Perspective

Pristinity, degradation and landscaping: the three angles of human impact on islands

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Abstract: This paper presents three extreme examples of the potential consequences of human settlement on oceanic and continental islands. The Neotropical Pantepui continental archipelago of sky islands is an example of pristinity, which is due to the almost nonexistent human impact because of the remoteness and inaccessibility of these islands as well as the lack of natural resources to exploit. Easter Island is used to illustrate almost total landscape degradation by deforestation and the exhaustion of natural resources, which has transformed the island into badlands with no signs of recovery. The Azores Islands have been chosen to illustrate landscaping as, after initial postsettlement deforestation and extractive practices, a further transformative phase consisting of creating an almost totally anthropogenic landscape with mostly exotic species occurred. The paper describes in some detail the developments of each case and the historical context in which they took place using historical, archeological and paleoecological evidence. Many intermediate states are possible among these three extremes, which can be represented with a ternary diagram (the PDL diagram), which is useful for characterizing the state of each island or archipelago in terms of human impact and informing conservation and restoration practices.

Keywords: Archeology, Azores Islands, Degradation, Easter Island, History, Landscaping, Last millennium, Paleoecology, Pantepui, Pristinity

1. Introduction

Human impacts on insular environments vary depending on the particular features of the target islands and archipelagos and the cultural particularities of the colonizer [1,2]. In general, original island landscapes have been changed to support human life at variable intensities, ranging from full ecosystem degradation to the total or partial replacement of the autochthonous biota with species of varied geographical and ecological origins, which can be considered true (intentional or nonintentional) experiments of ecosystem engineering [3]. The less frequent situation has been the persistence of preanthropic island ecosystems due to little or no human impact. This paper revisits three contrasting case studies representing a variety of possible human impacts on island landscapes and ecosystems along latitudinal and longitudinal gradients, including (i) the Azores Islands, a temperate oceanic archipelago in the northern Atlantic Ocean; (ii) Pantepui, a tropical continental archipelago in northern South America; and (iii) Easter Island, a subtropical island in the southwestern Pacific (Fig. 1). Other marine and continental islands and archipelagos, regardless of their geographical location and geological origin, may provide similar examples, but these case studies were selected because they are part of the author's firsthand experience. The impact of human settlement on these islands is outlined, mostly in terms of vegetation, as a fundamental element affecting landscape configuration and dynamics. The main traits of these case studies are summarized in a conceptual framework useful for characterizing the current status of each island or archipelago and devising more suitable conservation or restoration actions.

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This paper describes three case studies representing three extreme situations of human impact on islands, namely, pristinity, degradation and landscaping. While the meaning of pristinity – i.e., the natural condition of a landscape and its living communities, which are free from any direct or indirect human influence – seems self-evident, the terms “landscaping” and “degradation” may need some clarification. In this paper, the term “landscaping” (or “landscape rebuilding”) refers to the anthropogenic replacement of natural species and communities of a given landscape by others (usually exotic), including planted forests, crops, pastures, gardened parks and similar features. Eventually, a number of the introduced species may become naturalized and colonize new terrains, which is also part of the landscaping category. It is important to distinguish between landscaping, in the sense used in this paper, and restoration, which involves the reestablishment of the natural original landscape. Degradation occurs when natural living communities are removed but not replaced by others and the landscape is finally transformed into badlands due to soil erosion, aridification, salinization and/or nutrient depletion. The replacement of the original landscape by infrastructures needed for human life (cities, communication networks, etc.) is also considered a degradation process. Usually, degradation and landscaping are both manifestations of intense anthropogenic impact, and the difference between these two outcomes is that the first involves continuous deterioration, whereas the second includes active landscape rebuilding. Degradation occurs when the extractive phase is never overcome, which leads to the exhaustion of natural resources. Landscaping, in contrast, involves the undertaking of a further transformation phase. Degradation may also occur due to natural hazards (floods, landslides, volcanism, and tsunamis).

Pristinity is represented here by the Pantepui continental archipelago of “sky islands”, i.e., highland summits separated by the surrounding lowlands [4], which remains virtually untouched because of its remoteness, difficulty of access and lack of natural resources to exploit. Degradation is illustrated by Easter Island, where the initial forest cover was removed and the landscape has continually deteriorated since human settlement, without any significant regeneration or restoration efforts. Landscaping is exemplified by the Azores Islands, which were also deforested but on which the landscape was almost completely rebuilt with exotic species, leading to a mosaic of luxuriant natural-like forests coexisting with other vegetation types, crops and pastures.

Knowledge regarding island colonization and further ecological change may be obtained from documentary historical records that, in some cases, may be abundant and detailed, thanks to the accurate logbooks produced by European explorers during previous centuries. However, many islands and archipelagos were settled by humans well before the relatively recent European discoveries, and their human and ecological histories can be revealed only by archaeological and paleoecological records. One of the more relevant examples is the peopling of land masses of the Pacific Ocean from the easternmost Asian coasts, which lasted for more than five millennia [5]. The lack of written documents in many island civilizations prior to European contact makes it difficult to follow their settlement details, which can be addressed only on the basis of oral tradition, with the corresponding limitations of this method [6]. Archaeological evidence commonly informs studies of cultural developments once the colonizing civilization has established, but the understanding of the initial exploration and colonization attempts, as well as the environmental conditions favoring human presence before full establishment and affecting further cultural developments, usually requires paleoecological evidence. This paper combines historical, archaeological and paleoecological evidence to briefly explain each case study and then summarizes the information into a graphical synthetic framework that may be useful in addressing the topic of human impact on islands in a general fashion.

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2. Pantepui: pristinity

Pantepui is an archipelago of highland islands formed by the summits of a cluster of ~70 table mountains (tepuis) situated between the Orinoco and Amazon basins, known as the Guiana Highlands (Fig. 1). Most of these summits are located in Venezuela, with a few representatives in Guyana and Brazil. The elevations of these sky islands range from ~1500 to almost 3000 m, and the islands are isolated from the surrounding uplands and lowlands by spectacular vertical cliffs of up to ~1000 m with frequent waterfalls (Fig. 1). The surface area of these summits is between <1 km^2 and >1000 km^2, for a total of approximately 5000 km^2 [7]. Pantepui is considered one of the most characteristic continental archipelagos, with biodiversity and endemism patterns comparable to those of oceanic islands [8] and that have been the basis for the definition of the Pantepui biogeographical province within the Guiana region [8]. The Pantepui landscape is varied, including bare rock environments with scattered colonizing communities and extensive peatlands [10], supporting several vegetation types – forests, shrublands, grasslands and broad-leaved meadows – that are unique to this biogeographical province [11] (Fig. 2). Paleoecological studies have shown that these vegetation types have remained more or less constant during the Holocene, but their elevational patterns have changed as a consequence of climatic shifts [12,13]. The Pantepui summits are remote, mostly inaccessible and unpopulated. The indigenous groups living in the surrounding lowlands and uplands do not climb to the summits because of religious constraints [14]. Activities such as hydrocarbon exploitation, mining, hydroelectricity production, forestry and farming are not possible in Pantepui due to its special geological, edaphic and biotic features. The main activities are touristic and scientific fieldtrips, but permanent facilities for these tasks (hotels, scientific stations, etc.) are lacking, and these activities are carried out by camping. Only a couple of the Pantepui summits are accessible by foot, while the others must be reached by helicopter. As a result, the Pantepui archipelago is one of the few still untouched areas on the planet and represents a natural laboratory for studying Neotropical diversification and community assembly in the absence of human disturbance [15].

There is no information regarding prehistoric Pantepui disturbances caused by indigenous populations living in the surrounding lowlands and uplands, but based on the present-day beliefs that Pantepui is a sacred land and the home of gods among some of these indigenous groups, it may be assumed that these cultures have not impacted the Pantepui biome. The Gran Sabana uplands, which surround the easternmost Pantepui sector, are the most populated and active and are the homeland of the Pemon indigenous group. Historical records suggest that the Pemon people, for whom fire is a fundamental component of their culture and is used for multiple purposes, were present in the Gran Sabana between 300 and 600 years ago [16,17], but paleoecological records document fire regimes similar to the present ones since 2000 years ago [18,19], suggesting that the Pemon or a similar culture was already present in the Gran Sabana a couple of millennia ago. The possibility of indigenous fires reaching the tepui summits is suggested by the continued occurrence of fire on the summit of the Uei-tepui during the last 2000 years [20]. However, no archaeological evidence is available regarding the occupation of the Gran Sabana before the last few centuries. The first European incursions were performed by the Spanish explorers who arrived in the Gran Sabana by 1750 CE and founded several Catholic missions. This altered the lifestyle of the Pemon people, who shifted from nomadic to sedentary practices and experienced significant population growth [17]. The European settlement coincided with significant fire exacerbation, according to paleoecological records, that drastically reduced the *Bonnetia tepuiensis* (Bonnetiaceae) cloud forests of the Uei-tepui summit and transformed the landscape into broad-leaved meadows dominated by *Stegolepis guianensis* (Rapateaceae) along with the pyrophilous shrub *Cyrilla racemiflora* (Cyrillaceae) [20]. This fire increase took place near the end of a regional Little Ice Age (LIA) drought, which suggests possible climate-human synergies causing fire exacerbation.

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The modern exploration of Pantepui and its surroundings began in the mid-19th century, when the German brothers Robert and Richard Schomburgk collected plant and animal specimens on the southern slopes of the Roraima-tepui (1838-1842). Approximately 40 years later (1881 and 1883), British ornithologist Henry Whitely explored the upper slopes of the Roraima-Kukenán massif but did not reach its summits. Only a few years later (1884 and 1898), British botanist Everard im Thurn and his colleagues managed to climb to the summit of the Roraima-tepui (Fig. 1) and collected the first rare plants and animals from this hitherto new and strange life zone [21]. The oddity of the biological specimens collected during these first expeditions suggested that the tepui summits were a separate world different from what was known at that time and inspired the famous fantasy novel entitled "The Lost World" published by Arthur Conan Doyle in 1912. The first scientific explorers managed to access some tepui summits by foot after long and difficult trips, but this was only possible - and still is today - on only a few of these table mountains. The exploration of Pantepui underwent a decisive bourgeoning after the Second World War, with the use of helicopters, which are still the preferred and, in many cases, the only means to reach the tepui summits. A detailed account of the history of Pantepui scientific exploration can be found in Huber [21].

The consequences of scientific exploration for the Pantepui landscape have been negligible, but fire has continued to be locally important on the Uei-tepui and on some surrounding tepuis. The fire exacerbation initiated during Spanish settlement of the Gran Sabana did not stop and peaked at 1900-1930 CE [20], coinciding with historical records of Gran Sabana fires, especially a huge one that occurred in 1926 that affected the slopes of several tepuis near the Uei [22-24]. The consequences of this large fire event can still be seen on the summit of this tepui, mainly in the form of charred trunks still in the growth position, whose death was radiocarbon dated to 1926-1948 CE [20]. The Uei-tepui may be considered a very special tepui, as its summit is not isolated from the surrounding uplands by vertical cliffs but by fully vegetated gradual slopes through which fire can be easily propagated. On other nearby tepuis, only the slopes were affected, and fires did not reach the summits due to the impossibility of propagating through the rocky vertical cliffs. As a result, these tepui summits remain virtually untouched, which does not mean that their biota and ecosystems have remained constant through time but that they have evolved only under the action of natural drivers [15,25]. An exception is the Roraima-tepui, whose summit is reachable by foot and open to touristic visits, and the first symptoms of garbage accumulation, alien introductions and water contamination are already appearing [26]. However, Pantepui, as a whole, is one of the few pristine regions remaining on Earth.

3. Easter Island: degradation

Easter Island is a tiny volcanic island of 164 km^2 isolated by thousands of kilometers of open ocean from the easternmost Polynesian archipelagos, to the west, and South America, to the east (Fig. 1). Geographically, the island is part of Polynesia, but politically, it has belonged to Chile since 1888. Several hypotheses and theories have been proposed regarding the timing of its colonization and the origin of the first settlers, but archaeological evidence indicates that the island was settled between 800 and 1200 CE by Polynesian navigators, who established the Rapanui culture, which is still present, although with significant modifications, on the island [27]. This island is perhaps the most famous example of total landscape degradation as a consequence of human disturbance. According to the traditional view, based on palynological analyses of lake sediments [28,29], the island was fully covered by palm forests with a shrubby understory during the last 34,000 years, but the arrival of Polynesian colonizers represented the onset of a full deforestation event that left the island devoid of forests by approximately 1600 CE [30] (Fig. 3). The palm species dominating the forests remains unknown, and it is believed that it was endemic to Easter Island and is now extinct [31]. According to this view, deforestation was a manifestation of the overexploitation of natural resources that caused the cultural collapse of the ancient Rapanui civilization

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[32]. Others contend that Pacific rats (*Rattus exulans*) introduced by Polynesian colonizers played a role in forest clearing by actively eating palm fruits, thus preventing forest regeneration [33]. However, recent paleoecological evidence has shown that (i) it is unlikely that forests covered the entire island [34], (ii) forest clearing was gradual, rather than abrupt, and heterogeneous in time and space across the island [35-37], and (iii) not only humans but also the climate (notably droughts) and climate-human feedbacks and synergies were involved in the deforestation process [38]. In addition, recent archaeological evidence has shown that the ancient Rapanui civilization was not severely affected by deforestation and that its society remained healthy until European contact (1722 CE), despite total forest removal [39,40]. Therefore, the traditional view of Easter Island's socioecological collapse is not supported by recent paleoecological evidence [41].

Another interesting finding is that forest clearing seems to have started well before Polynesian settlement, as suggested by palynological records of forest retraction and grassland expansion in approximately 450 BCE, coinciding with an increase in fire incidence and the appearance of *Verbena litoralis*, a weed of American origin linked to human presence [35]. However, this earlier human presence has been interpreted in terms of presettlement ephemeral/intermittent occupation events that did not leave relevant ecological imprints or archaeological remains on the island [27]. The true degradation process began with postsettlement deforestation.

Landscape degradation did not stop with forest clearance but was exacerbated after European contact. Initially, several unsuccessful attempts to introduce exotic species such as goats, pigs, sheep, corn and a number of fruit trees were carried out. Major deterioration occurred in 1875 CE when the whole island was transformed into a ranch, mostly for sheep, but cows, horses, pigs and chickens were also introduced. This caused the second island-wide degradation, after deforestation. Former forest removal eliminated the palm trees, but intensive and extensive grazing removed most of the autochthonous plant species that remained. After a pause in which more alien species were introduced, notably coconut trees, a second and even more intense landscape degradation event took place as a result of the reactivation of extensive livestock practices. In 1903 CE, the number of sheep increased to approximately 70,000 (~430 per km^2), and the island experienced the worst vegetation deterioration of its entire history [42,43]. The introduction of exotic species continued with the planting of *Eucalyptus* forest stands, which are still standing on the island. At present, 85-90% of the island is covered by grass meadows, while planted forests represent 5% of the island's surface, shrublands represent 4%, and pioneer and ruderal vegetation associated with human activities represent 1% [44]. Of the ~180 plant species known on the island, almost 80% are introduced (half of them are naturalized), and fewer than one-fifth (17%) are autochthonous, with the remaining 4% being of uncertain origin. Only 4 extant species, specifically, three grasses and a legume, are endemic to the island [45]. The legume is the toromiro (*Sophora toromiro*), which is extinct in its natural habitat and is maintained only via cultivation on the island and in several botanical gardens elsewhere [46]. In general, alien species dominate the vegetation, whereas autochthonous representatives are scarce and have little ecological importance, living mostly in restricted habitats.

In summary, the environmental and ecological histories of Easter Island have been characterized by continued landscape degradation since Polynesian settlement, which occurred roughly a millennium ago. The first phase was total forest removal – and the corresponding extinction of the endemic palm that dominated these forests – and the formation of extensive grass meadows. The second phase consisted of the exploitation of these grass meadows as pastures, which led to the extinction of a significant part of the remaining autochthonous flora and vegetation. The first phase occurred during the occupation of the island by the Rapanui Polynesian culture, which was prehistoric and Neolithic, as they did not use writing and metals. Several wood tablets with likely symbolic scripts known as rongorongo exist, but both historical

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studies and radiocarbon dates indicate that this is a postcontact feature [47,48]. During the second phase, the island was ruled mostly by postcontact European colonizers, mainly of French and British origin. In 1935, the Chilean government created the Rapa Nui National Park to protect its natural and archaeological heritage. By that time, however, the island's landscape had already been severely and irreversibly devastated.

4. The Azores Islands: landscaping

The Azores Islands form one of the North Atlantic Macaronesian archipelagos, along with Madeira, the Canary Islands and Cape Verde. All these archipelagos are of volcanic origin. The Azores archipelago is composed of nine islands and has been subdivided into three groups, namely, western, central and eastern (Fig. 1). The most accepted date of human colonization of the Azores Islands is 1432, when Gonzalo Velho Cabral arrived at Santa Maria and took possession of the island in the name of the King of Portugal. The official Portuguese settlement of the islands began in 1449 [49]. Some historians believe that the Azores Islands, similar to many other archipelagos in the North Atlantic region, were already known, although not settled, a century before the Portuguese colonization [50]. This idea is based on maps from the 14th century (1339 CE), in which the islands Corvo and São Miguel were already present, although with different names: Corvinaris for Corvo and Caprara for São Miguel [51].

Historical documents describe with detail the impact of human arrival and colonization on the Azorean vegetation and landscape. When the Portuguese settlers arrived, the islands were covered with luxuriant and dense laurisilvas dominated by *Laurus azorica* (Lauraceae), *Juniperus brevifolia* (Cupressaceae), *Prunus azorica* (Rosaceae) and *Morella faya* (Myricaceae) [52]. Today, the vegetation is largely anthropogenic as a consequence of centuries of deforestation and the introduction of exotic species, leading to the replacement of most original laurisilvas, which are restricted to a few small sites that are under protection [53]. The landscape has been almost completely rebuilt in a process that has been subdivided into three main phases: a presettlement phase, an extractive phase and a transformative phase [52,54]. During the presettlement phase, several types of domestic animals (sheep, goats, pigs, and horses) were released on the islands in the hope that they would increase in population size and therefore be able to sustain future human populations (the islands were devoid of terrestrial vertebrates at the time of human discovery). During the extractive phase, the forests were intensively exploited for construction (houses and ships), firewood and charcoal production. The transformative phase consisted of the replacement of the original forests by planted forests of varied origins, exotic monocultures (mostly cereals but also sugar, vines, pepper, pineapple and oranges) and many ornamental species of alien origin. Human pressure has been variable on the different islands, with Corvo and Flores being the least affected and São Miguel being among the most disturbed islands, with an almost totally anthropogenic landscape [55]. São Miguel Island, the largest (745 km^2) and most transformed by human action, is taken here as an example of anthropogenic landscaping, that is, intentional landscape transformation to fulfil human needs, including the establishment of populated centers, communication infrastructures, crops, pastures and all the components of the so-called physical technosphere [56].

The historical landscape transformation of São Miguel Island was described in detail by [51] and is summarized below. The first large-scale transformation was the extensive cultivation of wheat (*Triticum* spp.) in the coastal lowlands (up to 350-400 m in elevation), where most people lived, and the use of upper terrains for pastures to produce meat and milk. Wheat cultivation declined after the mid-16th century due to recurrent rust attacks and the impoverishment of soils. The next great agricultural success was the extensive cultivation of orange trees imported from China (*Citrus sinensis*), whose maximum development was attained at the beginning of the 18th century and transformed the landscape and the economy of the

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island. Most forests were cut down to obtain the timber needed to make the boxes in which the oranges were exported. At this time, the Australian tree *Pittosporum undulatum* (Pittosporaceae) was introduced as a hedgerow species to protect the orange crops from wind. The orange industry declined by 1830 CE for economic reasons (lack of profitability and external competition) and because of the action of parasites such as the fungus *Phytophthora* and the insect *Coccus hesperidum*. By 1860 CE, large-scale pineapple (*Ananas comosus*; Bromeliaceae) cultivation was introduced to replace the orange crops. Again, large amounts of timber were needed for pineapple exportation, but the island was largely deforested and had to be reforested using several European *Pinus* (Pinaceae) species, Japanese *Cryptomeria japonica* (Cupressaceae) and Australian *Eucalyptus* spp. (Myrtaceae) and *Acacia melanoxylon* (Fabaceae). These species, together with *P. undulatum*, still dominate the forests of São Miguel (Fig. 4), which occupy 25% of the island's surface, whereas the other 75% is dedicated to human activities (46% to crops, 15% to towns and 14% to other purposes) [52]. During the 18th and 19th centuries, many exotic ornamental species were introduced to decorate public and private parks and gardens. Some of these species became naturalized and are successful invaders, such as *Hedychium gardnerianum* (Zingiberaceae), which is native to the Himalayas and is dominant in the understory of many planted forests, mainly those of *Cryptomeria* (Fig. 4). Another naturalized species that is widespread across the island, especially in ruderal habitats, is *Hydrangea macrophylla* (Hydrangeaceae), which is native to Japan. Among the trees, *P. undulatum* and *Clethra arborea* (introduced from Madeira) are the most successful invaders.

Historical documents are useful to unravel ecological developments after human settlement but what happened on the Azores Islands before Portuguese occupation remains unknown. There is no archaeological evidence of previous human settlements, and it has been speculated whether the islands were inhabited before the mid-15th century. Paleoecological studies have provided some insights in this sense. The first palynological records did not find evidence of anthropogenic landscape disturbance prior to Portuguese contact [54], but further investigations reported small-scale cereal cultivation (*Secale cereale*) on São Miguel Island by 1290 CE, more than a century and a half prior to the official Portuguese colonization (1449 CE) [3]. Other studies currently in progress suggest that humans could have been present on the Azores even earlier. The potential impact of these early colonization events is currently under evaluation.

In summary, the present-day landscape of São Miguel is almost entirely a human fabrication – except <9% of the island's surface, which is considered to be covered by natural vegetation [55] – that has recurrently been rebuilt according the economic and aesthetic requirements of each historical phase. For this reason, the Azores Islands are considered a true botanical garden in the Atlantic [52] and a large-scale ecological experiment of community assembly [3]. The present vegetation of São Miguel is dense, varied and luxuriant and confers to the island its characteristic color that has led to the name "green island". A hypothetical nonbotanist visitor unaware of the historical developments of the island could easily have the impression that most of the vegetation is natural and possibly primeval.

5. The PDL framework and conservation/restoration insights

The pristinity-degradation-landscaping trichotomy can be expressed in a ternary diagram in which the vertices are pristinity (P), degradation (D) and landscaping (L) and all other possible intermediate situations can be represented as combinations of these three states (Fig. 5). Such a diagram is called here the PDL diagram of human impact on islands and may be useful for characterizing this impact in graphical and quantitative terms. The PDL framework should be considered a first approach able to provide a quick diagnosis useful for local (archipelago), regional (sea or ocean) and global comparisons. Such exploratory analysis may provide a quick assessment of the critical areas or aspects that require further and more detailed studies to inform conservation and restoration practices.

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Several real examples of the use of the PDL framework are presented. It has not been easy to locate suitable case studies, as the parameters P, D and L are not commonly measured and published in papers and databases, but the examples used here are illustrative of a variety of situations. Two archipelagos with quantitative vegetation data, in terms of % cover, suitable for easy transformation into P, D and L values are the Azores Islands and the Canary Islands [55,57]. Most of the Azores Islands are located near the L corner, with only two islands, namely, Flores (Fl) and Corvo (C), in an intermediate position between P and L (Fig. 5). D values are minimal for all islands of this archipelago. The same situation can be represented using maps and pie charts (Fig. 6), which would be more useful for GIS databases and analyses. In this case, island-wide restoration actions would be reasonable only for the Corvo and Flores islands, whereas for others, conservation of the few areas with preanthropic vegetation and eventual restoration of adjacent areas would be the best options. The Canary Islands are more widespread across the PDL diagram, with Fuerteventura (F) in the L corner, Lobos (Lo) in the P corner and Palma (Pa) and Tenerife (T) near the center of the diagram. In this case, conservation and restoration strategies should be evaluated island by island, which involves more detailed studies on the degraded and landscaped parts of each island.

Other individual islands with information useful for PDL representation have been included for comparison. For example, Taiwan (Tw), situated ~200 km off the SE Chinese coast, is in an intermediate position (in the PDL diagram) between Corvo (Azores) and Lobos (Canaries), and the opportunities for conservation and restoration are high, especially in the uplands and highlands, where the natural forests are relatively well preserved [58]. Two islands have been chosen to represent the D corner: the island of Malé (Mé), in the Kaafu atoll of the Maldives archipelago, located ~1000 km south of India, and the island of Manhattan (Mh), which is part of New York City (USA). Despite their disparate location and geological nature, both islands are totally populated, with no pristine areas and only some parkland areas, which are negligible in Malé and comprise ~18% of the surface in Manhattan [59,60]. Another case of total degradation to be placed in the D corner, but in this case due to natural causes, is the island of Krakatau (K), situated between Java and Sumatra in Indonesia. In 1883, the Krakatau volcano erupted, eradicated all forms of life and covered the island with a 100-m-deep layer of volcanic ash, thus creating a new volcanic landscape and resetting life on the island. The process of recolonization by long-distance dispersal and further ecosystem rebuilding has proceeded in a natural fashion, and it is estimated that more than 100 years will be necessary for Krakatau to be covered by a mature forest again [61].

Regarding the conservation and restoration opportunities in the three cases that are close to the P, D and L angles, which have been the origin of this discussion, the case of the Azores Islands has already been addressed above, and a combination of conservation and restoration actions, according to the particular conditions of each island, seems the most appropriate procedure. For Pantepui, it is clear that conservation in its present state is the priority. For Easter Island, landscape conservation does not make much sense, and restoration of the original landscape prior to human settlement is not possible, as the palm that dominated the former forests is unknown and likely extinct. In this case, all options remain open, and the final decision should consider cultural aspects of the problem.

A worldwide database based on preliminary quantitative estimates such as these and further meta-analyses using GIS applications might provide a first approach to evaluating the global state of islands in relation to human impact with the ability to prioritize island research and conservation needs. This would also provide tools for quick evaluation of the potential effects of future global change on islands characterized by PDL diagrams. For example, for many oceanic islands, sea-level rise will reduce the total island surface, thus modifying the PDL relationships, which may be the basis for reconsidering island-wide conservation plans and strategies in order to adapt to global change. Similarly, global warming will affect sky islands, and part

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of their biota may go extinct due to habitat loss caused by the impossibility of migrating upwards. This would reduce pristinity and increase degradation, thus affecting the corresponding PDL relationships. There are many other possibilities for global change to be manifested in PDL diagrams, and therefore, such diagrams could be sensitive tools for quickly identifying changes in each specific island or archipelago, which would be useful for informing conservation and adaption strategies.

In this paper, the PDL approach is suggested for sky islands and volcanic islands for reasons explained above, but it may also be used for any island type, regardless of the geological origin, and in continental environments and regions of a natural (biomes, ecosystems, protected areas, lakes, and watersheds) or political (countries and their subdivisions) character. Regarding marine environments, habitats such as coral reefs and other similar habitats can also be analyzed using the PDL framework. The same is true for deep-sea and sea-floor environments. Pelagic habitats may also eventually be characterized by PDL diagrams, provided that they can be reasonably delimited in terms of surface or volume. In general, any habitat or environment where it is possible to estimate pristinity, degradation and landscaping in terms of percentage can be submitted to PDL analysis.

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Figure captions

1. Sketch map of the Azores Islands (above), Easter Island (center) and Pantepui (below) and their location in a worldwide context (center). In the case of Pantepui, Roraima is shown as an example of a sky island.
2. Representative vascular plants endemic to Pantepui. A) *Bonnetia roraimae* (Bonnetiaceae) forms the characteristic cloud forests on the tepui summits. B) *Chimantaea mirabilis* (Asteraceae) dominates the so-called "paramoid shrublands", an endemic Pantepui vegetation type. C) Inflorescences of *Stegolepis ligulata* (Rapateaceae), which forms the characteristic endemic broad-leaved meadows of Pantepui. D) Vegetative part of *S. ligulata*. E) and F) Colonies of *Heliamphora minor* (Sarraceniaceae), a very characteristic endemic carnivorous plant of Pantepui. Photos: V. Rull.
3. Comparison between a hypothetical reconstruction of the formerly forested Easter Island (A) and the present-day landscape (B), using the Poike peninsula as an example. The tree cluster at the top of the hill (B) is a recently planted *Eucalyptus* stand. Drawing by Gerd Close, courtesy of Andreas Mieth. Photo: V. Rull.
4. *Cryptomeria* forests on São Miguel Island. A) General view of extensive monospecific forests. B) Closer view showing the understory, which is dominated by *Hedychium*. C) Detail of *Hedychium gardnerianum* (Zingiberaceae). Photos: V. Rull.
5. Graphical representation of the PDL diagram of human impacts on islands, considering the three angles (P for pristinity, D for degradation and L for landscaping), with some examples for individual islands (K – Krakatau, Mé – Malé, Mh – Manhattan, and Tw – Taiwan) and archipelagos, namely, the Azores Islands (C – Corvo, Fa – Faial, Fl – Flores, G – Graciosa, Ma – Santa Maria, Mi – São Miguel, P – Pico, SJ – São Jorge, and T – Terceira) and the Canary Islands (Ch – Chinijo, F – Fuerteventura, GC – Gran Canaria, Go – Gomera, H – Hierro, L – Lanzarote, Lo – Lobos, Pa – Palma, and Te – Tenerife).
6. Sketch map of the Azores archipelago, with the percentage of pristine (P), degraded (D) and landscaped (L) areas for each island and for the whole archipelago (average).

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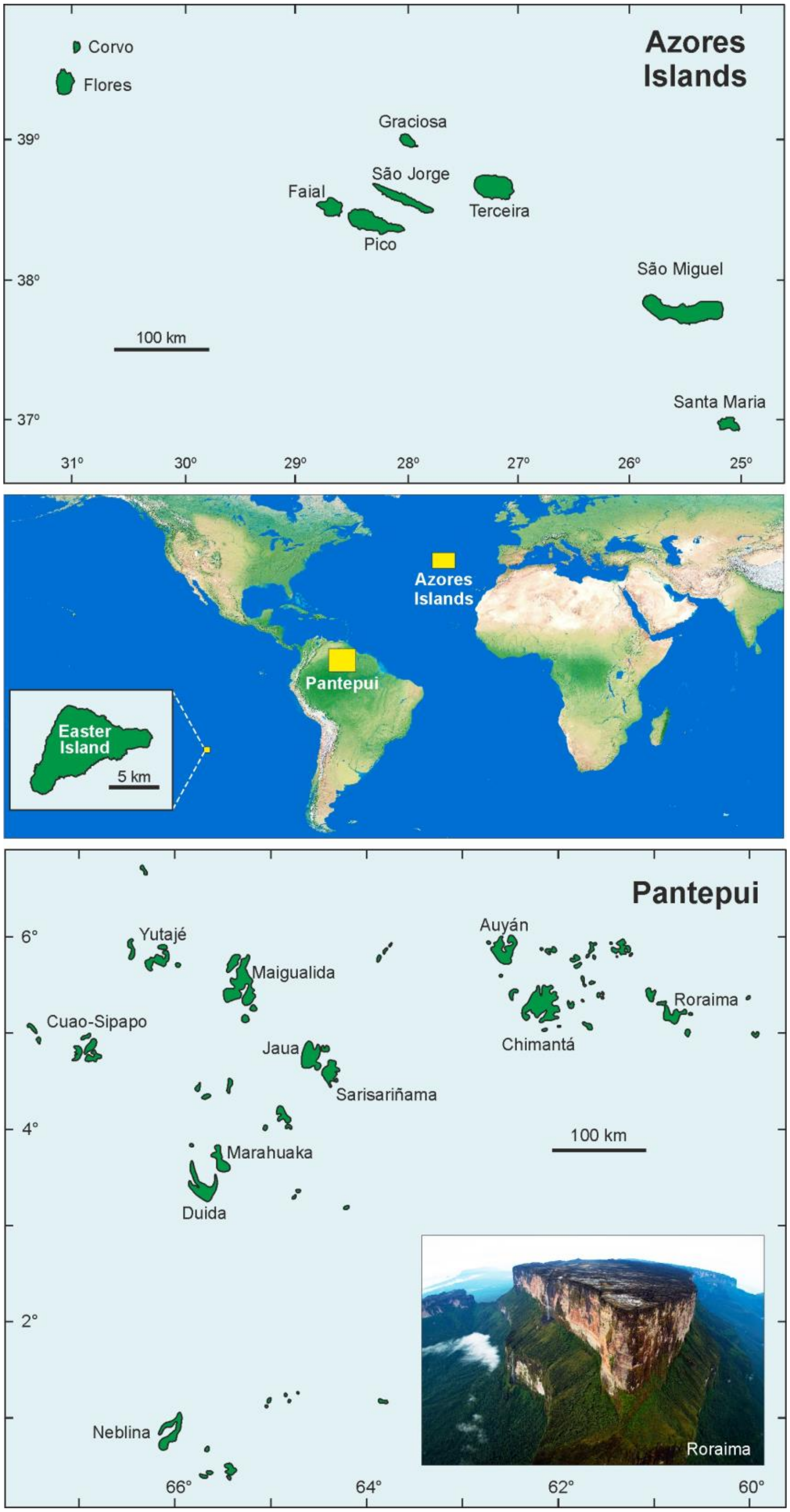

Figure 1

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Figure 2

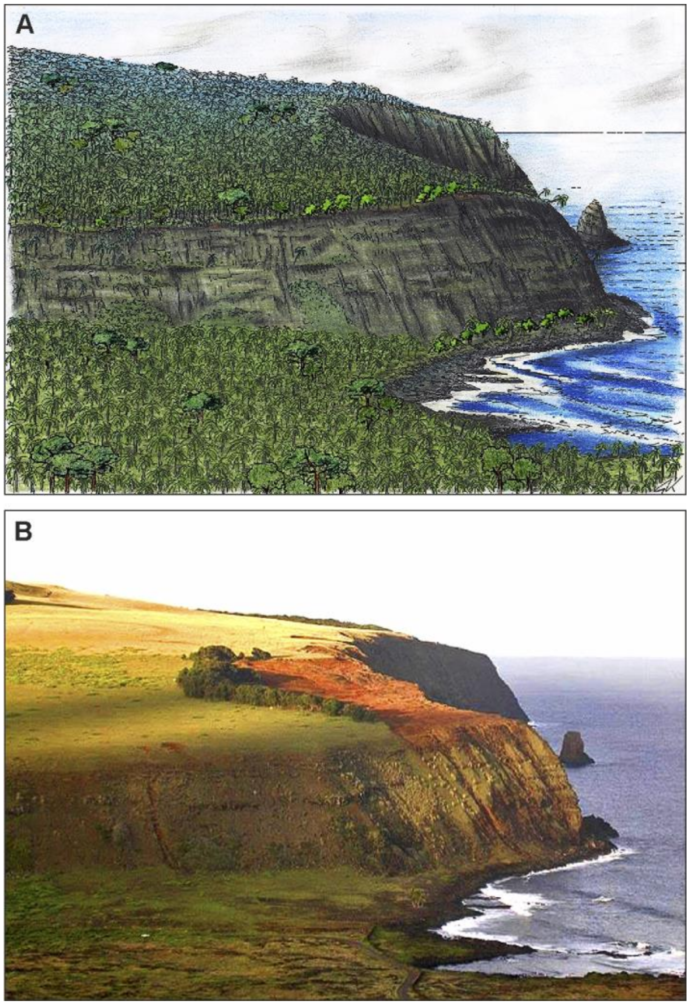

Figure 3

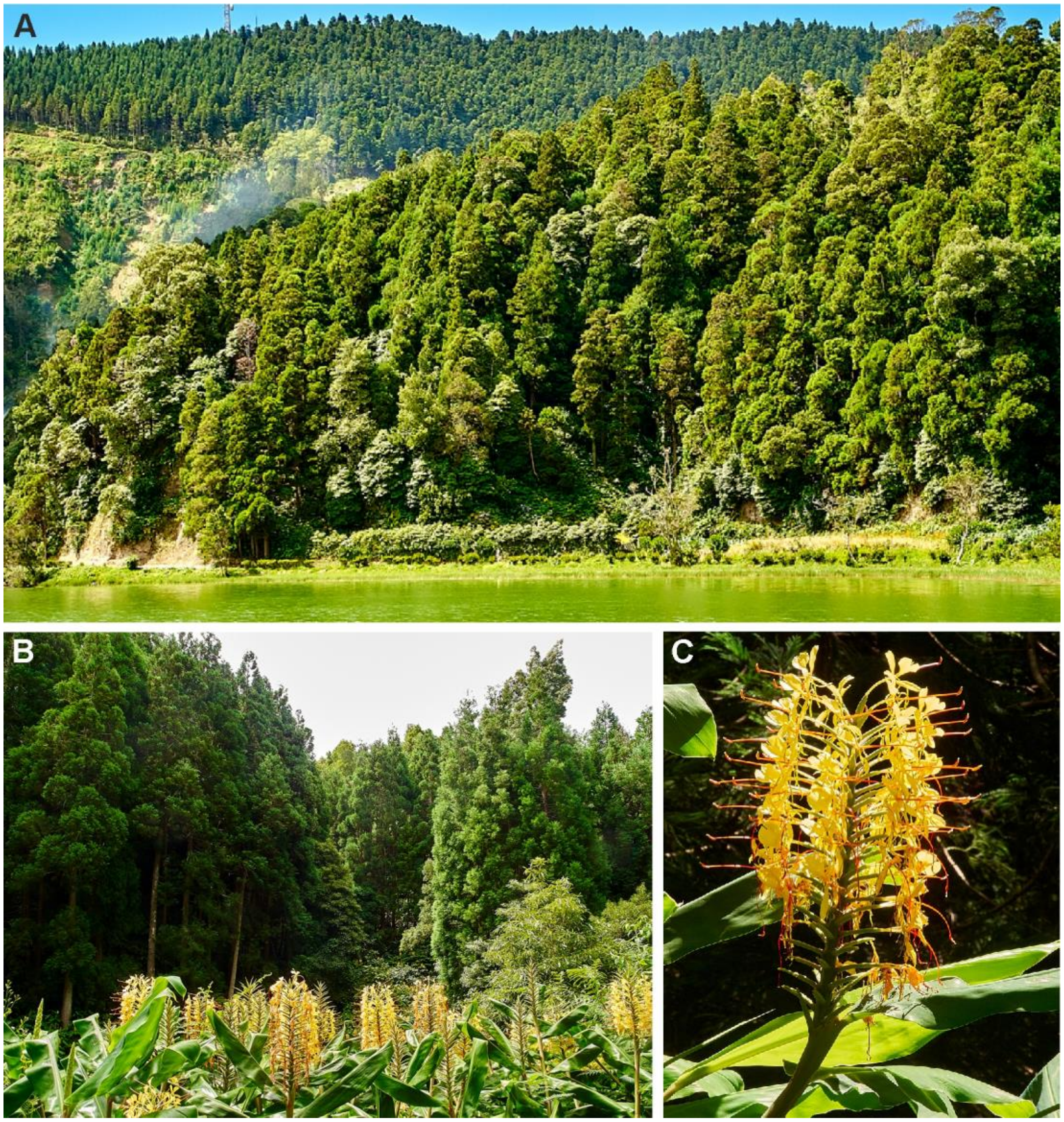

Figure 4

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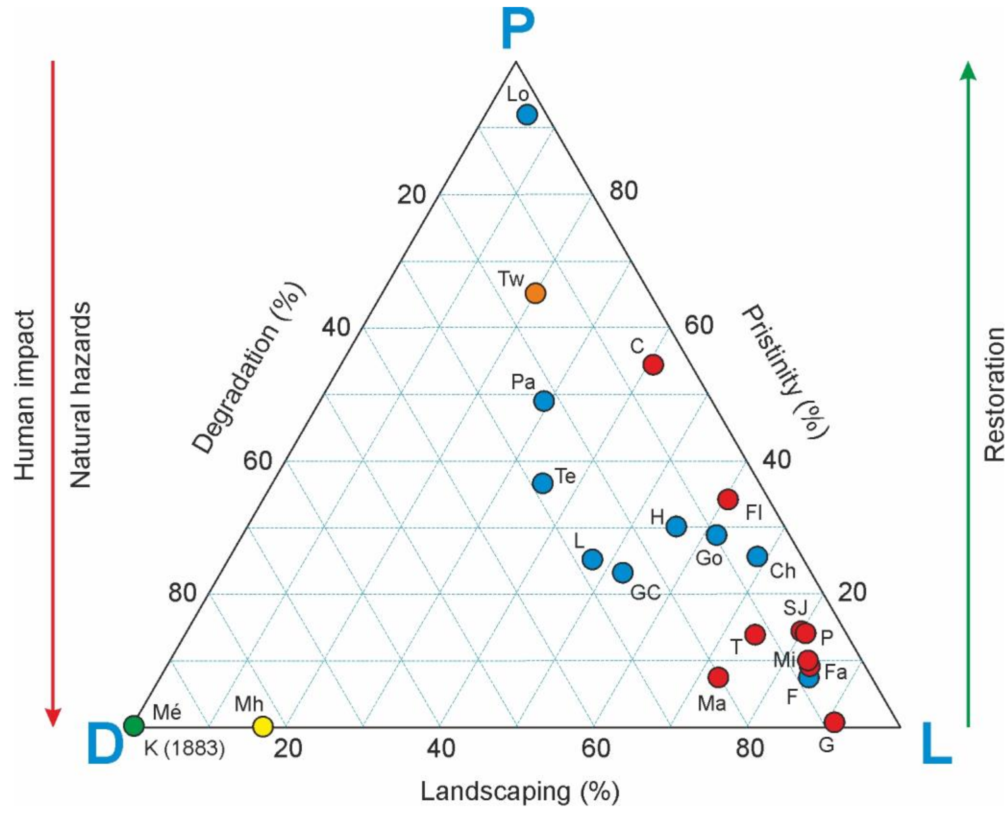

Figure 5

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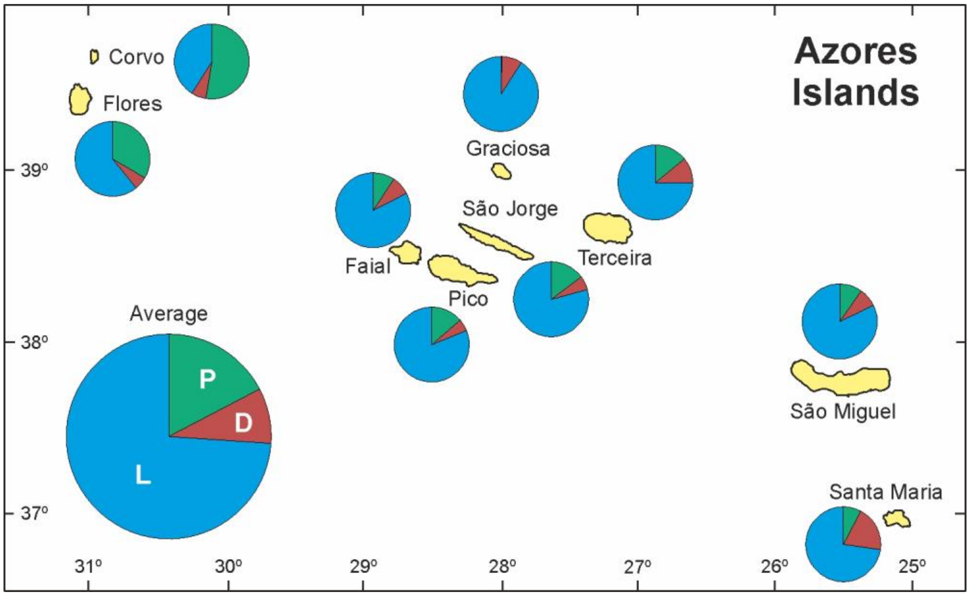

Figure 6

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