Chapter

Conserving Endemic Plant Species in Oceanic Island's Protected Areas

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Abstract

Oceanic islands are known for their high levels of plant diversity, due to disjunct geographical distribution that leads to speciation. The main factors contributing to genetic speciation includes the creation of a barrier within a previously widely distributed taxon and the limited dispersal of seeds, which favours genetic differentiation and, thus, fosters rapid speciation. Plant survival and population fitness vary according to environmental factors and to human interference. This chapter depicts the importance of oceanic islands as biodiversity hotspots, discusses the threats to which endemic plants on islands are exposed, namely climate change, invasive alien species, urbanisation, touristic activities, fire, changes in agriculture practices and collecting pressure. The best practices worldwide to protect endemic plant species in protected areas are also addressed, namely the implementation of prevention and mitigation actions, the programs executed to protect endemic species, and management plans to avoid future threats.

Keywords: small islands, vegetation, invasive alien species, climate change, endemism, conservation

1. Introduction

Oceanic islands are those that never had a connection to continental land masses, being generally composed of volcanic rock, reef limestone or both. Those of volcanic origin are formed over oceanic plates, being a product of volcanism or tectonic uplift. These islands tend to be steep and relatively high for their area and, over time, become highly sheared due to erosion processes. Usually, they lack native mammals and amphibians, but a fair number of birds and insects, as some reptiles are usually present [1]. Not classified as "real" islands, atolls and reef are marine habitats islands, built up by small coelenterate animals (corals) that secrete a calcareous exoskeleton. These form an annular reef rim surrounding a central lagoon, with the rim being more or less occupied by calcareous sand or coral shingle and rubble [2], such as the reef islands of the Maldives, the Solomon Islands, the Bahamas, the Tarawa atoll in Kiribati, and many other islands and atolls in the Pacific Ocean. Coral islands tend to be very low-lying and flat; some only raised a few meters above sea level [1]. As defined by Paulay [3] all these are considered oceanic islands (**Figure 1a** and **b**).

Oceanic island are mainly small islands, which are defined as those which present less than 10,000 km^2 [4]. The largest oceanic island on Earth is Iceland, with more than 100 thousand square kilometres, but all the other oceanic island

Figure 1.
Examples of oceanic islands: left: S. Miguel, one of the nine islands of the Azores volcanic archipelago; right: an atoll at the Maldives, one of the 1192 coral islands that are grouped in 26 atolls.

are much smaller, being New Britain (Papua New Guinea), Grande Terre (New Caledonia), Negros (Philippines), and Hawaii (USA), the other large oceanic islands.

Besides these, there are millions of small islands and islets. **Table 1** states these small oceanic islands and oceanic archipelagos throughout the globe, being referred the main island of the archipelago (if any), the size, and the location. To avoid being over-exhaustive in this analysis, only the main oceanic island of each archipelago is presented, in addition to the isolated islands.

In contrast to oceanic islands, continental islands were joined to continental land in the past, namely during the Quaternary ice ages, and becoming separated owing to sea level rise or to tectonic events, and still sit on the continental shelf. As such such, terrestrial mammals and amphibians are usually present [1, 3]. Most of the larger islands are of continental origin, such as Greenland, New Guinea, Borneo, Madagascar, Baffin Island, Sumatra, Honshu, Victoria Island, or Great Britain.

Oceanic islands are usually smaller, younger, more isolated from the continent, more isolated from the nearest neighbour island and present less plant species than continental islands [5]. Their climate has, evidently, a strong oceanic influence, with the low islands being much drier and the high islands presenting heavy orographic rainfall. Most oceanic islands have freshwater reservoirs, both volcanic and atolls, which depend on rainfall percolating through the island. Small islets, however, may lack such lens, being therefore adverse for plant growth [1].

When a new island emerges, an ecological succession begins with the species that were able to reach the land colonising the island but subjected to island isolation. High dispersal capabilities are more likely to overcome distance, which determines that plants, birds, and insects, for example, are much more common on islands than other taxa with lower dispersal capacity. Of the newly arrived species, only a few will be able to survive and establish new populations. As a result, islands have fewer species than mainland habitats. Island populations are small, exhibit low genetic variability and are isolated from the predators and competitors with which they initially evolved [6]. These small islands are also known to present high levels of endemism, mainly due to disjunct geographical distribution and limited dispersal of seeds. These favour genetic differentiation, which, in turn fosters endemism [7–9]. These endemisms have small population distribution, and present low competitive ability [6].

The isolation and small size of the oceanic islands makes them very vulnerable, highly susceptible to threats such as climate change, natural catastrophes, coastal erosion, seawater intrusion, and overexploitation of natural resources [10]. They are also very vulnerable to invasive alien species, that compete with the native taxa,

Main island	Is. area [km^2]	Archipelago (Ac)	Ac area [km^2]	Country	Ocean	Coordinates
Iceland	102,775			Iceland	Arctic	64°08′N 21°56′W
Santorini	73	Cyclades	2,572	Greece	Mediterranean	36° 23′ N 25° 27′ E
Lipari	37	Aeolian Islands	115	Italy	Mediterranean	38°28′N 14°57′E
S. Miguel	759	Azores	2,351	Portugal	North Atlantic	37°44′28″N 25°40′50″W
Tenerife	2,034	Canary Islands	7,493	Spain	Northeast Atlantic	28°28′N 16°15′W
Santiago	991	Cape Verde	4,033	Cape Verde	Northeast Atlantic	14°55′N 23°31′W
Madeira	740	Madeira	801	Portugal	Northeast Atlantic	32°39′N 16°55′W
Bermuda	53	The Somers Isles		UK	Northwest Atlantic	32°18′N 64°47′W
New Providence	207	Bahamas	13,878	Bahamas	West Indies, Atlantic	25°4′N 77°20′W
Fernando Noronha	18	Atlantic Islands	26	Brazil	Southwest Atlantic	3°51′13″S 32°25′25″W
Montague	120	South Sandwich Islands	3,903	UK	South Atlantic	58°25′S 26°23′W
Tristan da Cunha	96	Tristan da Cunha Islands	207	UK	South Atlantic	37°4′S 12°19′W
Heard	368	Heard Isl. & McDonald Isls.	371	Australia	Atlantic (Antarctic)	53°06′S 73°31′E
La Grande Terre	6,675	Kerguelen Islands	7215	France	Atlantic (Subantarctic)	49°20′55″S 70°13′09″E
Île de la Possession	67	Crozet Islands	352	France	Atlantic (Subantarctic)	46°24′S 51°46′E
Bouvet	49			Norway	Atlantic (Subantarctic)	54°25′S 3°22′E
Guadeloupe	1,628	Antilles volcanic arc	14,364	France	Caribbean Sea, Atlantic	16°02′04″N 61°41′56″W
Grande Comoro	1,147	Comoros Islands	1,861	Comoros	Western Indian	11.699°S 43.256°E
La Réunion	2,511			France	Western Indian	21°06′52″S 55°31′57″E
Malé	8	Maldives	300	Maldives	Indian	4°10′31″N 73°30′32″E
Diego Garcia	30			UK	Indian	7°18′48″S 72°24′40″E
St. Paul	6			France	Indian	38°43′S 77°13′E
Unimak	4,070	Aleutians	17,670	Russia/USA	North Pacific	52°02′N 174°02′W
Iturup	3,139	Kuril Islands	10,503	Japan, Russia	Northwest Pacific Ocean	45°02′N 147°37′E

Main island	Is. area [km^2]	Archipelago (Ac)	Ac area [km^2]	Country	Ocean	Coordinates
Hokkaido	378	Japanese	83,424	Japan	Northwest Pacific	43°4′N 141°21′E
Tidore	1,550	Moluccas Islands	74,505	Indonesia	Western Pacific	0°41′N 127°24′E
Negros	13,350	Visayas	71,503	Philippines	Western Pacific	10°40′35″N 122°57′03″E
New Britain	36,520	Bismarck	49,700	Papua-New Guinea	Western Pacific	5°44′S 150°44′E
Bougainville Island	9,318	Solomon Islands	28,400	Papua-New Guinea	Melanesia, Pacific	6°14′40″S 155°23′02″E
Espiritu Santo	3,955	New Hebrides	12,189	Vanuatu	Melanesia, South Pacific	17°44′S 168°19′E
Grande Terre	16,372	New Caledonia	18,576	France	Melanesia, South Pacific	22°16′S 166°28′E
Tarawa	31	Kiribati	811	Kiribati	Micronesia, Pacific	1°28′N 173°2′E
Majuro	10	Marshall Islands	181	Marshall Islands	Micronesia, Pacific	7°7′N 171°4′E
Guam	540	Mariana Islands	1,036	USA	Micronesia, Pacific	16°37′N 145°37′E
Hawaii	10,432	Hawaiian	28,311	USA	Polynesia, Pacific	19°34′N 155°30′W
Savai’i	1,694	Samoa	2,842	Samoa	Polynesia, Pacific	13°50′S 171°45′W
Vaitupu	6	Ellice Islands	26	Tuvalu	Polynesia, Pacific	07°28′S 178°41′E
Nuku Hiva	339	Marquesas Islands	1,049	France	Polynesia, Pacific	8°52′S 140°08′W
Tahiti	1,044	Society islands	1,590	Tahiti	Polynesia, Pacific	17°40′S 149°25′W
Tongatapu	260	Tonga Islands	750	Tonga	Polynesia, Pacific	21°08′S 175°12′W
Rarotonga	67	Cook Islands	237	Cook Islands	Polynesia, Pacific	21.235°S 159.778°W
Tubual	45	Austral islands	152	France	Polynesia, Pacific	23°22′12″S 149°28′48″W
Henderson Island	37	Pitcairn Islands	47	UK	Polynesia, Pacific	24°22′01″S 128°18′57″W
Isabela	4,586	Galápagos Islands	7,880	Equator	East Pacific	0°30′S 90°30′W
Socorro	132	Revillagigedo	158	Mexico	East Pacific	18°50′N 112°50′W
San Ambrosio	3	San Félix Islands	5.36	Chile	East Pacific	26°20′37″S 79°53′28″W
Easter Island	164			Chile	East Pacific	27°7′S 109°22′W
Selkirk	50	Juan Fernández Islands	100	Chile	East Pacific	33°45′04″S 80°47′00″W

Main island	Is. area [km^2]	Archipelago (Ac)	Ac area [km^2]	Country	Ocean	Coordinates
Auckland	443	Auckland islands	626	New Zealand	South Pacific	50.7°S 166.1°E

Table 1.
Main oceanic islands, including the archipelago, the country, the ocean, the island and the archipelago total area, and the coordinates of the main city.

causing severe ecological and economic problems. Besides, deforestation is frequently a major problem, both for agriculture and for timber, and tourism is causing additional infrastructural and pollution pressure [6]. Biodiversity conservation and sustainability are accordingly major concerns in relation to the oceanic island, to preclude the degradation and destruction of the natural heritage.

The effort of creating protected areas is the first key step to the conservation of threatened natural and cultural heritages. This step should be followed by a successful management of the protected area, which considers both the conservation of ecosystems and the socio-economic development of island inhabitants and considers the specificities of island territories.

This chapter discusses the importance of the oceanic islands, of its endemic plants, the threats they are currently facing, and the conservation measures being implemented to protect these important ecosystems.

2. Biodiversity and endemism of oceanic islands

There are around 374,000 plants species on earth [11], but their distribution is uneven, with the tropical environments presenting larger numbers than other environments. This is a result of ecoevolutionary drivers which include the climatic stability over the past million years associated with time, energy availability, and biotic interactions [12]. Consequently, some areas of the globe have been recognised as global biodiversity hotspots as they exhibit exceptionally high species richness and high endemism levels [13]. Mittermeier et al. [14] have defined 35 biodiversity hotspots, many of which are oceanic and continental island archipelagos.

The colonisation of the small oceanic islands depends on geographical and environmental drivers, being inversely related to the distance to other lands [15]. Another important factor is the dispersal ability of the organisms. The geographical range of a *taxon* depends on its ability to disperse its pollen and its seeds. In the case of an island, this dispersal can occur through anemocory (wind dispersal), endozoochory (in the gut of animals), epizoochory (attached to the exoskeleton, fur, feathers of scales of animals) or thalassochory (floating in the water) [16].

When a plant species is able to reach a new territory, it depends on its ability to adapt to the physical and chemical characteristics of the island, and to other biotic factors such as competition, herbivory, parasitism, and symbiosis [3]. The few taxa that survived and adapted to the new environment may therefore evolve into new species. Due to the time these adaptive processes take, island age is an important factor for the biodiversity of oceanic islands, as older islands have a higher probability of successful colonisation. They also had more time for selection processes to act on the first colonisers, so that natural selection takes place, thus constituting a favourable factor for speciation. Because of their evolutionary processes, oceanic islands are poor in the number of species for their size, but present a remarkable high ratio of endemism, and the ecosystems exhibit much higher biodiversity than terrestrial ecosystems for the same area [1, 6]. E.g., the East Melanesian Islands,

Figure 2.
Endemic plant species from oceanic islands. Top left: Hibiscus arnottianus*, from Hawaii; top right:* Brachycereus nesioticus *from Galapagos; bottom left:* Bikkia tetrandra *from Mariana; bottom right:* Viola paradoxa *from Madeira.*

comprising the Solomon islands, Vanuatu and Papua New Guinea, include around 8,000 plant species of which about 3,000 are endemic, the Atlantic islands of Macaronesia are the third richest hotspot in the world in terms of its plant biodiversity (25,000 species); 5,330 species of native vascular plants are native to Polynesia-Micronesia, of which more than 3,070 are endemic, Japan has more than 5,600 plant species of which roughly a third are endemic [17]. Hawaii archipelago also has about 1180 native vascular plants, of which 1000 are angiosperms. Of these, about 900 are endemic (**Figure 2**) [18].

These endemic species, however, present restricted geographical range, specialised environmental niche, limited dispersal ability and reduced size population and distribution [19]. The islands with high large proportion of endemic plants are mainly the high volcanic islands, while most the low islands are species poor. The smaller the island is, the more isolated, and the less the topographic relief, the poorer the island. This is due to the reduced variety of habitats and the broad mix of the typically sea-dispersed strand species that dominate their floras [1].

3. Natural and anthropogenic disturbance

All habitats are exposed to an ecological succession and to natural disturbances, namely volcanic eruptions, or tropical cyclones, that significantly alter the animal and plant populations. As defined by Pickett, disturbance is "a change in the minimal structure of an object caused by a factor external to the level of interest" [20].

Oceanic islands are also subject to numerous disruptive events such as hurricanes, high winds, heavy rains, high pressure systems, earthquakes, volcanic eruptions, tsunamis, extreme tides, the introduction of exotic species and human activities. These have mechanical, physiological, or biotic impacts that can last for years. In fact, because most oceanic islands are small and located in harsh environments, these disturbance events tend to have more severe consequences on oceanic islands than on continental land masses [1].

In addition to these natural disturbances, humans have had a profound impact on biodiversity, altering the composition and functioning of ecosystems. These events are of the utmost importance for the survival of wild habitats and the viability of populations.

After a disturbance event, when the number of individuals falls below a specific threshold, the species loses genetic diversity, which reduces its ability to adapt to change and therefore increases the risk of extinction. Island endemic species are usually very localised and have small numbers of individuals, which makes them highly vulnerable to disturbance and therefore to extinction [21].

3.1 Biological invasions

With human settlement on oceanic islands new species were introduced as farm stock, crops, for fibres or furs, domestic animals, pets, sports, or solely as ornamentals [22, 23]. Other species, however, were introduced due to military operations, international trade, and globalisation, either ship cargoes, ballast water, shipwrecks, which unintentionally transported these exotic species to the island, whether plants or animals (**Figure 3**) [24]. More recent invasions drivers are climate change, land-use change providing new habits, pollution, and the positive interaction among non-native species, a process known as invasion meltdown [25, 26].

Figure 3.
*Invasive alien mammals: top right: mouse (*Mus muscullus*) native to south Asia is invasive worldwide; top centre: rabbit (*Oryctolagus cuniculus*) native to Europe; top right: feral goat (*Capra hircus*); bottom left: wild boar (*Sus scrofa*) native to Eurasia and Africa; bottom centre: red deer (*Cervus elaphus*) native to Europe; bottom right: grey-squirrel (*Sciurus carolinensis*) native to America.*

An introduced species is a species that (1) owing to human activity colonises a new area where it was not previously present, (2) is remotely dispersed with a wide geographic discontinuity, and (3) becomes naturalised by perpetuation of new generations without human intervention [27]. Luckily, most introduced species do not become established, due to mortality during translocation, unsuitable environmental conditions and biotic resistance exerted by the host community [28].

Nevertheless, once established, it can become a new invasive alien species (IAS) when it has an undesirable effect on the native ecosystems. The ecological and economic impact of IAS may be after the invader is well established and have wide range, and then the damage may be extremely severe. IAS are responsible for altering the ecosystem functioning, modifying native species richness and abundance, and increasing the risk of extinction, breaking down biogeographic realms, affecting the genetic biological diversity, changing the phylogenetic diversity across communities, and modifying the trophic networks, as well as disturbing human health and/or socioeconomic values at the individual, population, or community level [25, 29–31]. "Habitat transformers" species, which cause changes in ecosystem nutrient cycling at microbial or higher plant levels [32] and "ecosystem engineer" species, which are landscape modifier species [33], are particularly dangerous for they are strongly competitive IAS with the ability to alter environmental conditions, being a major contributor to species diversity loss. As such, IAS alter the composition of plant and animal communities, and also interfere with other ecosystem processes such as nutrient cycling, hydrological cycles, and primary productivity [34].

Accordingly, IAS may have severe negative impacts on oceanic islands because these ecosystems are species-poor and have few highly competitive species [30]. IAS impacts on islands are intensified through the interaction with other global change threats, including over-exploitation of natural resources, agricultural intensification, urban development, and climate change, exacerbating some invasions, and facilitating others, escalating the impact and the extent of IAS [35]. Currently, IAS may be the main cause for ecological disintegration globally, and thus the early detection, rapid action in eradication and good planning is of utmost importance, mainly on islands or other limited habitats [23].

3.2 Climate change

Climate change poses serious risks for human and natural systems. Species are shifting their geographic ranges and altering the numbers of individuals in their populations, variations in seasonal activities, migration patterns and interactions between different species are also occurring in response to ongoing climate change. The impact from recent climate-related extremes, such as heat waves, floods, droughts, cyclones, and fires, reveal significant vulnerability and risk of many ecosystems, some irreversible. To make matters worse, carbon stored in the terrestrial biosphere in peatlands, permafrost, and forests, among others, may be lost to the atmosphere, exacerbating ecosystem degradation. Furthermore, the sea level rise projected for the 21st century and beyond will have an enormous impact on coastal systems, islands, and low-lying areas, which will suffer adverse impacts such as submergence, flooding and coastal erosion. These impacts will be extremely severe on low-lying developing countries and small island states [36].

Due to climate change, the intensity and frequency of wildfires is also increasing [37]. Besides the noticeable economic impact, heat dramatically disturbs soil surface, often causes a decrease in diversity and abundance of soil biota, and strongly increases the risk of erosion by wind and water [38]. These effects depend upon fire severity, and some fire regimes are beneficial to ecosystems. These are controlled by environmental factors such as amount, nature, and moisture of live and dead fuel, air temperature and humidity, wind speed, and topography of the site [39, 40]. Due to climate change, induced wildfires are becoming more frequent and are more aggressive and, thus, have frequently severe negative impact on the vegetation and on sensitive species.

Islands are particularly vulnerable to climate change disturbance, owing to the vulnerability of island endemic plants, due to habitat loss and interactions with introduced species [41]. The IAS may benefit from climatic change, as they are opportunistic, very competitive species, thus less vulnerable due to their adaptability to new environments [42]. Manes et al. [41] study stated a 100% risk of extinction for island ecosystem due to climate change and a risk of extinction 3 and 10 times higher for endemic than native and introduced species, respectively.

As such it is expected a decline of endemic plants in oceanic islands, a degradation of mangroves, wetlands, and seagrass around small islands, a degradation of groundwater and freshwater ecosystems due to saline intrusion, a spread of warm water species into the Mediterranean, namely IAS, among many other negative impacts attributed to climatic change [36].

Steffen et al. [43] postulate that the Anthropocene' era is rapidly approaching levels of human-induced greenhouse gases that are approaching critical levels. When reaching an irreversible threshold, the devastating consequences will be irreparable for the distributions of species and in the composition of biological communities. Many of these impacts may already be permanent.

3.3 Tourism and recreation

Disregarding the impact of the pandemic Tourism and Leisure are among the fastest growing economic activities of recent decades [44]. Yet, touristic activities are well known by their negative consequences, being responsible, for instance, for greenhouse gas emissions [45], high patterns of visitor consumption and waste generation [46], for plant damage, including vegetation removal and changes in land cover and land use [47], tourists trampling and spreading weeds and pathogens, and altering fire regimes [17, 48]. Tourists also often pick flowers, threatening the more charismatic species [49]. Tourism, thus, have negative impact in the wildlife, health, physiology, reproduction rate, and behaviour of the wild species [45, 50–53], prompting the decline of sensitive plants, while favouring the growth of resistant species, frequently opportunistic and exotic ones [49].

Thus, tourism is frequently an unsustainable activity not complying with the UNWTO definition of sustainable tourism as "tourism that takes full account of its current and future economic, social and environmental impacts, addressing the needs of visitors, the industry, the environment and host communities" [54].

The presence of tourists in Protected Areas is especially sensitive, for the number of visitors in a protected area increase the number of exotic species on site, since visitors increase propagule pressure and disturbance [28]. More disturbed habitats create open space that may allow IAS to establish and, thus, offer invaders an edge against native species [24].

Yet, due to the dependence on a healthy and safe environment, a social change seems to be arising within tourists and policymakers, increasingly seeking more environmentally friendly practices and tourism activities, through the development of nature-based tourism and ecotourism [55, 56]. In fact, more sustainable tourism activities are increasingly supporting wildlife conservation and local populations welfare are becoming a reality in many countries with pristine ecosystems and charismatic species [57–59].

3.4 Agriculture, and deforestation

Agriculture is intensifying at global level, and this trend will continue in the next years, to meet the growing human population needs. This agriculture expansion will bring ecosystem simplification, loss of ecosystem services, and species extinctions [60]. The agricultural spreading could have major impacts on biodiversity hotspots, as these are areas where there is significant population growth, often poor and with a low development index, where there is an increasing pressure to produce food and promote economic growth through the commercial use of natural resources [61]. In fact, many tropical protected areas, are suffering forest loss through agricultural intrusion, often to grow palm trees for biofuels, being a cheap source of oil [62].

Forest loss has also been occurring through legal or illegal logging, conversion to small-scale agriculture, and larger-scale commercial plantations, namely in the Amazon, Africa, and Asia, but also in small tropical islands, such as New Britain [63]. At the community level, large trees contribute extensively to ecosystem functioning and provide key habitats for biodiversity [64]. Logging is known to degrade forest structure, creating gaps, removing soil, and fostering the proliferation of IAS [65].

3.5 Urbanisation

Human population has more than doubled since 1950 and for the next half century there should be a continued rapid growth in the least developed regions [66]. This massive growth in human population has serious consequences for natural habitats, with increasing pollution, the spread of IAS, carbon emissions and the consumption and destruction of natural resources, resulting in the change of many of the last remaining wild spaces on the planet [67]. Therefore, fewer world ecosystems are away from human pressure, and many are experiencing biodiversity loss and ecosystem degradation due to the construction of infrastructures, for vehicles, for the industry, for hydraulic and harbour set-ups, hydroelectric infrastructures, among others, with severe impacts on many ecosystems and species. Roads, for example, open new opportunities for habitat fragmentation, fires, logging, and land speculation [68, 69]. The rapid proliferation of roads will also strongly influence the footprint of agriculture. Thus, wild regions, parks and protected areas, relics of intact habitat within biodiversity hotspots, such as islands, are among the environments where roads and other infrastructure should be limited, allowing the conservation of such habitats and species [68, 70].

Besides the roads, the building of infrastructures for urban expansion, tourism, or for other economic activities, has, evidently, direct impact in the vegetation clearance, to open the area. However, beyond the immediate impact on the vegetation, such infrastructures have a long-term impact, due to habitat fragmentation, the changes caused on the soil hydrology, pollution runoff, and as already mentioned, as a corridor for the introduction of pathogens and IAS [71, 72].

4. Conservation measures

Protected areas (PAs) are the main pillar of conservation activities and are therefore the first integrated approach for the conservation of biodiversity and ecosystem services worldwide [73]. Acknowledging the worldwide recognition of the importance of the PAs as a tool for the economic, social, and scientific importance, and for their role in environmental well-being, the total PA has increased tenfold from 1959 until 2016, from roughly 2 Mkm^2 to almost 20 Mkm^2, corresponding to 202,467 total PAs. In 2014 around 17% of the world island biomes were protected, mainly temperate (23%) and polar ecosystems (17.5%), while less than 13% of tropical islands were protected, where endemism is higher [74]. Also, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services report [36] and the recent Global Biodiversity Outlook [75] noted some interesting progress in the conservation and sustainable use of biodiversity in PAs.

Although more recent reports do not include data on islands, between 2014 and 2020 the protected land and inland water ecosystems increased from 15.4% to 16.64% (with a total of 22.5 million km^2 and 248,113 protected areas), and the protected coastal waters and the ocean increased from about 4.5% to 7.74% (28.1 million km^2 and 17,828 protected areas) [76, 77]. This growth falls within the conservation efforts tackled by the Aichi Biodiversity Targets under the Convention on Biological Diversity (CBD). Still, despite the progress in conservation and sustainable use of biodiversity, the Strategic Goal 11 has been tightly missed: "by 2020, at least 17% of terrestrial and inland water areas and 10% of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services" [78].

While many of the endemic species' populations are within protected areas, often these are not enough to fully protect them, because, among other problems, management quality is not satisfactory, and thus biodiversity loss has persistently continued [79]. Therefore, it seems that the extensive conservation efforts are not being successful and new approaches are needed.

Current conservation strategies are still largely based on the assumption that we live in a dynamic but slowly changing world. Such an assumption needs to be revised considering the rapid rate of climate change already experienced in recent years, which is expected to continue at this pace if not increasing, over the coming decades, forcing researchers and managers to rethink and recalibrate the conservation responses [80]. On the other hand, conservationist classical approaches are based mainly on *ex-situ* conservation of endangered species, and reintroduction measures from which they have been lost, while restoring degraded or lost ecosystems [81]. When it comes to conservation of plants, and endemic species in particular, the scenario seems even more ineffective, with plants becoming increasingly rare around the world. Successful plant conservation includes research on the species distribution and rarity. Then an efficient management plan to tackle conservation efforts, prioritisation of measures, stakeholders' interests, and training capacity are important to mitigate threats facing threatened species. To implement such plans, policy and funding are foundation stones to support continued capacity of conservation. Ultimately, the last but not the least, a deep education plan for the public, so to understand and support the importance of plants and the need for their conservation is of utmost importance to achieve efficient conservation. These are not simple or isolated actions. Coordination of plant conservation efforts is also needed to ensure that resources and expertise are used in a strategic, efficient, and effective manner [82].

4.1 Data collection

Due to lack of knowledge and interest, plants are often under protected by policy, their conservation efforts are underfunded, and their importance is under cherished. To overcome such lack of information, an Important Plant Areas (IPAs) criteria system was defined, offering a pragmatic and scientifically rigorous mean of delivering these datasets, assisting the informed decision making and conservation prioritisation [83]. This database generates essential data for other databases such as the IUCN Key Biodiversity Areas (KBAs) programme [77] producing a worldwide network of relevant information. The database, however, is still rather limited, for many countries have not yet made available the data on the distribution, rarity and threat status of plant species and their habitats, mainly in the tropical areas.

The IPA criteria, for the first time, recognises the socio-economically valuable plant species providing essential goods, such as the importance of plants as a food source, medicines, timber, fuel, materials for clothing, ornamental, social and cultural traditions, besides the vital ecosystem services [83].

The identification of the biodiversity hotspots and endemism centres, along with the assessments summarised by the IUCN red list categorisation [84] and creating global, national, and regional lists of threatened species, are, likewise, valuable tools in conservation prioritisation and planning [85]. Most countries have national agencies responsible for gathering information on native ecosystems, habitats, endemic species, PAs, in regional or national databases, fundamental information for the implementation of conservation actions.

The improvement of biological and ecological knowledge will allow to better target conservation measures.

4.2 Legal protection

Besides the legal protection at regional and national levels, there are several international cooperation treaties to tackle the threats on wildlife and nature protection. The following are some of the most important, within the plant conservation:

1. Ramsar Convention on Wetlands (1971) which promotes de wise use of wetlands, encouraging the research, training, and management of these ecosystems [86].

2. The Convention for the Protection of the World Cultural and Natural Heritage (1972), aiming to ensure the identification, protection, conservation, presentation, and transmission to future generations of the cultural, and natural heritage [87].

3. Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (1973), seeking to regulate the international trade in endangered animals and plants, and in products derived from them [88].

4. Convention on Biological Diversity (1992), which aims at the conservation of biological diversity, the sustainable use of its components, and the fair and equitable sharing of the benefits of utilising the genetic resource. It also set ambitious goals to restore and safeguard ecosystems, promote sustainability, halt biodiversity loss, combat desertification, among others [74].

5. International Plant Protection Convention (1951) aims to protecting the world's plant resources from the spread and introduction of pests and promoting safe trade [89].

Although each of these international treaties stand on its own, regarding their objectives and commitments, they are inter-linked between their goals and complement each other. Each convention governing body set out specific mandates for cooperation between the biodiversity-related conventions, providing a framework for joint action of biodiversity and a foundation for sustainable development [74].

4.3 Creation and management of protected areas

The PA creation, as stated, is probably the number one national and international conservation policy. They are regarded as the primary defence against biodiversity loss, as long as they are well maintained and managed [6, 67, 81]. The Aichi Biodiversity Targets are a strong showcase of the political priority given to the creation of protected areas at the international level. The following are key messages to achieve the Aichi Targets for APs [77]:

1. Ensuring a more sustainable future [...] will require greater recognition of the important role that PAs play in underpinning sustainable development.

2. Making PAs a key part of national and local responses to address harmful incentives to biodiversity (Target 3), biological invasions (Target 9), anthropogenic impacts and climate change challenges (Targets 10, 15) will help to halt biodiversity loss (Targets 5 and 12), [...].

Complying with these guidelines, IUCN developed a set of educational tools for teaching about PAs and governance aiming to produce a "well-implemented legal frameworks [to create and maintain] effective and sustainable PAs, which provide fundamental infrastructure for conservation of biological diversity and ecosystem services" [90]. These guidelines are helping to create and implement efficient management plans, making them an effective tool to guide managers and other stakeholders in the decision-making process towards achieving the conservation goals.

However, PAs coverage and management plans are not enough to ensure the PA conservation success. Presently, not all the important biodiversity hotspots occur inside the PAs [91–94], because the PA area is at times inadequately defined in terms of extent, ecological representation, and key biodiversity areas [95]. Another major bottleneck is that many PA are inadequately managed and, therefore, do not fulfil their goal of providing a safe and secure site for the species, populations, and ecosystems to thrive.

While biodiversity conservation is the primary objective of a PA, successful management must also address the funding and training requirements of conservation actions, as well as ensuring the sustainability and socio-economic development of local communities [6]. Balancing conservation interests and human well-being is often the most difficult challenge to successfully manage a PA. Therefore, local populations ought to be involved at all stages of the PA management planning, notably in defining the mission, vision, and goals of the PA [6].

Besides all these challenges, in the present days, the greatest threat to PAs is, probably, climate change. How far protected areas will continue to be effective in protecting biodiversity under projected climate change scenarios is still uncertain, but it is expected that some PAs will virtually cease to function, with massive species loss and shift, others may survive relatively undisturbed, while others may even experience an increase in species, leading to changes in the species assemblages [81].

When it comes to island PAs, the intrinsic characteristics of island species and ecosystems cause a particular vulnerability due to the small population sizes, low habitat availability, and isolated evolution [96, 97]. Strong local anthropogenic pressure added to the impacts of climate change increase the threats to island ecosystems and plants. Due to the high degree of endemism in island floras, there is a particularly high potential for biodiversity loss in these ecosystems. Climate change impacts on oceanic island, though, are not evenly distributed, with the greatest vulnerabilities to be expected on smaller islands with low elevation and uniform topography, which will experience higher disruptions rates associated with ecosystems co-modification and co-extinction [98]. Thus, islands PAs are much more vulnerable than other land ecosystems, and management plans must take this into account.

4.4 Control of invasive species

In oceanic islands, as stated, biological invasions can lead to severe large-scale ecosystem alterations. Thus, the eradication of IAS has been a common management practice in island PAs, being widely recommended [23, 96, 99–104].

Eradication of IAS in general is a complex and controversial management action. On islands it is attainable in the early stages of invasion [35], but later it is largely restricted to a few invasive mammals such as rabbits and rats [105] and then, for most species, permanent pest control is the only option.

Most of the already mentioned measures must be applied to the control of IAS. First, the knowledge of the IAS present is fundamental. There are many IAS listed around the world, a study that has been undertaken during the past 50 years or so. The Invasive Species Specialist Group developed a global invasive species database [106], and many countries have regional and national databases, although there is still work to do on this subject.

Coordination between countries and trans-national management plans are required to allow the development of joint actions across geographical areas that go beyond each country's frontiers. To this purpose the Aichi Target 9 established "By 2020, invasive alien species and pathways are identified and prioritized, priority species are controlled or eradicated, and measures are in place to manage pathways to prevent their introduction and establishment" [78].

This target addressed the following implementation measures:

1. Improved border controls and quarantine [...].

2. Development of early warning mechanisms, rapid response measures and management plans.

3. Prioritise control and eradication efforts to those species and pathways which will have the greatest impact on biodiversity and/or which are the most resource effective to address.

4. A special reference is made for the island's ecosystems, due to the acute impact of invasive alien species on island ecosystems.

The Invasive Species Specialist Group also developed a Toolkit for the economic analysis of Invasive species [107] which addresses the causes and the impacts of IAS, the related costs and benefits, the valuation of ecosystem impacts and the actions to address IAS.

Besides the information, the international and national legislations, the definition of biosecurity programs is also important, identifying IAS that pose a high risk of causing damage, and establishing measures to protect natural resources and citizens. Currently, biosafety on plant IAS is governed internationally by the International Plant Protection Convention, which establishes harmonised guidelines and standards between countries to limit the spread of IAS while promoting free trade [25].

Addressing IAS control in islands is less difficult than in continental land masses since it may be possible to prevent the entry of these IAS at the border in the management plan. Yet, it is a complex operation. The engagement of the community (citizen science) is of utmost importance, to allow early identification of new invasions. Engaging volunteers in surveillance and monitoring is also a low-cost, large-scale, and a long-term option, for those countries that are not able to implement integrated IAS surveillance programs [25].

Established populations of IAS have traditionally been managed by mechanical or physical control, chemical control, and biological control, all with successes and failures, but with increasing efficiency [108]. New management and innovative eradication technologies have been implemented in recent years, based on molecular genetics, notably the use of gene-silencing for the control of invasive populations that affect plants [109], or gene-editing technology, together with transgenes, which is a whole new technological approach that can help in the control and management of IAS [110].

4.5 Conservation and restauration

As defined by article 8 of the CBD, *in-situ* conservation is "the conservation of ecosystems and natural habitats and the maintenance and recovery of viable populations of species in their natural surroundings [...]" [74]. This definition includes the conservation of natural and semi-natural ecosystems in various types of PAs, aiming to conserve the ecosystem biodiversity, the landscape, to provide habitat for targeted organisms, such as endemic species. It also involves the conservation of targeted species in their natural habitat or ecosystem through conservation or management plans, the definition of recovery programmes for threatened, rare or endangered wild species and the restoration, and the recovery, or rehabilitation of habitats [111].

The *in-situ* conservation action is often complemented with *ex-situ* conservation actions, such as the cultivation in botanical gardens, the maintenance of seeds in seedbanks, arboreta collections, clone banks, cryopreservation, seed production, or other activities, while removed from many of their natural ecological processes, and being managed by humans [112]. The *ex-situ* conservation has enabled research into the causes of the primary threats, such as habitat loss, IAS, and exploitation, while also enabling conservation training and education activities. Different *ex-situ* activities allow the restauration of threatened wild populations, which can be used for population restauration (reinforcement or reintroduction) or conservation introduction, improve the demographic or genetic viability of wild plant populations by reducing the impact of anthropogenic or stochastic threats on these populations [112].

The use of *in-situ* and *ex-situ* conservation action has been an integrated approach increasingly used in the management of islands PAs, namely, to conserve endemic species [105, 111, 113–116]. The Hawai'i islands alone, e.g., have 14 state, federal, non-profitable and international institutions involved in *ex-situ* and *in-situ* conservation programmes, which are responsible for research in plant conservation, native ecosystems, managing wild plants, tissue culture, seed bank maintenance, species populations recovery, besides data management, defining strategy, priorities and planning, outreach, and training, among other activities [117]. A good example is the *ex-situ* conservation of the Hawaiian Vulcan palm (*Brighamia insignis*) which currently survives mainly in gardens.

Inter-situ conservation is a mixture of the *in-situ* and *ex-situ* conservation practices, creating a new community or ecosystem that is partly managed and partly wild. This conservation strategy is used when a threatened species had to be removed from its original range due to threats, and, thus, is conserved in a new location where those threats could be mitigated or are absent [118]. A step forward in conservation measures is "conservation-oriented restoration"

[119], which aims to conserve biodiversity in partially degraded habitats, either for assisted establishment or assisted colonisation. The concept aims to create partially new ecosystems with species compositions that differ from their historical analogues. This restoration aims to conserve endangered species and their habitats, rather than to improve the well-being of local communities by improving ecological services. The concept makes ecological restoration an integral part of conservation planning and implementation and uses threatened plant species in habitat restoration. Another interesting approach within the restauration measures are the Nature based Solutions (NbS), defined as "actions to protect, manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" [120]. This rather new concept aims to work with the ecosystems and the native species within these ecosystems, using them to adapt and mitigate climate change. NbS are categorised into five main approaches [121]:

1. Ecosystem restoration approaches, including ecological restauration.

2. Issue-specific ecosystem-related approaches, including ecosystem-based adaptation, and ecosystem-based disaster risk reduction.

3. Ecosystem-based management approaches, such as integrated coastal zone management.

4. Ecosystem protection approaches, including protected area management.

5. Natural and green infrastructure-related approaches.

Accordingly, many NbS being implemented in PAs fall within the species and ecosystems conservation measures, as well as within the management tools that must be adopted when PAs are involved. In small oceanic islands, NbS can provide significant human wellbeing and biodiversity benefits, linking ecological, climate, and human wellbeing issues in an integrated, ocean-focused, and climate-responsive manner [122, 123].

5. Conclusions

The conservation of endemic plants in protected areas of oceanic islands is a vast, complex, and challenging topic, which has received the attention of many researchers in the past. These plants grow in small population due to low habitat availability, and isolated evolution. Therefore, the islands' ecosystems and their endemic plants are very vulnerable to current threats, such as climate change and the introduction of invasive alien species, but also to pollution, habitat fragmentation, fire, and other anthropogenic threats.

The conservation measures implemented so far are not consensual and many have not been successful, although important steps have been taken. The study and definition of major biodiversity hotspots, the establishment of thousands of protected areas, the creation of databases with information on relevant habitats and species, and the implementation of many *in-situ* and *ex-situ* conservation projects, with their pros and cons, are some of the cornerstones of conservation knowledge and management.

New scientific approaches are appearing in conservation, namely the Nature Based Solutions, the conservation-oriented restoration, the gene-editing technology together with transgenes, which are already showing promising results in plant conservation.

Despite the scientific efforts, the importance of efficient management of protected areas and of the political priority given to conservation should be stressed. Without them, all scientific achievements are irrelevant.

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