, highlighting the key role it can play in the circulation of alien species within the Mediterranean Sea. In particular, as highlighted in this study, the southern and south-eastern coasts, bordering the Strait of Sicily, would deserve particular attention.

The three invasive taxa showed different spread dynamics. *Caulerpa cylindracea* and *C. taxifolia* var. *distichophylla* behaved as fast-spreading algae whereas *C. taxifolia* did not behave in the same manner. Divergent spread dynamics between *C. cylindracea* and *C. taxifolia* were already highlighted by Montefalcone & al. (2015) in the Ligurian Sea. As the authors stated, it is not possible to generalize the future behaviour of invasive species in the Mediterranean Sea. Moreover, the evaluation of the spread dynamics of invasive species requires long periods of study (Boudouresque & Verlaque 2012).

For a better understanding of the invasive potential and spread dynamics of alien species such as *Caulerpa* ones, a quick sighthing of any newly colonized area is fundamental (Klein & Verlaque 2008). Moreover, the establishment of regular monitoring programs, as also prescribed by the Marine Strategy Framework Directive (MSFD), including public awareness campaigns (e.g. the Project "*Caulerpa cylindracea* – Egadi Islands" sponsored by the Department of Biological Chemical and Pharmaceutical Sciences and Technologies, University of Palermo and the Egadi Islands Marine Protected Area), citizen science initiatives (e.g. "Seawatchers" available at http://www.observadoresdelmar.es/?idioma=en), online databases or networks such as ELNAIS (Ellenic Network on Aquatic Invasive Species) by the Hellenic Centre for Marine Research (HCMR), available at http://elnais.hcmr.gr, regular surveys and mapping by scientists, are welcome and necessary in order to assess the spread dynamics of those invasive species that raise serious concern. All these activities are fundamental to manage continuous spillover effects, especially in the areas which are more vulnerable to marine biological invasions and along the protected coasts. All information, regularly updated, would allow the creation of permanent observatories and warning systems of detection and if possible of control, but also the planning of suitable management activities.

Lastly, the Mediterranean region, which is described as one of the main climate change "hot-spots" (Giorgi 2006), should become warmer and drier during the 21st century, mirroring the global ocean tendency with an increase of about 3.1 °C predicted in the coming century (Ben Rais Lasram & al. 2010). Undoubtedly, the distribution of marine species, alien and native, in the Mediterranean Sea is currently changing as a consequence of sea-warming. Tropical species are expanding in the southern Mediterranean areas whereas the northern Mediterranean areas are being more and more occupied by thermophilic indigenous species (Bianchi 2007). The possibility of a gradual westward expansion of tropical species has been already predicted by Por (1990). The abundance, distribution and geographic expansion of thermophilic species, alien or indigenous (the so-called phenomenon of "tropicalization", Bianchi & Morri 2003) are expected to increase, as a consequence of sea warming, Atlantic flux, lessepsian migration and human activities. Climate changes, making the Mediterranean Sea a favourable biogeographic area, will certainly facilitate the expansion of alien *Caulerpa* species within this Sea, and directly affect the indigenous macrophyte-dominated ecosystems (e.g. Harley & al. 2012), further confirming that monitoring programs are of great importance to gauge the spread dynamics of these marine alien species.

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