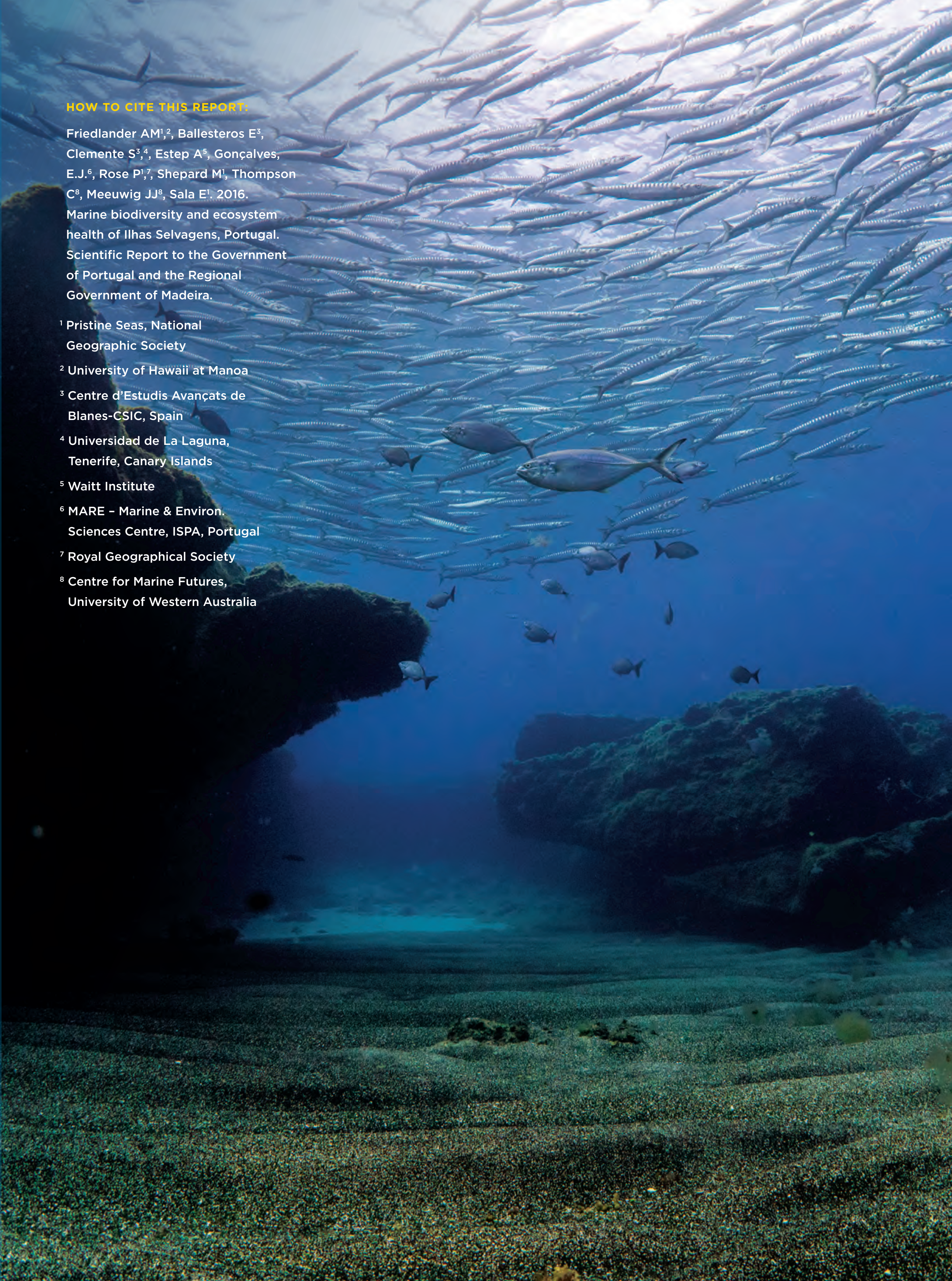
MARINE BIODIVERSITY AND ECOSYSTEM HEALTH OF ILHAS SELVAGENS, PORTUGAL

SCIENTIFIC REPORT

May 2016

National Geographic Pristine Seas



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EXECUTIVE SUMMARY

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The marine environment of the Ilhas Selvagens of Portugal, located between Madeira and the Canary Islands, is little known. In September 2015, National Geographic Pristine Seas, in conjunction with the Instituto Universitário-Portugal, The Waitt Institute, the University of Western Australia, and partners conducted a comprehensive assessment of the rarely surveyed Ilhas Selvagens, especially the poorly understood deep sea and open ocean areas, and quantified the biodiversity of the nearshore marine environment.

In September 2015, National Geographic's Pristine Seas project, in conjunction with the Instituto Universitário-Portugal, The Waitt Institute, the University of Western Australia, and partners conducted a comprehensive assessment of the rarely surveyed Ilhas Selvagens to explore the marine environment, especially the poorly understood deep sea and open ocean areas, and quantify the biodiversity of the nearshore marine environment.

We conducted *in situ* surveys of fishes, algae, and other components of the benthic community at 29 locations within two depth strata (10 and 20 m) in > 150 hours of scientific diving. Twelve drop-cam deployments were conducted between 164 and 2,294 m to survey the deep-sea ecosystem. A total of 57 mid-water baited remote underwater video systems (mid-water BRUVS) deployments assessed the pelagic (open-ocean) community.

The nearshore marine ecosystem was found to be healthy with a diverse algal assemblage consisting of at least 47 different taxa. Sea urchin barrens, often a symptom of extensive overfishing, were rare and found to cover only 8% of the bottom. Approximately 71% of the species and 91% of the numerical density of mobile invertebrates consisted of species with Eastern Atlantic or Mediterranean biogeographic affinities.

The intertidal community was noteworthy for its abundance of large sun limpets (*Patella candei*), particularly on Selvagem Pequena. This species has become rare throughout much of its range due to overfishing and is listed as in danger of extinction in the Canary Islands. In addition, top-shell snails (*Phorcus atratus*) and other limpets, mainly *Patella aspera* and *Siphonaria pectinata*, were also common. The extremely high densities of intertidal grazers appear to limit macroalgal growth, which was restricted to small patches of turf algae, mainly Jania cf. rubens in the lower intertidal zone.

We observed 51 species of fishes from 28 families overall, with 39 species from 20 families occurring on quantitative transects during the expedition. Species richness per transect was relatively low (7.8 ± 1.4 sd), but biomass (1.6 t ha^{-1} ± 2.2 sd) was high compared to other locations within the region. Several commercial species (e.g., groupers, jacks, triggerfishes) that have been overfished in other locations within Macaronesia (the northeastern Atlantic islands of Azores, Madeira and Canaries) were common and of large size at Ilhas Selvagens. Species known to feed on and control sea urchins (e.g., hogfish, triggerfishes) were also in high abundance compared to heavily fished locations nearby.

We conducted the first fisheries-independent description of the pelagic (open ocean) marine fauna assemblage around Ilhas Selvagens. Our pelagic cameras revealed a number of protected species such as Bryde's whale (*Balaenoptera brydei*), Atlantic spotted dolphins (*Stenella frontalis*), as well as loggerhead turtles (*Caretta caretta*). Ilhas Selvagens appears to be an important location for both adult and juvenile fisheries species such as pompano dolphinfish (*Coryphaena equiselis*), juvenile blue marlin (*Makaira nigricans*), Atlantic horse mackerel (*Trachurus trachurus*), and several other species of jacks.

Our deep-sea video cameras showed a diverse and rich fauna that included at least 24 different taxa of deep-water fishes from 17 families. Deep water habitats were either sandy, flat areas with limited relief, or high relief island slopes consisting of basalt rock with sand channels. The fishes in these deep-water habitats were dominated by grenadiers and cutthroat eels. The shallow community (100–300 m) consisted of high relief basalt covered mostly by sponges, gorgonians, and black coral. We observed one smalltooth sand tiger shark (*Odontaspis ferox*) at 1200 m. In addition, we observed a wide range of mobile and sessile invertebrates, with crustaceans (primarily shrimp) being the most diverse and numerous.

We conducted water samples for microplastics at 20 locations around the islands to better understand their presence in the ocean food web. We found 85% of the samples to have microplastics in them, with an average of 1.4 (± 1.0 sd) pieces per liter.

In addition, we collected sediment samples at 13 locations (N = 39 individual samples) to determine the community of benthic microfossils present at Ilhas Selvagens. Microfossils are excellent indicators of general environmental conditions such as temperature, salinity and organic enrichment. They will provide us a better understanding of the broad environmental conditions of the area, and produce a reference collection for this remote marine archipelago.

Current threats to Ilhas Selvagens include illegal fishing within the reserve and unregulated or weakly monitored fishing for tuna and other target species surrounding the reserve. Previous shipwrecks have altered the nearshore and intertidal ecosystems, although the full extent of the impacts is unknown. In addition, climate change will likely influence the primary productivity of the region in the future. Changes in ocean primary production can have important consequences for the trophic structure of ecosystems, especially in oligotrophic regions such as the Selvagens.

The current reserve around Ilhas Selvagens extends to 200 m water depth. This depth is reachable within a few hundred meters from the coastline due to its steep volcanic slope. This does not provide protection for many of the wider ranging species such as seabirds, marine mammals, and tuna that rely on this important area, with fishing activity often occurring in close proximity to the coastline. The expansion of the reserve around Ilhas Selvagens would provide protection for both the coastal species occurring in nearshore waters and the valuable pelagic resources, allowing them to grow larger, become more abundant, and generate higher reproductive output. This would benefit the fishing outside the protected area, protect biodiversity by providing a larger area where individuals can grow and reproduce and reduce by-catch of a wide range of species that are critical to ecosystem function. Additionally, the expansion of the Ilhas Selvagens reserve would be an outstanding opportunity to protect a unique ecosystem in the North Atlantic. The expansion of the reserve would provide greatly needed baselines for the region, protect the entire ecosystem—from land to deep sea to open ocean environments—and allow a comprehensive approach to management and conservation in a near-pristine environments. The currently designated Special Protection Area (SPA) under the Birds Directive of the European Union is a good starting point to effectively increase protection of the Selvagens Archipelago. Having sites like this in place will be critical to face the challenges of climate change and predict the impacts its impacts in near future, since healthy ecosystems are more resistant and resilient to both chronic and episodic disturbances.

INTRODUCTION

INTRODUCTION

The Selvagens islands belong administratively to the Madeira archipelago in the North Atlantic, located between Madeira and the Canary Islands, and are the southernmost point of Portugal. The Selvagens comprise two major islands and several islets of varying sizes. It is administered by the Portuguese municipality of Funchal, and is part of the Madeiran civil parish of Sé. The Permanent Commission of International Maritime Law clarified sovereignty of the Selvagens to Portugal on 15 February 1938. While the sovereignty of the islands is currently settled, their status in face of the United Nations Convention on the Law of the Sea is still disputed by Spain concerning the criteria on whether they are considered islands or rocks, which has important consequences for the definition of the southernmost border of the Portuguese Exclusive Economic Zone (with Spain). This could also influence protection measures around the islands with the Portuguese authorities claiming a 200 nm EEZ and Spain recognizing only a 12 nm territorial sea. Both countries have submitted their extension of the continental shelf processes to the United Nations' Commission on the Limits of the Continental Shelf, which are currently being evaluated.

CONSERVATION STATUS

In 1959, the World Wildlife Fund became interested in the islands and signed a contract/promise with the owner, Luís Rocha Machado. In 1971 the Portuguese government intervened and acquired the islands, converting them into a nature reserve. The Selvagen Islands Reserve includes the surrounding shelf to a depth of 200 m (total marine area = 34 km^2) was created as part of the Madeira Nature Park and is one of the oldest nature reserves in Portugal. In 1976, permanent surveillance of the reserve began, and in 1978 the reserve was elevated to the status of Nature Reserve. In 2002, part of the nature reserve was nominated for UNESCO's list of World Heritage Sites and is currently included in the tentative World Heritage Site list. In 2014, a Special Protection Area (SPA) of Selvagens Islands was designated by the Regional Government under the Birds Directive of the European Union. This SPA encompasses 124.5 hectares.

Currently the Selvagens Islands are managed and patrolled by a team of park rangers from Madeira Nature Park. On Selvagem Grande there is a permanent research station with two rangers who are stationed on the island year-round, while Selvagem Pequena is usually manned by two rangers between May and October. These are the only human inhabitants on the islands.

THREATS

The current threats to the Selvagens marine ecosystems and reserve are:

- Surrounding fishing by Spanish and Madeira vessels, mostly for tuna and other pelagics.
- Illegal fishing within the reserve boundaries
- The small size of the protected area is insufficient to address these threats (Koldewey et al. 2010, Edgar et al. 2014) as it does not encompass the larger ecosystem that harbors the pelagic fishes on which nesting seabirds depend.

THE OPPORTUNITY FOR PORTUGAL

The government of Portugal has submitted a proposal to the United Nations' Commission on the Limits of the Continental Shelf, requesting an extension of its Exclusive Economic Zone (EEZ). In addition, the government announced last year its intention to create new marine protected areas covering a total of 400,000 km^2 (see attached news story). The largest areas protected are areas mostly outside of Portugal's current EEZ, deep, and currently not threatened by bottom trawling. It seems these are "low conflict" areas to assist Portugal to achieve its commitment to the Convention on Biological Diversity to protect 10% of its EEZ by 2020. If the UN Commission does not accede to Portugal's request, a large portion of those areas could not be protected. If the UN response is positive, there is an opportunity for the government to create additional zones, including at the Selvagens, that would be ecologically more significant and less “residual” (Devillers et al. 2015). As it is likely that the UN decision will be made in 2018, the surveys reported on here are timely as we encourage the government of Portugal to expand the Selvagens reserve, thereby assisting Portugal and the Madeira regional government to advance significantly their commitments to ocean conservation, and become relevant players at the international level.

OBJECTIVES OF THE PRISTINE SEAS EXPEDITION

Due to their remoteness, there has been limited scientific research conducted around Ilhas Selvagens and our understanding of the marine ecosystem is still very limited (Figure 1). The EMEPC/M@rbis/Selvagens expedition in 2010 involved more than 80 participants and greatly increased our scientific understand of these remote islands. National Geographic’s Pristine Seas, The Waitt Institute, the University of Western Australia and other collaborators (Appendix I) conducted a 10-day expedition to Ilhas Selvagens in September 2015 to survey the health of its underwater ecosystems, from shallow to deep, and to document this ecosystem in film. The results of the expedition will be used to increase public awareness on the extraordinary value of this gem of the Atlantic and recommend to the Portuguese government on the expansion of the current marine protected area around the Selvagens, which currently covers only the waters down to 200 m depth.

FIGURE 1.

The little-known underwater ecosystem of Ilhas Selvagens.

SITE DESCRIPTIONS

SITE
DESCRIPTIONS

The Ilhas Selvagens Archipelago consists of two main island groups (Selvagem Grande and Selvagem Pequena) which are ~ 15 km apart from one another (Figure 2).

Selvagem Grande – The northeast group comprises Selvagem Grande and three smaller islets, Sinho Islet, Palheiro da Terra and Palheiro do Mar. Selvagem Grande has an area of 2.45 km^2 with steep cliffs rising 70–90 m high above sea level. The interior is flat, with three summits, remnants of former volcanic cones, having a maximum height of 163 m (Pico da Atalaia).

Selvagem Pequena – The southwest group comprises Selvagem Pequena (0.3 km^2) and Ilhéu de Fora (0.08 km^2), as well as numerous smaller islets, including Alto, Comprido and Redondo, and the small group of the Norte Islets. Pico Veado is the highest point on Selvagem Pequena (49 m), with the remainder of the island relatively flat and only 5–10 m above sea level.

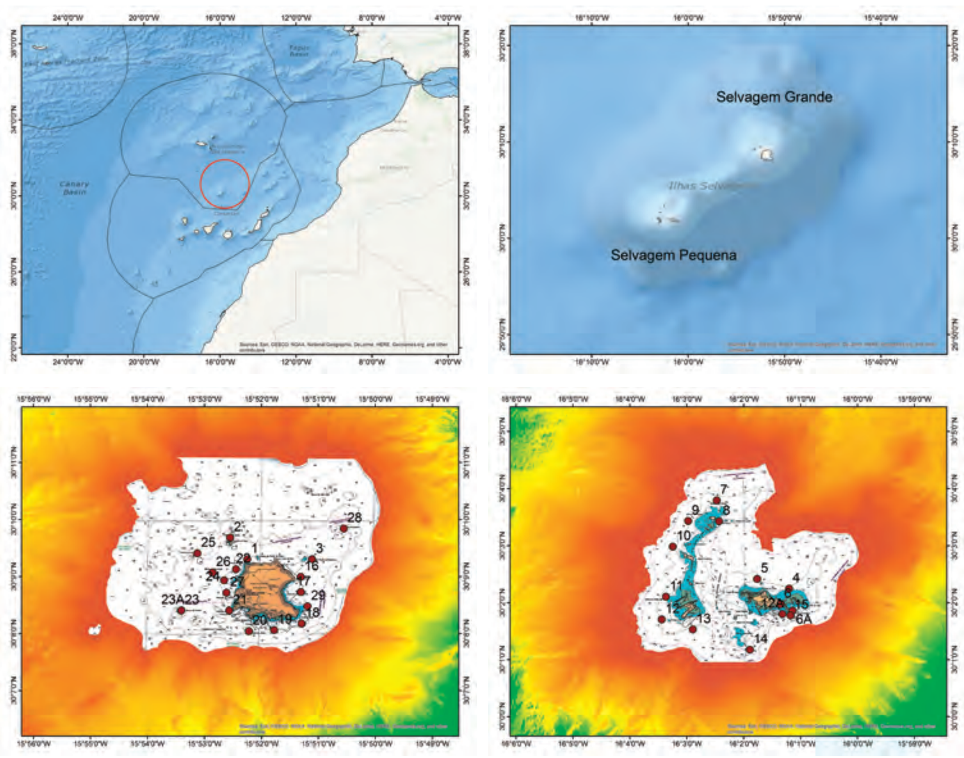


FIGURE 2.

Ilhas Selvagens and sampling locations around Selvagem Grande and Selvagem Pequena.

RESULTS

RESULTS

We surveyed a total of 29 stations at two depths (10 and 20 m) around Selvagem Grande (N = 17, N = 34) and Selvagem Pequena (N = 12, N = 24) (Figure 2, Appendix II). All methods are fully described in Appendix III.

Habitats

INTERTIDAL ZONE

The most conspicuous feature of the intertidal zone at both islands was the lack of macroalgae. Instead, this habitat was dominated by the Macaronesian endemic limpet *Patella candei* and the endemic top snail *Phorcus atratus*. Another limpet, *Patella aspera*, was also present in abundance. Small carpets of turf algae, mainly *Jania* cf. *rubens*, were the only algae present in the intertidal zone. Beaches are uncommon in the Selvagens, although Selvagem Pequena hosts some beaches of cobbles and coarse and medium sands.

SUBTIDAL HABITATS

Most of the subtidal habitats of the Selvagens consist of flat lava benches, with moderate relief in the shallows. Depth increases gradually from shore around both islands, although some seamounts and islets of Selvagem Grande have steep slopes. The subtidal (2–30 m) areas around the main islands are covered by small mats of turf algae interspersed by small barren areas created by sea urchins. Algal cover is dominated by the laminar brown alga Lobophora variegata and the filamentous red alga *Lophocladia trichoclados*. The green alga *Pseudotetraspora marina*—a recently reported opportunistic Caribbean species currently blooming in the Canary Islands—was also abundant at some locations.

In the shallows, the sea urchin *Paracentrotus lividus* was common—usually hiding in holes and cracks in the reef. The dominant sea urchin was *Diadema africanum*, which sometimes forms barren areas in the uppermost part of the seamounts and along most vertical walls. These barrens also host encrusting bryozoans, and the sponges *Phorbas* cf. *fictitious* and *Crambe crambe*. The brown algae *Lobophora variegate, Cystoseira abies-marina* and *Sargassum* spp.—canopy-forming algae that usually make seaweed beds in the exposed sites of the nearby Canary Islands — are extremely rare in Selvagens. Sedimentary bottoms are scarce, at least at depths shallower than 30 m, and consist of dark volcanic sand. Maërl beds were frequent in number and develop mainly in small patches surrounded by rocks.

The vertical walls in waters > 30 m were dominated by coralline algae and invertebrates. Walls at Palheiro da Terra, an islet at the north-west of Selvagem Grande, hosted a bed of black coral (*Antipathella wollastoni*), sponges and non-zooxanthellate hard corals. The vertical walls and small caves and tunnels found around the main islands and islets have an assemblage dominated by benthic invertebrates such as the sponges *Pleraplysilla spinifera*, *Chondrosia reniformis*, *Ircinia oros*, *Axinella damicornis*, *Phorbas* cf. *fictitious*, *Clathrina coriacea*, and *Hexadella racovitzai* (among others), the corals *Caryophyllia inornata*, *Madracis asperula*, *Polycyathus muellerae* and *Phyllangia americana mouchezii*, several encrusting bryozoans and the tunicate *Aplidium* sp.

Sessile Benthic Community

There were 69 different sessile benthic taxa observed on transects around Ilhas Selvagens (Table 1). The most diverse groups were brown algae (N = 20), red algae (N = 16), and sponges (N = 10). Algae were classified into functional groups to facilitate comparisons between islands and depths. Turf algae comprised 35% (± 19% sd) of sessile benthic cover overall and was similar in percent cover between islands (Figure. 3). Erect (non-canopy) algae comprised an additional 30% (± 14% sd) of the bottom cover overall and was 56% higher at Selvagem Pequena. Cover of encrusting (non-calcareous) algae was 13.4% at Selvagem Grande, and nearly 1.5 times lower at Selvagem Pequena (5.5%). Barrens accounted for 8.4% (± 10.5% sd) of the bottom cover overall, with similar percentages between islands.

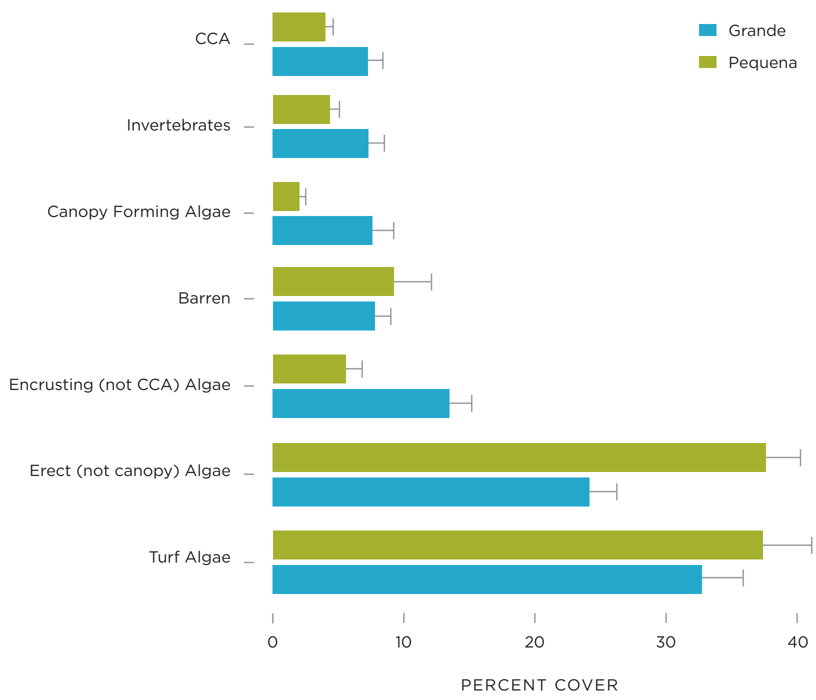
TABLE 1.

Sessile benthic groups observed on transects around Ilhas Selvagens.

Group	Common Name	Number Taxa
Rhodophyta	Red algae	16
Ochrophyta	Brown algae	20
Chlorophyta	Green algae	8
Cyanobacteria	Blue-green algae	3
Porifera	Sponges	10
Cnidaria	Corals & anemones	4
Bryozoa	Moss animals	4
Crustacea	Crustaceans	2
Mollusca	Molluscs	2

FIGURE 3.

Percent cover of sessile benthic functional groups between islands. Values are means and standard error of the mean. Canopy forming algae includes species of the genus *Cystoseira* and *Sargassum*. Erect (not canopy) forming algae includes those erect species with a thallus higher than 3 cm. Turf algae includes species with a thallus lower than 3 cm. CCA includes encrusting calcareous algae. Encrusting (not CCA) includes encrusting, non-calcareous algae.



There was a significant difference in assemblage structure of sessile functional groups between islands (p = 0.01), but not between depths or their interaction (Table 2). Although turf algae was the most abundant sessile functional group at both islands, it accounted for 27% of the dissimilarity between islands, with higher cover observed at Selvagem Pequena (Table 3). Erect (non-canopy) algae were 56% higher at Selvagem Pequena and this group contributed an additional 23% to the dissimilarity between islands.

TABLE 2.

Multivariate analysis of variance (PERMANOVA) comparing differences in the sessile benthic community between islands and depth strata (10 and 20 m).

Source	df	MS	Pseudo-F	P(perm)
Island	1	1899	5.2	0.01
Depth	1	388.0	1.1	0.33
Island x Depth	1	245.5	0.7	0.53
Residuals	54	363.3		
Total	57			

TABLE 3.

Similarity of Percentages (SIMPER) for sessile benthic groups most responsible for the percent dissimilarities between islands using Bray-Curtis similarity analysis of hierarchical agglomerative group average clustering. Dissim. = dissimilarity with one standard deviation of the mean in parentheses. Average dissimilarity = 40.0%. Abundance values are mean cover.

Species	Grande Abundance	Pequena Abundance	Dissim.	Contribution %	Cumulative %
Turf algae	32.6	37.3	10.8 (1.4)	27.1	27.1
Erect (Non-canopy) algae	24.1	37.6	9.2 (1.4)	23.1	50.1
Encrusting (Non-CCA) algae	13.4	5.5	5.5 (1.2)	13.8	64.0
Barrens	7.8	9.2	5.0 (1.2)	12.5	76.5
Canopy forming algae	7.6	2.1	3.6 (0.8)	8.9	85.4
Invertebrates	7.3	4.3	3.1 (1.0)	7.7	93.2

At least 21 taxa of turf algae were observed during the expedition (Appendix IV). More than half were too small to be identified, with the red algae *Jania* cf. *rubens* comprising an additional 26% of the turf assemblage, followed by the cyanobacteria *Symploca* cf. *hydnoides* (13%). *Lophocladia trichoclados*, a red erect alga, was the most abundant sessile benthic species observed at Ilhas Selvagens (Figure 4). A large west swell during the expedition dislodged large amount of *Lophocladia* into the water column, greatly reducing visibility in some locations. At least six species of *Dictyota*, accounting for nearly 6% of the benthic cover, were observed at Selvagens during the expedition (Figure 4).

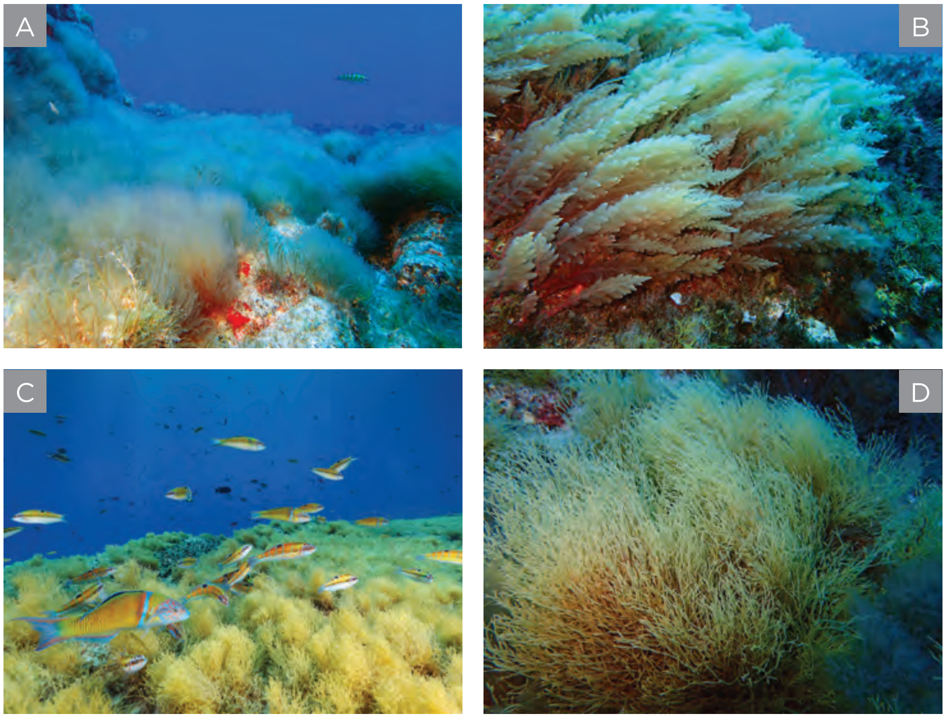


FIGURE 4.

A. *Lophocladia trichoclados*, a red erect alga, was the most abundant sessile benthic species observed at Ilhas Selvagens, B. Red algae *Asparagopsis taxiformis*, C & D. Several species of *Dictyota* made up a diverse algal assemblage.

The toothed feather hydroid *Aglaophenia* cf. *pluma* comprised 2.6% of the bottom, while the sponge *Phorbas* cf. *fictitious* accounted for an additional 1.7% (Figure 5). Several notable species of sessile invertebrates were observed including: the black coral *Antipathella wollastoni*, the giant anemone *Telmatactis cricoides*, the yellow tube sponge *Verongia aerophoba* as well as the bivalves *Pinna rudis* and *Spondylus senegalensis*. Populations of the latter two species are currently endangered by human activities (e.g., extraction for ornamental purposes, loss of habitat, and pollution) in other locations within Macaronesia, but are common in Ilhas Selvagens.

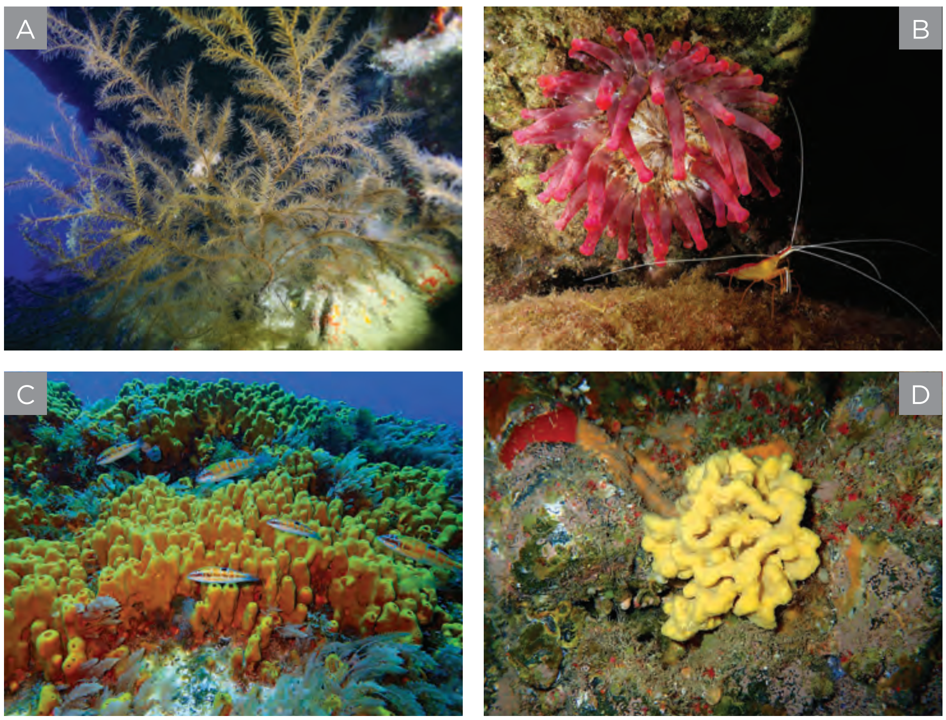


FIGURE 5.

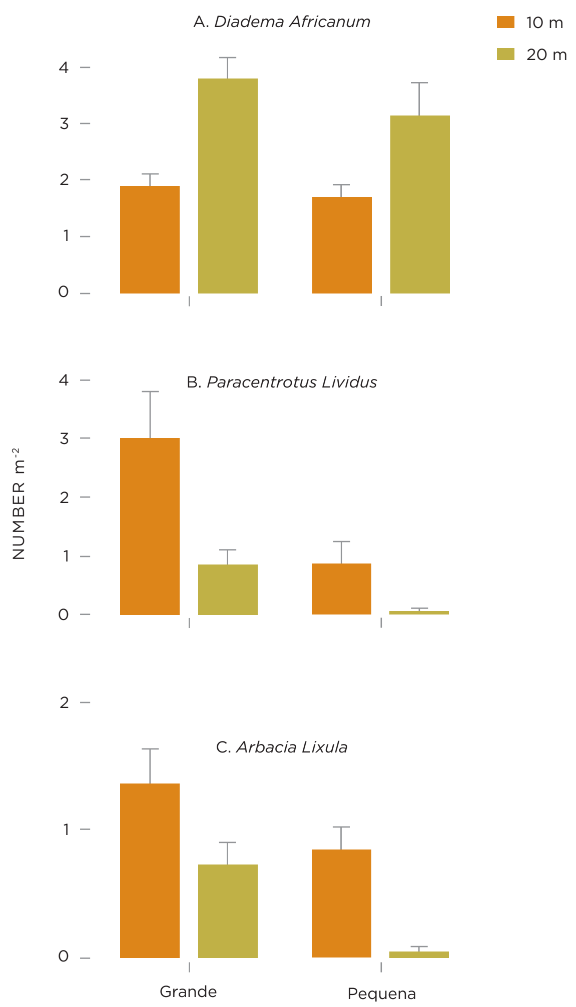
Sessile benthic fauna: A. Black coral *Antipathella wollastoni*, B. Giant anemone (*Telmatactis cricoides*) with white-striped cleaner shrimp (*Lysmata grabhami*), C. Yellow tube sponge *Aplysina aerophoba*, D. Yellow sponge—*Axinella damicornis*.

Mobile Invertebrates

A total of 31 taxa of mobile invertebrates from 30 families, 20 orders, 9 classes, and 4 phyla were recorded on quantitative surveys around Ilhas Selvagens during our expedition (Appendix V). The sea urchin *Diadema africanum* was the most common mobile invertebrate observed during our surveys (Figure 6). The average density was 2.7 individuals m^{-2} (± 3.3 sd), and occurred in 76% of transects. Densities between islands were similar but were nearly twice as high at 20 m (3.5 ± 4.1) compared to 10 m (1.8 ± 2.0). Another sea urchin, *Paracentrotus lividus*, was the second most abundant mobile invertebrate observed, with an average density of 1.3 individuals m^{-2} (± 4.6 sd), less than half that of *Diadema africanum*, and only occurring in 22% of the transects.

FIGURE 6.

Numerical density of the most abundant mobile invertebrate species observed on transects. Values are means and standard error of the mean.



Densities were four times higher at Selvagem Grande compared with Selvagem Pequena, and four times higher at 10 m vs. 20 m. *Arbacia lixula*, another sea urchin, ranked third in total abundance (0.81 ± 1.8 sd) and was recorded on 36% of the transects. Other mobile invertebrate species that appeared in the surveys in moderate abundances were the fireworm *Hermodice carunculata* (0.16 ± 0.37 sd), the grapsid crab *Percnon gibbesi* (0.14 ± 0.42 sd), the gastropod snail *Stramonita haemastoma* (0.12 ± 0.32), the sea cucumber *Holothuria sanctori* (0.05 ± 0.23), and the sea star *Coscinasterias tenuispina* (0.03 ± 0.19) (Figure 7). Golden sponge snails, *Tylodina perversa*, were observed mating on a yellow tube sponge colony (*Aplysina aerophoba*) (Figure 8).

FIGURE 7.

Thorny Seastar, *Coscinasterias tenuispina*, in crevice.

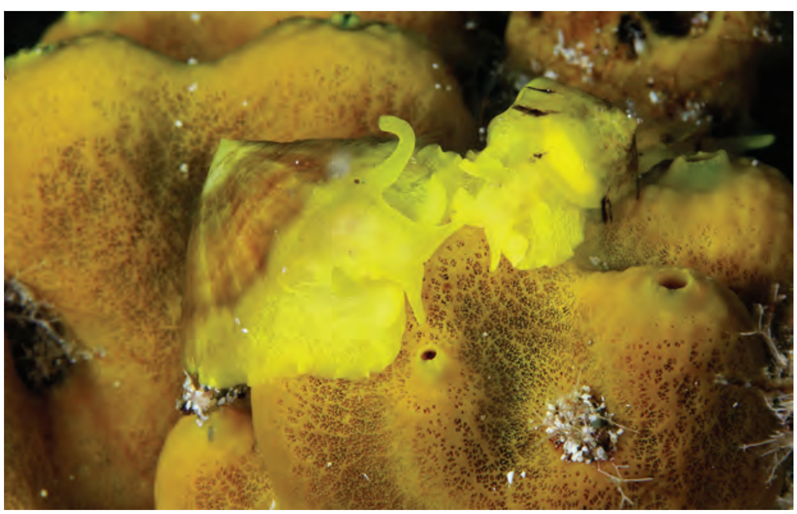


FIGURE 8.

Mating golden sponge snails, *Tylodina perversa* on yellow tube sponge colony (*Aplysina aerophoba*).

Biogeographic Affinity of Benthic Community

Approximately 71% of the species (N = 31) and 91% of the numerical density of mobile invertebrates consisted of species with Eastern Atlantic or Mediterranean biogeographic affinities (Table 4). Species with Amphi-Atlantic (those found on both sides of the Atlantic), Mediterranean, or warm-temperate distributions comprised an additional 26% of the species but < 9% of the numerical abundance of mobile invertebrates observed.

TABLE 4.

Biogeographic affinities of mobile invertebrates observed on transects. Num. = number of individuals m^{-2}. N = number of species.

Affinity	Num. m^{-2}	% Num. m^{-2}	N	% N
Eastern Atlantic /Mediterranean	2.34	42.59	18	58.06
Eastern Atlantic	2.68	48.72	4	12.90
Amphi-Atlantic /Mediterranean	0.32	5.82	4	12.90
Amphi-Atlantic /Warm-temperate	0.14	2.50	1	3.23
Cosmopolitan	0.01	0.10	1	3.23
Amphi-Atlantic	0.01	0.25	3	9.68
	5.50	100.00	31	100.00

Intertidal Areas

The intertidal areas of Ilhas Selvagens are one of the least impacted in Macaronesia (Figure 9, 10). Intertidal platforms are small, but the coastline is fringed with numerous rock ledges characteristic of volcanic landscapes. The sun limpet, *Patella candei*, has been overexploited throughout much of the region, but was present in large numbers and sizes (10–15 cm), particularly around Selvagem Pequena. The top-shell snail, *Phorcus atratus*, was also an abundant component of the intertidal ecosystem. Other limpets, *Patella* spp. and *Siphonaria pectinata*, were also abundant just below the high tide level. Limpets and other intertidal grazers are known to play a major role setting the upper limits of low-shore macroalgae in intertidal rocky substrates and consequently, determine algae composition and their canopy growth. Therefore, the scarcity of macroalgae in the intertidal was not surprising, and it was mostly restricted to small patches of turf algae, mainly *Jania* cf. *rubens*, low in the intertidal.

FIGURE 9.

The intertidal areas of Ilhas Selvagens possess one of the least impacted representation of this ecosystem in Macaronesia.

FIGURE 10.

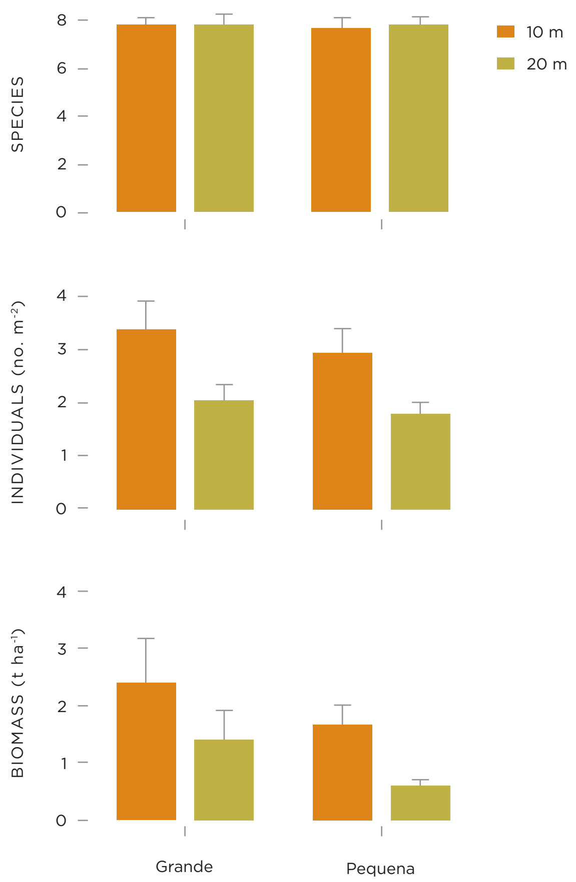
Intertidal and shore habitats of Ilhas Selvagens are some of the least disturbed within the region. A. Land snail shells cover the Selvagem Grande plateau. B. The highly prized sun limpet (*Patella candei*) with acorn barnacles (*Chthamalus stellatus*). C. Sun limpets were common and grow to large size, particularly around Selvagem Pequena. D. White limpet (*Patella aspera*) with acorn barnacles cover the rocky intertidal area.

Reef Fish Assemblage Structure

We observed 51 species of fishes from 28 families overall with 39 species from 20 families occurring on quantitative transects during the expedition (Appendix VI). The average number of species per transect was 7.8 (± 1.4 sd) and did not differ significantly by depth or island ($F_{3,57}$ – 0.04, p = 0.98) (Figure 11). The number of individuals was similar between islands (p = 0.57) but was significantly higher in the 10 m vs. the 20 m depth stratum (p = 0.01). Overall fish biomass was 1.6 t ha^{-1} (± 2.2 sd) and followed a similar trend to numerical abundance with no difference between islands (p = 0.26) and higher biomass in the 10 m depth stratum (p = 0.01). We performed several clove oil stations in search for cryptobenthic fish species and found a low abundance of gobies, blennies and gobiesocids. The clingfish *Lepadogaster candolii*, the goby *Muligobius maderensis* and the triplefin *Tripterygion delaisi* were the most observed species in these stations.

FIGURE 11.

Comparison of fish assemblage characteristics between islands and depth strata. Values are means and standard error of the mean.



Fish Trophic Structure

Herbivores accounted for 45% of the total fish biomass, followed by apex predators (22%), secondary consumers (19%), and planktivores (14%). There was a significant difference in fish trophic structure between depths ($p = 0.004$), but not between islands or their interaction (Table 5). Herbivore biomass was 3.8 times higher in the shallow vs. deep depth stratum (Figure 12), and was responsible for most of the separation of depth strata in ordination space (Figure 13). Apex predation biomass was orthogonal to herbivore biomass.

FIGURE 12.

Comparison of f trophic biomass (t ha^{-1}) between depths. *** = statistically different at $p < 0.001$ (Wilcoxon Z = 3.37).

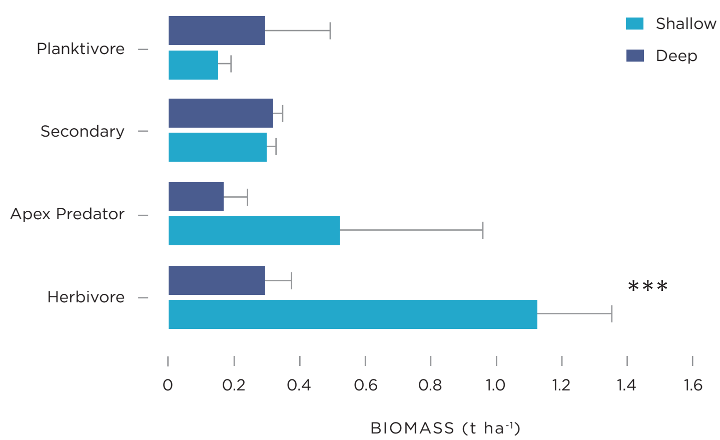


FIGURE 13.

Ordination of fish trophic biomass by island and depth. Results of non-metric multidimensional scaling. Vectors are the primary trophic groups driving the ordination (Pearson Product movement correlations). Herb = herbivores, Plank = Planktivores, Sec = Secondary consumers (carnivores), Apex = Apex predators.

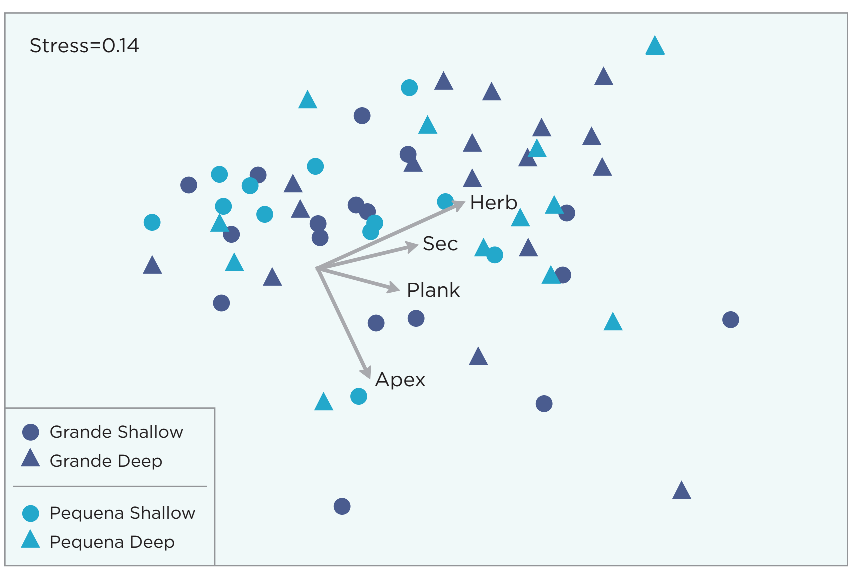


TABLE 5.

Multivariate analysis of variance (PERMANOVA) comparison of fish trophic assemblage based on biomass between islands and depth strata (10 and 20 m).

Source	df	MS	Pseudo-F	P(perm)
Island	1	1169	1.5	0.176
Depth	1	4451	5.8	0.004
Island x Depth	1	890	1.2	0.331
Residuals	54	765		
Total	57			

Fish Species

There was 70% dissimilarity in fish assemblages between depth strata based on fish species biomass (Table 6). The rudderfish or chub, *Kyphosus sectatrix*, was the most abundant species by weight overall, comprising 34% of the total biomass (Figure 14). Biomass of this species was six times greater in the shallow vs. deep stratum, contributing to 39% of the dissimilarity between depth strata. The amberjack *Seriola dumerili* was the next most important species by weight with 16% of the total biomass. It accounted for an additional 7% of the dissimilarity between depth strata. This species was 6.6 times more abundant by weight in the shallow compared to the deep depth stratum. Despite its small size (~ 16 cm total length), the Azores Chromis, *Chromis limbata*, was the third most important species by weight, accounting for 10% of total biomass at Ilhas Selvagens. In contrast to the two previous species, it was > 4 times more important by weight in the deep depth stratum.

FIGURE 14.

The rudderfish or chub, *Kyphosus sectatrix*, was the most abundant fish species by weight and is an important herbivore.

TABLE 6.

Similarity of Percentages (SIMPER) for fish species biomass most responsible for the percent dissimilarities between depths using Bray-Curtis similarity analysis of hierarchical agglomerative group average clustering. Dissim. = dissimilarity and one standard deviation of the mean in parentheses. Average dissimilarity = 70.1%. Abundance values are means and one standard deviation of the mean in parenthesis.

Species	Shallow Abundance	Deep Abundance	Dissim.	Contribution %	Cumulative %
Kyphosus sectatrix	93.0 (122.1)	15.5 (39.9)	27.8 (1.1)	39.1	39.1
Seriola dumerili	43.3 (224.7)	6.5 (20.3)	5.2 (0.3)	7.3	46.5
Chromis limbata	6.1 (9.7)	25.7 (107.6)	5.0 (0.5)	7.1	53.5
Sparisoma cretense	13.4 (9.2)	11.7 (8.1)	4.9 (0.9)	6.9	60.5
Thalassoma pavo	13.4 (9.8)	9.4 (6.2)	4.7 (1.0)	6.7	67.1
Boops boops	8.8 (15.4)	3.5 (10.7)	4.6 (0.6)	6.5	73.6
Epinephelus marginatus	2.4 (7.3)	6.0 (21.9)	2.6 (0.4)	3.7	77.3
Bodianus scrofa	3.1 (3.6)	4.6 (5.0)	2.4 (0.8)	3.4	80.7
Seriola rivoliana	5.4 (16.0)	3.9 (11.7)	2.3 (0.4)	3.3	84.0
Sarpa salpa	5.9 (21.2)	1.9 (7.2)	2.2 (0.4)	3.1	87.1
Serranus atricauda	4.8 (2.8)	6.4 (2.9)	2.1 (0.8)	3.0	90.0

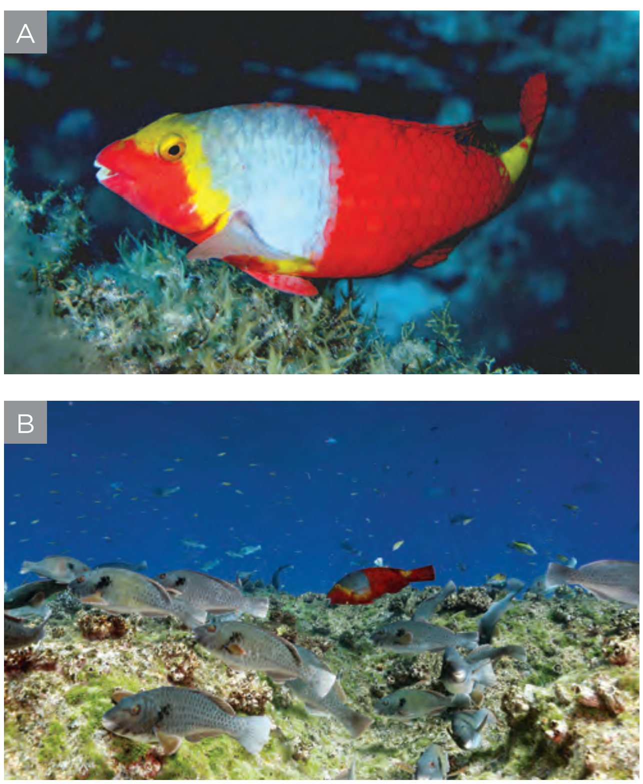


FIGURE 15.

A. Female parrotfish *Sparisoma cretense*. B. Group of males with single female. *S. cretense* exhibits a dual mating system where males hold female harems within year-round territories or live in multi-male groups (Afonso et al. 2008). Group behavior predominates in smaller size classes in the shallows and territoriality in larger size classes deeper down.

The parrotfish *Sparisoma cretense* was the fourth most abundant species by weight and was more common in the shallow compared to the deeper depth stratum (Figure 15). This species is the target of important artisanal fisheries throughout the Macaronesian archipelagos and it is also an important keystone species for the stability of benthic communities and resilience to trophic cascades (Tuya et al., 2004).

The Madeira rockfish (*Scorpaena maderensis*) was abundant in most stations and is a known predator of small fish and invertebrates. However, individuals at Selvagens were very small, rarely exceeding 7–8 cm (maximum size for the species is 18 cm). Whether the adults were in deeper waters or there are some differences in maximum size to the other Macaronesian islands and the Mediterranean is an open issue.

Fish Species Affinity

Based on fish numerical abundance (number m^{-2}), more than 74% of the fish species had tropical West African/Mediterranean biogeographic distributions (Table 7). An additional 18% of the total biomass consisted of species with Amphi-Atlantic/Mediterranean affinities.

TABLE 7.

Fish species affinities based on numerical abundance.

Affinity	Num. m^{-2} (sd)	%
Tropical West African/Mediterranean	1.468 (1.141)	58.95%
Tropical West African	0.376 (0.236)	15.10%
Amphi-Atlantic	0.371 (0.571)	14.90%
Eurythermic Eastern Atlantic/Mediterranean	0.155 (0.367)	6.23%
Amphi-Atlantic/Mediterranean	0.084 (0.141)	3.39%
Cosmopolitan	0.009 (0.018)	0.92%
Endemic Macaronesian	0.009 (0.018)	0.37%
West Atlantic	0.002 (0.003)	0.08%
Warm-temperate	0.001 (0.003)	0.05%
Temperate/Mediterranean	<0.001 (0.002)	<0.01%

Commercial Fish Species

Several commercial species that have been overfished in other locations within the region were common and of large size at Ilhas Selvagens. The Dusky grouper (*Epinephelus marginatus*) is the best-known grouper of the Mediterranean Sea and adjacent European and North African coasts, and has been overexploited throughout much of its range. It is currently classified as endangered by the IUCN. We observed 15 dusky groupers on our quantitative surveys with an average size of 77.3 cm TL (24.3 ± sd) and a range from 40 to 120 cm TL (Figure 16). On non-quantitative dives, this fish was also present at almost every location.

Two species of amberjacks, *Seriola dummerili* and *S. rivoliana*, were present at Ilhas Selvagens, sometimes in large mixed schools (Figure 17). Grey triggerfish (*Balistes capriscus*) are an important resource species and also an important predator on sea urchins (Figure 18). There were 18 records of *B. capriscus* during our surveys with an average size of 30.3 cm (± 6.6 sd) and a range of 20 to 38 cm TL. Barred hogfish (*Bodianus scrofa*), another sea urchin predator, was abundant (mean = 40.2 ha^{-1} ± 38.4 sd) and present at 78% of the locations (station x depth combinations, N = 45 of 58) (Figure 19).

FIGURE 16.

The Dusky grouper (*Epinephelus marginatus*) is listed as endangered by IUCN but were common and large at Ilhas Selvagens.

FIGURE 17.

Amberjacks, *Seriola dummerili* and *S. rivoliana*, are highly valued fisheries species that were abundant at Ilhas Selvagens.

FIGURE 18.

Grey triggerfish (*Balistes capriscus*) use their powerful teeth to break open sea urchins.

FIGURE 19.

Large male barred hogfish (*Bodianus scrofa*) are highly prized, but are heavily overexploited elsewhere in Macaronesia and are listed as vulnerable by IUCN. They prey on sea urchins and help to keep their populations in check.

Pelagic Environment

We recorded 1,590 individual pelagic fishes at Baited Remote Underwater Video Stations (BRUVS) representing eight species from four families across 19 sites at the three locations surveyed (Selvagem Pequena, Selvagem Grande East, Selvagem Grande West; Table 8, Figure 20). We observed two species of marine mammals: a single Bryde's whale (*Balaenoptera brydei*) and several groups of Atlantic spotted dolphin (*Stenella frontalis*) with 6 to 14 individuals per group. In addition, we recorded two loggerhead turtles (*Caretta caretta*) (Figure 21). No sharks were observed on any deployments.

The fish assemblage was depauperate. The overall species pool was small (N = 8), and the average number of species per sample was low (1.47 ± 1.2 sd), with a number of stations having no animals present at all. Total abundance was also low with 1.5 animals per sample (± 1.2 sd). The exception was West Selvagem Grande where a large school of ~ 500 juvenile Atlantic horse mackerel (*Trachurus trachurus*) was recorded. The average abundance for other species was < 0.5 per sample, and very patchy (Table 8). The exception to this low frequency of occurrence was the pilot fish (*Naucrates ductor*), which was observed at 37% of the sites.

Lengths were measured for all observed species with the exception of the Bryde's whale, which was estimated to be ~ 10 m long. The smallest observed fishes were unidentified juvenile jacks (1.5 cm) and juvenile white trevally (*Pseudocaranx dentex*) (2.6 cm ± 1 sd). The largest observed fish was a blue marlin (*Makaira nigricans*) measuring 2.1 m with a second blue marlin measuring 1.1 m.

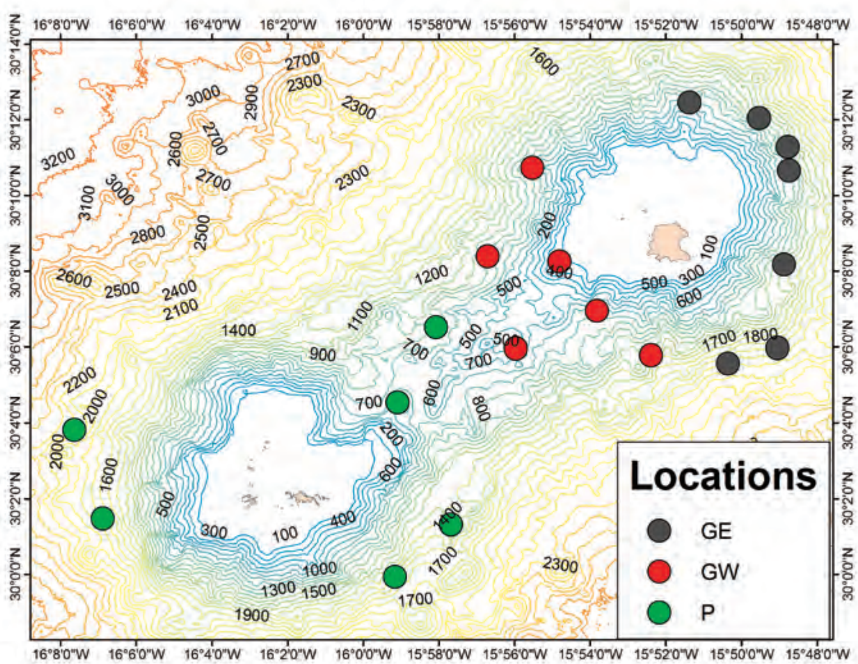


FIGURE 20.

Locations of Baited Remote Underwater Video Stations. GE = East Selvagem Grande, GW = West Selvagem Grande, and P = Selvagem Pequena. Contours are 100 m.

FIGURE 21.

A. Loggerhead turtle (*Caretta caretta*). B. Atlantic spotted dolphins (*Stenella frontalis*). C. The little known Bryde's whale (*Balaenoptera brydei*) inspecting the baited midwater camera.

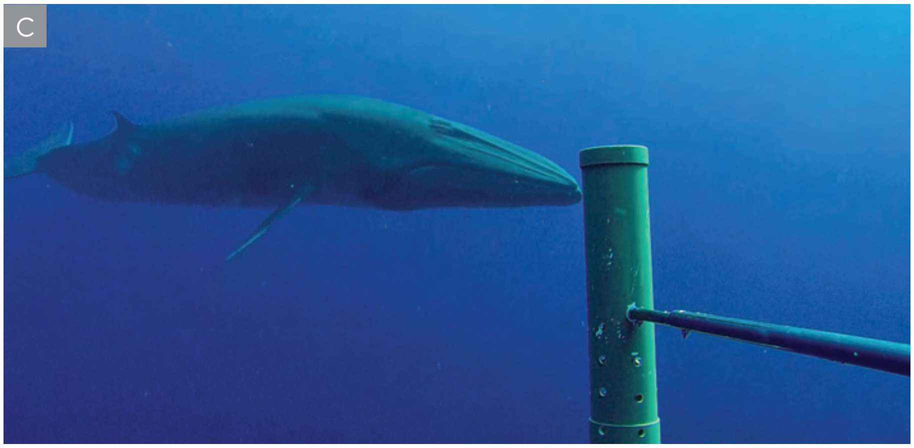


TABLE 8.

Fish species observed at Baited Remote Underwater Video Stations. % Freq. Sites = percent frequency in which species was observed (N = 19). MaxN = total number of individuals observed with mean MaxN (average number of individuals per species per sample) in parentheses. FL is the average fork length (cm) with one standard deviation of the mean in parentheses.

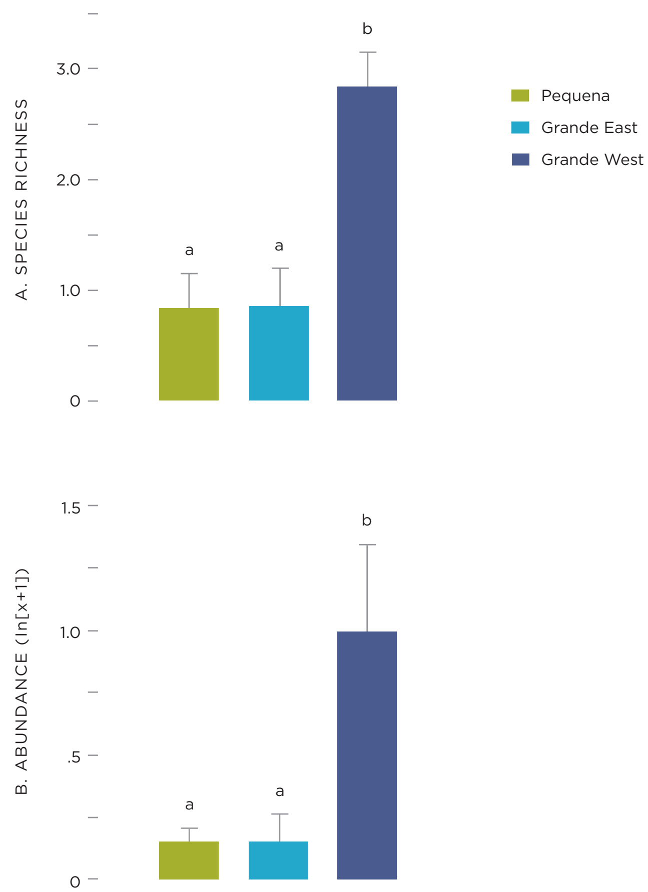
Family	Scientific Name	Common Name	% Freq. Sites	MaxN	FL cm (sd)
Balistidae	*Balistes capriscus*	Grey triggerfish	21.1	4 (1)	44.6 (13.5)
Carangidae	Carangidae sp.	Juvenile carangids	21.1	12 (3)	1.5 (0.5)
	Naucrates ductor	Pilotfish	36.8	17 (2.4)	16.4 (11.4)
	Pseudocaranx dentex	White trevally	26.3	10 (2)	2.6 (1.0)
	Seriola rivoliana	Longfin yellowtail	10.5	17 (8.5)	91.7 (16.3)
	Trachurus trachurus	Atlantic horse mackerel	21.1	1511 (377)	13.4 (2.6)
Coryphaenidae	*Coryphaena equiselis*	Pompano dolphin fish	26.3	15 (3)	42.5 (9.4)
Istiophoridae	*Makaira nigricans*	Blue marlin	21.1	4 (1)	162 (72.3)

The schooling Atlantic horse mackerel were small (mean = 13.4 cm ± 2.6 sd) relative to adult size. Similarly, the blue marlin observed were small relative to adult size. Adult loggerhead turtles are typically 85–100 cm carapace length with the two individuals of this species observed here measured at 60.2 and 69.3 cm, suggesting they are juveniles. The mean length of the Atlantic spotted dolphins was 1.47 m (± 0.43 sd), approximately 64% of the maximum size reached for this species.

There were spatial differences between the 19 sites across the three main locations for both species richness ($Pseudo\text{-}F_{2,18} = 12.3$, $p = 0.002$) and total abundance ($Pseudo\text{-}F_{2,18} = 5.6$, $p = 0.001$). In both cases, West Selvagem Grande differed from both East Selvagem Grande and Salvagem Pequena, with no differences between the latter two locations (Figure 22).

FIGURE 22.

Estimates of A. Species richness and B. Total abundance (ln[x+1]) per sample for Selvagem Pequena, East Selvagem Grande, and West Selvagem Grande. Values are means and standard errors. Locations with the same letter are not significantly different (*a* = 0.05).



Deep Sea

Twelve drop-cam deployments lasting from 3 to 5 hours were conducted during the expedition between 112 m and 2,294 m (Table 9, Figure 23). Our deep video cameras showed a diverse and rich fauna that included at least 24 different taxa of deep-water fishes from 17 families (Appendix VII). Deep water habitats were either sandy, flat areas with limited relief, or high relief island slopes consisting of basalt rock with sand channels. These deep water habitats were dominated by grenadiers and cutthroat eels. The shallow community (100–300 m) consisted of high relief basalt with the biotic cover dominated by sponges, gorgonians, and black coral (Figure 24). We observed one smalltooth sand tiger shark (*Odontaspis ferox*) ~ 1200 m (Figure 25). In addition, we observed a wide range of mobile and sessile invertebrates, with crustaceans (e.g., shrimps and crabs) being the most diverse and numerous.

TABLE 9.

Drop-cam deployment statistics.

Drop No.	Date	Start time	Latitude	Longitude	Depth (m)	Duration (hrs)
1	2015/09/06	13:51	30.11977	-15.8902	546.6	3.0
2	2015/09/07	11:55	30.02101	-15.9592	1429.4	3.0
3	2015/09/07	12:46	30.02744	-15.9796	1198.4	3.0
4	2015/09/08	13:33	30.01456	-16.1229	2294.4	3.0
5	2015/09/08	14:01	30.04543	-16.1325	2254.1	3.0
6	2015/09/09	14:01	30.07858	-15.9872	687.4	5.0
7	2015/09/09	08:17	30.07688	-15.9833	432.5	5.0
8	2015/09/10	11:00	30.10058	-15.9298	366.2	5.0
9	2015/09/11	10:21	30.18938	-15.8588	112.1	4.0
10	2015/09/12	11:00	30.12631	-15.8776	243.2	3.5
11	2015/09/13	15:10	30.11073	-15.8709	918.3	3.0
12	2015/09/14	12:00	30.19519	-15.8592	207.0	4.75

FIGURE 23.

Deep-sea drop-cam deployed off Selvagem Grande.

FIGURE 24.

Image of habitat at 112 m off Selvagem Grande from drop-cam. The habitat is dominated by sponges, coralline algae, and black corals.

FIGURE 25.

Smalltooth sand tiger shark (*Odontaspis ferox*) investigating the baited camera at 1,200 m.

Seabirds and Terrestrial Environment

Ilhas Selvagens are the world's largest breeding area for Cory's Shearwaters (*Calonectris diomedea*) (Figure 26). This species is widely distributed in the Atlantic and the Mediterranean, where two different subspecies breed: *C. diomedea diomedea* along the Mediterranean Sea, and *C. diomedea borealis* on the Macaronesian islands. Both subspecies are currently threatened and undergoing contractions in their populations despite protective measures undertaken in the past two decades. Various causes contributing to these declines include: 1) decreased food availability as a consequence of overfishing and 2) the introduction of exotic predators. Since the eradication of rabbits and mice at Ilhas Selvagens, the number of Cory's Shearwater chicks completing their development has increased greatly. Other notable seabirds at Ilhas Selvagens include: Bulwer's petrel (*Bulweria bulwerii*), little shearwater (*Puffinus assimilis*), and the Madeira storm-petrel (*Oceanodroma castro*).

The unique land fauna on these isolated islands includes the Maderian wall lizard (*Lacerta dugesii*), which is endemic to Madeira and Ilhas Selvagens, and Boettger's Wall Gecko (*Tarentola boettgeri bischoffi*), a medium sized nocturnal gecko endemic to Ilhas Selvagens.

FIGURE 26.

Cory's Shearwaters and chick at Selvagem Pequena.

Microplastics

Given the increasing levels of plastic pollution in the oceans, it is important to better understand the impact of microplastics in the ocean food web. We are partnering with National Geographic Emerging Explorer Gregg Treinish of Adventurers and Scientists for Conservation to sample microplastics during our expedition. We collected samples of sea water in 20 one liter bottles at 20 locations during the expedition. Samples were sent to ASC for analyses and we found 85% of these samples to have microplastics in them, with an average of 1.4 (± 1.0 sd) pieces per liter. Blue filaments accounted for 67% of the microplastics, followed by transparent filaments (31%), and red filaments (2%) (Table 10).

TABLE 10.

Microplastics identified in samples around Ilhas Selvagens.

Sample Date	Latitude	Longitude	Blue	Red	Transparent	Total Pieces/L
9/12/2015	30.14009	-15.87603	0	0	0	0.00
9/12/2015	30.134	-15.87030	2	0	2	2.96
9/12/2015	30.13434	-15.86291	0	0	1	0.57
9/11/2015	30.13626	-15.85488	0	0	1	0.59
9/11/2015	30.14548	-15.85511	1	0	0	0.67
9/11/2015	30.14995	-15.85514	0	0	0	0.00
9/10/2015	30.02962	-16.01961	2	0	2	2.50
9/10/2015	30.01959	-16.03149	1	0	1	1.43
9/10/2015	30.02548	-16.04824	1	0	1	1.25
9/9/2015	30.02843	-16.05731	2	0	1	2.00
9/9/2015	30.03508	-16.05608	1	0	1	1.25
9/9/2015	30.04973	-16.05405	0	0	0	0.00
9/8/2015	30.05721	-16.04960	1	0	0	1.33
9/8/2015	30.05710	-16.04051	1	0	0	0.67
9/8/2015	30.06321	-16.04126	2	1	3	4.00
9/7/2015	30.03288	-16.01217	3	0	0	1.76
9/7/2015	30.04027	-16.02938	2	0	0	1.17
9/7/2015	30.03743	-16.02005	2	0	0	1.18
9/6/2015	30.16137	-15.87577	4	0	0	2.35
9/6/2015	30.15503	-15.15503	3	0	0	1.76
Total/Average			28	1	13	1.37

Micropaleontology Collections

Microfossils are excellent indicators of general environmental conditions such as temperature, salinity, organic enrichment, etc. We sampled at 13 locations for microfossils collected from the top 1 cm of sediment. Approximately 100 ml of sand was collected from the top 1 cm of the sediment at three different sites within a location. Samples were preserved in 100% isopropyl alcohol and are being analyzed by National Geographic Emerging Explorer Dr. Beverly Goodman at Haifa University in Israel.

DISCUSSION

DISCUSSION

The small size, remote location and harsh sea conditions of Ilhas Selvagens has greatly limited our knowledge of the marine species diversity of this archipelago (Figure 27). The nearshore marine ecosystem was found to be healthy with a diverse algal assemblage consisting of at least 47 different taxa. Sea urchin barrens, often a symptom of extensive overfishing, were rare and found to cover only 8% of the bottom. Large mollusks such as the spiny pen shell, top-shell snail, and African thorny oyster are common at Ilhas Selvagens but have suffered from overexploitation, habitat loss, and pollution in other parts of Macaronesia. The intertidal around these islands was striking and likely represents one of the few remaining intact ecosystems of its kind in the region. The sun limpet is nearly extinct throughout Macaronesia (González-Lorenzo et al. 2015), yet were abundant and of large size at Ilhas Selvagens.

FIGURE 27.

Our understanding of the marine environment of Ilhas Selvagens has been limited by their remote location and harsh sea conditions.

Despite their small size, the Selvagens Islands exhibit relatively high fish species diversity compared to the large islands nearby in the northeastern Atlantic (Almada et al. 2014). Commercial species such as grouper, amberjacks, and triggerfishes were commonly observed and of large size at Ilhas Selvagens. These species have been overexploited throughout much of the region. Several of these fishes (e.g., hogfish, triggerfishes) are known predators on sea urchins and the limited amount of urchin barrens that we observed is likely a result of the high predation by these species.

In the pelagic environment, Ilhas Selvagens were outstanding for the presence of marine mammals, with the rare Byrde's whale and Atlantic spotted dolphin observed in the channel between island groups. The area may be a nursery habitat as juveniles of several species were observed. The absence of sharks during our surveys was of concern. Similar surveys from ten locations around the world show nearly one shark per sample on average (Meeuwig, unpubl. data) compared to none in this survey. Our pelagic survey also showed low species diversity compared to comparable surveys in other regions of similar latitude. Total abundance of fish was high compared to other locations, however this was driven by the large schools of juvenile Atlantic horse mackerel at a single site. When excluded from the analysis, the remaining fish showed some of the lowest observed abundances within the global sample.

The patterns in pelagic richness and abundance are consistent with known biogeographical patterns, with declining species richness and increasing biomass with higher latitudes. The spatial patterns in diversity and abundance within the archipelago indicate environmental heterogeneity that deserves further exploration. Critical now is to monitor this baseline through time and determine how diversity and abundance vary, and in particular, to track the frequency and density of large schools of forage species and predators. It is especially important to have abundant schools of small prey near seabird breeding colonies because it is much harder for newly hatched and inexperienced birds to find food and successfully feed far from shore and return home safely (Balance et al. 2001). Large predatory fish also depend heavily on the abundance of these fish schools and further help to drive schools near the surface where seabirds feed.

Ilhas Selvagens lies in the northeastern part of the oligotrophic (low productivity) North Atlantic Subtropical Gyre. The isolation, limited habitat and low productivity of these islands means that sustainability of the marine populations relies on replenishment that may be locally derived or episodic from elsewhere within the region. As a result, persistence of these populations is sensitive to changes in oceanographic conditions.

Threats

Overfishing – Large predatory fishes such as sharks and tunas have declined by nearly 90% worldwide (Myers and Worm 2003). The complete absence of sharks from our pelagic camera surveys is alarming and it is clear, as has been shown in several other locations, that these top predators are being unsustainably fished, and that without drastic improvements in management they will not recover.

The loss of these top predators also has significant impacts on the structure of the entire ecosystem (Heithus et al. 2008, Ritchie et al. 2009, Estes et al. 2011, Britten et al. 2014). Tunas are important to the success of foraging seabirds as they drive small fish and squid to the surface where they are accessible to diving seabirds. The observed decline of tuna stocks due to overfishing is likely having deleterious effects on island seabird populations.

Ecosystem Effects of Fishing – In subtropical regions of the Canary Islands, and in other Macaronesian areas, macroalgal beds are the main habitat-forming species at subtidal reef habitats (Clemente et al. 2010). However, barren grounds generated by the sea urchin *Diadema* aff. *antillarum* are increasingly common (Hernández et al. 2008a), and their presence is thought to be one symptom of intensive overfishing (Bas et al. 1995, Tuya et al. 2006, Hernández et al. 2008a). Daytime predators of *Diadema* aff. *antillarum* included a guild of 8 fish species, dominated by the balistids *Balistes capriscus* and *Canthidermis sufflamen*, and the labrid *Bodianus scrofa* (Clemente et al. 2010).

Illegal Fishing – It is widely reported that fishermen, primarily spearfishermen, from the Canary Islands frequent Ilhas Selvagens, particularly in the fall when the rangers are gone from Selvagen Pequena. Several of the reef predators such as groupers, which are often the target of spearfishers, are long lived and are very susceptible to fishing pressure. This is particularly pronounced on small isolated islands as population densities can become too low to allow for successful reproduction. The intertidal community is remarkable in the abundance and size of limpets and other highly valued species. These communities are easily caught and very sensitive to overfishing since they have limited larval dispersal, meaning that population success is directly related to local abundance.

FIGURE 28.

A shipwreck from 1971 still threatens the pristine environment of Selvagem Pequena.

Ship Groundings – A number of ships have run aground at Ilhas Selvagens over the years. Wreckage from the "Cerno" in 1971 still remains on the intertidal reef flat at Selvagem Pequena, threatening this pristine environment (Figure 28). This oil tanker sailing under a Norwegian flag came too close to the islands to illegally wash its tanks. Three months afterwards another oil tanker, the "Morning Breeze" sunk at Selvagem Grande. Wrecks and/or oil spills would likely have devastating and long-lasting effects on the nearshore marine ecosystem, particularly the nearly pristine intertidal zone.

Microplastics – Our oceans are awash with plastics. A recent study found by 2050, the oceans will have more plastics than fish (van Sebille et al. 2015). We found 85% of water samples around Ilhas Selvagens had microplastics present. Public concern is growing regarding the impact on marine species that ingest this plastic and the accumulation of plastics along coastal and remote areas. The global environmental, economic, and health costs associated with microplastics require immediate international attention.

Reserve Expansion

The waters and seafloor surrounding Ilhas Selvagens harbor some of the best-preserved ocean habitats in Macaronesia, and are home to many species of key ecological and commercial importance. Large tunas provide an important ecological function to foraging seabirds at these remote islands. However, the current reserve around Ilhas Selvagens extends to 200 m depth, encompassing an area of only 124.5 hectares. This area is extremely small relative to the growing number of large MPAs globally. This area does not provide protection for many of the wider ranging species such as seabirds, marine mammals, and tuna that rely on this important area. An example of this connectivity is a Bulwer's petrel (*Bulweria bulwerii*), tagged with a GPS satellite tracker off Desertas islands (near Madeira) that traveled over 5,000 km during an 11-day trip, after which time it returned to participate in egg incubation. The Cory's shearwater shows similar long-range movements. That pelagic fish diversity and abundance is so low may also reflect the significant pressures around this relatively small marine reserve, and its inadequacy in relation to protection of pelagic fishes. The expansion of the reserve around Ilhas Selvagens would provide protection for these valuable pelagic resources, allowing them to grow larger, become more abundant, and generate higher reproductive output.

Although the protection of far-ranging species presents a major challenge for spatial management, there is good evidence that open ocean MPAs have the potential to dramatically reduce the overall mortality of these species by protecting critical areas necessary for reproduction and feeding (Norse et al. 2005, Game et al. 2009; Koldewey et al). Despite the ability of many pelagic species to move great distances, some individuals will likely spend their entire life inside an expanded sanctuary, thus increasing the density of marine life inside the area, boosting genetic diversity, and increasing local reproductive output, which will in turn benefit adjacent fisheries (Hooker and Gerber 2004, Pala 2009, Grüss et al. 2011). The currently designated Special Protection Area under the Birds Directive of the European Union could provide additional protection to the islands' biodiversity if these waters became more strongly protected and enforced.

An increasing body of research worldwide also shows that no-take marine reserves result in improved, more stable, and more profitable fisheries around the reserves. Expanded protection will also promote additional scientific research.

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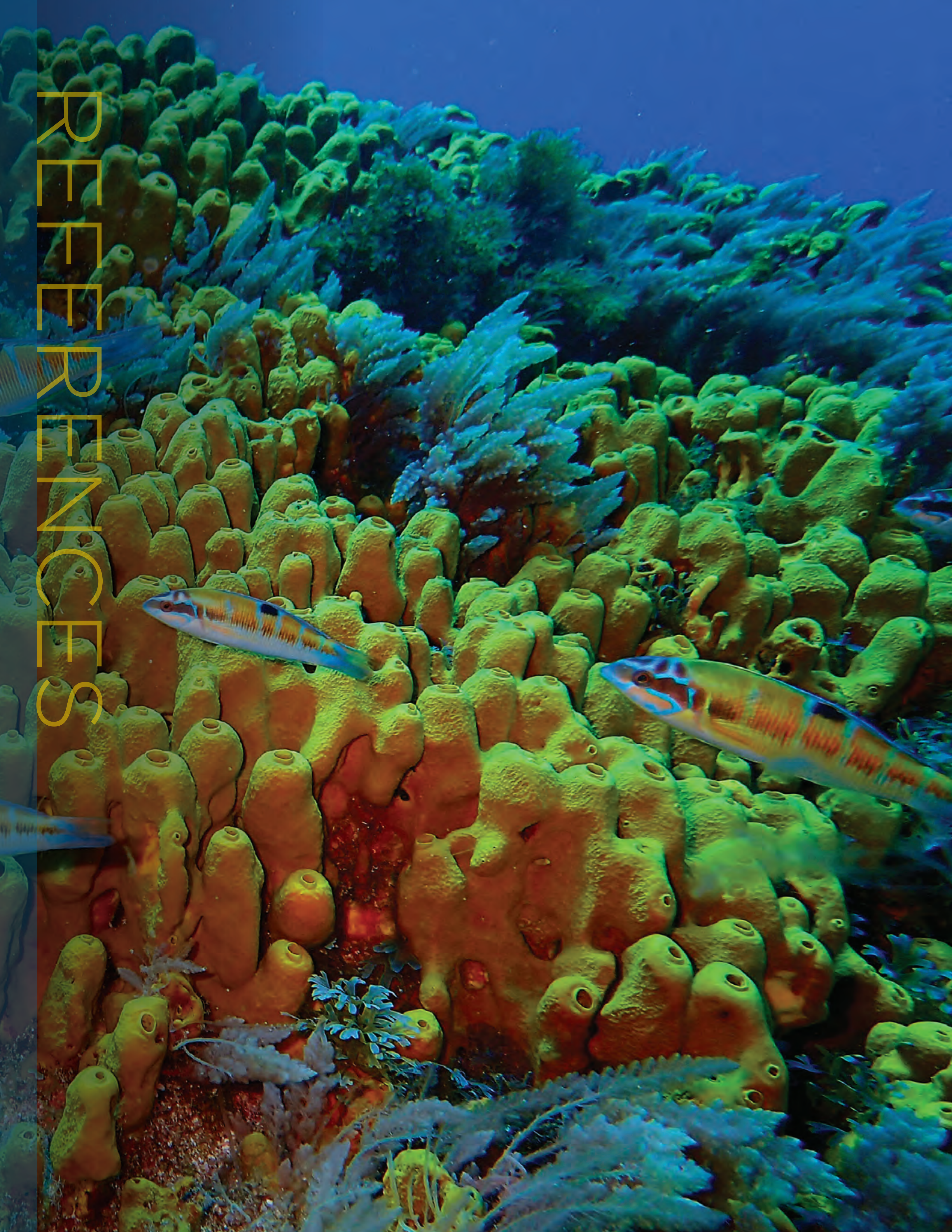

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APPENDICES

Appendix I.

Expedition Team.

Name	Role	Institution
Paul Rose	Expedition leader	Pristine Seas–National Geographic/ Royal Geographical Society
Alan Friedlander	Chief Scientist – fishes	Pristine Seas–National Geographic/University of Hawaii
Enric Ballesteros	Algae/benthos	Centre d'Estudis Avançats, Spain
Sabrina Clemente	Invertebrates/ benthos	Universidad de La Laguna, Tenerife, Canary Islands
Emanuel Gonçalves	Fishes/MPAs	MARE – Marine & Environ. Sciences Centre, ISPA, Portugal
Mike Shepard	Drop-camera	National Geographic Remote Imaging
Andy Mann	Producer/ camera	Pristine Seas–National Geographic
Manu San Félix	UW camera	Pristine Seas–National Geographic
Cristina Ozores	UW assistant	Pristine Seas–National Geographic
Christopher Thompson	Pelagic survey	University of Western Australia
Andrew Estep	General science	Waitt Institute

Appendix II.

Sampling stations around Selvagem Grande and Selvagem Pequena.

Date	Island	Station	Time	Latitude	Longitude	Exposure
6-Sep-15	Grande	1	10:10	30.15503	-15.87079	North
6-Sep-15	Grande	2	12:20	30.16137	-15.87577	North
6-Sep-15	Grande	3	14:45	30.15506	-15.85177	North
7-Sep-15	Pequena	4	8:50	30.03743	-16.02005	North
7-Sep-15	Pequena	5	10:55	30.04027	-16.02938	North
7-Sep-15	Pequena	6	13:20	30.03288	-16.02250	North
8-Sep-15	Pequena	7	8:30	30.06321	-16.04126	East
8-Sep-15	Pequena	8	10:30	30.05710	-16.04051	North
8-Sep-15	Pequena	9	13:30	30.05721	-16.04960	West
9-Sep-15	Pequena	10	8:30	30.04973	-16.05405	West
9-Sep-15	Pequena	11	10:30	30.03508	-16.05608	West
9-Sep-15	Pequena	12	13:00	30.02843	-16.05731	West
10-Sep-15	Pequena	13	8:40	30.02548	-16.04824	West
10-Sep-15	Pequena	14	10:30	30.01959	-16.03149	West
10-Sep-15	Pequena	15	13:00	30.02962	-16.01961	West
11-Sep-15	Grande	16	8:40	30.14995	-15.85514	East
11-Sep-15	Grande	17	10:40	30.14548	-15.85511	East
11-Sep-15	Grande	18	13:00	30.13626	-15.85488	East
12-Sep-15	Grande	19	8:40	30.13434	-15.86291	South
12-Sep-15	Grande	20	10:30	30.13400	-15.87030	South
12-Sep-15	Grande	21	13:00	30.14009	-15.87603	South
13-Sep-15	Grande	22	8:40	30.15214	-15.87411	West
13-Sep-15	Grande	23	11:00	30.14006	-15.89010	West
13-Sep-15	Grande	24	3:36	30.14887	-15.87758	West
14-Sep-15	Grande	25	8:40	30.15678	-15.88536	North
14-Sep-15	Grande	26	10:40	30.15118	-15.88097	North
14-Sep-15	Grande	27	13:30	30.14529	-15.87686	West
15-Sep-15	Grande	28	8:50	30.16403	-15.84251	North
16-Sep-15	Grande	29	11:00	30.14131	-15.85316	East

Appendix III.

Methods.

IN-WATER BIOLOGICAL SURVEYS

Benthos – Characterization of the benthos was conducted along 50 m-long transects run parallel to the shoreline at each sampling depth strata. For algae, corals, and other sessile invertebrates we used a line-point intercept methodology along each transect, recording the species or taxa found every 20 cm on the measuring tape. For mobile invertebrates, we counted individuals in 25 50 x 50 cm quadrats randomly placed along each of the 50 m transects.

Fishes – At each depth stratum within a site, divers counted and estimated lengths for all fishes encountered within fixed-length (25-m) belt transects whose widths differed depending on the direction of swim. All fish ≥ 20 cm total length (TL) were tallied within a 4 m wide strip surveyed on an initial "swim-out" as the transect line was laid (transect area = 100 m^2). All fishes < 20 cm TL were tallied within a 2 m wide strip surveyed on the return swim back along the laid transect line (transect area = 50 m^2). Sampling was conducted at 10 and 20 m depth strata. Three replicate transects were performed at each depth stratum.

Fishes were identified to species level in all cases. Fish length was estimated to the nearest cm TL. Fishes were tallied by length and individual-specific lengths were converted to body weights. Numerical density (abundance) was expressed as number of individuals per m^2 and biomass density was expressed as tons per ha. The biomass of individual fishes was estimated using the allometric length-weight conversion: $W = aTL^b$, where parameters a and b are species-specific constants, TL is total length in cm, and W is weight in grams. Length-weight fitting parameters were obtained from FishBase [35]. The sum of all individual weights and numerical densities was used to estimate biomass density by species. Fishes were categorized into four trophic groups (apex predators, herbivores, secondary consumers and planktivores) based on published literature.

DEEP DROP-CAMERA SURVEYS

National Geographic's Remote Imaging Team has developed deep ocean drop-cams, which are high definition cameras encased in a borosilicate glass sphere that are rated to a depth of 10,000 m. Drop-cams have an onboard VHF transmitter that allows for recovery using locating antennae with backup location achieved via communication with the ARGOS satellite system. Drop-cameras were deployed on seamounts and other unique geological features on an opportunistic basis and relied on local expertise and bathymetric charts for optimal deployment locations.

APPENDIX III. CONTINUED.

PELAGIC CAMERAS

We used stereo mid-water Baited Remote Underwater Video Stations (BRUVS; Letessier et al., 2013) to survey the pelagic fish assemblage of Ilhas Selvagens, and to determine how mid-water communities vary across the archipelago. Each BRUVS rig consisted of a metal bar with two GoPro cameras 80 cm apart with an inward convergent angle of 8°. Three rigs were deployed concurrently at each site in a longline formation, each separated by 200 m of surface line (400 m in total). The longline was deployed perpendicular to the current. Rigs were baited with ~ 800 g of mashed bonito and deployed twice daily, with a minimum recording time of two hours. A single longline of 3 rigs was deployed at 19 sites across 3 locations: Selvagem Pequena (6 sites), East Selvagem Grande (7 sites) and West Selvagem Grande (6 sites). This sampling design resulted in 57 samples from 19 sites, with three samples per site.

On return to the laboratory, the video from each rig was processed. All individual fish observed were identified to the lowest possible taxonomic resolution and the maximum number of individuals per frame of video estimated for each species. This number, maxN, is a relative measure of abundance and avoids double counting of individuals within the same video. Fork lengths were also determined for a subset of individuals by using both the right and left camera vision for each rig. All video analyses were based on methods described in Letessier et al. (2013) and used SeaGis software.

All estimates of species richness, total abundance, and abundance of individual species are calculated as the mean of the replicates within a given longline formation. As such, values for richness and abundance are reported per sample, where a sample is the two-hour standard video period analyzed per deployed rig. Statistical analysis was carried out at the level of three locations (Selvagem Pequena, East Selvagem Grande and West Selvagem Grande) with sites as the independent replicates within locations. Analysis consisted of fixed single factor ANOVA for both univariate and multivariate data. All analyses were carried out using PERMANOVA with unrestricted permutation of data. Where significance was observed, pair-wise tests were used to discriminate which locations differed from one another. Univariate data analyses were based on a Euclidean resemblance matrix as the data for species richness and total abundance were continuous and zero values are meaningful. Multivariate data were first transformed to presence-absence given the extreme values for the Atlantic horse mackerel and the lack of variation in abundance of other species, followed by calculation of the Bray-Curtis resemblance matrix as joint-zeros are non-informative in this case.

MICROPLASTIC SAMPLING

Water samples were collected at 17 sites around the Selvagen Islands. Samples were collected from a 1 liter Nalgene bottle that was rinsed 3 times prior to collection. At each site we recorded the date, time, time of high tide, and GPS coordinates. Samples were sent to ASC in Maine for processing. Once received, the water was vacuum pumped over a gridded 0.45-micron filter and dried from a minimum of 24 hours. Using a microscope at 40x magnification, pieces of microplastic (<5mm) on the filter were systematically counted along the grid lines. Each plastic piece was categorized based on shape (round, filament/microfiber, other) and color (blue, red, green, black, transparent/white, other). The volume of water was recorded and the final count for the sample was divided by the quantity of water to obtain a density estimate for each.

MICROPALEO SAMPLING

We collected samples from the top 1 cm of sediment to determine the community of benthic microfossils present in different subtidal environments in these remote locations. Microfossils are excellent indicators of general environmental conditions such as temperature, salinity, organic enrichment, etc. While some species are cosmopolitan and found worldwide, others are unique to certain geographic locations. The sediment was characterized for their minerological and granulometric characteristics, as well as elemental composition. An aliquot of sample was selected for microfossil characterization. The microfossils (foraminifera, in particular; but any ostracods, diatoms, or radiolarians will also be documented) will be isolated to produce a community assemblage and catalogue of the microfossil community for each sampling location. The aims of the project are to provide some insight into the state of the environment of the sites studied during the Pristine Sea's expeditions, to document any new species, to create a baseline catalogue for sites that have no previous comparative samplings, and to provide an updated set for sites with a previous record. Three samples were collected at each site. Approximately 100 ml of sand was collected from the top 1 cm of the sediment. Samples were preserved in a solution 95% ethanol with rose Bengal stain and shipped off to National Geographic Emerging Explorer Dr. Beverly Goodman at Haifa University in Israel. Results will be published separately.

STATISTICAL ANALYSIS

Drivers of sessile benthic community structure and fish trophic structure based on biomass were investigated using permutation-based multivariate analysis of variance (PERMANOVA, Anderson et al. 2008). Similarity percentages analysis (SIMPER) was used to determine the living sessile benthic taxa, and fish species most responsible for the percentage dissimilarities between islands using Bray-Curtis similarity analysis of hierarchical agglomerative group average clustering (Clarke 1993).

Non-metric multi-dimensional scaling (nMDS) analysis was used to examine differences in fish based on trophic biomass by island and depth strata (Anderson et al. 2008). Prior to conducting the nMDS, data were square root transformed.

Two-way Analysis of Variance (ANOVA) with interaction was used to examine differences in fish assemblage characteristics (species richness, abundance, and biomass) between islands and depth strata. Numerical abundance (number of individuals m^{-2}) and biomass (t ha^{-1}) were ln(x+1) prior to analysis to conform to the assumptions of parametric statistics (e.g., normality and homogeneity of variances). Wilcoxon Rank Sum tests were used to compare fish trophic biomass between depth strata.

Appendix IV.

Algae identified during the expedition.

Phylum	Class	Order	Family	Taxa
Chlorophyta	Chlorophyceae	Chlamydomonadales	Palmellopsidaceae	*Pseudotetraspora marina*
	Ulvophyceae	Bryopsidales	Caulerpaceae	*Caulerpa mexicana*
	Ulvophyceae	Bryopsidales	Caulerpaceae	*Caulerpa webbiana*
	Ulvophyceae	Bryopsidales	Udoteaceae	*Pseudochlorodesmis furcellata*
	Ulvophyceae	Cladophorales	Anadyomenaceae	*Microdictyon* sp.
	Ulvophyceae	Cladophorales	Cladophoraceae	*Cladophora liebetruthii*
	Ulvophyceae	Dasycladales	Dasycladaceae	*Dasycladus vermicularis*
	Ulvophyceae	Dasycladales	Polyphysaceae	*Polyphysa polyphysoides*
Cyanobacteria	Cyanophyceae	Oscillatoriales	Microcoleaceae	*Symploca* cf. *hydnoides*
				Cyanobacteria unidentified
Ochrophyta	Phaeophyceae	Dictyotales	Dictyotaceae	*Canistrocarpus cervicornis*
	Phaeophyceae	Dictyotales	Dictyotaceae	*Dictyota aff. dichotoma*
	Phaeophyceae	Dictyotales	Dictyotaceae	*Dictyota bartayresiana*
	Phaeophyceae	Dictyotales	Dictyotaceae	*Dictyota* cf. *canariensis*
	Phaeophyceae	Dictyotales	Dictyotaceae	*Dictyota* cf. *pleicantha*
	Phaeophyceae	Dictyotales	Dictyotaceae	*Dictyota fasciola*
	Phaeophyceae	Dictyotales	Dictyotaceae	*Dictyota implexa*
	Phaeophyceae	Dictyotales	Dictyotaceae	*Lobophora variegata*
	Phaeophyceae	Dictyotales	Dictyotaceae	*Padina pavonica*
	Phaeophyceae	Dictyotales	Dictyotaceae	*Taonia atomaria*
	Phaeophyceae	Ectocarpales	Scytosiphonaceae	*Colpomenia sinuosa*
	Phaeophyceae	Ectocarpales	Scytosiphonaceae	*Hydroclathrus clathratus*
	Phaeophyceae	Fucales	Sargassaceae	*Cystoseira abies-marina*
	Phaeophyceae	Fucales	Sargassaceae	*Cystoseira compressa*
	Phaeophyceae	Fucales	Sargassaceae	*Sargassum* sp. *(furcatum?)*

Phylum	Class	Order	Family	Taxa
Ochrophyta	Phaeophyceae	Fucales	Sargassaceae	*Sargassum vulgare*
	Phaeophyceae	Sphacelariales	Lithodermataceae	*Pseudolithoderma adriaticum*
	Phaeophyceae	Sphacelariales	Sphacelariaceae	*Sphacelaria cirrosa*
	Phaeophyceae	Sphacelariales	Sphacelariaceae	*Sphacelaria* sp.
	Phaeophyceae	Sphacelariales	Stypocaulaceae	*Halopteris scoparia*
Rhodophyta	Florideophyceae	Bonnemaisoniales	Bonnemaisoniaceae	*Falkenbergia hillebrandii*
	Florideophyceae	Ceramiales	Rhodomelaceae	*Lophocladia trichoclados*
	Florideophyceae	Ceramiales	Dasyaceae	*Dasya baillouviana?*
	Florideophyceae	Ceramiales	Rhodomelaceae	*Laurencia* sp.
	Florideophyceae	Ceramiales	Sarcomeniaceae	*Cottoniella filamentosa?*
	Florideophyceae	Corallinales	Corallinaceae	*Hydrolithon onkodes*
	Florideophyceae	Corallinales	Corallinaceae	*Jania* cf. *rubens*
	Florideophyceae	Corallinales	Corallinaceae	*Jania* sp.
	Florideophyceae	Corallinales	Corallinaceae	*Lithophyllum incrustans*
	Florideophyceae	Corallinales	Corallinaceae	*Neogoniolithon* sp.
	Florideophyceae	Gigartinales	Cystocloniaceae	*Hypnea* cf. *cervicornis*
	Florideophyceae	Nemaliales	Galaxauraceae	*Galaxaura* cf. *obtusata*
	Rhodophyceas	Nemaliales	Bonnemaisoniaceae	*Asparagopsis taxiformis*
	Florideophyceae	Peyssonneliales	Peyssonneliaceae	*Peyssonnelia boergesenii*

Appendix V.

Invertebrates identified during the expedition.

Phylum	Class	Order	Family	Taxa	Common Name
Annelida	Polychaeta	Amphinomida	Amphinomidae	*Hermodice carunculata*	Bearded fireworm
	Polychaeta	Sabellida	Serpulidae	*Lygdamis wirtzi*	Devil worm
	Polychaeta	Sabellida	Serpulidae	*Protula tubularia*	Christmas tree worm
Arthropoda	Malacostraca	Decapoda	Diogenidae	*Calcinus tubularis*	Hermit crab
	Malacostraca	Decapoda	Diogenidae	*Dardanus calidus*	Hermit crab
	Malacostraca	Decapoda	Hippolytidae	*Thor amboinensis*	Squat shrimp
	Malacostraca	Decapoda	Xanthidae	*Xantho spp.*	Mud crab
	Malacostraca	Decapoda	Galatheidae	*Galathea squamifera*	Black squat lobster
	Malacostraca	Decapoda	Inachidae	*Stenorhynchus lanceolatus*	Arrow crab
	Malacostraca	Decapoda	Paguridae	*Pagurus anachoretus*	Hairy hermit crab
	Malacostraca	Decapoda	Percnidae	*Percnon gibbesi*	Sally Lightfoot crab
	Malacostraca	Decapoda	Plagusiidae	*Plagusia depressa*	Tidal Spray Crab
	Maxillopoda	Sessilia	Balanidae	*Megabalanus azoricus*	Azorean Barnacle
	Maxillopoda	Sessilia	Chthamalidae	*Chthamalus stellatus*	Acorn barnacle
Bryozoa	Gymnolaemata	Cheilostomatida	Bitectiporidae	*Schizomavella* sp.	Red encrusting bryozoan
	Gymnolaemata	Cheilostomatida	Schizoporellidae	*Schizoporella* cf. *longirostris*	Brown encrusting bryozoan
				Grey bryozoan (unid.)	Grey bryozoan (unid.)
	Gymnolaemata	Cheilostomatida	Adeonidae	*Reptadeonella violacea*	Black encrusting bryozoan
Chordata	Ascidiacea	Enterogona	Polyclinidae	*Aplidium* sp.	Colonial sea squirt
Cnidaria	Anthozoa	Actiniaria	Actiniidae	*Anemonia melanaster*	Sargassum anemone
	Anthozoa	Actiniaria	Actiniidae	*Anemonia sulcata*	Snakelocks anemone

Phylum	Class	Order	Family	Taxa	Common Name
Cnidaria	Anthozoa	Actiniaria	Isophelliidae	*Telmatactis cricoides*	Clup-tipped anemone
	Anthozoa	Antipatharia	Myriopathidae	*Antipathella wollastoni*	Black coral
	Anthozoa	Corallimorpharia	Corallimorphidae	*Corynactis viridis*	Jewel anemone
	Anthozoa	Scleractinia	Astrocoeniidae	*Madracis asperula*	Green reef coral
	Anthozoa	Scleractinia	Caryophylliidae	*Caryophyllia inornata*	Solitary cup coral
	Anthozoa	Scleractinia	Caryophylliidae	*Phyllangia americana mouchezii*	Hidden cup coral
	Anthozoa	Scleractinia	Caryophylliidae	*Polycyathus muellerae*	Solitary cup coral
	Anthozoa	Scleractinia	Dendrophylliidae	*Balanophyllia regia*	Solitary cup coral
	Hydrozoa	Anthoathecata	Pennariidae	*Pennaria disticha*	Athecate hydroid
	Hydrozoa	Leptothecata	Aglaopheniidae	*Aglaophenia* cf. *pluma*	Toothed feather hydroid
	Hydrozoa	Leptothecata	Sertulariidae	*Sertularia* sp.	Sea fir
Echinodermata	Asteroidea	Forcipulatida	Asteriidae	*Coscinasterias tenuispina*	Thorny sea star
	Asteroidea	Spinulosida	Echinasteridae	*Echinaster sepositus*	Red spiny sea star
	Crinoidea	Comatulida	Antedonidae	*Antedon bifida*	Feather star
	Echinoidea	Arbacioida	Arbaciidae	*Arbacia lixula*	Black sea urchin
	Echinoidea	Camarodonta	Parechinidae	*Paracentrotus lividus*	Rock sea urchin
	Echinoidea	Camarodonta	Toxopneustidae	*Sphaerechinus granularis*	Purple spined sea urchin
	Echinoidea	Diadematoidea	Diadematidae	*Diadema africanum*	Long-spined sea urchin
	Holothuroidea	Aspidochirotida	Holothuriidae	*Holothuria sanctori*	Sea cucumber
	Ophiuroidea	Ophiurida	Ophiodermatidae	*Ophioderma longicauda*	Annulated brittle star
Mollusca	Bivalvia	Pterioida	Pinnidae	*Pinna rudis*	Spiny pen shell
	Gastropoda	Littorinimorpha	Vermetidae	*Vermetidae* unidentified	Worm snails
	Bivalvia	Limoida	Limidae	*Limaria hians*	Flame shell
	Bivalvia	Pectinoida	Spondylidae	*Spondylus senegalensis*	African thorny oyster
	Cephalopoda	Octopoda	Octopodidae	*Octopus vulgaris*	Common octopus
	Gastropoda		Haliotidae	*Haliotis tuberculata coccinea*	Abalone

APPENDIX V. CONTINUED.

Phylum	Class	Order	Family	Taxa	Common Name
Mollusca	Gastropoda		Turbinidae	*Bolma rugosa*	Rough star shell
	Gastropoda	Anaspidea	Aplysiidae	*Aplysia dactylomela*	Annulated sea hare
	Gastropoda	Caenogastropoda	Cerithiidae	*Cerithium vulgatum*	Common cerith
	Gastropoda	Littorinimorpha	Cypraeidae	*Luria lurida*	Fallow cowry
	Gastropoda	Littorinimorpha	Ranellidae	*Charonia variegata*	Triton
	Gastropoda	Neogastropoda	Columbellidae	*Columbella adansoni*	Adanson's dove-shell
	Gastropoda	Neogastropoda	Mitridae	*Mitra cornea*	Spindle mitter
	Gastropoda	Neogastropoda	Muricidae	*Stramonita haemastoma*	Red-mouthed rock-shell
	Gastropoda	Nudibranchia	Chromodorididae	*Hypselodoris picta webbi*	Seaslug
	Gastropoda	Umbraculida	Tylodinidae	*Tylodina perversa*	Golden sponge snail
	Gastropoda		Patellidae	*Patella aspera*	White limpet
	Gastropoda		Patellidae	*Patella candei*	Sun limpet
	Gastropoda		Siphonariidae	*Siphonaria pectinata*	False limpet
	Gastropoda		Trochidae	*Phorcus atratus*	Top-snail
Porifera	Demospongiae	Chondrosida	Chondrillidae	*Chondrosia reniformis*	Kidney-shaped sponge
	Demospongiae	Dendroceratida	Dictyodendrillidae	*Spongionella pulchella*	Tube sponge
	Demospongiae	Dictyoceratida	Irciniidae	*Ircinia oros*	Grey encrusting sponge
	Demospongiae	Dictyoceratida	Irciniidae	*Sarcotragus spinosulus*	Grey-brown massive sponge
	Demospongiae	Haplosclerida	Petrosiidae	*Petrosia ficiformis*	Stony sponge
	Demospongiae	Poecilosclerida	Crambeidae	*Crambe crambe* (cf.)	Orange encrusting sponge
	Demospongiae	Poecilosclerida	Hymedesmiidae	*Phorbas fictitius*	Red encrusting sponge
	Demospongiae	Poecilosclerida	Mycalidae	*Hemimycale columella*	Crater sponge
	Demospongiae	Verongida	Aplysinidae	*Aplysina aerophoba*	Yellow tube sponge
	Demospongiae	Axinellida	Axinellidae	*Axinella damicornis*	Sponge
	Demospongiae	Dictyoceratida	Dysideidae	*Pleraplysilla spinifera*	Sponge
	Demospongiae	Verongiida	Ianthellidae	*Hexadella racovitzai*	Sponge
				Brown sponge (unidentified)	

Appendix VI.

Fish species observed during expedition.

Family	Species	Common Name	Trophic Group
Apogonidae	Apogon imberbis	Cardinalfish	Planktivore
Atherinidae	Atherina presbyter	Sand smelt	Planktivore
Aulostomidae	Aulostomus strigosus	Atlantic coronetfish	Secondary consumer
Balistidae	Balistes capriscus	Grey triggerfish	Secondary consumer
	Canthidermis sufflamen	Ocean triggerfish	Secondary consumer
Blenniidae	Lipophrys pholis	Shanny	Secondary consumer
	Ophioblennius atlanticus	Redlip blenny	Herbivore
	Parablennius parvicornis	Rock-pool blenny	Herbivore
Bothidae	Bothus podas	Wide-eye flounder	Secondary consumer
Carangidae	Pseudocaranx dentex	White trevally	Secondary consumer
	Seriola dumerili	Greater amberjack	Apex predator
	Seriola rivoliana	Longfin yellowtail	Apex predator
	Trachinotus ovatus	Pompano	Secondary consumer
Clupeidae	Sardinella maderensis	Madeira sardinella	Planktivore
Dasyatidae	Dasyatis pastinaca	Common stringray	Secondary consumer
Diodontidae	Chilomycterus reticulatus	Spotfin burrfish	Secondary consumer
Gobiesocidae	Lepadogaster candolii	Connermarra clingfish	Secondary consumer
Gobiidae	Gobius paganellus	Rock goby	Secondary consumer
	Mauligobius maderensis	Madeira rock goby	Secondary consumer
Kyphosidae	Kyphosus sectatrix	Bermuda chub	Herbivore
Labridae	Bodianus scrofa	Barred hogfish	Secondary consumer
	Coris julis	Mediterranean rainbow wrasse	Secondary consumer
	Symphodus trutta	Atlantic wrasse	Secondary consumer
	Thalassoma pavo	Ornate wrasse	Secondary consumer
Muraenidae	Enchelycore anatina	Fangtooth moray	Secondary consumer
	Gymnothorax unicolor	Brown moray	Secondary consumer

APPENDIX VI. CONTINUED.

Family	Species	Common name	Trophic Group
Muraenidae	Muraena augusti	Black moray	Secondary consumer
	Muraena helena	Mediterranean moray	Secondary consumer
Myliobatidae	Myliobatis aquila	Common eagle ray	Secondary consumer
Phycidae	Phycis phycis	Forkbeard	Apex predator
Pomacentridae	Abudefduf luridus	Canary damsel	Secondary consumer
	Chromis limbata	Azores chromis	Planktivore
Scaridae	Sparisoma cretense	Mediterranean parrotfish	Herbivore
Scombridae	Scomber colias	Atlantic chub mackerel	Planktivore
Scorpaenidae	Scorpaena maderensis	Madeira rockfish	Apex predator
	Scorpaena notata	Small red scorpionfish	Secondary consumer
Serranidae	Epinephelus marginatus	Dusky grouper	Apex predator
	Mycteroperca fusca	Island grouper	Apex predator
	Serranus atricauda	Blacktail comber	Secondary consumer
Sparidae	Boops boops	Bogue	Planktivore
	Diplodus cervinus	Zebra seabream	Secondary consumer
	Diplodus sargus	White seabream	Secondary consumer
	Oblada melanura	Saddled seabream	Secondary consumer
	Sarpa salpa	Salema	Herbivore
Sphyraenidae	Sphyraena viridensis	Yellowmouth barracuda	Apex predator
Synodontidae	Synodus saurus	Atlantic lizardfish	Secondary consumer
	Synodus synodus	Diamond lizardfish	Secondary consumer
Tetraodontidae	Canthigaster capistrata	Macronesian sharpnose puffer	Secondary consumer
	Sphoeroides marmoratus	Guinean puffer	Secondary consumer
Torpedinidae	Torpedo marmorata	Spotted torpedo ray	Apex predator
Tripterygiidae	Tripterygion delaisi	Black-faced blenny	Secondary consumer

Appendix VII.

Fishes observed on drop-cams around Ilhas Selvagens.

Family	Taxa	Common Name	Minimum Depth (m)	Maximum Depth (m)
Odontaspididae	*Odontaspis ferox*	Smalltooth sand tiger shark	1198	1198
Acropomatidae	*Synagrops bellus*	blackmouth bass	687	687
Antherinidae	*Antherina* sp.	Silversides	112	112
Carangidae	*Caranx hippos*	Crevalle jack	112	112
	Trachurus picturatus	Blue jack mackerel	207	207
Carapidae		Pearlfish	547	1429
Etmopteridae	*Etmopterus* sp.	Lantern shark	1198	1198
Halosauridae		Halosaur	1198	1198
Labridae	*Bodianus scrofa*	Hogfish	112	112
Macrouridae	*Bathygadinae*	Grenadier	1198	2254
	Coryphaenoides armatus	Abyssal grenadier	2254	2254
Muraenidae	*Muraena helena*	Mediterranean moray	112	207
Nettastomatidae		Duckbill eel	1198	1198
Phycidae	*Phycis phycis*	Forkbeard	207	207
Scorpaenidae	*Pontinus kuhlii*	Offshore rockfish	207	207
Sebastidae	*Helicolenus dactylopterus*	Blackbelly rosefish	687	687
Serranidae	*Anthias anthias*	Swallowtail seaperch	112	207
	Epinephelus marginatus	Dusky Grouper	112	112
	Serranus cabrilla	Comber	112	207
	Polyprion americanus	Wreckfish	112	112
Synaphobranchidae	*Synaphobranchus affinis*	Grey cutthroat	207	207
	Synaphobranchus sp.	Cutthroat eel	547	1429
	Synaphobranchus kaupii	Cutthroat eel	366	918
Trachichthyidae	*Hoplostethus atlanticus*	Orange roughy	207	207

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