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Introduction of exotic woody plant species in a degraded island ecosystem (Porto Santo in the Madeiran Archipelago)

Abstract

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Assays of introduction and screening of woody plant species were initiated on Porto Santo in January 1990. The aims of the project were: (1) to find suitable species for afforestation in order to diversify the existing, almost monospecific plantations of *Pinus halepensis;* (2) to find species that could be used to control soil erosion; (3) to enrich the assortment of ornamental species for gardening and landscaping; and (4) to compare the performance of autochthonous species and those already adapted to the conditions of Porto Santo with that of newly introduced exotic woody plants. The preliminary results are presented, potentially useful species are identified, and problems related to the introduction of exotics, such as the risk of uncontrolled dissemination, are discussed.

Introduction

Porto Santo is located in the Atlantic Ocean, c. 45 km N.E. of Madeira. It consists of one main island, of 4000 ha, with about 5000 inhabitants, surrounded by 7 small uninhabited islets (Fig. 1). Porto Santo originated from submarine volcanic activity during the Tertiary (12-15 million years ago), and due to subsequent sedimentation and upheavals the island's geology is very complex (Faust-Lichtenberger 1988). Soils vary from loamy aeolian sands to silty clay with stones and boulders and are generally alkaline (pH between 7 and 9). The highest point in Porto Santo is the Pico do Facho, 517 m a.s.l., and another three summits exceed 400 m.

The climate belongs to the dry Mediterranean type. Mean annual rainfall is 380 mm, with about 90 % concentrated on the cooler season, October to April. During the first three years of the project period, yearly precipitation was, respectively, 18 %, 35 %, and 30 % below average. The deficits were even greater for the spring rains (January to April): 61 %, 68 %, and 26 % below average. Northerly winds predominate, and monthly average wind strength varies between 19 km/h in winter and 15 km/h in the calmest month, October.

At its discovery in 1419 the vegetation of Porto Santo was dominated by *Dracaena draco, Juniperus phoenicea* L., *Olea europaea* subsp. *maderensis* Lowe, and *Erica scoparia* L.; species such as *Apollonias barbujana* and *Sideroxylon marmulano* Lowe were other important components of the island's flora (Pereira 1989). During the following 300 years this vegetation was nearly wiped out by agriculture, grazing, and increasing demand for timber and fuel. Grazing also restrained regeneration, and the early (15th century) introduction of rabbits proved fatal to, i.a., *Dracaena.* Today only a few specimens of the island's native woody species, e.g. *Olea europaea* subsp *maderensis, Sideroxylon marmulano,* and maybe the Madeiran endemic *Chamaemeles coriacea* Lindl., have survived on inaccessible cliffs (Robertson & al. 1995).

The first introductions of exotic woody species. – Systematic introduction of exotic woody species began in the 18th Century with *Lycium europaeum* and *Elaeagnus angustifolia* L. Later came, i.a., *Tamarix gallica* L. They were mainly used for fencing and to control erosion. *Phoenix canariensis* Chab. and *P. dactylifera* L. were introduced during the 19th century, together with many other species which are common or commonly grown in Mediterranean countries (e.g. *Araucaria heterophylla, Nerium oleander, Myoporum tenuifolium, Quercus ilex* L., and *Olea europaea* L.).

Afforestation. – Regular afforestation was initiated just before 1900. The dominant species were *Cupressus macrocarpa* Hartw. and *Pinus halepensis,* while others such as *Pinus pinaster* Aiton, *P. radiata* D. Don, *P. pinea* L., *Quercus ilex, Olea europaea,* and a few species of *Eucalyptus* and *Acacia* occur sporadically in the plantations. The shrubby *Atriplex halimus* L. is widespread on the island; it is used for fencing and has penetrated some of the plantations. From the mid-20th Century plantation forestry gained momentum (Campos Andrade 1990). In 1990 c. 300 ha were covered by forests, with *Pinus halepensis* alone accounting for more than 90 % of the trees.

Increased species diversity of woody plants. – The dominance of *Pinus halepensis* on Porto Santo – almost a monoculture – means that the whole afforested area is at risk from potential attack by diseases or pests, or in case of forest fires. Consequently the local Government encouraged research on a broader variety of species in view of their possible use for afforestation on Porto Santo. This research was not to be limited to tree species, but was to include various types of bushes and shrubs for use in a general restoration of the island's vegetation, i.a. to halt the widespread and serious soil erosion.

Procedures and material

The present project was agreed in 1989 between the Regional Government of Madeira and the Danish Land Development Service (Hedeselskabet), and was funded by the European Community. Field work started in January 1990. Trial plots were located and fenced in different areas of the island (Fig. 1), all of them on open, formerly cultivated land between 100 and 350 m a.s.l., more or less exposed to the frequent and strong winds. At the same time propagation of plant material was started at the local nursery belonging to the Madeiran Forest Service. The first plantings in the trial plots took place between October 1990 and February 1991. A second planting was made in April 1992, and a third during January and February 1993.

Seeds were obtained from the Australian Tree Seed Centre, Canberra; the Centre National de Semences Forestières, Burkina Faso; the Danida Forest Seed Centre, Denmark; CIRAD Forêt, Paris; the Henry Doubleday Research Association, Coventry; the Société Versepuy, France; and the Station de Recherches Forestières, Rabat, Morocco. Seeds and cuttings were also collected by the Madeiran Forest Service in Madeira and Porto Santo, and by the author in Morocco (i.a., *Argania spinosa*). Nomenclature is in accordance with standard reference works, such as Hansen & Sunding (1993), Carlowitz (1986), and Boland & al. (1984)

Many of the plants in genera such as *Acacia* and *Eucalyptus* were too young for final verification of their names when the project was closed in 1994. However, preliminary verification by the author did not reveal any obvious error of identification and precludes confusion in the process of collecting and handling the seed and transplanting to the trial plots.

Fig. 1. Map of Porto Santo, showing location of the trial plots. – 1-3, Morenos area (1, Lombo do Mayo Costa Norte; 2, Lombo do Mayo Costa Sul; 3, Cabeco das Flores); 4, Alentejo; 5, Pico do Juliana; 6, Matinho (Pe do Pico).

Table 1. Survival and vigour of plants cultivated in three plots at Matinho, Alentejo and Pico do Juliana. Names of taxa planted Nov 1990./Jan 1991 (3 growing seasons) appear in ***bold,*** contrary to those planted Apr 1992 (2 growing seasons) at Alentejo and Matinho only. – Vigour categories: G = good and healthy plants; N = normally developed plants (with limited damage due to physical and/or biotic factors); B = badly developed plants (scorched, attacked by diseases or, or generally weak). – The first two digits of the accession number (Acc.) stand for the year of accession and sowing of the seed lot; *n* = number of planted specimens.

Taxon	Acc.	Survival (%) 91	92	93	Cat. G (%) 91	92	93	Cat. N (%) 91	92	93	Cat. B (%) 91	92	93	*n*
Acacia blakelyi Maiden	9139	–	60	60	–	0	0	–	0	0	–	60	60	5
cupularis Domin	9141	–	100	60	–	80	33	–	20	27	–	0	0	15
cyanophylla Lindl.	9002	76	76	76	68	58	60	8	15	10	0	3	6	62
cyclops G. Don	9142	–	80	67	–	80	33	–	0	27	–	0	7	15
gummifera Willd.	9001	88	82	71	21	4	1	52	46	25	14	32	45	84
jennerae Maiden	9145	–	90	60	–	40	0	–	0	0	–	50	60	10
ligulata Benth.	9146	–	73	60	–	27	0	–	40	33	–	7	27	15
melanoxylon R. Br.	9003	47	38	23	17	15	10	17	8	2	13	15	12	60
pendula G. Don	9147	–	100	100	–	0	0	–	0	0	–	100	100	5
saligna (Labill.) H. L. Wendl.	9150	–	80	54	–	33	27	–	47	27	–	0	0	15
xanthina Benth.	9151	–	100	60	–	93	13	–	7	27	–	0	20	15
Adansonia digitata L.	9086	30	19	4	0	0	0	4	0	0	26	19	4	54
Albizia lebbekoides (DC.) Benth.	9004	62	52	28	0	2	0	17	5	0	45	45	28	60
lophantha (Willd.) Benth.	9005	45	18	15	25	7	0	20	8	2	0	3	13	60
Apollonias barbujana (Cav.) Bomm.	90102	30	22	13	0	0	7	5	10	3	25	12	3	60
Araucaria heterophylla (Salisb.) Franco[1]	90114	36	27	0	22	22	–	11	4	–	2	0	–	45
Argania spinosa (L.) Skeels	9006	76	76	76	38	24	14	29	48	33	9	5	29	21
Bauhinia rufescens Lam.	9077	23	22	10	3	0	0	15	2	2	5	20	8	60
Cassia siamea Lam.	9073	0	–	–	–	–	–	–	–	–	–	–	–	55
sieberiana DC.	9079	15	0	–	0	–	–	0	–	–	15	–	–	60
Casuarina cristata Miq.	9156	–	100	100	–	0	0	–	0	100	–	100	0	5
cunninghamiana Miq.	9009	55	45	42	2	2	3	7	10	0	47	33	38	60
cunninghamiana Miq.	9157	–	100	100	–	0	100	–	100	0	–	0	0	5
equisetifolia L.	9010	48	42	42	24	10	2	14	25	24	10	7	17	59
glauca Spreng.	9159	–	100	100	–	0	20	–	100	80	–	0	0	5
huegeliana Miq.	9153	–	40	0	–	0	–	–	0	–	–	40	–	5
obesa Miq.	9160	–	100	100	–	67	67	–	0	33	–	33	0	15
stricta Aiton	9011	89	58	47	33	4	0	15	20	0	42	35	47	55
Ceratonia siliqua L. [France]	9007	50	43	40	27	17	0	17	27	33	7	0	7	30
siliqua L. [Porto Santo]	90110	32	32	32	20	18	2	7	5	18	5	8	12	60
Cistus ladanifer L.	9131	–	100	60	–	100	60	–	0	0	–	0	0	5
Combretum aculeatum Vent.	9083	12	4	0	0	0	–	4	0	–	8	4	–	50
micranthum G. Don	9082	0	–	–	–	–	–	–	–	–	–	–	–	50
Cupressus atlantica Gaussen	9008	91	59	56	21	24	21	50	26	26	20	9	9	34
Dodonaea viscosa Jacq.	9012	15	12	12	10	7	12	5	5	0	0	0	0	60
Dracaena draco (L.) L.[2]	90101	68	55	35	18	32	13	37	22	12	13	1	10	60

Table 1 (continued).

Taxon	Acc.	Survival (%) 91	92	93	Cat. G (%) 91	92	93	Cat. N (%) 91	92	93	Cat. B (%) 91	92	93	n
Eucalyptus astringens (Maiden) Maiden	9161	–	80	75	–	75	75	–	0	0	–	5	0	20
brockwayi C. Gardner	9162	–	100	100	–	100	100	–	0	0	–	0	0	20
calophylla Lindl.	9016	40	27	23	7	10	10	17	10	7	17	7	7	30
camaldulensis Dehnh.	9163	–	100	95	–	100	95	–	0	0	–	0	0	20
citriodora Hook.	9015	40	38	38	23	18	15	12	10	10	5	10	13	60
cladocalyx F. Muell.	9165	–	100	100	–	100	100	–	0	0	–	0	0	20
cneorifolia DC.	9166	–	100	100	–	100	100	–	0	0	–	0	0	10
cornuta Labill.	9167	–	90	80	–	90	80	–	0	0	–	0	0	10
ficifolia F. Muell.	9013	60	48	32	30	14	14	20	18	6	10	16	12	50
fraseri (Brooker) Brooker	9168	–	90	80	–	90	80	–	0	0	–	0	0	10
gomphocephala DC.	9169	–	100	100	–	100	100	–	0	0	–	0	0	10
longicornis (F. Muell.) Maiden	9171	–	100	100	–	100	100	–	0	0	–	0	0	10
occidentalis Endl.	9174	–	100	100	–	100	100	–	0	0	–	0	0	10
platypus var. *heterophylla* Blakely	9175	–	100	100	–	100	100	–	0	0	–	0	0	10
salubris F. Muell.	9177	–	100	100	–	100	100	–	0	0	–	0	0	10
sideroxylon Woolls	9014	70	70	70	38	33	42	18	35	25	13	2	3	60
terebra L. A. S. Johnson & K. D. Hill	9179	–	100	100	–	100	80	–	0	20	–	0	0	5
tessellaris F. Muell.	9017	76	73	69	22	22	24	33	29	22	20	22	22	45
woodwardii Maiden	9180	–	90	90	–	90	90	–	0	0	–	0	0	10
Grewia bicolor Juss.	9081	40	20	0	0	0	–	10	0	–	30	20	–	10
Juniperus cedrus Webb & Berthel.	90116	32	20	15	0	0	0	2	5	0	30	15	15	60
Leucaena leucocephala (Lam.) De Wit	9190	–	100	100	–	50	0	–	0	0	–	50	100	10
Lycium europaeum L.	90112	85	80	57	38	18	12	28	50	30	18	12	15	60
Melia azedarach L.	9032	53	62	33	11	5	0	9	5	0	33	51	33	76
Myoporum tenuifolium G. Forst.	90106	67	63	65	58	43	50	7	17	12	2	2	3	60
Nerium oleander L.	90113	98	98	98	75	82	52	23	12	38	0	5	8	60
Olea africana Mill.	9188	–	100	80	–	100	60	–	0	0	–	0	20	5
Parkia biglobosa (Jacq.) D. Don	9074	0	–	–	–	–	–	–	–	–	–	–	–	60
Parkinsonia aculeata L:	9035	88	82	67	7	3	0	18	22	3	63	57	63	60
Pinus brutia Ten.	9040	64	52	48	4	4	16	44	40	28	16	8	4	25
canariensis DC.	9039	50	43	43	43	25	7	4	14	22	4	4	14	25
halepensis Mill.	90103	100	100	98	93	100	98	7	0	0	0	0	0	60
Pistacia atlantica Desf. (France)	9033	76	76	74	4	0	0	50	26	15	22	50	59	46
atlantica Desf. (Morocco)	9034	95	53	58	0	0	0	32	30	15	32	23	43	40
Populus alba L.	90107	40	40	0	0	0	–	0	0	–	40	40	–	5
Prosopis africana (Guill. & Perr.) Taub.	9087	0	–	–	–	–	–	–	–	–	–	–	–	20
cineraria (L.) Druce	9038	25	8	5	0	0	0	7	0	0	18	8	5	60
juliflora (Sw.) DC.	9037	18	7	3	0	0	0	3	0	0	15	7	3	60
juliflora (Sw.) DC.	9183	–	100	40	–	20	0	–	0	0	–	80	40	5
Pyrus mamorensis Trab.	9132	–	90	70	–	50	50	–	40	0	–	0	20	10

Table 1 (continued).

Taxon	Acc.	Survival (%) 91	92	93	Cat. G (%) 91	92	93	Cat. N (%) 91	92	93	Cat. B (%) 91	92	93	*n*
Retama monosperma (L.) Boiss. (Morocco)	9041	85	70	70	35	25	10	25	30	40	25	15	20	20
monosperma (L.) Boiss. (Portug.)	90108	12	12	5	0	0	0	0	0	0	12	12	5	60
sphaerocarpa (L.) Boiss. (Portug.)	90109	6	5	2	0	0	0	0	0	0	6	5	2	60
Schinus terebinthifolius Raddi	9043	93	93	93	93	87	93	0	7	0	0	0	0	15
Simmondsia chinensis (Link) C. K. Schneid.	9044	43	40	40	33	0	0	0	0	3	10	40	37	30
Tamarindus indica L.	9078	27	13	7	0	0	0	8	0	0	18	13	7	60
Thevetia peruviana (Pers.) K. Schum.	9047	84	80	78	35	38	31	38	9	18	11	33	29	55
Ziziphus mauritiana Lam.	9080	12	10	3	5	0	0	7	0	2	0	10	2	60

[1] All *Araucaria* plants in Alentejo were dug up and removed (to gardens?) during 1992 and 1993.
[2] 10 plants of *Dracaena* were destroyed by human action, partly cut down and partly uprooted, March to October 1993.

Results and discussion

From the results of the assays, summarized in Table 1, it appears that there were good reasons for the choice of *Pinus halepensis* as the main species in the Porto Santo afforestation programme. The Aleppo pine is unchallenged with regard to both survival and performance. The plants were produced from seed collected in local stands on Porto Santo.

Myoporum tenuifolium, another species that has been grown on Porto Santo for maybe a century, for amenity and shade, also performed very well in the trials and tended to grow even faster than the Aleppo pine, but is less resistant to wind.

Acacia cyanophylla probably has been grown in gardens and parks of Porto Santo since at least 50 years. The new introduction of this species (French provenance) had a high survival rate and was the fastest growing of all species on trial (while the related *A. saligna* collected in Australia was less convincing). *Nerium oleander* is doing amazingly well under the dry conditions of Porto Santo.

Partly due to wanton destruction, only 35 % of the dragon trees, *Dracaena draco,* survived. Those that remain are generally in good shape, apart from one plot where rabbits did some damage, but they are slow growers, attaining heights of c. 2 m after 20 years.

The other native species, *Apollonias barbujana,* did not respond favourably to the exposed situation of the trial plots, where the plants were scorched by strong winds. However, specimens that were planted 10-20 years ago in the shelter of old plantations are doing quite well.

Among the new introductions a promising species, with regard to strong growth and resistance to wind, is *Schinus terebinthifolius,* originating from seed collected on street trees in Agadir, Morocco.

The endemic Moroccan species, *Argania spinosa, Acacia gummifera,* and *Cupressus atlantica,* are slow starters but good survivors. They give an impression of toughness and could be interesting for afforestation on Porto Santo.

Eucalyptus sideroxylon and *E. tessellaris* are the most convincing among eucalypt species on three-year trial. Other species of *Eucalyptus* and *Acacia* seem very promising after two growing seasons. Most of them were collected in areas close to the ocean in Western Australia.

Preliminary conclusions and recommendations

Growing conditions are very harsh on Porto Santo due to its semi-arid climate exacerbated by frequent and strong winds. Shelter is crucial, and is absolutely necessary if a wider range of woody plant species is to succeed in cultivation on the island. The present project was scheduled to be closed at the end of 1993, after 4 years of trial. This is much too short a period for obtaining conclusive results. Procuring seed of appropriate species is complicated, and most often seed is unavailable when needed. Propagation, which may need much more time than expected, is another bottleneck. Close to 300 different species were sown in the nursery; so far only 80 have reached the trial plots.

The Porto Santo climate belongs to the "infidèle" Mediterranean type. Yearly rainfall, during the four years of observation, was from 17 % to 34 % below average. During the first nine months of 1994 (January to September) only 59 mm were recorded on Porto Santo, and 1994 stands to become the driest among the last fifteen years. A trial period of at least ten years is considered necessary in order to experience the main fluctuations in climate and to obtain reliable results to guide future afforestation and arboriculture on Porto Santo. It is therefore recommended to maintain and develop the current trial plots (varying in size from 0.5 ha to 1 ha) as small arboreta, where the long-term development of the various species can be studied.

It was not possible to include all the autochthonous Porto Santo species in the trials because seed and plant material of some were not available. They all should be tested before definite conclusions are drawn. Concurrently, further trials should be made with other promising exotic species and further provenances.

Pinus halepensis, which has proven its qualities as a reliable pioneer species on Porto Santo, is recommended for the first stages in continued afforestation. However, new plantings of *Pinus halepensis* might be mixed with hardy and fast-growing broad-leaved species such as *Acacia cyanophylla* and other *Acacia* species, which show promise and can improve soil conditions. *Myoporum tenuifolium* should be included on a trial basis in mixed plantings. Some shrubs may also be used in mixed afforestation, e.g. *Retama monosperma* for which the unsatisfactory results with Portuguese material probably can be explained by inappropriate handling of plants in the nursery.

As a next step, well established plantations of *Pinus halepensis* might be transformed into mixed and, hopefully, less vulnerable stands. Indigenous species such as *Dracaena draco, Apollonias barbujano, Olea europaea* subsp. *maderensis,* and *Sideroxylon marmulano* should be planted in the shelter of the pine trees, and such mixed plantations might eventually develop into a forest type reminiscent of the vanished natural forests of Porto Santo. Simultaneously a "pure" Porto Santo forest could develop out of a small 10-year-old plantation of dragon trees into which the indigenous species mentioned above would be introduced together with shrubs such as *Echium nervosum* Dryand. and *Euphorbia piscatoria* Aiton.

Restoration of the natural vegetation will probably be endeavoured only in part of the island. In other areas interesting mixed plantations could be established by using some well surviving but slow-growing introduced species such as *Ceratonia siliqua, Pistacia atlantica, Casuarina* spp., and *Argania spinosa. Quercus ilex* was not included in the trial, but has adapted well to the conditions of Porto Santo and is important in soil conservation because of its deep and strong root system. *Tamarix gallica* should also be borne in mind, particularly in the fixation of moving sands where it already plays an important role on Porto Santo.

Particular care should be devoted to the problem of potentially invasive species. A frightening example is the Macaronesian endemic, *Myrica faya* Aiton, which became an obnoxious weed when introduced to Hawaii during the late 1800s (Smith & al. 1995). *Schinus terebinthifolius* can become invasive, e.g. in Florida and S.W. Europe (Little 1974, Kunkel 1978), but has apparently not behaved as a weed in Morocco where it has been used in amenity plantings under semi-arid conditions since 50 years.

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