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# ANTHROPOGENIC DISTURBANCES AND CONSERVATION OF COASTAL ENVIRONMENTS IN AN OCEANIC ARCHIPELAGO

Juan D. Delgado[1 @], Rodrigo Riera[2]

**ABSTRACT:** Oceanic islands are biotically fragile environments prone to suffer irreversible anthropogenic disturbances. The growth of the human population and the intensive occupation of the coastline are the cause of great ecological pressure on global insular coastal ecosystems. We review the current situation and future scenarios on a paradigmatic oceanic archipelago (Canary Islands, NE Atlantic Ocean), as a case study of the human footprint on marine coastal communities. The role of humans is pivotal, as we directly affect patterns of coastal occupation, pollution, invasive species or fishing. Here we synthesize the information that describes the current situation of the coastal ecosystems of the Canary Islands, indicating the main sources of environmental conflict and impacts. In addition, we review the state of the most relevant or threatened habitats and the taxonomic groups as actors of the main disturbances in the coastal ecosystems of the archipelago. We propose future general scenarios about expected changes, and foreseeable interactions that could occur to transform the coastal environments of the islands, in order to indicate areas susceptible to improvement for the conservation of these ecosystems. Integrative coastal actions are urgently needed for sustainable future scenarios to oppose deleterious trends such as tropicalization, fisheries collapse and extensive coastal degradation due to urbanization and infrastructure construction.

**Keywords:** Coastal development, overfishing, overpopulation, human-induced disturbance, introduced species, islands, oceanic archipelago.

**RESUMO:** As ilhas oceânicas são ambientes bioticamente frágeis e sujeitos a distúrbios antropogénicos irreversíveis. O crescimento da população humana e a ocupação intensiva do litoral são a causa de uma grande pressão ecológica sobre os ecossistemas costeiros insulares globais. Com o presente trabalho pretende-se rever a situação atual e os futuros cenários num arquipélago oceânico paradigmático (Ilhas Canárias, NE do Oceano Atlântico), como um caso de estudo da pegada humana nas comunidades costeiras marinhas. O papel dos humanos é fundamental, dado que afetam diretamente os padrões de ocupação costeira, a poluição, as espécies invasoras e/ou a pesca. Aqui sintetizamos a informação que descreve a situação atual dos ecossistemas costeiros das Ilhas Canárias, indicando as principais fontes de conflito ambiental e seus impactos. Adicionalmente, analisou-se o estado dos habitats mais relevantes ou ameaçados e os grupos taxonómicos como atores dos principais distúrbios nos ecossistemas costeiros do arquipélago. Propoem-se futuros cenários gerais sobre as mudanças esperadas e as interações previstas que podem . Alsotransformar os ambientes costeiros das ilhas, no intuito de indicar áreas suscetíveis de melhorias para a conservação desses ecossistemas. São necessárias ações costeiras integrativas urgentes para futuros cenários sustentáveis em oposicao a tendências deletérias, tais como tropicalização, colapso da pesca e extensa degradação costeira devido à urbanização e construção de infraestruturas.

**Palavras-chave:** Desenvolvimento costeiro, pesca excessiva, superpopulação, perturbação induzida pelo homem, espécies introduzidas, ilhas, arquipélago oceânico.

1 Ecology Area, Dept. of Physical, Chemical and Natural Systems, Pablo de Olavide University, Seville, Spain.

@ Corresponding author: jddelgar@upo.es

2 Grupo en Biodiversidad y Conservación, IU-ECOAQUA, Universidad de Las Palmas de Gran Canaria, Las Palmas, 35017, Canary Islands, Spain. Email: rodrigo.riera@ulpgc.es

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## 1. INTRODUCTION

Oceanic islands are inherently fragmented environments that shelter relatively species-poor but endemism-rich biotas (Whitakker and Fernández-Palacios 2007). Species richness in oceanic islands, particularly in the tropics and subtropics, is very high in relation to its small surface area. Thus, many of them are threatened biodiversity hotspots and their contribution to global biodiversity is of paramount relevance (Myers *et al.*, 2000, Kueffer and Kinney 2017). Climatic and oceanographic variables, mainly currents and prevailing winds, along with distance to mainland (remoteness), location regarding frequented trade routes, which is a today's proxy for effective isolation (Helmus *et al.*, 2014, Delgado *et al.*, 2017), and island attributes such as island origin and type (Nunn *et al.*, 2016), topography, area and elevation (Brown and Lomolimo 1998; Whitakker and Fernández-Palacios 2007) are main determinants for the colonization of islands by species from the adjacent continents or other islands. The interaction of these features with geographical and anthropogenic factors also confers susceptibility for alien species invasions and human occupation (Russell *et al.*, 2017).

The major immediate environmental threat to island biodiversity is the presence of humans and their associated impacts (Kier *et al.*, 2009). Oceanic islands are usually considered more fragile than mainland areas due to combined effects of stochastic climatic events and anthropogenic disturbances that have driven extinction processes since the arrival of humans (Simberloff 1995; Graham *et al.*, 2017). The role of human activities and related shifts in disturbance regimes on island ecosystems are often studied from a short-term perspective (<50 years) (*e.g.* Helmus *et al.*, 2014). However, palaeocological studies on islands worldwide have shown that human impacts are not new; in most cases, the effects of human settlement are noticeable even at early stages and for long periods (Connor *et al.*, 2012; Braje *et al.*, 2017).

Coastal deterioration on islands has experienced severe increases during the last five decades, through peaks in touristic, constructive and extractive industries (Brooks *et al.*, 2002; Arenas 2010; Halpern *et al.*, 2015; Semeoshenkova and Newton 2015). This has led to a necessity of new or enhanced Marine Protected Areas (MPA) as a mean of protecting habitats and species, and of recovering biotic resources such as fisheries (Roberts *et al.*, 2002; Edgar *et al.*, 2014). This growing concern has led to a reinforcement of legality to detect weak points in environmental protection. In this sense, progress has been made with an overall decrease in infractions associated with several types of impacts on the marine ecosystem (Figure 1). However, this does not guarantee the absence of multidimensional and diffuse coastal impacts that escape strict legal control.

Anthropogenic disturbances, especially on oceanic islands, include irreversible abiotic and biotic alterations, such as changes in community composition, species loss (and/or gain, as invasive taxa are concerned), and biodiversity disturbances of global resonance. Often intertwined and synergic, most of these disturbance factors are commonly treated with independence from one another, and concrete impacts in different areas are reported as scattered items both in the specialized literature and from the legal and management points of view.

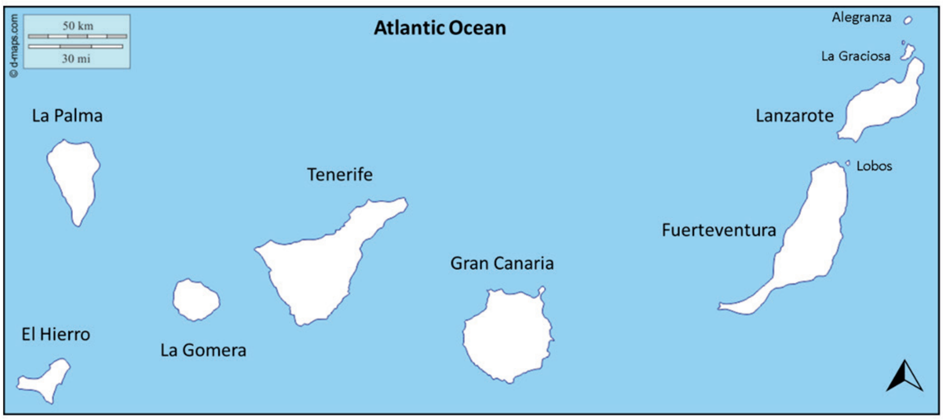


Figure 1. Map of the Canary Islands.

Here we review the status of conservation and anthropogenic disturbances of insular coastal ecosystems, taking an oceanic archipelago, the Canary Islands (E Atlantic), as reference case. An approach to this archipelago's concrete conservation issues seems opportune because it is a well-known oceanic territory located in a secularly disturbed region of great geostrategic, economic and ecological relevance. We aimed to characterize the human footprint on these islands, providing a synthetic frame of the main causes of ecosystem degradation at the archipelago scale. We concentrated in deterioration of the biotic values of coastal assemblages, *i.e.* those disturbances and deleterious forces affecting mostly habitats and species, rather than focusing in general eco-health issues of the marine realm.

We approached this multifaceted problem as follows:

1. We describe the current situation, reviewing the state of habitats and relevant taxonomic groups as descriptors of the coastal marine ecosystems.
2. We outline scenarios regarding expected changes, foreseeable interactions and synergies between different sources of disturbance, which could concur to transform the coastal island environments. This would aid to identify susceptible areas to introduce strategies leading to improved sustainability.

## 2. THE CURRENT SITUATION

The key threats to the coastal ecosystems in oceanic archipelagos are those globally affecting marine flora and fauna, including climate change, non-indigenous species, and human-induced disturbances, such as overfishing and coastal development (Riera *et al.*, 2014). There is an unprecedented rate and scale of development on oceanic islands. Such threats are accentuated in oceanic archipelagos due to massive growth of coastal settlements in the last decades, together with the presence of narrow island platforms where most of the coastal resources are confined.

### 2.1 Human-induced perturbations

A great variety of anthropogenic perturbations is currently occurring all over the planet, mostly due to the concentration of the population on coastal settlements and its subsequent pressure on the surrounding environments. Human activities present considerable threats to coastal ecosystems and resources in the following areas:

(i) structure and function of natural ecosystems;

(ii) shifts in natural resources, especially commercial fisheries;

(iii) extensive transformation of coastal natural landscapes.

#### *2.1.1 Large scale and recreational overfishing*

Overfishing is a major anthropogenic perturbation in coastal ecosystems. Coastal resources have been overexploited throughout the last decades in many oceanic islands (*e.g.* Falcón *et al.*, 1996; Tuya *et al.*, 2004) and currently, this situation is worsening because of the growing importance of shore recreational fishing, and other activities such as uncontrolled shellfishing or indiscriminate harvesting, as well as to a lesser extent illegal underwater fishing (Castro and Hernández-García 2012, Corral *et al.*, 2017). Canarian fishery catcheries have experienced a sharp decrease in the last four decades, from 2.2 kg trap$^{-1}$ day$^{-1}$ in the 1970's to 0.15-0.19 kg trap$^{-1}$ day$^{-1}$ (Castro and Hernández-García 2012; García-Mederos *et al.*, 2015). The development of an efficient management plan is a daunting task (*e.g.* Martínez-Saavedra 2011). Meanwhile, other factors need to be taken into account, *e.g.* oversizing of professional fleet and recreational fishing through the last decades (Zeller *et al.*, 2008; Sistiaga 2011). Other "biological" factors contribute to this situation, such as the high variety of commercial fish, approximately 100 species, and the necessity to update the minimum size of captures (García-Mederos *et al.*, 2015).

An important aspect is the increasing number of recreational anglers in the last decades. Current studies have shown that recreational fishing is responsible of >50% of the total catches landed (Jimenez-Alvarado 2010). This trend is more accentuated in islands with scarce presence of professional fishermen, where over 60% percentages of catches comes from recreational fishing. During the last decade, the impact of recreational fishing in reducing fish stocks and invertebrates has increased substantially (Martínez-Saavedra 2011).

#### *2.1.2 Impacts from coastal development and infrastructures*

##### *2.1.2.1 Littoral development*

The coastal perimeter of the Canary Islands is dominated by rocky cliff shores with interspersed beaches (mainly pebble and to a lesser degree sand beaches) (Table 1). This configuration creates limited space for coastal works, and hence lesser chance to correct biotic impacts from these constructions by selecting alternative suitable locations. The coastal development includes building for residential and tourist purposes; it can be associated with installation of land transport infrastructure for access to the

Table 1. Morphological characterization of the coastal perimeter of the Canary islands (length, in km). Data source: Instituto Canario de Estadística (ISTAC), Gobierno de Canarias.

| Coast configuration | Canary archipelago | Lanzarote | Fuerteventura | Gran Canaria | Tenerife | La Gomera | La Palma | El Hierro |
|---|---|---|---|---|---|---|---|---|
| High cliffs | 720.04 | 110.59 | 99.68 | 104.49 | 137.80 | 99.43 | 102.00 | 66.05 |
| Low cliffs (up to 20 m height) | 319.36 | 47.79 | 64.23 | 33.77 | 119.68 | 0.50 | 25.69 | 27.70 |
| Low coast | 170.22 | 2.20 | 82.18 | 17.38 | 47.96 | 1.50 | 11.90 | 7.10 |
| Pebble beach | 65.59 | 6.64 | 3.10 | 24.26 | 29.64 | 0.05 | 1.90 | 0.00 |
| Pebble and sand beach | 93.03 | 16.94 | 22.29 | 13.37 | 12.40 | 14.62 | 8.11 | 5.30 |
| Fine and coarse sand beach | 106.77 | 9.64 | 51.69 | 18.94 | 25.10 | 0.30 | 1.10 | 0.00 |
| Artificial coastal works (ports) | 78.88 | 19.46 | 2.74 | 24.43 | 25.60 | 1.25 | 5.05 | 0.35 |
| Total length (km) | 1553.89 | 213.26 | 325.91 | 236.64 | 398.18 | 117.65 | 155.75 | 106.50 |

sea (roads and promenades) and marine (pontoons, marinas, and larger ports with eminently touristic use but also with commercial or industrial purposes).

The economy of this archipelago, like that of other oceanic islands, is strongly dependent on sea transport (Tovar *et al.*, 2015). However, despite the increase in the extension and number of port infrastructures there has not been an increase in maritime traffic in the Canary Islands. Several of these large projects have indeed experienced abandonment without succeeding in stimulate local economies of that area. Some new port works have been approved with significant reductions of their original spatial and use scope, although they continue to cause significant alterations in the local coastal marine ecosystems.

Extensive projects have been developed, *i.e.* waterfront settlements, ports, marinas and piers, whereas in most cases lacking a sound environmental perspective, leading to severe impacts. For some projects, at least, mitigating measures have been taken, including: a) prohibition of anchoring vessels in the area of coastal influence near the port to avoid disturbances to the remaining *Cymodocea* beds; b) permanent sand transfer from N to S to reduce the impact of sediment loss south of port infrastructure, among others. Compensatory measures have also been addressed, mainly aimed at qualifying protected areas and restoring habitat (*i.e.* planting *Cymodocea* seagrass to rehabilitate seagrass meadows, and habitat restoration of nearby terrestrial areas).

Coastal development has significantly transformed shallow and productive coastal ecosystems into land for recreational and industrial purposes, introducing a variety of anthropogenic stressors to the coastal environment in many oceanic archipelagos. The steadily growing trend human population along and near the coast has been accompanied by new infrastructures occupying the coastal area, including the intertidal and supratidal environments (Bulleri and Chapman, 2010). Moreover, extensive coastal works have had both direct and indirect environmental effects on the ecosystems (Relini *et al.*, 2002; Sheehy and Vik, 2010). For example, dredge and fill procedures for construction of ports and marinas not only cause short-term problems of sedimentation and turbidity, but also postponed impacts due to re-suspension of fine sediments (Erftemeijer *et al.*, 2012).

Coastal Canarian ecosystems are heavily impacted by overpopulation (with an average of 254 ind./km$^2$, and ca 500 ind./km$^2$ on the islands of Tenerife and Gran Canaria; see Riera and Delgado 2019), an upward trend that still does not stop. To the pressure of the resident population must be added the “floating” or tourist population, which exceeded 6000 tourists per kilometer of coastline between 2005 and 2013 (MAGRAMA 2014; Riera and Delgado 2019). Almost 10% of the Canary Islands’ coastal perimeter is heavily transformed by the construction of breakwaters, groins, dykes and other rigid linear structures, as well as artificial beaches (*ca.* 80 km of diffrent structures along the shoreline), especially on the coasts of the southern slope of the capital islands Tenerife and Gran Canaria the use of artificial beaches (Riera *et al.*, 2014).

As remarked by Nunn *et al.*, (1999), smaller oceanic islands (the vast majority of them) are differentially vulnerable to coastal human impacts due to their greater amount of coastline compared to island area. It has also been argued that the distinctive nature of small islands (driven mostly by size and isolation) could determine levels of anthropogenic development in their ecologically limited environments (Fernandes and Pinho 2017, Delgado *et al.*, 2017). In this sense, an influential feature conferring some passive protection from development would be the ruggedness and relief, which would be a chief constraint to urban sprawl on smaller islands with smaller availability of buildable areas (Nunn *et al.*, 1999).

The fragmentation and individualization of coastal infrastructural projects may derive in a lack of anticipation of cumulative effects, of especial concern for small and isolated islands, exemplified by some archipelagos in the Indo-Pacific (Bass and Dalal-Clayton 1995). Solutions to such conflicts for small islands include multifunctional artificial reefs, as in Azores in the Atlantic (Ng *et al.*, 2013), and consideration of intrinsic protective qualities integrated with sound management of native coastal ecosystems (Gracia *et al.*, 2017).

#### *2.1.2.2 Pipelines, desalination and aquaculture*

Some activities on the coast cause a localized impact that, when repeated and accumulated along the coastal perimeter of the islands, causes synergistic and cumulative effects on a wider scale. Here we include buffer zones of pipelines, desalination plants, and aquaculture offshore cages. The environmental affection of these perturbations is limited to the adjacent area (10s to 100s meters). The addition of POM (particulate organic matter) and brine from sewage and desalination plant effluents, respectively, only affect the communities located on the proximity of the outfall (Riera *et al.*, 2011b, 2012). This pattern is also observed on the surroundings of power station outfalls (Riera *et al.*, 2011a), because of the presence of coastal currents through the whole water column and the rapid temperature dissipation as a consequence of temperature differences between the outfall and the receiving coastal water mass.

Offshore cages also originate a “footprint” of environmental perturbations limited to the aquaculture lease (Riera *et al.*, 2013). However, their development has so far limited to certain archipelagos such as Canary Islands, Madeira or Hawaii, with suitable conditions for culturing temperate-water species (*e.g.* Kam *et al.*, 2003). The most noticeable effects of this activity are concomitant factors, *i.e.* fish aggregates that are attracted by the excess organic input from uneaten pellets and fish droppings (Boyra *et al.*, 2004). One of the main issues about fish aggregates is their concentration in a limited area, on the surroundings of cages that make them vulnerable to fishermen. Fish aggregates are characterized to be diverse and formed by several species that dominate overwhelmingly these assemblages (Riera *et al.*, 2014). The increase of taxonomic and ecologic diversity of fish aggregates also occurs in functional terms (Riera *et al.*, 2017), with a functionally more diverse fish community compared to sites far from cages.

### 2.2 Coastal ecological imbalance

The high degree of restriction in biotic resources, generating increased vulnerability to human exploitation, and in part as a result of this, of coupling between the marine and terrestrial biotic environments in small oceanic islands conditions the nutrient fluxes between both compartments and thus indirectly the biodiversity present in both environments (Hunt 2007). Furthermore, immigration rates to the more isolated islands like Fiji, Samoa, Easter Island and Galápagos are commonly lower than for most continental grounds or even continental platform islands, and hence losses of biotic elements from islands are more difficult to replace (Whittaker and Fernández-Palacios 2007).

In addition, smaller oceanic islands have very limited capacity to compensate for both natural and anthropogenic impacts, as well as constrained capacity to regulate its local climate. Hence, for smaller islands, mesoclimate would be strongly governed by regional-scale climate, and ecosystems would suffer from overspecialization in ecologically impacting activities such as tourism (see Wong *et al.*, 2005, for the so-called Small Island Developing States). Coastal ecological imbalances may thus derive in a great deal from an interaction between these intrinsic vulnerabilities of oceanic islands.

Current imbalance of coastal ecosystems is perceived in several ways in oceanic archipelagos like the Canary Islands. There are consistent differences among islands within the same archipelago in human population size and density, and hence in the number and intensity of human-induced environmental disturbances. Overpopulated islands are currently suffering coastal ecological imbalance because of degradation of environmental processes, both direct and indirectly linked to human activities. Most human direct and indirect impacts occur within the first 50 m depth, where about half of the described species can be found (Martín 2010). These processes may be summarized in two categories: (i) outbreak of opportunistic and fast-growing species; and (ii) meteorological stochastic events.

#### *2.2.1 Outbreaks or die-offs of opportunistic and fast-growing species*

The proliferation of the sea urchin *D. africanum* has been responsible for an impoverishment of coastal rocky substrates in the Canarian archipelago, with the exception of El Hierro

Table 2. Casuistic scheme of coastal management and conservation problems on oceanic islands worldwide. The list does not pretend to be exhaustive, but to review the most prevalent causes of environmental degradation in insular coastal ecosystems, with proposals for improvement from the local to the global scale.

| Example problems | Solutions/proposals of management, protection and mitigation | Site/Reference |
|---|---|---|
| • Coastal degradation (seagrass beds),<br>• Resort construction at the shoreline<br>• Harbours and marinas<br>• Pollution control<br>• Tourism impact<br>• Beach nourishment | • Urgent review of EIA licensing and resolutions for coastal developments<br>• Revising strategy for marine protection and management<br>• Aquatic tourism impact control | Mauritius, Indian Ocean/Daby (2003)<br>Madeira (Abrantes, 2017)<br>Canary Islands (Riera *et al.* 2014) |
| • Local fisheries affected by climate change<br>• Illegal fishing (including spearfishing and angling)<br>• Interference of foreign fleets and loss of insular fishing sovereignty | • Consider needs and claims of insular artisanal fishermen communities (*i.e.* “include all stakeholders”)<br>• International protection of local traditional fisheries<br>• Modelling approaches for temporal and spatial predictions<br>• Creation of fishing reserves (Marine Protected Areas) and marine sanctuaries (no-take) | Indonesia (Sumatra, Sulawesi –Spermonde Islands)/Glaeser and Glaser (2010)<br>Guadeloupe (Guyader *et al.* 2013) |
| • Overexploitation, coastal fisheries depletion<br>• Illegal fishing (including spearfishing and angling)<br>• Lack of marine reserves acting as reservoirs in the face of natural/human catastrophes | • Consider needs and claims of insular artisanal fishermen communities<br>• Management takeover by island fisheries associations with sound scientific advice<br>• Reconstruction of fisheries data for trends and predictions<br>• Management of recreative fishermen<br>• Creation and buffering of fishing preserves and marine sanctuaries<br>• More restrictive fishing measures at the regional scale for reef fish communities | El Hierro and Tenerife, Canary Islands/ Manrique de Lara and Corral (2017); Castro et al (2019)<br>Guadeloupe (Frotté *et al.* 2009)<br>Galápagos (Eastern Island (Zylich et al 2014) |
| • Biodiversity loss, pollution, waste management and urban and industrial sewage in islands with reefs, lagoons and narrow coastal areas.<br>• Growing population/tourism concentration along coastal strips.<br>• Lack of trained personnel for conservation policy inforcement.<br>• Monitoring difficulties due to natural isolation and insularity.<br>• High economic cost of measures in impoverished island nations<br>• Partial abandonment/substituion of traditional activities by less sustainable ones (forced by external market pressures) | • Coral reef protection and restoration<br>• Education/formation<br>• Enhancing environmental awareness<br>• Mixing traditional and modern practices [enhance traditional cultural practices of exploitation, including tourism]<br>• Preserve societal nets traditional to certain smaller island communities from external market interference<br>• Reinforcement of environmental laws, particularly in edification and EIA [and public information process]<br>• Long term planning of activities with environmental incidence (including tourism)<br>• Ecological coastal zonation for allowing ample spawning and nursery areas for fish [umbrela effect for biodiversity]<br>• Pollution and sewage monitoring and waste treatment [it should be approached on a per-island basis to increase efficiency] | Pacific Ocean Islands- Oceania; Indonesia; Philippines/ Thistlethwait and Votaw (1992); Nunn *et al.* (1999); Campbell (2000); Hay (2013); SPREP (2016)<br>Canary Islands (Riera *et al.* 2014)<br>Martinica (Bocquéne & Franco, 2005) |
| • Sea level rise;<br>• Water temperature rise;<br>• Ocean acidification;<br>• Other climate change consequences (especially related to inherent vulnerability and low resources of isolated small island states)<br>• Macro-scale oceanographic processes (El Niño or La Niña, among others) | • International compliance with climate agendas<br>• Strengthen and adapt local socio-economic systems<br>• Improve and adapt coastal protections with adequate engineering (may require external technological support)<br>• Coral reef and mangrove protection and restoration will favor habitat integrity, sediment stability, fisheries nurturing, shoreline protection | Pacific Ocean Islands (including small island states); Indonesia/ Mimura and Nunn (1998); Nunn *et al.* (1999); Christie (2005); Gilman *et al.* (2006); Campbell (2009); Ellison (2010); Hay (2013)<br>Galápagos (Eddy *et al.* 2019) |
| • Degradation by urbanization of intertidal rocky and sandy shores, halophytic vegetation and dune fields. | • Monitoring and protection of scarcer sedimentary coasts (*i.e.* sand dunes)<br>• Coastal moratory | Canary Islands/ Bianchi (2004); Otto *et al.* (2007); Fernández-Cabrera *et al.* (2011); Delgado *et al.* (2017); Ferrer--Valero *et al.* (2017) |
| • Fisheries and shellfish over-exploitation in relation to poor self-management of local fishermen guilds (“cofradías”); commercialisation problems; por co-management strategies; illegal fishing; artisanal fishing decline | • Adapt regulations to the needs and integrate knowledge of the local fishermen’s guilds; promote fishermen participation and collaborative strategies | Tenerife, Canary Islands/ Corral *et al.* (2017) |

Table 2. Casuistic scheme of coastal management and conservation problems on oceanic islands worldwide. The list does not pretend to be exhaustive, but to review the most prevalent causes of environmental degradation in insular coastal ecosystems, with proposals for improvement from the local to the global scale.

| Example problems | Solutions/proposals of management, protection and mitigation | Site/Reference |
|---|---|---|
| • Elevated population density<br>• Tourism, beach disturbance<br>• Agriculture (fertilizers, pesticides); eutrophication<br>• Oversedimentation<br>• Overfishing/aquaculture<br>• Industrial pollution (heavy metals, hydrocarbons)<br>• Silting and pollution of coastal lagoons and estuaries<br>• Sewage discharges<br>• Maritime traffic<br>• Invasive alien species (*i.e.* algae)<br>• Loss of seagrass meadows and associated biodiversity | • Strengthen legal protection in biodiversity hotspots<br>• Measures to minimize eutrophication and reduce phytoplankton blooms<br>• Functional monitoring in sensible sites<br>• Protect sensible sites from further port and marina development; strengthen Environmental Impact Assessment | Mediterranean Sea/ European Communities (1999, 2000); Güreen *et al.* (2020); Waycott *et al.* (2009); Myers *et al.* (2000) |
| • Trade-off between coastal conservation and human behavior at a local scale | • Analyzing perceptual social data for improving resource management | Caribbean Sea coasts and islands, and other global coastal regions/ Aswani (2019) |
| • Macro- and microplastic pollution in coastal waters, beaches, and seafloor sediments, reaching even remote oceanic islands. | • Palliative cleanups<br>• Preventive actions (prohibition/banning of packaging & other non-biodegradable plastic ítems)<br>• Shift to biodegradable materials<br>• Education to consumers<br>• Control spilling from both land- (rivers, submarine sewage outfalls), and marine-based sources<br>• Analysis of presence in trophic chains | Global islands and coasts, all oceans/ Monteiro *et al.* (2018); Ling *et al.* (2017) |

where the fishing pressure has been lower and more strictly regulated in recent decades (Tuya *et al.*, 2004). Several environmental factors are likely to have played a role in the demographic explosion of *D. africanum* populations in the Canaries (Clemente *et al.*, 2009), being the overfishing of predators, *e.g.* hogfishes, snappers and groupers, the most important (Tuya *et al.*, 2004). Also, other anthropogenic factors are considered to be associated with increased abundances of *D. africanum*, such as the population density and the numbers of fishing boats (Hernández *et al.*, 2008). The outbreak of this voracious sea urchin results in commonly spreading barren grounds throughout the entire archipelago (Brito *et al.*, 2004), reaching up to 50 m depth and covering approximately 75% of rocky substrates of the Canary Islands (Barquín *et al.*, 2004). Even, small densities (< 5 ind. $m^{-2}$) can remove up most of the algal cover and thus reduce significantly macroalgal diversity, resulting in impoverished bottoms dominated by encrusting algae (Sangil *et al.*, 2012).

In comparison, in the Caribbean islands, the situation is radically different with major algal growths developed over reefs following the mass mortality throughout the 80s of the long-spined sea urchin *Diadema antillarum* caused by a toxic infection (Hughes *et al.*, 1985). The current population densities are *ca.* 12% of those before the die-off, and still the factors are unclear though recruitment limitation seems to be a pivotal factor (Lessios, 2016). This urchin is a keystone herbivore on Caribbean coral reefs, controlling benthic algae growth by grazing on macroalgae; this species is responsible for 40% of the grazing activity that occurs on a coral reef (Mumby *et al.*, 2006). Thus, the die-off of this sea urchin species underpinned a shifting baseline from coral-dominated to algae-dominated communities, since macroalgae compete and harm corals (Rivers and Edmunds, 2001).

Climatic variables are primary drivers of distributions and dynamics of marine communities in coastal ecosystems (Parmesan 2006). However, global climate change is affecting the marine realm in different ways, *e.g.* warming waters, acidification and anoxia, and thus, several species are favored by these changes compared to other. Moreover, coastal ecosystems are subjected to multiple drivers of human-induced environmental changes. One of the consequences of these changes is the increase of opportunistic fast-growth species, better adapted to the current fluctuating conditions. These outbreaks in turn may cause changes in the structure and function of the broader ecological community, with modifications in physical-chemical properties of the ecosystem (Valiela *et al.*, 1997). Most of the blooms are normally formed by opportunistic algae, which are a natural component of shallow subtidal marine communities, however, humans promote the magnitude, frequency and duration of their proliferation by increasing nutrient loads in coastal waters, *e.g.* pipelines, run-offs, etc. (Eriksson *et al.*, 2009).

In the Canary Islands, blooms of the blue-green algae *Lyngbya majuscule*, linked to declines in the abundance of the seagrass *Cymodocea nodosa*, have been observed in the eastern islands (Martín-García *et al.*, 2014). In addition, two green algae (*Caulerpa racemosa* and *C. prolifera*) have proliferated in cover and extension in *C. nodosa* meadows (Tuya *et al.*, 2014a). These algae are better adapted to eutrophic conditions, and even manipulative experiments have shown faster growth rates of *Caulerpa* occupying *C. nodosa* habitats (Tuya *et al.*, 2013). In addition, the growth of *Caulerpa* is favored by high sedimentation and resuspension rates (Williams 2007). Other factors that are steadily increasing in importance affecting seagrass ecosystems include pollution from several industrial and aquaculture activities (Riera *et al.*, 2013).

#### *2.2.2 Non indigenous species (NIS)*

Probably, a net gain of species has been shown in the last decades as consequence of the non-indigenous species reports, mostly associated to fouling (Godwin, 2003) and shipping traffic (Ware *et al.*, 2014). However, this species increase is not relative to the species loss that is positively correlated to the human pressure on the coastal environment, *e.g.* Canary Islands (Riera *et al.*, 2014).

Non-native, introduced marine organisms can act as competitors, predators and as ecological engineers in the recipient ecosystems (Wallentinus and Nyberg 2007). The threat to biodiversity posed by invasive taxa is increasing as the arrival of new species is facilitated by ocean warming and international maritime traffic (Occhipinti-Ambrogi and Savini 2003; Molnar *et al.*, 2008). For example, the species *Zoobotryon verticillatum*, originally from the Mediterranean Sea, have greatly expanded its biogeographic range by the proliferation of marinas and vessel traffic in the Atlantic Ocean (Minchin 2012).

Hull fouling, ballast waters and sediments from commercial ships and recreational yachts constitute important vectors for introducing NIS to oceanic archipelagos. Oil platforms have also recently been identified as a vector of exotic tropical fish from Brazil, Guinea, or the Caribbean (Falcón *et al.*, 2015). Sea warming is also an environmental factor creating favorable conditions for an increase in tropical and subtropical fauna and flora, partially due to latitudinal shifts or range expansions (*e.g.* Brito *et al.*, 2005). However, in several cases the arrival of exotic species cannot be plainly interpreted as a human-mediated invasion, but as a spontaneous process, although human activities can introduce favoring synergies (*i.e.* oil platforms and ships as vectors for algae, invertebrates and fishes, fish farming cages) in an already-occurring tropicalization scenario.

Ballast water transported by globally increased ship traffic, along with other interacting factors such as nutrient imbalances, salinity, acidity and temperature changes, and coastal degradation, may be enhancing the risk of toxic microalgal outbreaks (Ruiz, 2000). Shipping traffic has other inherent consequences concerning antifouling products, especially in the last decades after the ban-use of Tributyltin (TBT) due to its toxicity and persistence. Currently, other biocides for ship hulls of any length have been tested (Sánchez Rodríguez *et al.*, 2011); however, their toxicological effects are not well studied, especially for non-target species, *e.g.* gastropods and bivalves (Sánchez Rodríguez *et al.*, 2011).

## 3. FUTURE SCENARIOS

The current environmental situation in most of oceanic archipelagos is a consequence of several factors and will be accentuated in the next decades, with an increase of coastal degradation and the number of environmental perturbations that interact and establish ecological synergies deserving further attention.

### 3.1 Prospects of a gradual tropicalization of the Canary islands

Seawater warming has profound consequences on coastal populations, community composition and ecosystem functions (IPCC 2014). For example, the tropicalization of ecosystems drives changes in herbivory, with a deforestation of temperate algal forests and seagrass beds due to the expansion of tropical herbivores (Vergés *et al.*, 2014). In some coastal temperate areas, the increase of sea surface temperature and a rise of tropical fish abundance have coincided with a dramatic decline in macroalgal beds (Nagai *et al.*, 2011). In the last decades, sea warming has been starting to affect the structure of coastal ecosystems in the Canaries with the appearance of species with tropical affinities, from Cape Verde, the West African coast and the Caribbean as main biogeographic origins (Riera *et al.*, 2014).

The growing prevalence of tropicalized climate, *i.e.* sea warming temperature (Parrilla *et al.*, 1994; Santos *et al.*, 2012), including warming of the Canary Current upwelling, (Arístegui *et al.*, 2009), and other influential phenomena such as increases in algal fertilization from Saharo-Sahelian dust plumes (Alonso-Pérez *et al.*, 2007), may establish favorable conditions for phytoplankton blooming events. Many new species are being described with the mentioned potential for ecological change of coastal ecosystems and with repercussions in other environments, as occurred to the recently discovered dinoflagellates *Gambierdiscus excentricus* (Fraga *et al.*, 2011) and *G. silvae* (Fraga and Rodríguez 2014).

An obvious tropicalization of littoral fish fauna has been experienced in the Canarian archipelago over the last two decades (Falcón *et al.*, 2015). Examples of this process are the ocean triggerfish (*Canthidermis sufflamen*) and goldspot goby (*Gnatholepis thomsoni*) (Brito *et al.*, 2005). In contrast, there are evidences showing the regression of temperate species such as the seastar *Marthasterias glacialis* (Authors *pers. obs.*) and fucoid algae, *i.e. Fucus guiryi* (Riera *et al.*, 2015). Even a decreasing trend in coral populations has been observed in the black coral *Antipathella wollastoni* at shallow seabeds throughout the Archipelago, with most of the remaining populations at higher depths (> 45 m) forming dense aggregations (Martín-García 2013).

### 3.2 Fisheries collapse

Catcheries have shown clear symptoms of overfishing throughout the last decades (García-Mederos *et al.*, 2015). The steadily increasing pressure from recreational fishermen is a factor of utmost importance to take into account for future works on fisheries effort and landings. Professional fishers are currently limited to certain coastal settlements, focused on a very limited array of target species (Balguerías 2001), and represent a minor fraction of the landings. The collapse of several commercial species is eminent in the near future since the fishing pressure is not decreasing and stocks are on the brick of sustainability for most of the species, with special emphasis on groupers and snappers (García-Mederos *et al.*, 2015).

Riera *et al.*, (2016) have shown a dramatic decrease of two commercial limpet sizes (*Patella candei crenata* and *Patella aspera*), indicative of overharvesting, mainly conducted by recreational harvesters. The limpet size is considered a surrogate of the state of the conservation of their stocks, and thus, the low viability of limpet populations is evident in the Canarian archipelago.

### 3.3 New pollution concerns

Increasing coastal human presence and seaside recreation at a global scale is related to pollution through microplastics, metals, ultraviolet (UV) filters and other pollutants that bioaccumulate in marine organisms with potential risks for both humans and the marine environments (*e.g.* coral bleaching by viral infections, among other effects) (Danovaro *et al.*, 2008; Sánchez Rodríguez *et al.*, 2015). The rise of plastic in human industrial chains means a new quanti- and qualitative leap in our way of damaging marine ecosystems. It represents the epitome of an unsustainable use of the oceans as a garbage dump.

In this sense, recent studies have alerted of pervasive presence of microplastics in sandy substrata, although biotic effects are still poorly known (Baztan *et al.*, 2014). Little is known of the long-term effects of plastics and microplastics at different levels of the marine food chain. The type of compounds derived from the degradation of plastics, associated with the type of damage they can cause in different types of organisms, including humans, is scarcely known. Methods to characterize and identify composition and origin of plastic debris are being developed (La Daana *et al.*, 2017, Serranti *et al.*, 2018). A low prevalence of microplastics has been found in fish caught in coastal waters of the South Pacific. This has been explained by low human presence in that region and by the great dynamism of the currents that move coastal water outwards through upwelling and (Ory *et al.*, 2018). However, contamination by plastics in coastal waters and beaches of the Atlantic islands (*e.g.* Makaronesia and the Caribbean) is already an important problem (Monteiro *et al.*, 2018). The information again seems to be more focused on sandy beach environments because these are the most accessible for human use. Other coastal configurations, dominant in certain volcanic islands, are poorly studied. In a study from beaches in the Canary Islands, the characteristic debris types collected pointed to open-sea sources rather than land-based or local ones (Herrera *et al.*, 2018). However, the relative importance of diffuse sources compared with point sources of plastic discharge to the sea is not well known, although certainly a very high percentage would come from river discharge and land-based industries and cities (Herrera *et al.*, 2018).

The long-term global effects of microplastics and other pollutants on biodiversity and the integrity of marine trophic networks are difficult to predict. Certain questions remain thus open. How do microplastics interact with other types of contaminants? What are its short and long-term effects on food webs and finally on human health? How can pollution by microplastics affect fisheries? Above all, what mechanisms and strategies are we applying to tackle this global problem?

### 3.4 Extensive coastal degradation

Coastal development affects over 80% of the coastline in many European regions, and it is responsible for much of the observed habitat degradation and loss (Airoldi and Beck, 2007). Coastal occupation underpins profound changes in ecosystem functioning, which are not limited to short-term effects since drivers or consequences that may be developed because of these changes (Biggs *et al.*, 2009). Ecological consequences of coastal transformation have not been fully appreciated or brought into a proper conservation context, due to a preponderance of management implementations and infrastructure schemes applied in response to emergence situations, or in exclusive dedication to human welfare, leisure or economic criteria (Semeoshenkova and Newton 2015).

Degradation of coastal and marine ecosystems through urbanization has been increasing on the islands during the last half century, long before the first marine reserves were firstly conceived and proposed in the 1980s (*e.g.* Bacallado *et al.*, 1989). Coastal development, urbanization, intensive agriculture and mass tourism pressure have contributed to an irreversible transformation of several coastal habitats from oceanic archipelagos (Otto *et al.*, 2007; Bertocci *et al.*, 2016). Such activities interact (and compete) with other activities in the primary sector such as both recreational and traditional fisheries, as well as aquaculture industry (Chuenpagdee *et al.*, 2013).

On the other hand, the construction of “mega” infrastructures such as ports affects extensive coastal areas (Sundblad and Bergström, 2014). The development plans of several islands include the construction of future harbor infrastructures, as well as the creation of artificial beaches with subsequent beach nourishment actions. The environmental affections of these infrastructures are not exclusively limited to the coastal area but to the surrounding environment, with changes in hydrodynamics, physico-chemical and biological factors, among others (Martins *et al.*, 2016).

Besides, impacts of land logistic facilities and transport infrastructure associated to harbors and marinas would add additional impacts (*i.e.* changes in water runoff affecting sedimentation, and pollution sources) at different levels upon mesolittoral and sublittoral habitats. Moreover, such land changes add and accumulate with landscape transformation (urbanization, agriculture; see Otto *et al.*, 2007); this implies indirect effects on the marine environments. The stakeholders have traditionally shown reticence against the creation of marine reserves and protection of relevant marine environments around the islands, although already even some fishermen associations have acknowledged the benefits on the long term, for example in the MPA Mar de las Calmas (El Hierro) (Jentoft *et al.*, 2012).

Finally, the worldwide approach to the conservation schemes of species is becoming growingly reactive and species-focused, rather than adaptive and habitat- or ecosystem-focused. This approach seems to favor species over habitats as protection subjects, and responds to a generalized prioritization of the development of coastal infrastructure and logistic schemes over efficient habitat conservation. In terrestrial coastal ecosystems, it has been suggested that protection of relatively small areas does not avoid massive loss of natural areas (Otto *et al.*, 2007). Far from slowing down, the last decades have seen further irreversible coastal degradation and destruction of natural areas due to coastal development. In the Canary Islands, this has occurred simultaneously to reductions in protection status of concrete figures for both species and habitats, and to the inclusion of “selected” taxa in protection lists within the category “Species of Interest for the Canary Islands”, rather than enhancing protection of certain idiosyncratic and singular environments whose preservation would render improved conservation status of species in the future, if basic principles of biological conservation were applied.

Nevertheless, in the last decade, conservation efforts have shown some positive results, with the recovery of populations of endangered species such as, cetaceans, turtles and seals (Bejder *et al.*, 2016, Piacenza *et al.*, 2016, Magera *et al.*, 2013), as well as signs of reverse of the decline of exploited species, *e.g.* fish commercial stocks in several areas where they were depleted by industrial fleet (*e.g.* Froese *et al.*, 2018). Recently, Duarte *et al* (2020) outlined the importance of fulfilling the Sustainable Development Goal 14 of the United Nations aims to “conserve and sustainably use the oceans, seas and marine resources for sustainable development”. This goal is achieved by rebuilding not only species on decline but ecosystems that have disappear or in at risk of destruction from human-driven perturbations. In the last decade, an increase number of restoration projects and initiative have been developed worldwide on declining coastal ecosystems, namely mangroves, seagrass meadows, kelp forests and coral reefs.

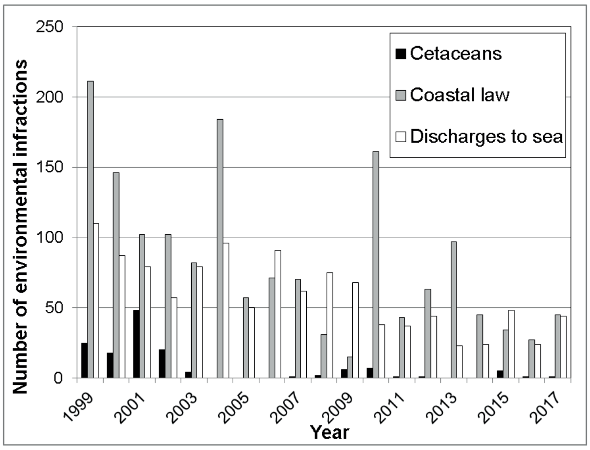


Figure 2. Evolution of the absolute number of environmental infractions related to marine ecosystems in the Canary archipelago. The data relating to infractions on cetacean conservation, illegal discharges to the sea and infractions of the Coast law are shown. Data source: ISTAC (Instituto Canario de Estadística; Estadística de Vigilancia Ambiental / Resultados principales. Islas de Canarias. 1999-2017).

## 4. CONCLUSIONS

The increase in resource exploitation, extractive activities and use and abuse of the coastline entail onerous environmental costs in the Canarian archipelago and other islands worldwide. Society-environment positive synergies should be pursued to ameliorate exacerbated pressure on island coastal resources. Involvement of public administrations, citizenship environmental education to minimize diffuse pollution, updated and effective fisheries management supported by a strict surveillance and gremial participation, monitoring of ballast waters and hull fouling of vessels and oil platforms, and legal control of development within integrated coastal zone management (ICZM), are all urgently needed measures for sustainable future scenarios in most oceanic archipelagos.

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