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Review

Out of sight, out of mind: Threats to the marine biodiversity of the Canary Islands (NE Atlantic Ocean)

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ABSTRACT

Lack of knowledge of the marine realm may bias our perception of the current status and threats to marine biodiversity. Less than 10% of all ecological literature is related to the ocean, and the information we have on marine species that are threatened or on the verge of extinction is scarce. This lack of information is particularly critical for isolated areas such as oceanic archipelagos. Here we review published and grey literature on the current status of marine organisms in the Canary Islands as a case description of the consequences that current out-of-sight out-of-mind attitudes may have on this unique environment. Global change, as represented by coastal development, pollution, exotic species and climate change, are currently affecting the distribution and abundance of Canarian marine organisms, and pose multiple threats to local species and communities. Environmental risks are significant at community and species levels, particularly for threatened species. Failure to address these trends will result in shifts in local biodiversity with important ecological, social, and economic consequences. Scientists, policy makers, educators, and relevant societal groups need to collaborate to reverse deleterious coastal biodiversity trends.

1. Introduction

Conservation practitioners often consider extinctions to be a minor issue for marine plants and animals compared with terrestrial species (Edgar et al., 2005). However, the relatively low proportion of threatened marine species on the Red List (IUCN, 2006) may be due to low threat levels in marine realm, or to the out-of-sight and data deficient nature of the marine environment where population trend data are extremely scarce (Raffaelli et al., 2005). Thus, poor knowledge of biodiversity may lead to an underestimation of the number of threatened species in the marine realm (Roberts and Hawkins, 1999).

Oceanic island ecosystems are disproportionately threatened, with about half of the 724 animal extinctions documented over the past 400 years relating to island species (CBD, 2010). They harbour concentrations of endemic species and unique biological assemblages, with many regarded as biodiversity hotspots (Mittermeier et al., 2004; Whittaker and Fernández-Palacios, 2007). For example, over 90% of Hawaiian species are endemic (Gagné, 1988), while >50% of vertebrates are endemic in Mauritius (Jones and Hartley, 1995). Oceanic islands are inherently less resilient to biodiversity loss than their continental counterparts (Frankham, 2005); they are typically more at risk of natural disturbances (e.g. strong storms, volcanic eruptions) while human-induced threats (e.g. introduced species, habitat destruction) may be more concentrated, and recruitment may depend on propagules travelling long distances (Kinlan et al., 2005).

Here, we use the Canary Islands as a case example of an oceanic archipelago affected by local (e.g. coastal development, pollution, industrial activities, fishing) and global (e.g. climate change) human-induced threats. Along with the Hawaiian Islands, the Canary Islands comprise the most heavily populated oceanic archipelago and amongst the best studied. Moreover, its subtropical location constitutes an intermediate step between Atlantic-Mediterranean and Tropical Atlantic regions, and can be used as a reference to better understand tropicalization processes caused by global sea warming.

There are four major groups of Macaronesian seamounts along with four emerged archipelagos (Fernández-Palacios et al., 2011). In relation with island ontogeny, the process of island emergence would be expected to enhance speciation and regional marine

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biodiversity through the long term, compensating losses due to catastrophic events and island submergence (Whittaker et al., 2007). However, in the Canary Islands and further afield across Macaronesia, marine geological studies (i.e. seamount exploration, ocean-floor scanning) have largely been used to model present and past patterns in terrestrial biotas (Fernández-Palacios et al., 2011) rather than in the marine realm.

The Canary archipelago covers 7493 km^2 and is situated between 27°39′N to 29°24′N and 13°25′W to 18°10′W. It comprises seven major islands (Lanzarote, Fuerteventura, Gran Canaria, Tenerife, La Gomera, La Palma and El Hierro) and several islets, such as La Graciosa (an inhabited and heavily visited islet) and Alegranza off Lanzarote, and Lobos off Fuerteventura. Tenerife is the largest island (2034 km^2) while Fuerteventura is the second largest (1660 km^2) and the closest to the African continent (90 km distance).

The unique wildlife of the Canary Islands has long been recognized worldwide, with about 4000 known endemic species in terrestrial and marine realms (Martin et al., 2010). However, steadily increasing environmental problems threaten biodiversity of this archipelago. For example, one of the most important stressors in the marine realm is coastal population pressure, which is patchy and heavily concentrated in the overcrowded capital islands of Tenerife and Gran Canaria, where density exceeds 400 people per km^2. The remaining islands are less affected by anthropogenic pressures associated with urbanization, including harbours, pipelines and desalination plants. The western islands (La Palma, La Gomera and El Hierro), in particular, have been developed without the massive coastal tourism resorts typical of the capital islands.

The Canarian marine environment is publicly perceived to be in a threatened condition, with local media regularly focusing on four issues: (i) overfishing (recreational and commercial), (ii) uncontrolled population expansion of the sea urchin *Diadema africanum*, (iii) spread of coastal development (e.g. harbours, marinas, resorts), and (iv) proliferation of jellyfishes (see Fig. 1).

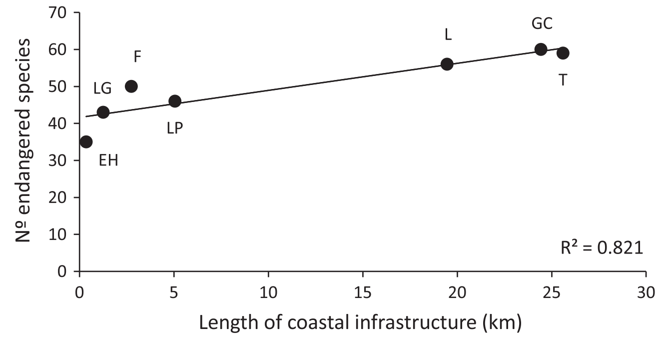

Fig. 1. Correlation between number of endangered species and the total length of coastline infrastructure (km) on each island. EH, El Hierro; LG, La Gomera; LP, La Palma; F, Fuerteventura; L, Lanzarote, GC, Gran Canaria; T, Tenerife.

1.1. Threatened species

Compared to terrestrial species, few marine species are listed under the Canarian Threatened Species Protection Act (Law 4/2010, Boletín Oficial de Canarias (BOC), 4th June 2010). A total of zero "Extinct", four "Endangered", nine "Vulnerable", and six in need of "Special Protection" are recognized, with an additional 39 marine species included within a new category of "Species of Interest for Canarian Ecosystems". Listed species in the Canarian catalogue mostly comprise algae (15 species) and molluscs (12 species).

Discrepancies exist between the IUCN Red List, National Catalogue of Endangered Species, and Canarian Catalogue of Endangered Species (Martin, 2009). The IUCN criteria are designed to identify global threat status (Butchart et al., 2005), however distribution ranges are based on absolute thresholds, which are rarely consistent with range sizes typical of species in smaller islands (Martin, 2009).

Here we discuss several threatened species in the Canary Islands that are included in the Canarian Endangered Species List, as well as other species that have undergone recent population declines. Where provided, distribution range sizes were calculated as area of occupancy based on the number of 500 m × 500 m grid cells in which the species is known to occur. This provides only an approximation to the true range size occupied by a species.

Overall trends in the classification of species in Catalogues and re-evaluations made in the last two decades point to a net decrease in the number of species classified as threatened. In addition, discretionary changes in the nomenclature of categories and selection criteria have apparently altered the effective levels of species protection, with terms that are somewhat vague from a conservational perspective (Tables 1 and 2). Only two explicit categories ("Threatened with Extinction" and "Vulnerable") have survived these subsequent changes, though with a net reduction in the number of taxa included. In recent years, for example, fewer species are listed in the "Threatened with Extinction" sections for cetaceans and turtles in the Canarian Lists (Table 3). These changes may reflect: (i) updating of species status due to new information, such as revised taxonomy, distribution, population sizes and trends, (ii) prevalence of more inclusive categorization at a Spanish national scale though delisting from the Canarian region, or (iii) political interference to effectively reduce protection status of areas and species to ease development schemes (i.e. "political dismantling of the conservation network", Fernández-Palacios and de Nascimento, 2011). The more important of the listed species are described below.

The four marine species currently included as "In danger of extinction" in the Canarian Catalogue of Endangered Species comprise the alga *Gracilaria cervicornis*, the seagrass *Zostera noltei*, the lobster *Palinurus echinatus* and the seal *Monachus monachus*. These species are restricted to only one or two coastal localities in the Canary archipelago, with the exception of *P. echinatus*, which has several populations formed by a low number of individuals (<3) that are probably unviable.

Table 1
Evolution of numbers of taxa in different categories of threat, showing changes in categories applied for marine taxa from the Canary Islands.

Status	2001[a]	2009[b]	2010[c]	2011[d]
Threatened with Extinction	15(3)	6	4	6
Sensitive to Habitat Alteration	11(2)			
Vulnerable	37(5)	3	8	12
Of Special Interest	16			
Not threatened[f]	0(33)			
To be removed from catalogue[e]				
Of Interest for Canarian Ecosystems		19	35	
Special Protection Regime[e]				27
Total taxa	79	28	47	45

[a] Decree 151/2001, July 23th, the Canarian Catalogue of Threatened Species was launched (within parentheses, taxa from the 2001 list evaluated in 2004).
[b] Legislative Proposal (7L/PPL-0011 Del GP Coalición Canaria (CC), del Catálogo Canario de Especies Protegidas).
[c] Law 4/2010, June 4th, the Canarian Catalogue of Protected Species.
[d] Canarian species included in the "Decree 139/2011, February 4th, to the establishment of the List of Wild Species of Special Protection Regime and the Spanish Catalogue of Threatened Species.
[e] Category announced only in one year, with a different category announced in subsequent years. The category "Sensitive to Habitat Alteration" has not been applied from 2004 onwards.
[f] Following the Canarian Government 2004 Evaluation.

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Table 2
Changes in species protection status in threatened Canarian marine taxa by taxonomic group. The total number of species included in each category is shown.

Status	Algae, seagrasses	Invertebrates	Fishes	Turtles	Marine mammals	Total
2001	19	30	9	5	16	79
Threatened with Extinction	1	4		5	5	15
Vulnerable	8	19	5		5	37
Sensitive to Habitat Alteration	4	6	1			11
Of Special Interest	6	1	3		6	16
2009	8	8	2	2	8	28
Threatened with Extinction	3	3				6
Vulnerable	1				2	3
Of Interest for Canarian Ecosystems	4	5	2	2	6	19
2010	16	23	6		2	47
Threatened with Extinction	2	1			1	4
Vulnerable	5	1	1		1	8
Of Interest for Canarian Ecosystems	9	21	5			35
2011	1	7	5	5	27	45
Threatened with Extinction		4			2	6
Vulnerable	1	1	1	1	8	12
Special Protection Regime		2	4	4	17	27

Table 3
Cetaceans recorded by the Center for Wildlife Recovery "La Tahonilla" in Tenerife (Canaries) between 2000 and 2010.

Species	No. individuals	Percentage	Canarian list (2010)
Stenella frontalis	26	16.25	NI
Globicephala macrorhynchus	24	15.00	Special Protection[a] (V)
Tursiops truncatus	21	13.13	Special Protection[a] (V)
Physeter macrocephalus	19	11.88	Vulnerable
Kogia breviceps	14	8.75	Anex VI (SI)
Stenella coeruleoalba	13	8.13	Anex VI (SI)
Delphinus delphis	13	8.13	Anex VI (SI)
Ziphius cavirostris	8	5.00	NI
Grampus griseus	5	3.13	Anex VI (SI)
Mesoplodon europaeus	5	3.13	NI
Stenella spp.	4	2.50	–
Kogia simus	2	1.25	NI
Balaenoptera acutorostrata	1	0.63	NI
Lagenodelphis hosei	1	0.63	NI
Mesoplodon densirostis	1	0.63	NI
Steno bredanensis	1	0.63	NI
Balaenoptera sp.	1	0.63	–
Ziphidae indet.	1	0.63	–
Total	160	100	

[a] The category Special Protection is regarded as supplementary in the 2010 Canarian Catalogue of Protected Species. SI = Special Interest in the State Catalogue. V = Vulnerable in the State Catalogue. NI = Not Included.

1.2. Species at risk

1.2.1. Algae and seagrasses

Benthic cover of brown macroalgae has been steadily declining in the Canary Islands in the last decades, as has been recorded in other regions nearby (Thibaut et al., 2005). The most affected species are *Fucus spiralis*, and *Cystoseira* spp. (*C. tamariscifolia*, *C. mauritanica* and *C. abies-marina*), for which declines appear to be linked to increasing sea surface temperature and growing populations of the sea urchin *D. africanum* on shallow rocky seabeds (Hernández et al., 2008).

The red alga *G. cervicornis* is widely distributed in the Caribbean Sea and West Atlantic Ocean. A single population is known in the East Atlantic, located in Gran Canaria, where it is currently found in a range of only 2 km^2 (i.e. it is found in only 8 grid cells of 500 m × 500 m). Its coverage at Gran Canaria has decreased dramatically over the last 10 years due to coastal development, including brine from desalination plants and sewage from pipelines (Sosa et al., 1996). Although this species is not threatened at a global level, the East Atlantic population is likely to disappear soon.

The red alga *Gelidium canariense* is endemic to four islands of the archipelago (La Palma, La Gomera, Tenerife and Gran Canaria), and possesses a known range of 88 km^2 (Canarian Government, 2009). Population declines of this species have been observed in Tenerife and Gran Canaria during the last 20 years, with increasing fragmentation of populations in the intertidal (Bouza et al., 2006).

Similar to *G. cervicornis*, the seagrass *Z. noltei*, has a broad distribution in the Atlantic but with a Canarian population restricted to one patch of intertidal sandy seabed in Lanzarote, in a highly modified coastal area near Arrecife (the capital city of Lanzarote) (Diekmann et al., 2010). Genetic analyses have shown that the entire population consists of only a single clone (Rumeu et al., 2007).

Two other important phanerogams are *Halophila decipiens* and *Cymodocea nodosa*. Formerly (2001 List), *H. decipiens* was included as "Of Special Interest", whereas *C. nodosa* was catalogued as "Sensitive to Alteration of its Habitat". *H. decipiens* often grows in the vicinity of *C. nodosa* (Haroun et al., 2003) so populations of both taxa likely experience similar threats and impacts. Both have also been recently included into a new and poorly defined category "Of Interest for Canarian Ecosystems" (2010 List; see below). Tuya et al. (2013) observed a drastic decline of *C. nodosa* meadows in terms of shoot density and biomass throughout the last decade.

1.2.2. Sponges

The sponge *Corallistes nolitangere* is restricted to few marine caves in the western islands of the archipelago (Tenerife, La Palma and La Gomera), within a range of only 1.75 km^2. Populations have dramatically decreased in recent years, possibly due to scuba diving (collection, sediment resuspension and bubbles within caves), as well as pollution from water percolation (Anonymous, 2003; Canarian Government, 2009).

1.2.3. Cnidaria

Palythoa canariensis (Canarian sea mat) is an endemic zoanthid, an encrusting colonial anemone-like species. No baseline data are available for this species, but current populations are dispersed in the archipelago (all main islands with probable exception of Lanzarote) and appear highly vulnerable to human activity, with increasing pollution impacting its intertidal rock pool habitat (Martín-Esquivel et al., 2004).

The congeneric zoanthid *Palythoa caribaeorum*, or Caribbean sea mat, is characterized by an even more restricted distribution, found in a total area of only 2.25 km^2 over five islands (El Hierro, La Palma, Tenerife, Fuerteventura and Lanzarote) (Canarian Government, 2009). Although it may be favoured by warmer sea temperatures, this species appears to have become scarce at Tenerife in recent years.

Isaurus tuberculatus and *Dendrophyllia laboreli* are other cnidarian species with restricted populations, but insufficient temporal data are available to evaluate population trends (López-González et al., 2011).

1.2.4. Molluscs

Several molluscs are threatened because of overexploitation. Although the harvesting of these species is currently forbidden by the Canarian Law of Fisheries (Law 182/2004, 21th December 2004), illegal collection is common throughout the archipelago.

The limpet *Patella candei* is included within the category of "Interest for Canarian Ecosystems" although the National catalogue considers this species as Endangered. This species is endemic to the Macaronesian region, where it is heavily exploited for consumption (Núñez et al., 2003) to the point of becoming virtually extinct (Navarro et al., 2005). Canarian populations are restricted to limited intertidal platforms in Fuerteventura and Lobos islet (Núñez et al., 2003). Recovery rates are low due to slow growth (Núñez et al., 2004).

The abalone *Haliotis tuberculata coccinea*, commonly named "Canarian clam", has been subjected to intense harvesting during the last decades and populations are currently scarce. Extraction is prohibited, while recent developments in aquaculture have suggested culture may be economically viable (Bilbao et al., 2010).

The bivalve *Spondylus senegalensis* ("thorny oyster") suffered a drastic decline in the 1980s due to a viral outbreak. Recovery appears to have been poor in the Macaronesian region (Lopez, 2010), but no long-term data are available other than casual observations by recreational divers.

The sea slug *Taringa bacalladoi* is possibly now extinct. It was previously found only in a small bay of Arrecife (Lanzarote), with only 4 individuals (1 holotype and 3 paratypes) ever observed. The cryptic coloration of this species makes it difficult to find, consequently it is possible that the species persists despite a lack of records during the most recent surveys in the area (2003) (Canarian Government, 2009).

Another nudibranch, *Taringa ascitica*, known only from one coastal location in the Canaries, has also not been recorded in the last decade. Despite the severe rarity and possible extinction of these two sea slug species, both are in the category "Of Interest for Canarian Ecosystems".

1.2.5. Polychaetes

The polychaete *Gesiella jameensis* is only found in the cave system and volcanic tubes of Jameos del Agua (N Lanzarote), with a range of 1.25 km^2. The mean density of this species is about 8–9 ind per 100 linear meters, but this has potentially decreased due to increasing predator abundance (e.g. echiuriid *Bonellia viridis*) and pollution from water percolation, as well as scientific collections (Wilkens et al., 2009).

1.2.6. Crustaceans

The remipede species *Morlockia ondinae* is restricted to Jameos del Agua (N Lanzarote), together with another remipede species *M. atlantica*, discovered in 2009 (Koenemann et al., 2009). Both species are characterized by low abundances and are likely sensitive to environmental shifts (e.g. pollution, light intensity).

The lobster *Scyllarides latus* has traditionally been harvested in the Canary Islands by artisanal and recreational fishermen and was included in the "Vulnerable" category. However, despite a sharp population decline across the Canary archipelago in the recent past (González-Pérez, 1995), it is no longer protected from fishing in the recent Canarian Catalogue.

The total population of the lobster *Panulirus echinatus* in the Canary archipelago is estimated at 55 individuals (Canarian Government, 2009), with a high likelihood of local extinction (González-Pérez, 1995). The stronghold for the species in the Canaries was in El Hierro, in the "Mar de Las Calmas" marine reserve. However, volcanic eruptions in October 2011 in this region may have drastically affected the population. Post eruption surveys have not yet been undertaken to examine the potential impacts. Other major threats to this lobster are extraction by recreational scuba divers and commercial by-catch. It is not commercially fished due to its low density.

1.2.7. Fishes

The rockling *Gaidropsarus guttatus* lives in tide pools and shallow marine caves, most of which have been substantially impacted in coastal areas of the Canary archipelago. In addition to habitat modification and loss, recent exponential growth of sea urchin populations (*D. africanum*) poses another major threat, since echinoid barrens do not appear to be a suitable habitat for this cryptic fish, which feeds on algae and algal-associated crustaceans (Canarian Government, 2009).

No reliable data are available to assess population trends in other fish species in the Canarian Catalogue of Endangered Species list (*Gymnothorax bacalladoi*, *Hippocampus ramulosus*, *Pomastoschistus microps* and *Chilomycterus atringa*).

1.2.8. Marine turtles

Five turtle species (*Caretta caretta*, *Chelonia mydas*, *Dermochelys coriacea*, *Eretmochelys imbricata* and *Lepidochelys olivacea*; $N = 1003$ individuals) have been recorded by the Center for Wildlife Recovery "La Tahonilla" in Tenerife (CWR) between 1998 and 2010. The first four species are included in the Spanish State Catalogue as "Of Special Interest". The vast majority of records relate to *C. caretta*, with *ca.* 980 animals managed by the center (97.7% incidence), followed by *C. mydas* (17 animals, 1.7%) and <1% for *D. coriacea* and *E. imbricata*. Most turtles (*ca.* 88% live animals, 12.4% recorded as dead) were reported from the south coast municipalities of Tenerife (70.7%). Fishing net entanglement, ingested plastics, chemical pollution, collisions with marine vehicles and destruction of egg nests (and disturbance of potential laying beaches) are the main factors threatening turtles in the Canary Islands (Camacho et al., 2013).

1.2.9. Marine mammals

Around 32 marine mammal species have been recorded in the Canary Islands (López and González, 1995; Aguilar and Brito, 1999; Carrillo et al., 2010), including seals, baleen whales and dolphins and other toothed whales. Apart from the Endangered monk seal (*M. monachus*), this number includes what is likely an extralimital record of two individuals of the hooded seal *Cistophora cristata*, captured in Güímar (S Tenerife) in 2001 and released in Scotland in 2002 (data from the CWR). This species is classified as Vulnerable by the IUCN. Information on movements of vagrant seals from northernmost ranges in these islands is scarce.

Fifteen cetacean species ($N = 160$ individuals) have been recorded in the Tenerife CWR between 1998 and 2010 (Table 3), with the majority (97%) dead before arrival at the Center. More than 87% of the animals arrived from south or southwest locations off Tenerife. However, up to 596 strandings of at least 23 cetacean species had been recorded for the period 2000–2012 (Gobierno de Canarias, 2012). Most deaths analyzed forensically (70%) were attributed to natural causes, whereas 18% were explained by human impacts (pollution and ship traffic, among others) (Gobierno de Canarias, 2012). South and southwest waters off Tenerife are especially important for reproduction and calving for many cetacean species with stable populations, and distribution of species seems to be in part determined by depth (Carrillo et al., 2010). A significant proportion of cetacean mortalities resulted from collision with vessels, with the most affected species being *Physeter macrocephalus*, *Kogia breviceps*, *Ziphius cavirostris* and *Globicephala macrorhynchus*, in decreasing order (Carrillo and Ritter, 2010). Most strandings reported by Carrillo and Ritter (2010) also occurred in southern and southwestern locations in Tenerife and in eastern Gran Canaria, regions, where important cetacean habitat occurs close to areas of busy naval traffic.

Apart from species cited in Table 3, the Sei Whale *Balaenoptera borealis* is "Endangered" for the IUCN, but the 2010 Canarian Catalogue includes it in the Anex VI (i.e. "Vulnerable" at the State scale, and "Special Protection" as a "Supplementary category in the Canarian Catalogue"). Two species, the North Atlantic right whale, *Eubalaena glacialis* and the monk seal *M. monachus* are "In Danger of Extinction". The local protection areas and the Canary Islands as a whole are regarded as internationally critical areas for cetaceans (Aguilar and Brito, 1999), but local species protection lists seem inconsistent with the global importance of the region for marine mammals (see also Fernández-Palacios and de Nascimento, 2011). This is especially true with projected extractive and infrastructural developments such as oil platforms off Fuerteventura and Lanzarote, and with increasing maritime traffic and associated impacts (noise, chemical pollution, collision, behavioral and dispersal alterations, reduction of prey density and availability, among other factors; Aguilar et al., 2000; Faerber and Baird, 2010).

2. Threats

The key threats to Canarian marine biodiversity are no different from those affecting coastal marine flora and fauna across the globe, including climate change, non-indigenous species, excessive fishing, pollution, and coastal development. These threats have differing local importance, as discussed below.

Population declines observed in several Canarian species during recent decades may progress to extinction. If threatening processes act within a subset of the range of a species, then local extinction is possible, whereas total extinction is unlikely. Nevertheless, a wide species distribution provides little insurance against extinction if the scale of a threatening process fully encompasses that range.

Most marine species possess a planktonic dispersal phase and are often distributed over large distances. However, some have direct development from eggs to juveniles and can be highly localized in distribution (often small organisms, macrofauna and meiofauna; Jablonski and Lutz, 1983). Regardless of dispersal mode, many marine species lack resilience mechanisms to the main environmental threats.

2.1. Climate change

Global warming associated with climate change arguably poses the largest contemporary threat to the Canarian marine ecosystems, particularly the western islands (e.g. El Hierro, La Gomera and La Palma), which are less affected by the Saharian upwelling off the African coast (Barton et al., 1998). A progressive tropicalization of coastal ecosystems of the Canary archipelago has been observed in the last decades, and 78% of the fish species newly-recorded in recent years are considered to have tropical origins (Brito et al., 2005). One tropical hydrocoral (*Millepora* sp.) was discovered on the east coast of Tenerife following the period of the warmest seawater registered in the Canary archipelago in 2004 (27.6 °C) (Clemente et al., 2011). Population increases in the warm-water sea urchin *D. africanum* have also been related to warmer oceanographic conditions (Hernández et al., 2010).

2.2. Increase of air temperature

A consistent increase of air temperature (0.09 ± 0.04 °C) per decade has been recorded in the last 60 years in the Canary Islands, especially night-time temperatures (0.17 ± 0.04 °C) (Martín-Esquivel et al., 2012). However, no ecological studies have been conducted on the effects of air temperature increase on intertidal and supralittoral marine communities. Given that a number of the species occupy tide pool habitats in the Canaries, increasing air temperatures may represent an underestimated threat.

2.3. Non-indigenous species (NIS)

The threat to biodiversity posed by invasive species is increasing as arrival of new species is facilitated by ocean warming and international maritime traffic (Occhipinti-Ambrogi and Savini, 2003; Molnar et al., 2008). Several invasive algal species, including the green alga *Caulerpa racemosa* aff. *cylindracea* and the cyanobacteria *Lyngbya majuscula*, have recently been recorded in *C. nodosa* meadows (R. Herrera pers. comm.). Increasing cover of *C. racemosa* aff. *cylindracea* has replaced *C. nodosa* meadows in several areas (Verlaque et al., 2004), while *Lyngbya majuscula* has overgrown *C. nodosa* in some eastern island meadows (Lanzarote and Fuerteventura). This species has been recorded overgrowing seagrasses after hurricanes and run-off discharges in Florida (USA) (Bartleson et al., 2006) and is capable of fixing its own nitrogen. The proliferation of the green alga *Penicillus capitatus* is currently being investigated following its discovery surrounding *C. nodosa* meadows on the east coast of the western island of La Palma (Sangil et al., 2010). These algal species all show an opportunistic behaviour and are likely favored by eutrophication and high sedimentation and resuspension rates (Williams, 2007).

Hull fouling, ballast water and sediments from commercial ships and recreational yachts constitute important vectors for introducing NIS to oceanic islands such as the Canary archipelago. NIS believed to have arrived at the Canaries in this manner include the African hind (*Cephalopholis taeniops*) from Guinea (W Africa), first recorded by Brito et al. (2010) near commercial harbours at Las Palmas de Gran Canaria and Santa Cruz de Tenerife. Stable populations of this predatory fish may now have established. The butterflyfish *Chaetodon sanctaehelenae* is another fish species believed to have arrived at the Canaries in ballast water (Brito et al., 2005).

2.4. Proliferation of the sea urchin D. africanum

This species has been responsible for an acute impoverishment of coastal rocky substrates in all Canarian islands, with the exception of El Hierro, where fishing pressure has been lower and more strictly regulated in recent decades (Tuya et al., 2004). Effects of ocean warming on recruitment and growth, topographic complexity, and release from predation due to overfishing of predators (*sensu* Ling et al., 2009) are all likely to have played a role in the explosion of *D. africanum* populations in the Canaries (Hereu et al., 2004; Clemente et al., 2007), with the latter mechanism appearing most important (Tuya et al., 2004). Sangil et al. (2012) recorded declines in *D. africanum* populations and a recovery of algal assemblages in a Marine Protected Area (MPA) in La Palma after 4 years, concurrent with increases in densities of predatory fishes (e.g. hogfishes, snappers and groupers). Hernández et al. (2006) suggested that under current predator densities outside of Canarian MPAs, settlement rates of *D. africanum* juveniles were high enough for a sufficient number of individuals to recruit and maintain the barren habitat.

2.5. Fishing pressure from artisanal fisheries and recreational fishers

Coastal fisheries have been massively overexploited in the Canary Islands (Falcon et al., 1996). Over 21 species now have fishing bans by the Canarian Law of Fisheries to safeguard populations. Chronic overfishing of finfishes was noted in the Canary Islands more than 20 years ago (Bortone et al., 1991), and reduced abundances and biomass of all target species in the archipelago are still being noted, particularly for the larger species such as groupers (Tuya et al., 2006). Overexploitation of larger carnivorous fishes such as hogfish (e.g. *Bodianus scrofa*), sea breams (*Pagrus* spp.) and groupers (e.g. *Mycteroperca fusca* and *Epinephelus marginatus*) has had notable effects on other levels of the ecosystem (see section on *Diadema* proliferation above; Tuya et al., 2004).

Collection of patellid limpets by both recreational and professional shellfishers has been extensive throughout the Canary archipelago (Navarro et al., 2005), and topshell snails (*Osilinus* spp.) have also been harvested more recently (Ramírez et al., 2009). Mean limpet densities in the Canaries are two to three orders of magnitude lower than those in nearby temperate areas (Tuya et al., 2006), including the heavily exploited coasts of the Mediterranean (Menconi et al., 1999) and Portugal (Boaventura et al., 2002).

2.6. Organic, inorganic, haline and thermal point source pollution

The waters surrounding the Canary Islands are oligotrophic, lacking the seasonal phytoplankton blooms that typify warm temperate seas elsewhere (Barton et al., 1998; Basterretxea and Arístegui, 2000). The archipelago also lacks permanent rivers, so nutrients and inorganic pollutants tend to enter the sea via smaller, isolated point sources such as pipelines (e.g. sewage), sea-cage aquaculture, and intermittent run-off drains which only flow following heavy episodic precipitation. Intermittent discharges following precipitation may represent an important local threat for marine biodiversity, as organic and inorganic pollutants from intensive farming (mainly banana and tomato) and developed areas accumulates between rainfall events and enters in higher concentrations than would be the case if more consistent flows existed. Riera et al. (2012a) recorded significantly lower meiofaunal densities immediately adjacent to an intermittent run-off drain, where accumulation of finer sediments in the intertidal beach sands coincided with a sharp decline of the most abundant nematode species.

Sea cage fish farming (mainly for seabass *Dicentrarchus labrax* and seabream *Sparus aurata*) also represents a substantial but localized source of allochthonous nitrogen through excess uneaten fish food and unnaturally high concentrations of nitrogenous waste (Holmer 2010). Increased aggregations of local pelagic fishes such as bogue (*Boops boops*) are typical of fish farms in the Canaries, consuming uneaten fish pellets (Riera et al., submitted). While studies in other locations have identified significant impacts of fish farm nutrient inputs on benthic communities (e.g. Neofitou et al., 2010), environmental impacts appear limited to tens of meters on the surroundings of the fish lease in the Canaries (Riera et al., 2012b).

Given the lack of permanent and significant freshwater bodies on the Canary Islands, desalination plants now provide the vast majority of freshwater to the large island populations. Brine releases from desalination plants have been observed to have local impacts on marine biodiversity in other regions (e.g. on giant cuttlefish aggregations in South Australia; Dupavillon and Gillanders, 2009), but little evidence exists for such impacts in the Canaries to date. Riera et al. (2011c, 2012c) observed only minimal evidence of brine impacts on benthic communities up to a maximum of 30 m from the outflow, and suggested impacts of brine in the Canaries are only likely to be significant in sheltered bays with water column stratification.

Thermal pollution occurs in the Canaries as a result of thermal power generation, but as with haline pollution, impacts are likely to be minor and only evident close to the point of warm water discharge (Riera et al., 2011b).

Fortunately, the presence of continuous coastal currents around the Canary Islands facilitates the dispersion of pollutants. Thus, while impacts may be acute near highly concentrated point sources, broader impacts of pollution along coastlines have not been identified. Monitoring of pollution impacts is currently limited to microbiological water testing near pipelines, but recent and current research is driving development of new bioindicators based on faunal and sedimentary features (e.g. organic matter) to be integrated into environmental reporting (Riera et al., 2011a, 2012b).

Chronic pollution derived from ship traffic is another potentially large, but understudied threat to the marine environment of the islands. On average, 30,000 commercial vessels per year entered and exited Canarian harbours (mostly in Gran Canaria and Tenerife) between 1998 and 2012 (ISTAC 2013). Aside from pollutant emissions from moving and docked ships, the impact for cetaceans posed by collisions and other disturbances (noise and vibration, human presence) is far from negligible. Extraction of construction materials from the seabed, and fuel prospecting and extraction, are two further disturbance sources for the marine biota of the Canary Islands, with unknown impacts.

2.7. Coastal development

Pressure on coastal ecosystems in the Canaries is driven by high population densities (average 254 ind km^{-2}, but *ca* 500 ind km^{-2} on the two capital islands, Tenerife and Gran Canaria), and continues to rapidly increase. About 9% of the Canarian coast is heavily transformed with the construction of rockwalls and other artificial structures on the shoreline (Spanish Government 2012). Highest concentrations of coastal structures (groins, dykes, breakwaters, etc.) and beach infrastructure (e.g. boardwalks) are located in tourism areas on the south coast of Tenerife and Gran Canaria to form, protect and encourage use of artificial beaches.

Likewise, a consistent increase of harbours and marina facilities has occurred along the Canarian coast, but little is known of the impacts of these coastal structures on marine biodiversity. About 80 km of coastal artificial installations have been constructed (Table 4). Some of these construction projects are ongoing, hence the above figure is a conservative estimate. Besides, impacts of land logistic facilities and transport infrastructure associated with harbours would add additional impacts and pollution sources at

Table 4
Natural and anthropogenic features of Canarian coastal areas and the numbers of threatened species per island. (Data: Instituto Canario de Estadística, ISTAC, 2013; except for threatened taxa: see main text.)

Islands	No. threatened spp. (all categories)	Island area (km^2)	Artificial structures (km)
Canaries	99	7446.95	78.88
Lanzarote	56	845.94	19.46
Fuerteventura	50	1659.74	2.74
Gran Canaria	60	1560.10	24.43
Tenerife	59	2034.38	25.6
La Gomera	43	369.76	1.25
La Palma	46	708.32	5.05
El Hierro	35	268.71	0.35

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different levels upon mesolittoral and sublittoral habitats. Riera et al. (2011a) studied the impacts of Puerto Calero, a marina in SE Lanzarote, and observed high concentrations of hydrocarbons (PAHs) and heavy metals, as well as distinctly different macrofaunal assemblages between sediments inside the marina, in the mouth, and in control locations in a similar habitat at distance from the marina.

Across the archipelago, a very high correlation is evident between the total length of artificial structures on different islands and the number of threatened species recorded for the different islands ($R^2 = 0.82$, $p = 0.004$; Table 4). This correlation was considerably higher than the correlation evident between island coastline length and number of threatened species ($R^2 = 0.65$).

2.8. Volcanic eruptions and other stochastic events

The Canary archipelago is an active volcanic region, and volcanic activity represents a significant potential threat to coastal fauna and flora, including through mega-landslides or gravitational flank landslides (Rivera et al., 2013). A recent eruption at El Hierro from 10th October 2011 to March 2012 (which also caused >10,000 low intensity earthquakes), resulted in physico-chemical abnormalities and major impacts on planktonic communities (Fraile-Nuez et al., 2012). However, effects on benthic assemblages were not monitored during this period and long-term data are lacking from affected locations.

Islands are natural laboratories for evolutionary diversification as well as for natural extinction processes such as those caused by catastrophic events like volcanic eruptions. Sessile assemblages such as corals that are locally-patchy and diverse may be differentially impacted by emissions of lava and gasses, and sudden alteration of physic-chemical parameters such as temperature, salinity, oxygen content, pH, turbidity and nutrients. Amongst such communities, dense patches of black coral *Antipathella wollastoni* are present at depths of up to 100 m in the Canaries, with large examples present at the volcanism site off El Hierro. Thought to be a Macaronesian endemic, it has been recently found elsewhere in the East Atlantic (Ceuta, Ocaña et al., 2006). Conservation of populations and habitats of cryptic species that are not explicitly protected is also an important concern, since many threatened species might be associated with such habitat types.

Compared to continental regions, the marine faunal and floral composition of the Canary archipelago is particularly affected by biogeographical processes associated with metapopulations. The Canary Islands are subtropical, so marine ecosystems are influenced by both high- (temperate) and low-latitude (tropical) waters and associated species. Some species are geographically limited to few sites since they appear poorly adapted to local conditions (i.e. the seagrass *Z. noltei* and the lobster *P. echinatus*), but populations persist to the present because of the continual supply of individuals from favorable areas nearby (e.g. Mediterranean Sea, Atlantic African coast). Marine species that are fully isolated from nearby areas and have genetically homogeneous populations likely face a relatively high probability of extinction in the near future.

Speciation processes may have recently occurred in the marine environment of the Canaries, most notably with the highly adapted community present in volcanic tubes and caves. A number of species are highly adapted to this environment, characterized by complete darkness, little water exchange, and food scarcity. Faunal communities in lava tubes are characterized by very low densities and high sensitivity to habitat variation, and are thereby threatened by anthropogenic (i.e. pollution) and natural stochastic impacts, perhaps even excessive scientific sampling.

In summary, the most threatened marine species in the Canary archipelago belong to three groups of species:

(i) Endemic species.
(ii) Edge populations of temperate or tropical species, such as several species of algae (e.g. *G. cervicornis*, *F. spiralis*, *Cystoseira* spp and *Gelidium* spp.).
(iii) Species adapted to volcanic caves, such as the remipedes *Morlockia ondinae* and *M. atlantica*, as well as some microscopic invertebrates (i.e. the polychaeta *Gesiella jameensis*).

In particular, several threatened species are present in a single enclosed bay (Charco de San Ginés) in Lanzarote. This bay is unique in the archipelago because of its mud-sand sedimentary composition and low tidal variation. This site may include species not recorded elsewhere that have recently become extinct (i.e. the nudibranchs *T. bacalladoi* and *T. ascitica*).

3. Addressing threats to marine biodiversity

We suggest that three primary mechanisms are required to address the key threats to marine biodiversity of the Canary Islands: (i) establishment of consistent marine environmental monitoring programs, (ii) establishment and enforcement of protection laws for species in the Canarian Catalogue of Endangered Species, and (iii) establishment and enforcement of a more extensive network of marine protected areas, which explicitly considers threatened species and habitats. In this sense, special effort should be devoted to the design of marine corridors and protected expanses in view of the large requirements of wide ranging, highly mobile, threatened vertebrates such as marine mammals and turtles, and their interaction with the intensive ship traffic and coastal occupation in the region (Schofield et al., 2013).

3.1. Environmental monitoring studies

The Environmental Agency of the Canary Government undertakes monitoring of threatened species and fragile ecosystems, with special emphasis recently placed on marine caves (R. Herrera and L. Moro *pers. obs.*). This monitoring has resulted in the discovery of new invertebrate species and extended the range of others already known from the archipelago (R. Riera *pers. obs*).

The only other major source of marine environmental monitoring occurs in response to requirements for coastal development, such as construction of pipelines, desalination plants, off-shore fish farms. Although ad-hoc, these studies can provide valuable marine biodiversity information in particular areas.

A more coordinated regional approach is nevertheless required, one that uses consistent methodology and includes locations known to support threatened species and threatening processes (modified coastlines, abundant NIS species etc.) as well as locations considered to be least impacted.

The Marine Strategy Framework Directive (MSFD) considers "*Non-indigenous species introduced by human activities are at levels that do not adversely alter the environment*" (Annex I, Descriptor 2). Despite this, marine biodiversity monitoring programs do not consistently assess levels, but are urgently needed in order to better understand impacts of populations of invasive species in the Canary archipelago. Monitoring control and inspection of tankers and container ships in Canarian commercial harbours (Las Palmas de Gran Canaria and Tenerife) should also be undertaken.

3.2. Protection laws

The last Canarian Catalogue of Endangered Species (Law 4/2010, June 4th) met with broad dissatisfaction from both the general public and the scientific community (Fernández-Palacios and De Nascimento, 2011). The new category ("Species of Importance for

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Canarian Ecosystems") implies that species included in this category are protected exclusively if they are found within the boundaries of the current Canarian MPA network and the Natura 2000 network. Several key organisms, including marine species, such as the seagrass *C. nodosa*, are included in this category.

3.3. Marine Protected Areas (MPAs)

Three MPAs have been proclaimed in the Canary archipelago ("La Restinga-Mar de Las Calmas" in El Hierro, "Isla de La Palma" in La Palma, and "Isla de La Graciosa e Islotes del Norte de Lanzarote" in Lanzarote). All are fisheries reserves, established for the conservation of coastal fisheries resources. Unfortunately, threatened species or sensitive ecosystems were not considered in their establishment, and the reserves thus provide little protection for species and habitats that are threatened.

Moreover, the current Canarian MPA Network is largely focused on outer islands where marginal populations of threatened species are protected, thereby limiting re-establishment of original distributions across the centre of ranges (Fernández-Palacios and De Nascimento, 2011). From the point of view of mitigating the effects of global change (e.g. ocean warming), more widespread geographic protection of threatened species than occurs with the current MPA network would improve opportunities for species to track their environmental niche (e.g. as has been observed in coral species moving deeper in response to warming; Narayanaswamy et al., 2010) and enhance resilience to large scale environmental impacts (Micheli et al., 2012; Bates et al., 2014).

As discussed above, trophic cascades have been reported in the Canaries where higher biomass of predatory fish reduce densities of the sea urchin *D. africanum*, and in turn this increases benthic macroalgal cover (Tuya et al., 2004). The increasing fish biomass in one Canarian MPA (La Palma) appears to have been critical in facilitating rapid increases in local macro-algal cover (Sangil et al., 2012). Given the severely depressed predator densities throughout the archipelago, establishment of new MPAs in locations important for threatened species should generate benefits additional to the direct protection of that species within their boundaries. Habitat protection and restoration are likely to be facilitated as predator assemblages recover and communities revert to more natural states (Edgar et al., 2009).

A number of future MPAs are currently waiting to be approved by the Spanish government; one on the north coast of La Gomera, two in Tenerife (Teno and Anaga) and one on the east coast of Gran Canaria. The creation of a network of marine reserves is considered a priority for the conservation of Canarian marine coastal ecosystems through the future.

4. Conclusions

The total magnitude of cumulative stressors (pollution, climate change, overfishing, urban and infrastructure pressure, etc.) is increasing the risk of extinction of marine species to unprecedented rates on Earth (Harnik et al., 2012). However, most documented marine extinctions and regressions are from intensively-studied areas (e.g. Atlantic coasts of Europe, Caribbean Sea), comprise prominent and conspicuous species (e.g. fishes, mammals, molluscs and corals), and focus on particular marine habitat types (e.g. coral reefs, mangroves).

Effective management action to reduce marine environmental degradation is hindered by the near absence of information for most regions and habitat types. Thus, effects of climate change on such habitat types as temperate reefs, sandy seabeds, mangroves, and the deep sea still remain unknown or very poorly known because of limited data. Consequently, marine extinction rates are likely to be grossly underestimated overall. A common element in this summary of known species at risk is a lack of adequate data on distribution and population trends through time. Extinctions and conservation outside protected areas are also an issue of regional concern. Less than 1% of the Canarian waters are protected under the Canarian Network of Protected Natural Spaces (Red Canaria de Espacios Naturales Protegidos).

In the Canary archipelago, the large range of some species is likely to confer passive protection at wider scales, but if threatening factors continue operating locally, some species will become locally or regionally extinct through accumulation of discrete, often small, population deletions.

Along with data paucity, threat abatement initiatives remain lacking for the most threatened populations in the Canaries. Furthermore, large inconsistencies between different threatened species lists, compounded with different interests and criteria at different geographical areas, are major impediments to conservation of threatened species at all scales. The situation is of particular concern for species that have been overlooked in listing processes and for which no commercial interest exists. While such species, which comprise the great majority of all marine species, are not exploited directly, consequences of changing community structure, including rearrangement of species at different trophic levels and modified ecosystem functioning, are unknown but potentially huge.

The Canarian archipelago provides a microcosm for threatened marine species associated with isolated island groups worldwide, albeit with extreme levels of human disturbance. Poor "visibility" (either public or academic) of the marine biota should not excuse inadequate reach and poor coordination of conservation strategies and environmentally-destructive developments. Even with limited current knowledge, several initiatives are imperative to achieve conservation objectives in oceanic island settings: (1) local recognition and enforcement of international conservation and trade laws, (2) coordinated management approaches between islands for species and populations, (3) appropriate regulation of commercial and extractive activities, and (4) their synergy and mutual feedback with conservation programs.

Oceanic islands are fragile and susceptible to perturbation. Human overpopulation is a key threat for marine species, resulting in extensive biodiversity loss, and with populations of some narrow-range species on the verge of extinction. Integrated coastal management is urgently needed together with the development of a network of marine protected areas (MPAs). The information provided from the Canary archipelago in the present study is also considered relevant to stakeholders and policy-makers operating in other overpopulated oceanic archipelagos.

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