ISLANDS AND PLANTS: PRESERVATION AND UNDERSTANDING OF FLORA ON MEDITERRANEAN ISLANDS

2nd Botanical Conference in Menorca
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THE UNIQUE NATURE OF MEDITERRANEAN ISLAND FLORAS AND THE FUTURE OF PLANT CONSERVATION

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Abstract

The biotic originality of Mediterranean islands can be explained by complex interactions between a highly heterogeneous historical biogeography and unique ecological processes linked to various insular conditions. But most of the ups and downs of this unique biodiversity are now closely linked with human population pressures, which have changed many times through the long history of insular systems. These impacts will probably be exacerbated on islands because of no (or highly limited) adjacent areas of expansion. Therefore, conservation and ecological monitoring of small islands and islets must be reinforced, since they constitute major refuge areas with the presence of endemic relict plants, often threatened on the continent.

This global overview presents some key issues for future research devoted to future conservation and monitoring of the Mediterranean islands' plants and habitats.

Keywords: *conservation biogeography, human impact, insular biogeography, islets, Mediterranean islands, mutual interactions, threats.*

THE UNIQUE NATURE OF MEDITERRANEAN ISLAND FLORAS

The unusual geographical, climatic and topographical diversities and the reticulate historical biogeography of the Mediterranean Basin explain the exceptional high plant diversity and endemism of this area, one of the 34 biodiversity hotspots identified around the world (Médail & Myers, 2004). With about 10,000 islands and islets, of which 244 are inhabited by humans (Arnold, 2008), the Mediterranean Sea encompasses one of the largest "archipelagos" in the world. Some Mediterranean countries such as Greece and Croatia, with *ca*. 1150 islands and islets according to Nikolic (2013), encompass a significant number of these islands. Insular areas harbour a significant component of the Mediterranean plant biodiversity, with the presence of narrow endemic plants or range-restricted ones, and the occurrence of genetically isolated populations. Factors explaining the biological unicity of these insular floras are manifold: (i) varied paleogeography and geology, (ii) different geographical situations, (iii) wide ranges of morphology, size (from the biggest island of Sicily with 25,700 km^2 to small islets of a few dozen square meters), or altitude (from 3342 m at Mt. Etna to flat islets of less of one meter).

If the unique richness of Mediterranean insular floras is mainly due to strong environmental heterogeneities between islands, another key factor is the long-lasting influence of man who acts as a major disperser of plants and as a huge «designer» of Mediterranean insular landscapes through burning, cutting, grazing and ploughing. Indeed, the considerable beta and gamma diversities of insular ecosystems are also the heritage of various human activities that have had profound consequences on the distribution and dynamics of species, ecosystems, and landscapes (Blondel, 2008; Vogiatzakis *et al.,* 2008).

For historical and geographical reasons, but also due to the particular biotic interactions between species, insular conditions determine a specific nature of plant assemblages and biodiversity. The percentage of endemism often reaches high levels while there is rather limited plant richness (eg. Whittaker & Fernández-Palacios, 2007). This general insular pattern is also found on the larger Mediterranean islands. Here, plant endemism is generally comprised of between 10-12% whereas the overall range of flora is greater than expected, including between 1,600 and 2,800 taxa (species and subspecies) (Médail, 2008). On insular mountain ranges, endemism level is clearly higher since at altitudes above 1,700 m a.s.l. endemics represent about 35-40% of the vascular flora in Corsica and in Crete.

If the global patterns of taxonomic diversity are now well estimated, at least for large Mediterranean islands (Greuter, 1995, 2001; Quézel, 1995), several gaps of knowledge exist in ecological research and conservation planning. This synthesis proposes some key issues for future ecological and evolutionary research on Mediterranean island plants in order to better assign conservation priorities and biodiversity monitoring.

BIOGEOGRAPHY AND EVOLUTION OF MEDITERRANEAN ISLAND FLORAS

Mediterranean islands represent major refuge areas and conservatories of old, often mid-Tertiary floras with numerous relict plants characterized by a prolonged evolutionary standstill (Médail & Diadema, 2009). The relict nature of Mediterranean island plants is well supported by the presence of palaeoendemics restricted to one or few of these islands, and by the existence of some relicts of the subtropical Tertiary environments. This is the case, for example, for the few populations of the fern *Woodwardia radicans* in Corsica and Crete, and for two small trees of the Elm family, *Zelkova sicula* in Sicily and *Z. abelicea* in Crete.

An outstanding example of the importance of ancient palaeogeography to explain current patterns of plant distribution and biogeographical links concerns the Tyrrhenian islands. The eastern Balearic Islands (Minorca and Majorca), Corsica, Sardinia, and part of Sicily are some of the remnant areas that once belonged to the Protoligurian massif, a west-Mediterranean Hercynian formation that was fragmented in the mid-Tertiary (Oligocene-Miocene), causing notably the rotation and migration of the Corsica-Sardinia block between 23 Ma and 16 Ma. The distribution of numerous Tyrrhenian endemic plants shared among these islands (eg. *Arenaria balearica, Delphinium pictum, Dracunculus muscivorus, Teucrium marum*) reflects this crucial palaeogeographical event. Nevertheless, more recent evolutionary history related to the climatic aridification since the Pliocene (ca. 3.2 Ma) and the onset of the Mediterranean climate influence also the phylogeography of species as suggested by *Thymus herba-barona* (Molins *et al.,* 2011).

In order to explain current patterns of plant distribution and endemism on the Mediterranean islands, two other major geological events must be invoked: the Messinian salinity crisis of the Late Miocene, and the severe cooling episodes along the late Pliocene and the Early-Middle Pleistocene (Tzedakis, 2009). The Messinian salinity crisis was provoked by the interruption of marine relationships between the Atlantic Ocean and the Mediterranean Sea. This has induced an almost complete desiccation of the Mediterranean Sea between 5.96 Myr and 5.33 Myr, with two evaporitic steps. During these two episodes, there were some opportunities for the migration and establishment of drought-resistant plant species as even the major islands were completely joined to the continent. Five million years ago, the beginning of the Pliocene was marked by the return of the sea and this resulted in the final separation of some major islands (Crete and Karpathos, Corsica, Sardinia, Balearic Islands) from the mainland. The second determinant episode is related to several drastic marine regressions that have occurred during the recurrent ice ages at the end of the Pliocene and until the Last Glacial Maximum (*ca.* 18,000 ± 2000 yr BP). Marine regressions consist in more or less severe decreases in sea level, between 100 and 150 m below the current level, inducing the possible terrestrial migration of a more competitive cool-temperate flora on some offshore islands. This is the case of most of the Aegean islands, except Rhodes, the Cyclades and the Crete-

Karpathos island group which remained insular throughout the Pleistocene. On the whole, the contribution of these land-bridge connections is important to explain biogeographical affinities between currently distant and isolated floras. Nevertheless, long-distance dispersal of seeds by birds or marine currents is also relevant to island colonisation but well-documented evidence is still rare except for common halophilous plants (Westberg & Kadereit, 2009). Nevertheless, an eastwards long-distance dispersal is invoked to explain the geographical disjunction of *Armeria pungens,* a disjoint western Mediterranean coastal sand-dune plant, and recent genetic analysis suggests that Corso-Sardinian populations originated from the southwest Portuguese ones (Piñeiro *et al.,* 2007).

If Mediterranean islands have served as important Tertiary and glacial refuges, their role in the local and more recent differentiation of plants is probably equally important. These islands possess highly polymorphic species and vicariant endemic plants stemming from more or less recent speciation events (eg. *Limonium, Centaurea*) (Rosselló, 2013). Isolation and environmental heterogeneity have favoured here diverse evolutionary processes of gradual speciation of plants, such as genetic drift or adaptive radiation. Several well-studied examples are found in the Aegean islands (*Eysimum* sect. *Cheiranthus, Nigella arvensis* complex), where the history of isolation of these multiple islands determine pronounced random plant differentiation following fragmentation of a former contiguous distribution area. Detailed molecular studies in *Nigella* of the Aegean archipelago demonstrate that the main diversification process occurs during Late Pleistocene (Bittkau & Comes, 2009). Therefore, if Mediterranean island floras are in part relict, their evolutionary dynamics are probably underestimated, in particular on small islands subject to harsh and stochastic environmental conditions.

INSULAR BIOGEOGRAPHY AS DETERMINANT OF CURRENT PLANT DIVERSITY

According to the seminal theory of insular biogeography developed by Robert H. MacArthur and Edward O. Wilson in the 1960s, there is a global dynamic equilibrium determining the number of species found on an island. This equilibrium theory of species richness is based upon the balance between species immigration to an island, and extinction from it of local populations, under the influence of island isolation and island area, respectively. Another classic rule is the strong and recurrent relationship between species number and area, but this pattern is not as simple as it may seem since the analysis of the species-area relationships (SARs) reveal a high level of uncertainty across biomes or taxa (Guilhaumon *et al.,* 2008). A study of the species composition of 48 small islands of the Provence archipelago (S.E. France) demonstrates the combined effects of physiographic variables (area, isolation, elevation and substrate) and habitat diversity on plant species richness and composition (Médail & Vidal, 1998). The cornerstone of this relationship is habitat diversity, which increases on larger islands, which have stronger topographical diversity and elevation, favouring the settlement and persistence of plant species and ecosystems not strictly linked to the presence of salt. For the Provence islands, there is a greater random variation in the number of plant species present and in presence/absence of plants on smaller islands (area less than 3.5 hectares) than on larger islands. Small islands are submitted to harsh environmental conditions (continuous sea-sprays and strong winds) but also often suffer greater disturbances (storms, nesting sea gulls), which explains why an important set of plant species cannot survive on islands below a critical size. This «small island effect» is perceptible for islands below 1-3 ha, and for some Aegean islets, a significant increase in plant richness is only detected when the land surface is greater than 500 m in length and has an altitude of at least 50 m a.s.l. (Höner & Greuter, 1988).

Due to the generally small distances of islands from each other and from the continent, the effect of isolation is not always so obvious and it is in general poorly correlated with plant richness. Nevertheless, there are often some striking differences in floristic composition between offshore islets and the roughly similar ecosystems located on the opposite coast, in spite of the reduced physical barrier, the short time of separation and their apparently similar environmental conditions. Furthermore, some remote islands exhibit a floristic pattern quite similar to those of the remote oceanic islands: this is the case of Alborán island (7.1 ha, 15 m a.s.l.) isolated between Spain (85 km) and Morocco (55 km) which includes very limited plant richness (20 species) but with the presence of three endemic plants (*Anacyclus alboranensis, Diplotaxis siettiana, Senecio alboranicus*) only restricted to this flat island (Mota *et al.,* 2006).

One of the most fascinating and intriguing patterns is related to the botanical unicity of each island. Some close islands show very different plant species composition, suggesting the existence of selective plant dispersal through some narrow stretches of sea, as well as random colonisation and extinction processes. For example, the distribution of *ca.* 60 plants species (notably *Campanula, Dianthus, Erysimum, Helichrysum*) restricted to mostly maritime cliffs (chasmophyte plants) of the Aegean show marked differences between islands, even on those less than 10-20 km apart. Recent investigations on Ionian Islands demonstrate indeed the high beta-diversity, i.e. floristic independence, for the Echinades islets group (Panitsa & Eleni, 2013). Despite repeated land-connections linked to sea-level changes during geological times, small distances have played here an effective barrier to plant dispersal, allowing plant population isolation and speciation processes.

INSULARITY, A FACTOR PROMOTING ORIGINAL PLANT DYNAMICS AND BIOTIC INTERACTIONS

Since islands constitute more simplified systems in terms of species richness -notably redundant ones- and ecosystem function, they represent robust "natural mesocosms" to test hypotheses related to the complex links between biodiversity, ecosystem structure and function.

Compared to the continent, island communities and ecosystems are more sensitive to exogenous disturbances and to environmental stochasticity, which promotes often rapid and contrasted dynamics. This is particularly the case of small islands and islets which often house large sea-bird colonies as they benefit from the tranquillity necessary to accomplish their nesting cycle. These colonial seabirds exert high pressure on ecosystems by modifying patterns and dynamics of plant communities. The impact of seabirds on the vegetation is severe, with physical (trampling, pulling-up, soil erosion, burrowing) or chemical (soil manuring induced by guano rich in phosphorous and nitrogenous compounds, salt deposition) disturbances (Vidal *et al.,* 1998, 2000; García *et al.,* 2002). These strong ecological pressures favour the most resistant (ruderal) plants at the expense of oligotrophic stress-tolerant species. Seagulls' influence may lead to severe imbalances for insular communities since (i) they often induce changes in the leaf nutrient status of the dominant plants, (ii) they alter the cover, composition or turnover of the plants, and (iii) they modify interactive processes between species. Besides wind, birds act also as important natural vectors for the dispersal of seeds from mainland or other islands. Thus, passive introductions of new islet plants are indeed frequently observed near nesting colonies of seagulls. The effects of an increasingly large yellow-legged gull *Larus cachinnans* colony on the flora of the Marseilles archipelago were studied through the analysis of floristic changes (*species turnover*) that have occurred in the past 40 years (Vidal *et al.,* 1998). Plant turnover appears to be positively linked to gull nesting density and it is inversely correlated to island area since small islets appear to be more affected than larger islands. Plants with the highest turnover rate were primarily ruderal, annual, wind-dispersed species, with a wide geographic distribution (Vidal *et al.,* 2000). Disturbance by seabirds favours the massive establishment of non-native species which has led to the extinction of some endangered plants on islets characterized by important species turnover.

Because of the intrinsic characteristics of island ecosystems, there exist particular types of plant-animal interactions. One of the most striking examples is the plant-lizard mutualism deeply studied in the Balearic archipelago. Here, endemic lizards (*Podarcis lilfordi* and *P. pityusensis*) acted as probably the only seed dispersers of a native shrub species *Cneorum tricoccon* (Riera *et al.,* 2002) and of an endangered endemic Minorcan shrub *Daphne rodriguezii* (Traveset & Riera, 2005). But introduction of carnivorous mammals in the Balearic Islands has caused a dramatic mutualism disruption, between *Daphne rodriguezii* and *Podarcis lilfordi*. Seed dispersal by lizards is the critical stage that limits population expansion and seedling recruitment, drastically reducing *Daphne* populations, except on the Colom islet where lizards still persist (Rodriguez-Pérez & Traveset 2010). Disperser loss also has a negative impact on the genetic diversity of this *Daphne,* which possesses higher relatedness among individuals for Minorcan populations (Calviño-Cancela *et al.,* 2012). Lizards can also pollinate some coastal Mediterranean plants (*Crithmum maritimum, Euphorbia dendroides*), notably on islets where they occur with a high density and are not threatened by the introduction of exotic carnivores.

Studies of reproductive ecology of plants on small islands appear also relevant to better understand the pollination syndrome occurring in isolated populations when insects are occasional (Pérez-Bañón *et al.,* 2007), or even absent as for the bee-pollinated endemic *Medicago citrina* in the Columbretes archipelago (Pérez-Bañón *et al.,* 2003).

Structuration / continent	Functioning
Plant communities with original floristic composition	Specific functional processes (flux, biotic interactions)
Poor communities with few redundant species	Impacts exacerbated by exogenous disturbances
Higher abundance of rare, endemic and relict species, often in range limit	Inflation density: relaxation of competition processes / expansion of ecological niches
Isolated populations, with few individuals	Processes of genetic differentiation (genetic drift, founding effects) and local adaptation
Communities subject to drastic ecological stress, with important stochasticity	Huge spatio-temporal fluctuations of plant richness and composition

Table 1. Main patterns determining the ecological and functional importance of small islands

THREATS TO MEDITERRANEAN ISLAND PLANTS

If the coupled natural and human influences contribute to the extreme heterogeneity and the biotic originality of Mediterranean islands (Vogiatzakis *et al.,* 2008), the current main threats faced by the island biodiversity are mostly due to direct and indirect human impacts.

Evidence of early insular colonisation by man are still debated in the Mediterranean, but a lower Palaeolithic occupation dated to at least 130,000 years ago in southern Crete (Plakias region) suggests that the early "inhabitants" reached this island using sea craft (Strasser *et al.,* 2010): this finding could push the history of seafaring in the Mediterranean back by more than 100,000 years! But the first proofs of long human presence on an island seem to occur on Cyprus -where the settlement of Mesolithic hunter-gatherers dates back at least 10,000 years b.C. and the development of agriculture occurs between 8700-8000 years b.C. (Guilaine *et al.,* 2011). Nevertheless, it is still highly difficult to assess the magnitude of plant extinction induced by man during Holocene history. The local disappearance of the Dwarf-Palm (*Chamaerops humilis* L.) in Crete during the Antiquity, because of over-exploitation, constitutes a rare well-documented case, already mentioned by Theophrastus (Amigues, 1991).

Current human-induced threats are manifold in the Mediterranean region and they can be ranked by decreasing order of global importance: urbanization, tourism and recreation, environmental changes (land-use and global warming), biological invasions, fires, collecting pressures.

The major islands are usually characterized by an increase in human population, whereas smaller islands (except some hotspots of tourism such as Capri, Corfou, Djerba) are subject to a clear demographic decline. Since the 1960s, tourism on islands has increased extensively, with a height on some Balearic Islands (Majorca and Ibiza) where a peak was reached in 2000-2001 with 11 million tourists. Therefore, on the Balearic Islands (López *et al.,* 2013), it is estimated that urbanization and infrastructure explain one third of the current threats concerning the 180 threatened plant taxa. This huge human pressure induces a strong urban development, which is concentrated along the coasts, destroying or threatening several fragile ecosystems such as sand-dunes and wetlands, and to a lesser extent, coastal rocky habitats. For example, on the Greek island of Skiathos (N. Sporades), tourism development since the 1970s has produced an 80% reduction of these coastal ecosystems.

Changes in agricultural and livestock farming extending inland have caused a recent collapse of the traditional Mediterranean triptyque of land-use (agriculture, grazing, forestry), which has moulded insular landscapes over several centuries (Rackham & Moody 1996; Blondel, 2008). Diverse trends in landscape dynamics cause major modifications to the structure and composition of ecosystems. In the western part of Crete, human immigration from arid mountains has lead to the decline of agricultural land surfaces by 39% between 1945 and 1990, and favoured expansion and the densification of forest ecosystems dominated by *Cupressus sempervirens* and *Pinus brutia*. On the contrary, high shrublands and natural forests of eastern Sardinia have diminished by 35% between 1955 and 1996, whereas grazing, burned low shrublands and deforestation are progressing. On this island, and on other smaller islands of the Aegean, uncontrolled grazing by sheep and goats can lead to overgrazing and even to desertification, i.e. land degradation under arid and semi-arid climates. Landscape dynamics are more contrasted in Corsica, because if land-abandonment determines a global increase of shrublands and forested areas, frequent fires linked to illegal pastoral practices can counterbalance this trend.

Islands of the world have proven to be especially sensitive to biological invasions in both frequency and the degree of impact when compared to the continent (Whittaker & Fernández-Palacios, 2007). Invasions often modify population dynamics, community structure, the composition and functioning of ecosystems and may accelerate the extinction of indigenous plants. Mediterranean islands and islets are also in places seriously threatened by aggressive alien plants, notably along coasts, in lowlands and along rivers. Exotic plant species represent 17% (473 taxa) of the Corsican flora but only

6% of which are well established (171 naturalized taxa), 9.2% (184 taxa) of the Sardinian flora, and 8.4% (124 taxa) of the Balearic Islands' flora. Small islands are probably the most threatened by plant invasions (Pretto *et al.,* 2012). Some these most invasive plants are *Acacia* spp.*, Ailanthus altissima, Carpobrotus* spp.*, Cortaderia selloana, Opuntia* ssp.*, Oxalis pes-caprae* and *Senecio angulatus.* Comparative studies conducted on several large Mediterranean islands demonstrate that impact depended on the identity of the invasive plant and the invaded island, suggesting that impact of invaders is context-specific (Traveset *et al.,* 2008).

Climatic changes represent a new threat for the persistence of several insular plant populations and communities, notably those linked to temporary wet habitats. This is the case of *Apium bermejoi*, a narrow endemic of Minorca located in a single area of 50m^2 where the *ca.* 100 individuals occupy only one square meter; this critically endangered plant (CR *sensu* IUCN) is highly vulnerable to prolonged drought period and its present decline is probably related to a series of dry summers (Moragues & Mayol, 2013). Regarding Cyprus, several populations of narrow endemics (*Sideritis cypria*, *Onosma caespitosa*, *Salvia veneris*) are also threatened by the strong reduction of annual rainfall (less than 20 to 40%) and the significant increase in temperatures (Kadis, 2013). Climate change will strongly affect orophilous plant diversity, species turnover and local endemics of the mountain zones, notably the spatially-restricted sub-alpine and alpine areas, as in the Lefka Ori massif of Crete (Kazakis *et al.,* 2007).

But despite these diverse threats and the fact that a large number of endemic plant species are narrowly distributed on a single island with few populations, only a reduced number of endemics seem to have still become extinct on the Mediterranean islands. Of the about forty Mediterranean plants presumed extinct, ten species are strictly insular endemics (Blondel & Médail, 2009). Two of these species are only extinct in the wild, *Lysimachia minoricensis* from Minorca and *Diplotaxis siettiana* from the Alborán islet, but in this latter case plant reintroduction was successful. Sicily seems to be the most impacted island with the extinction of four endemics (*Allium permixtum, Anthemis abrotanifolia, Carduus rugulosus, Limonium catanense*) and one from Lampedusa (*Limonium intermedium*). Over the course of history, Sicily has been at the crossroad of important trading routes and human presence has impacted ecosystems over an earlier and more constant period than on the Italian peninsula. Human activities caused a huge retraction of woodlands that occupy at present only about 10% of Sicily, mostly on Mount Etna and in the northern mountains (Madonie, Nebrodi, and Peloritani). In the eastern Mediterranean, two endemic species from the Thasos island (N. Aegean) (*Geocaryum bornmuelleri* and *Paronychia bornmuelleri*) are presumed extinct, and one endemic pink (*Dianthus multinervis*) from the remote islet of Jabuka in Croatia.

On large islands, the percentage of taxa that are threatened ranges from 2% (Corsica) to 11% (Crete). In Corsica, as much as 90% of the local extinct plants (74 taxa) occurred in low altitude, between 0 and 800 m a.s.l., and they were mainly located in arable fields, wetlands, coastal areas and rocky grasslands (Verlaque *et al.,* 2001). Therefore, the flora of Mediterranean islands is on the whole deeply threatened, especially the endemic species that grow in low altitude habitats and in wet habitats.

IMPORTANCE OF SMALL ISLANDS AND ISLETS FOR PLANT CONSERVATION

Most of the ecological studies carried out were devoted to large Mediterranean islands, but even the smallest ones should be better investigated since several studies point out their high biotic originality and their often high taxonomic diversity considering their reduced size: this is the case of the satellite islands of Sicily (Pasta and La Mantia, 2013) or the Balearic Islands (Rita and Bibiloni, 2013).

From the taxonomic diversity point of view, several comparative inventories demonstrate that small islands (i.e. size < ca. 1000 ha) play a disproportionate role for the magnitude of plant richness. On 71 satellite islands of Sardinia -which represent only 1.1% of the total surface of the main island- 1,200 plants were censused on the whole, i.e. almost half of the total Sardinian flora. In Corsica, 39 properly censused islets harbour 534 plant taxa, i.e. 21.6% of the whole Corsican flora on only 0.025% of the total surface of the main island (Serrano, 2008). The same pattern is found for the flora of the satellite islets of the Balearic Islands: 654 species occur on 91 islets, i.e. 40% of the flora of this archipelago, whereas 30% of these micro-insular plants are present on a single islet (Rita & Bibiloni, 2013).

Within these highly spatially-reduced territories occur rapid micro-speciation processes, and the combination with particular biotic assemblages and interactions between species favour the presence of some «islet specialists» (Höner & Greuter, 1988). These plants grow exclusively or are very abundant on these islets, but not on the mainland or on the closest larger island. They are often adapted to some disturbance or stress (ruderal and stress-tolerant strategies *sensu* Grime) and are salt-tolerant, but not strictly halophilous. Some possess a large pan-Mediterranean distribution (*Allium commutatum, Hymenolobus* *procumbens, Lavatera arborea*), others constitute narrow endemics (e.g. *Atriplex recurva* and *Silene holzmannii* in the Aegean islands, *Nananthea perpusilla* and *Silene velutina* on some satellite islets around Sardinia or Corsica, *Euphorbia margalidiana* on a unique Balearic islet). Their distribution and abundance can be explained by their optimal specialisation to the highly harsh and unusual environmental conditions of these islets. Islet specialists often possess a good ability for dispersal by sea drift over distances of hundreds of kilometres since floating diasporas can stand up to a month in the sea water.

Another interesting pattern is that small offshore islands can determine extreme limits of geographical ranges for some range-restricted plants. This is the case for the island of Zembra, which harbours the southernmost populations of some plants located mainly in Italy-Sicily (*Erodium maritimum, Iberis semperflorens*) or in the eastern Mediterranean (*Sarcopoterium spinosum*) and that are absent from the close (ca. 10 km) Tunisian continental coast. This pattern is also found on the Hyères archipelago, a remnant of the ancient Protoligurian massif, sheltering several Tyrrhenian endemics (*Delphinium pictum, Ptilostemon casabonae, Teucrium marum*), which are totally absent along the close mainland of the siliceous Provence, even though environmental conditions are similar.

Because of their significant number (more than 1,500 for the western Mediterranean), small islands and islets encompass a large range of environmental and biogeographical situations, forming suitable "experimental laboratories" to test evolutionary and functional hypothesis which are useful for a better implementation of conservation efforts. Small islands also represent current refuges of very scattered or highly threatened plants with regards to the disproportionate human impacts destroying the coasts of the mainland, and they need therefore to be included in international conservation networks. This task represents the main objective of the "Small islands initiative" ("PIM: Petites îles de Méditerranée") launched by the French Conservatoire du Littoral in 2006 (Renou, 2012).

WHAT IS NEEDED FOR THE FUTURE OF MEDITERRANEAN ISLAND FLORA CONSERVATION?

The complicated historical biogeography of the Mediterranean islands has induced the persistence of original and relict floras, but it has also favoured repeated local extinctions and re-colonisations of specialized plants. Therefore, the future of their conservation planning should be included within a conservation biogeography schedule (Ladle & Whittaker, 2011) in order to furnish the prerequisite tools for the identification of the most threatened plants and the crucial conservation areas in today's context of global change. Here, I propose some key issues for future research, in order to improve conservation and management of ecosystems and plant diversities on the Mediterranean islands and islets.

Prioritising scientific knowledge in order to increase conservation planning efficiency

i) Understanding evolutionary and biogeographical processes

Phylogenetical and phylogeographical studies have demonstrated the complex and reticulate historical biogeography of the Mediterranean region and the importance of large islands as reservoirs of unique genetic lineages, notably for most endemics and narrowly distributed plants (Médail & Diadema, 2009). Nevertheless, the time frame and evolutionary consequences of biogeographical events linked to repeated cycles of island connections and isolation, in relation to marine regressions-transgressions, remain largely unknown (Mansion *et al.,* 2008). This is particularly worrying because these aspects are essential for an optimal evolutionary conservation of these heterogeneous insular floras.

There is increasing evidence that primary speciation induced by geographical isolation (mainly by vicariance events), followed by inter-specific gene flow is deeply involved in the diversification and cryptic speciation in several insular plant groups of the Mediterranean (Rosselló, 2013). The few studies examining intra-island phylogeographies of endemic plants demonstrate the frequent split of populations into several isolated and genetically divergent lineages, and their persistence in some particular areas, an "island beneath island syndrome" (Bauzà-Ribot *et al.,* 2011). The narrow Balearic endemic *Senecio rodriguezii* exhibits a high number of haplotypes restricted to some small areas, probably shaped by the repeated cycles of sea-level changes during the Quaternary (Molins *et al.,* 2009), whereas for the Corso-Sardinian endemic *Mercurialis corsica*, AFLP markers allow to detect a clear geographical isolation of the Cap Corse genotypes in N. Corsica (Migliore *et al.,* 2011). This kind of genetic study also appears useful to perform the distinction between different Evolutionary Significant Units (ESUs) and for evolutionary conservation planning.

Despite a long tradition of studies concerning rare insular plants and endemics, a focus on the evolutionary process of this distinct component is still necessary (Rosselló, 2013). Phylogenetic studies have to be used to better assess endemic species' categories -and not only the classical categories based upon chromosome numbers and polyploidy level (Favarger & Contandriopoulos, 1961)- and to evaluate the spatial restriction of phylogenetic diversity, termed *phylogenetic endemism* by Rosauer *et al.* (2009). Some recent studies concerning continental regions point out that there is a non-random relationship between evolutionary distinctiveness and geographical rarity of species: rare species possess high levels of evolutionary distinctiveness (Tucker *et al.,* 2012; Taberlet *et al.,* 2012), and this pattern should be tested for insular Mediterranean floras of various sizes.

On short time-scales, mitigation of biodiversity loss requires estimation of populations and community responses to rapid environmental changes. This concern relies on the emerging concept of evolutionary rescue, "*the idea that evolution might occur quickly enough to arrest population decline and allow population recovery before extinction ensues*" (Gonzalez *et al.,* 2013).

Therefore, many more studies are needed: (a) to better define insular refuges at the scale of an archipelago or a larger biogeographic area; (b) to predict hotspots of evolutionary distinctiveness (evolutionary hotspots), based notably on endemic and rare plants; (c) to develop fine and local phylogeographies for conservation planning on the island scale; (d) to distinguish cryptic diversity linked to independently evolving lineages; and (e) to estimate short term evolutionary rescue of plants or communities.

ii) Reconstructing palaeoenvironments and estimating the magnitude of ancient human impacts

Due to their confined environment and their contrasted histories of human impacts, Mediterranean islands form suitable systems to better evaluate the influence of man on the structure and function of ecosystems and landscapes, but also to understand the dynamics of current biodiversity. Palaeoecological studies must indeed be developed (i) to obtain a better knowledge of past environments between and within islands, (ii) to infer vegetation dynamics in relation to human impact *versus* climatic forcing (eg. Djamali *et al.,* 2013), (iii) to identify tipping points of ecological collapse, and (iv) to propose suitable trajectories for ecological restoration. These results could also furnish new insights for the long-lasting debate about the nature of Mediterranean environments: the "lost Eden paradigm" *versus* the "cultural landscape paradigm" (Blondel, 2013). If palaeoecological data exists for some large islands (Corsica, Sicily, Malta, Balearic Islands), almost no data is available for medium and small islands, and this precludes a good estimate of vegetation dynamics and ecosystem naturalness.

iii) Identifying key biological interactions and ecosystem functions

Since functional diversity is often correlated with island area, isolation index, elevation and island age, it appears desirable to confront these aspects with a various range of insular conditions. Processes of interactions among organisms are related to ecosystem services that plants provide. But there are too few studies linking biodiversity of a community to ecological function and the delivery of ecosystem services for Mediterranean islands. Most of the works concern the biology of plants on large oceanic islands (eg. Bramwell & Caujapé-Castells, 2011), and there is indeed a serious need to identify the main functional drivers of biodiversity loss for continental and small Mediterranean islands because the magnitude of processes will be highly different among islands. The diversity of Mediterranean island situations should facilitate their integration as laboratories of testing grounds of extinction in relation to global change and human pressures. A worrying case is related to the disproportionate and detrimental effects of biological invasions on small islands. Despite several research projects, it appears still necessary to better evaluate the links between native species diversity and invasion by alien species and their consequences on ecosystem functions.

Insular systems have probably suffered from several dramatic losses of community function incurred by species extinction, especially on trophic-oversimplified small islands that exhibit particularly low resilience. But very few studies have taken into account the magnitude of biological interactions for rare or threatened taxa, whereas this represents proactive research to mitigate mutual disruptions or species extinction. Therefore, future research should identify key processes of biological interactions, quantify the loss of functional diversity and estimate the biogeography of functional diversity loss.

iv) Considering the spatial congruence between biodiversity levels and protected areas

The global taxonomic diversity of insular plants is now quite well-known for the largest Mediterranean islands, but serious gaps in knowledge persist for smaller islands; precise and current plant inventories (performed according a consistent taxonomic reference) are still scarce on some archipelagos, even for medium islands. These approaches are useful but they are not sufficient.

To date, most past and current conservation strategies in the world have focused on taxonomic diversity (TD) in order to protect threatened, endemic or total species. But the most widely used TD indicator, i.e. species richness, is uninformative about functional and phylogenetic differences among species, whereas phylogenetic diversity (PD) and functional diversity (FD) are both recognized as important components of biodiversity, respectively for ensuring ecosystem functioning and for assessing an evolutionary history of conservation interest (Diaz *et al.*, 2007). Phylogenetic diversity (PD) represents the accumulation of evolutionary adaptations in a group of species and may be related to evolutionary potential of those species. It is also often positively correlated with ecosystem function such as primary productivity (Cadotte *et al.*, 2009). Measuring PD in species assemblages appears to be a way to explain the role of species interactions and biogeographic history in community structures and composition. This refers to the fast-growing field of ecophylogenetics (Mouquet *et al.,* 2012). Functional diversity (FD) reflects the diversity of morphological, physiological and ecological traits within communities and is a way to explain ecosystem functioning. Plant traits determine where a species can live, how species interact with one another and the contributions of species to ecosystem functioning.

Therefore, recent results highlight the need for effective conservation planning measures that rely not only on the maintenance of species, but also on functional and evolutionary processes at different scales, and that incorporate multiple and complementary conservation indicators (Pio *et al.,* 2011). Gap analyses are also necessary to evaluate the proportion of each biodiversity component included and excluded from existing protected area networks. Areas of mismatch and congruence between biodiversity and protected areas will allow for the evaluation of short-term efficiency of current conservation policies and should include the deep uncertainties linked to global change on insular systems.

Some proposals for the future monitoring and conservation of Mediterranean islands' plants and habitats

i) Developing long-term monitoring in relation to global change

Because of an increase in key threats across the Mediterranean region (Underwood *et al.,* 2009) and the detrimental consequences of climate change here (Klausmeyer & Shaw, 2009), it appears increasing necessary to observe, monitor, and analyse vegetation and plant biodiversity changes through ecological and biogeographical gradients. Networking long term research sites and observation plots should become an integral part of biodiversity management and this monitoring must be coupled with functional-demographic studies, such as the analysis of consequences induced by extreme climatic events on the recruitment of keystone tree species (Matías *et al.,* 2011), or relict and threatened plants (eg. Hampe & Arroyo, 2002).

Mediterranean islands, notably the small ones, form favourable sites for these long-term biodiversity observations and monitoring at various spatial scales. Since the ecological consequences of global changes are highly complex, "natural insular microcosms" constitute indeed relevant systems to study adaptation to climate change of taxa or communities. As proposed by the Small Mediterranean Islands Initiative (PIM), a network of "Sentinel islands" where environmental and biological parameters would be censused using common methodologies, could allow a better understanding of the rate of environmental change, in order to mitigate biodiversity loss (Renou, 2012).

ii) Needs for a global insular ecology framework and to develop / reinforce cooperative networks

In the context of the biome crisis of the Mediterranean basin (Hoekstra *et al.,* 2005), islands constitute key biological systems to ensure both the preservation of plant biodiversity and the sustainable development of human activities. Because the most important changes in flora, vegetation and insular landscapes are, and will be, induced by human practices, the only sustainable solution depends on a systemic and interdisciplinary approach of biodiversity conservation considering the diverse socio-economic trajectories of each island. Therefore, it is necessary to develop ambitious integrated programmes taking into account biodiversity and ecosystem preservation, human well-being, and socio-economic trajectories as stated in the Millenium Ecosystem Assessment (Wong *et al.,* 2005). To perform integrated island systems management, a global ecology perspective is needed in order to prioritise actions in relation to the unicity and vulnerability of insular biodiversity but also according to the high economic vulnerability of Mediterranean islands (structural handicaps, low diversification of production, and high exposure to international and local fluctuations). It would be relevant to combine reactive approaches on the most threatened (often largest) islands, and proactive approaches on relatively less threatened islands (notably small islands and islets). From a biological and socio-economical point of view, it is necessary to launch international programmes to go beyond strict administrative frontiers. Ecologists and land-managers have to better consider the biogeographic dimension of insular biodiversity by developing trans-national actions of conservation biogeography defined as the *« Application of biogeographical principles, theories, and analyses, being those concerned with the distributional dynamics of taxa individually and collectively,* *to problems concerning the conservation of biodiversity* » (Whittaker *et al.,* 2005).

Cooperative networks between insular stakeholders should be implemented, notably between the European conservationists and those from the southern and eastern part of the Mediterranean. These tasks could be performed on a global biogeographical scale and on the island scale (Table 2). The Small Islands Initiative (PIM) of the French Coastal Protection Agency ("Conservatoire du Littoral") is a good example of this kind of international network between scientists and site managers of these insular microcosms (Renoud, 2012). There was also an IUCN plant specialist group devoted to Mediterranean island plants (Montmollin & Strahm, 2005). Unfortunately, this group is going to be included within a larger one devoted to the whole Mediterranean region, but it would be important to maintain in the future some "insular specificity" for this IUCN/SSC group. Otherwise, as for species, IUCN launched a few years ago a global process to establish a Red List criteria for threatened ecosystems (Rodríguez *et al.,* 2011), and this risk assessment system should be implemented between Mediterranean islands of the same biogeographical unit. For Mediterranean Europe, European projects, notably LIFE projects devoted to habitat and plant conservation, should be implemented like those successfully established in Crete (Thanos & Fournaraki, 2013) or in Minorca (Cardona *et al.,* 2013).

On the island scale, several interesting tools exist on some islands, and they could be beneficial in other insular conditions: (i) the concept of plant micro-reserves (PMRs) proposed by the Generalitat Valenciana in 1993 is a relevant implementation to protect taxa with a limited distribution, notably narrow endemics. This was already performed in Western Crete (7 PMRs) and on several Croatian islands, and this approach is ongoing in Minorca (24 PMRs are selected according to Fraga *et al.,* 2013) and in Cyprus (5 PMRs); (ii) the French coastline conservation authority "Conservatoire du Littoral", created in 1975, is an efficient structure to purchase coveted coastal sites that become inalienable. In Corsica, 68 sites have already been acquired, representing more than 18,000 hectares and 295 km of coasts, i.e. 20% of the coastline of the whole island; (iii) under the French environment ministry, the network of the National Botanical Conservatories ("Conservatoires botaniques nationaux") constitutes an efficient organisation devoted to the knowledge and the conservation (both *in-situ* and *ex-situ*) of local flora. In Corsica, the "Conservatoire botanique national de Corse" created in 2008, has undertaken several important actions in particular to increase the botanical knowledge of this highly heterogeneous island and to preserve the native flora.

If insular systems still represent fascinating ecological systems, they also form key entities to disentangling the role of environmental *versus* human pressures for the long-term maintenance and conservation of these biodiversity hotspots. Therefore, due to their unicity and fragility, Mediterranean islands, even the smallest ones, urgently need comprehensive and ambitious conservation planning for the long-term preservation of this outstanding biotic heritage. If we consider with Ricklefs & Cox (1978) that «*Each island population is an evolutionary unit with ecological changes occurring independently on each*», conserving the unique flora of the Mediterranean islands constitutes a disproportionate and highly complex task, but of major priority.

Insular biogeographical scale	Island scale
To perform an inter-island analysis of conservation priorities (with common databases), including comparative perspectives of territorial dynamics between islands	To include some medium-sized islands within the MAB Biosphere Reserve network (eg. the Gozo case in Malta)
To establish a IUCN Red List evaluation of threatened insular ecosystems at the relevant biogeographical scale	To develop integrative conservation frameworks between scientists and stakeholders
To develop the PIM initiative together with an Important Plant Areas (IPAs) programme devoted specifically to the Mediterranean islands	To establish networks of insular Plant Micro-Reserves (PMRs)
To develop European (LIFE) or trans-Mediterranean projects for biogeographical conservation of insular plants and habitats between islands	To extend some efficient national initiatives: - Protected coastal areas of the Conservatoire du Littoral in France - National botanical conservatories

Table 2. Some topics to develop cooperative networks of plant and habitat conservation, between and within Mediterranean islands

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