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Spatial and seasonal differences in the top predators of Easter Island: Essential data for implementing the new Rapa Nui multiple-uses marine protected area

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Spatial and seasonal differences in the top predators of Easter Island: essential data for implementing the new Rapa Nui multiple-uses MPA

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Abstract

1. Reef fishes are an important component of marine biodiversity and changes in the composition of the assemblage structure may indicate ecological, climatic, or anthropogenic disturbances. To examine spatial differences in the reef fish assemblage structure around Easter Island, eight sites were sampled during autumn and summer 2016-2017 with Baited Remote Underwater Video systems (BRUVs).
2. To determine seasonal changes, quarterly (seasonal) sampling was conducted at five of those eight sites. Fifteen pelagic species of fishes were recorded during this study, some of which have not previously been recorded in scuba surveys, including the Galapagos shark (*Carcharhinus galapagensis*, Snodgrass & Heller, 1905) and tunas (Scrombidae).
3. Significant spatial and seasonal differences were found in the fish assemblage. Fish assemblages from the south coast differed significantly from those along the west and east coasts, mainly due to the occurrence of top predators. Winter differed from other seasons, especially along the south coast where the island is more exposed to large oceanic swells and winds from Antarctica.
4. Due to the variety and high relative abundance of species recorded during this survey, BRUVs seemed to be an effective method for studying top predators at Easter Island.

The identification of priority zones for the protection of top predators species represent an important contribution of this study, in order to develop management and conservation strategies to be implemented in the newly created Rapa Nui multiple uses coastal marine protected areas (MUMPA).

Keywords

BRUVs, Easter Island, top predators, sharks, remote islands, trophic groups, management, conservation.

Introduction

Reef fishes play an important role in ecosystem function (Stevens, Bonfil, Dulvy, & Walker, 2000), and are the target of recreational, commercial, and subsistence fisheries in many coastal locations (Henry & Lyle, 2003; Kingsford, Underwood, & Kennelly, 1991). Precise and accurate information on the diversity and abundance of fish populations is important for understanding their ecology, and is critical for developing effective management and conservation strategies (Andrew & Mapstone, 1987; Pita, Fernández-Márquez, & Freire, 2014). Changes in the fish assemblage composition usually indicate alteration in the community structure in response to ecological, climatic, or anthropogenic drivers (Jeppesen et al., 2010; Schlosser, 1990; Westera, Lavery, & Hyndes, 2003).

Reef fish assemblages vary spatially and temporally in response to biotic variables, such as food availability (Tickler, Letessier, Koldewey, & Meeuwig, 2017), predation or competition (Almany, 2004), and abiotic variables, such as habitat complexity and environmental characteristics like wave exposure and temperature (Anderson & Millar, 2004; Coles & Tarr, 1990; Curley, Kingsford, & Gillanders, 2003; Friedlander & Parrish, 1998). For example, spatial variation in reef fish assemblages can occur on scales of metres to kilometres (Connell & Jones, 1991; Curley et al., 2003; Malcolm, Gladstone, Lindfield, Wraith, & Lynch, 2007), and are usually associated with habitat complexity and the environmental conditions that structure that habitat (Asher, Williams, & Harvey, 2017; Coles & Tarr, 1990; Friedlander & Parrish, 1998). Seasonal changes are more evident in reef ecosystems from sub-tropical latitudes because of greater environmental variability (Coles & Tarr, 1990; Friedlander & Parrish, 1998). However, these influences differ by location. For example, Coles and Tarr

(1990) found that the large variation in temperature between winter and summer (about 20ºC) in the Western Arabian Gulf determines the richness and abundance of inshore species. In Hawaii, Friedlander and Parrish (1998) observed that fish assemblages responded to high wind and wave energy during winter by taking refuge at deeper depths and in more complex habitats. Understanding the natural variations in the fish assemblage provides essential baseline information for designing and evaluating the effectiveness of marine protected areas (MPA) (Charton et al., 2000). Having accurate information of where to protect is especially valuable in highly urbanized areas, where area protection is constrained owing to conflicts among multiple users (Curley et al., 2003).

Marine Protected Areas (MPAs) have been shown to be a highly effective means of conserving biodiversity and managing fisheries, while also restoring and preserving overall ecosystem functions (Gaines, White, Carr, & Palumbi, 2010; Lubchenco & Grorud-Colvert, 2015). Through the establishment of fishing regulations such as minimum size, effort control and/or regulation of total catches (Botsford, Micheli, & Hastings, 2003; Hilborn, Micheli, & De Leo, 2006), MPAs are usually associated with the increase of abundance, biomass and size of focal species (Micheli, Halpern, Botsford, & Warner, 2004) as well as catch-per-unit-effort (CPUE) in adjacent areas (Roberts, Bohnsack, Gell, Hawkins, & Goodridge, 2001). In Chile, 23 MPAs have been created in the last decade, protecting over 41% of its economic exclusive zone (EEZ) (Petit, Campoy, Hevia, Gaymer, & Squeo, 2017). The most recent three MPAs were announced during the 2017 International Marine Protected Areas Congress (IMPAC4 2017): Islas Diego Ramirez-Paso Drake, Juan Fernandez archipelago and Rapa Nui. The Rapa Nui Multiple Uses Coastal Marine Protected Area (MUMPA) covers the entire Easter Island Ecoregion and extends from the Easter Island coastline to the limit of the EEZ, embracing ~579,000 km^2.

Easter Island, also known by its Polynesian name Rapa Nui, is the most south-eastern coral reef ecosystem in the Pacific Ocean and harbours a unique fish assemblage with a high level of endemism (Randall & Cea, 2010). Easter Island is one of the most isolated inhabited islands in the Pacific Ocean; yet, long-term overfishing has dramatically reduced the abundance of targeted species (Aburto, Gaymer, Haoa, & Gonzales, 2015; Friedlander et al., 2013; Randall & Cea, 2010; Zylich et al., 2014). Modern fishing equipment and the demand for local fish from increasing tourism has compounded the effects of overfishing (Randall & Cea, 2010; Zylich et al., 2014). There have been a limited number of surveys of fishes around Easter Island (e.g. Easton, Gaymer, Friedlander, & Herlan, 2018; Fernández, Pappalardo, Rodríguez-Ruiz, & Castilla, 2014; Friedlander et al., 2013), with most of these studies focusing on reef fishes, rather than pelagic species. Using underwater visual census (UVC), Friedlander et al. (2013) found contrasting reef fish assemblages between Easter Island and its nearest neighbour, Salas y Gómez, a small island located ~390 km to the east. Salas y Gómez is one of the most isolated islands in the Pacific Ocean and is fully protected from fishing as part of the Motu Motiro Hiva Marine Park. Sharks, primarily the Galapagos shark (*Carcharhinus galapagensis*), and jacks account for more than 40% of the fish biomass around Salas y Gómez, whereas Easter Island is dominated by smaller planktivorous species, with top predators virtually absent (Friedlander et al. 2013).

In the past, ecological studies of fishes at Easter Island have relied on fishery-dependent data from commercial fisheries and UVC, performed by scuba divers (Acuña et al., 2018). The use of fishery-dependent sampling is destructive (Skomal, 2007) and inefficient due to sampling biases from gear selectivity and different fishing effort between species, habitats, seasons, and vessels (Bishop, 2006; Murphy & Jenkins, 2010; Thorson & Simpfendorfer; 2009). Additionally, this technique is less effective in locations with insufficient and inaccurate landing information, like Easter Island (Aburto & Gaymer, 2018). UVC is the most-used observational technique for reef ecosystems (Medley, Gaudian, & Wells, 1993; Samoilys & Carlos, 2000). However, it also has several well-documented limitations and problems, including intra- and inter-observer variability (Thompson & Mapstone, 1997) and the effect of divers on the species behaviour (Chapman, Johnston, Dunn, & Creasey, 1974; Cole, 1994; Kulbicki, 1998; Gray et al., 2016; Emslie, Cheal, MacNeil, Miller, & Sweatman, 2018; Lindfield, Harvey, McIlwain, & Halford, 2014). In contrast, remote underwater video systems, such as Baited Remote Underwater Video Systems (BRUVs), are effective,non-destructive fishery-independent techniques used to sample fish assemblages without these diver-associated problems.

BRUVs attract a wide range of marine species from different trophic groups into the field of view of a camera so that they can be identified and counted (Dorman, Harvey, & Newman, 2012; Hardinge, Harvey, Saunders, & Newman, 2013). BRUVs increase the number of sampled species (Stobart et al., 2007; Willis & Babcock, 2000), and are especially effective in the detection of cryptic and rare predators, such as sharks and fishery-targeted species, that are not well sampled using UVC (Brooks, Sloman, Sims, Danylchuk 2011; Harvey et al. 2012; Malcolm et al., 2007; Watson, Harvey, Anderson, & Kendrick, 2005). Pelagic BRUVs are even more novel than traditional BRUVs, allowing the study of species that inhabit the water column, including highly mobile species (Santana-Garcon, Newman & Harvey, 2014; Santana-Garcon et al., 2014b). Pelagic species are ecologically important to marine ecosystems (Freon , Cury, Shannon, Roy, 2005) and highly valuable for the fishing industry (Pauly 2002; Worm et al. 2006). Despite their importance and that they are constantly threatened by multiple factors, such as pollution, climate change, and overfishing (see Game et al. 2009), the pelagic ecosystems, at a community scale, are still data poor worldwide.

Given the lack of quantitative data on the pelagic fish assemblages of Easter Island, the fragility of the marine ecosystem, and the importance of baseline information for the implementation of conservation strategies, the objectives of this study were: (1) to assess spatial and seasonal variability in the pelagic fishes around Easter Island using BRUVs; (2) to determine which environmental factors best explain the observed differences; and (3) to provide key data for advising management and conservation of the coastal areas, with particular emphasis on zoning the recently created MUMPA.

Material and Methods

Study area

Easter Island (27°13´S and 109°37´W) has a land area of 166 km^2 and ~5600 inhabitants. Located 2250 km east from Pitcairn Island and 3760 km south-west from mainland Chile, it is one of the most isolated places on earth. The nearest island is Salas y Gomez Island (26º28`S and 105º21`W), which is an uninhabited volcanic island with a total area of 0.15 km^2. Both islands and more than several dozen seamounts are part of the Salas y Gómez Ridge, which extends 2232 km before reaching the Nazca Ridge in the south-eastern Pacific Ocean (Randall & Cea, 2010; Friedlander et al., 2013).

Sample collection

Mid-water BRUVs were constructed according to Santana-Garcon et al., (2014a). Each BRUVs was constructed using a single GoPro Hero 4 camera (mono-camera) held in their own underwater housing. GoPros were set to record a wide-angle of view and 1080p. A mix of fresh local fishes (~300 gr) and one can of Chilean jack mackerel (*Trachurus murphyi*) were used as bait. Deployments were carried out during daylight hours, avoiding dusk and dawn. Four simultaneous 1-h deployments (replicates), having a minimum separation of 500 m to avoid plume dispersion overlap (Santana-Garcon et al., 2014a), were conducted at a depth of ~25 m at each site; a minimum of six deployments were conducted per site. Local knowledge, previous studies and limitations related to weather conditions were used to guide the spatial coverage of sites. Date, hour and location (latitude and longitude) were recorded during every deployment. To study spatial differences around Easter Island, eight sites were sampled during autumn and summer 2017 (Figure 1). To determine seasonal changes in the fish assemblage, quarterly seasonal sampling was undertaken at five of those sites during 2016-2017.

Every BRUVs was deployed for a minimum of 70 minutes. Following the recommendations of Acuña -Marrero et al. (2018), we discarded the first and the last 5 minutes from every video to avoid any potential influence caused by the presence of the boat. Species assignments were made following Randall and Cea (2010), FishBase (ver. 02/2018, R. Froese & D. Pauly, see www.fishbase.org, accessed 2018), and consultations with world fish specialists. Each species was assigned to a functional group (herbivores, planktivores, secondary consumers, and top predators) following Friedlander et al. (2013) and FishBase (ver. 02/2018, R. Froese & D. Pauly, see www.fishbase.org, accessed 2018). Additionally, all the species were classified as “Target Species” or “Not Target Species” according to Zylich et al. (2014) and discussions by the first author with local fishermen. The maximum number of individuals of the same species appearing in a video frame at the same time (MaxN), plus any other individual that was uniquely and clearly distinguishable from the other individuals, was used as an estimate of relative abundance or a corrected MaxN (*cMaxN*; see Acuña-Marrero et al., 2018). MaxN is a conservative measurement of relative abundance that avoids any error associated with recounting the same fish (Cappo, Harvey, Malcom, & Speare, 2003; Priede, Bagley, Smith, Creasey, & Merrett, 1994; Willis, Millar,

& Babcock, 2003); however, it usually underestimates the real abundance in a single deployment (Kilfoil et al., 2017). By including any other individual that was undoubtedly distinguishable within the deployment and that was not already included in the MaxN calculation, *cMaxN* tends to solve, in part, the underestimation problem of sampled species. *cMaxN* per hour was used to standardize effort across deployments of different soak times, as suggested by Santana-Garcon et al. (2004b). Measurement of length was not considered during this study, therefore, a biomass calculation could not be included in the analysis.

Data analyses

All statistical analyses were conducted in PRIMER v. 7.0.13 software package (Clarke & Gorley, 2006) with the PERMANOVA+ add-on (Anderson, Gorley, & Clarke, 2008), unless otherwise specified. A Bray–Curtis similarity matrix was created on the 4th-root transformed *cMaxN* data. All permutational multivariate analysis of variance (PERMANOVA) tests were run with default settings and 9999 permutations to obtain p-values (Anderson et al., 2008). Statistically significant ($p < 0.05$) interactions were further explored with appropriate post hoc pairwise tests. To test spatial variance around Easter Island, *cMaxN* data of each site were analysed using "Sites" as a fixed factor in a PERMANOVA. To test seasonal difference on fish assemblage, data were analysed using seasons (winter, spring, summer and autumn) and five sites as fixed factors. A canonical analysis of principal coordinates (CAP) was used as a general test to evaluate structural differences in overall fish assemblage. CAP maximizes group differences finding the axis that best separates each group (Anderson et al., 2008). CAP analyses were run on the resemble matrix of average values between sites and seasons.

Environmental data collection and analysis

To determine the role of seasonal and spatial environmental variation on the fish assemblage structure, sea surface temperature (SST), long-term and recent wave energy, distance of each deployment site from the shore, and shelf width were considered. For each site, SST MUR (Multi-scale Sea Surface Temperature) satellite data at a 1 km spatial resolution (https://mur.jpl.nasa.gov) were used after we verified the accuracy of these satellite data with in situ SST data collected at Omohi, Motu Tautara, Ovahe and Kari Kari sites by Evie Wieters (Pers. Comm., unpublished data) from deployed temperature sensors (Onset, tidbit) set to record SST every ten minutes at 12-15 m depth. Long-term and recent wave energy, were computed from NOAA's Wave Watch III (WWIII; http://polar.ncep.noaa.gov/waves), were binned into 16 discrete sectors each spanning 22.5 degrees. The long-term wave energy ranged from Jan 2010 to Jul 2015, meanwhile recent wave energy was calculated using mean values corresponding to the month each deployment was made. Distance from shore and shelf width were calculated for each site using Google Earth Pro (http://earth.google.com) (Table 1S). For seasonal analysis, only wave energy, long-term wave energy, and SST were considered. Environmental and biological data were analysed using distance-based linear modelling (DistLM) and a distance-based redundancy analysis (*db*RDA). DistLM is a routine for analysing and modelling the relationship between a multivariate data cloud, as described by a resemblance matrix, and one or more predictor variables. The *db*RDA analysis was used to visualize the given model in a multi-dimensional space (Anderson et al., 2008). Environmental values used in the DistLM-dbRDA are shown in Table S2.

Results

Fifteen species were recorded during the study (Table 1). Planktivores and herbivores were the largest components of the pelagic fish assemblage at Easter Island, accounting for 73.8% and 16.9%, respectively (Table 2). The most abundant species around Easter Island were *Xanthichthys mento* (Jordan & Gilbert, 1882) and *Chromis randalli* (Greenfield & Hensley, 1970). Both occurred at every site-season combination, except at Vaihu during spring. Top predators, while having the highest species richness (9 species), were not well represented in abundance except at Vaihu. *Fistularia commersonii* (Rüppell, 1838) was the most abundant species among top predators, followed by *Seriola lalandi* (Valenciennes, 1833) (Table 2). Some species such as *Aulostomus chinensis* (Linnaeus, 1766) and *Caranx lugubris* (Poey, 1860) showed seasonal occurrence and other species such as *C. galapagensis* (Snodgrass & Heller, 1905) and *Pseudocaranx cheilio* (Bloch & Schneider, 1801) displayed more site-specific occurrences. Nine target species were recorded, seven of which were top predators. The most abundant and well distributed was *Kyphosus sandwicensis* (Sauvage, 1880), which was abundant along the east and west coasts of Easter Island year-round; however, low abundances were reported at Vinapu, and it was absent at Vaihu. The black trevally *C. lugubris* was rare during the entire study.

Spatial differences

PERMANOVA revealed that the fish assemblages differed significantly among sites (Pseudo-F = 4.795, $p < 0.001$). Sites along the south-east side of Easter Island, Ana hukahu, Vaihu and Vinapu, were significantly different from all the other sites around the island (Table S3). CAP illustrates the difference in the fish assemblage found using PERMANOVA (Figure 2a). The size of the first two axes were $\delta_1 = 0.9823$ and $\delta_2 = 0.9339$, respectively, over 5 (m) principal coordinate axes. The estimation of misclassification error indicates low allocation success (31%); however most of the misclassifications occurred within two groups (Figure 2a): (1) Vinapu-Vaihu-Ana hukahu, and (2) Ovahe-Omohi-Poike-Kari Kari-Motu Tautara (Table S2). Vaihu was the only site with 100% allocation success. Vector length and direction from CAP revealed that the abundance of a few species such as *C. galapagensis*, *F. commersonii* and *P. cheilio* drove the differences between Vaihu-Vinapu-Ana hukahu, and all the others sites (Figure 2a). The occurrence of *Thunnus albacares* (Bonnaterre, 1788) and *Decapterus muroadsi* (Temminck & Schlegel, 1844) distinguished Poike from other sites (Figure 2a), meanwhile the occurrence of *Katsuwonus pelamis* (Linnaeus, 1758) was a consequence of the differences at Omohi.

Seasonal differences

Highest richness and abundances were found in autumn and summer. Fish assemblages during winter significantly differed from the other seasons (Pseudo-F = 3.366, $p < 0.001$, Table S3). Principal axes values from CAP were $\delta_1 = 0.909$ and $\delta_2 = 0.546$, over $m = 3$ principal coordinate axes (Figure 2b). The overall estimation of misclassification error showed an allocation success of only 60%. Winter had the highest allocation success with 80%, while success for autumn (60%), summer (60%), and spring (40%) were lower. In general, the occurrence and abundance of species such as *X. mento*, *A. chinensis* and *S. lalandi*, were associated with winter, while *Aluterus scriptus* and *C. lugubris* were associated with the summer season.

Environmental analysis

DistLM-dbRDA ordination showed that shelf width explained 26.6% of the spatial variation in the fish assemblage around Easter Island ($p = 0.002$). Recent wave energy and distance from the coast, when considered alone, explained 15.4 %, ($p=0.028$) and 14.5% ($p= 0.039$)

of the variation, respectively. Long-term wave energy was the only variable explaining significant seasonal variability (~ 17.2% of the variation, p = 0.031) (Table S4).

Discussion

This study is the first on spatial and temporal patterns of the pelagic fish assemblage at Easter Island, highlighting the importance of specific areas of occurrence and abundance. We found the pelagic fish assemblage at Easter Island to be dominated numerically by two small planktivore species, *C. randalli* and *X. mento*, followed by the herbivorous *K. sandwicensis.* The numerical dominance of planktivorous and herbivorous species observed in our study is consistent with Friedlander et al. (2013) findings that these two trophic groups accounted for 40% and 31% of the total reef fish biomass, respectively. Top predator species, although less abundant, constituted the richest trophic group in our study (nine species). In contrast, Friedlander et al. (2013) only observed six species of this trophic group, and with lower abundances. These differences in richness and abundance of top predators species might be explained by differences in sampling methods. UVCs is a reliable observational technique (Medley et al., 1993; Samoilys & Carlos, 2000), and it is widely used for sampling reef-associated species at shallow, nearshore habitats. However, the effect of divers on animal behaviour has led to the underestimation of some species abundance, such is the case of cryptic and fishery-target species within fishing areas (Chapman et al., 1974; Cole, 1994; Gray et al., 2016; Kulbicki, 1998; Lindfield et al., 2014), especially pelagic species (De Girolamo & Mazzoldi, 2001; Stanley & Wilson, 1995). The higher occurrence of rare species and species undersampled by UVCs, such as *C. galapagensis*, *K. pelamis*, *T. albacare* and *C. lugubris*, during our study proved the effectiveness of BRUVs in studying the pelagic fish assemblages at Easter Island, especially top predators.

Top predators play an important role in the top-down ecosystem regulation (Stevens et al., 2000), yet these species are the most vulnerable to overfishing and their removal could lead to environmental changes affecting ecosystem function in fragile ecosystems (Hughes, Graham, Jackson, Mumby, & Steneck, 2010; Shears & Babcock, 2002). The continued decline of top-predator populations at Easter Island has likely caused a phase shift from a healthy community dominated by large top predators, such as at Salas y Gómez, to a disturbed community dominated by smaller planktivorous species (Friedlander et al., 2013).

Seven of the nine species of top predators recorded in this study are targeted by fisheremen at Easter Island. Together with the herbivorous Pacific rudderfish, *K. sandwicensis*, top predators like *S. lalandi*, *S. helleri* and *T. albacares* are the most targeted pelagic fishes at Easter Island (Zylich et al., 2014). Subsistence catches are also dominated by *K. sandwicensis* and other jacks such as *C. lugubris* and *P. cheilio* (Zylich et al., 2014). According to local residents, *C. lugubris* was abundant in the past, but now is uncommon. Similarly, the Galapagos shark, which is currently classified as Near Threatened on the IUCN Red List, has been reported by local residents to have declined considerably around Easter Island, possibly as a result of direct and indirect fishing impacts (Zylich et al., 2014; N. Morales, pers. obs), although the overfishing of prey may also be contributing to this decline (DiSalvo, Randall, & Cea, 1988). Even though fishermen on Easter Island do not directly target the Galapagos shark, they seem to be susceptible to bycatch in coastal and offshore fisheries. Likewise, their population has declined considerably in Central America (Bennett et al., 2003), where the major threat comes from bait-fishing activities around islands and seamounts (Bennett et al., 2003; Zylich et al., 2014).

The Galapagos shark is the most common coastal shark around Easter Island (Randall & Cea, 2010; Zylich et al., 2014), and it was the only species of shark observed during the current study. A similar BRUVs study in the Galapagos Archipelago found that the Galapagos shark was also the most abundant among 12 species of sharks in the area (Acuña-Marrero et al. 2018). In that study, the Galapagos shark showed a similar mean cMaxN (0.52) per deployment to our observations (0.58), despite the fact that the highest cMaxN found in the Galapagos (8) was almost three times lower than in the current study (21). Total number of individuals observed was 334 in the Galapagos Archipelago, and 112 in the current study. These contrasting numbers could be a result of a higher local (i.e., site) concentration of this species but a lower regional (i.e., island) abundance at Easter Island than at the Galapagos Archipelago.

Spatial and seasonal differences in the composition of pelagic fish species were found during this study. Species composition along the south coast (Ana hukahu, Vaihu and Vinapu) was significantly different from the east and west coasts of the island. Spatial differences in assemblage structure were driven by the occurrence and abundance of the top predators such as *C. galapagensis*, *F. commersonii*, and *P. cheilio*, which showed more site specificity, suggesting the presence of specific habitat characteristics unique to certain areas. Habitat structure and complexity have been indicated as important characteristics in the composition of fish assemblages, e.g., more complex habitats provide greater food availability and refuge (Anderson & Millar, 2004; Asher et al., 2017; Coles & Tarr, 1990; Curley et al., 2003; Heupel & Hueter, 2002). Shelf width was the most influential pelagic fish assemblage driver. Along the southern coast of the island, the shelf break (30 m) occurs further from the coastline creating an extended shallow platform (Table S2). The sharks observed during this study were likely juveniles (less than 200 cm TL, Wetherbee, Crow, & Lowe, 1996), based on size estimates of those sharks that closely approached bait canisters (used for scale), suggesting juveniles have an apparent strong association with that shallow shelf habitat. Our observations suggests that the south-east coast of Easter Island could be serving as a nursery area for juvenile Galapagos sharks, which is consistent with nursery areas for *Carcharhinus* species often occuring in shallow waters (Springer, 1967) with a low-predation environment and ample prey availability (Branstetter, 1990; Heupel & Hueter, 2002; Simpfendorfer & Milward, 1993).

Abiotic (environmental) variables also influence the abundance of fish species within an area, leading to spatial variability within the ecosystem (Felley & Felley, 1986). Wave energy has been noted as an important driver of reef habitats and benthic communities at Easter Island where the dominance of different coral species depends on the degree of exposure (Easton, et al., 2018; Friedlander et al., 2013). Wave energy came mainly from the south-west (202°) (Table S1); however, it only explained a small amount of the spatial variability in the pelagic fish assemblage. These results may be explained by the low resolution of the satellite data for each site, which probably did not reflect the real effect of wave energy in the total area. Furthermore, *in situ* measurement of this environmental variable may provide finer resolution and explanatory power. Although, top predator species are often associated with high-energy environments, the occurrence of top predators and target species at the south-easternmost part of the island (From Vinapu to Poike) could be also explained by the effect of adverse weather conditions (e.g. wind, currents, and wave energy) on the local fishing effort, forcing fishing into more sheltered areas.

Conversely, the most abundant target species *K. sandwicensis* was rare on the south coast and virtually absent between Vaihu and Ana hukahu. The nanue (Rapanui name for the *K. sandwicensis*) is an herbivore species that feeds primarily on red algae. At Easter Island, the occurrence of algae is concentrated at the most protected sites (north-east) of the island (see Easton et al., 2018). On the other hand, this species is one of the most prized species on Easter Island and is considered over-exploited by local people (Gaymer et al., 2013). According to Acuña et al. (2018), nanue are usually caught by traditional shoreline fishing and spear-fishing, especially from Vinapu to Hanga Nui, where shoreline access is easier and fishing pressure is higher. The heavy fishing pressure together with the species habitat preference could explain the localized depletion in these areas.

Seasonal variability in pelagic fish assemblage structure was evident during this study, with winter been significantly different from the other seasons. Autumn and spring are transition seasons, as has been described from other subtropical areas (Friedlander & Parrish, 1998). Sites located along the coasts most exposed to winter swells and winds (Ana hukahu, Vaihu and Vinapu) showed higher variability among seasons in comparison with more protected sites. Similar results were found by Coles and Tarr (1990) in the western Arabian Gulf, and by Friedlander and Parrish (1998) in the Hawaiian Archipelago. In both cases, the authors noticed that some mobile fishes seem to migrate from exposed to more protected and deeper locations that provide refuge from high wave energy during winter. In contrast, more protected sites seem to have more stable assemblages throughout the year. Asher et al. (2017) also found an increase in abundance of jacks and sharks in shallow and mesophotic reefs in the Hawaiian Archipelago with increasing depth, due probably to the avoidance of environmental (e.g. wave energy) and anthropogenic factors (e.g. fishing) in shallow waters. Easter Island has been understudied in comparison to other islands in the Pacific Ocean, and studies at deeper depths are even more limited (Easton et al., 2017). *Seriola lalandi* and *P. cheilio* were recorded at ~280 m and ~170 m, respectively, using ROV (remotely-operated vehicle) and Drop-Cams around Easter Island and the surrounding seamounts (Easton et al., 2017). The occurrence of inshore species at deeper depths could also suggest that deeper habitats are being used as a refuge from natural and anthropogenic influences. The presence of particular species during certain seasons and at certain sites could be explored by expanding the survey area in order to include mesophotic zones and incorporate surrounding seamounts in future designs.

Conservation actions

Randall and Cea (2010) proposed the establishment of marine reserves around Rapa Nui to allow resident fishes to grow until they reached full reproductive maturity. Some of the areas suggested for reserves were Motu Nui and Motu Iti (in front of Kari-Kari), Ovahe, Motu Tautara, Hanga Nui, and Motu Marotiri. The last two areas correspond to the southeast side of the island, close to where the greatest abundance of top predators was recorded and a possible nursery area for Galapagos sharks was identified. The Galapagos shark show ontogenetic segregation, where juveniles are more likely to inhabit shallow coastal waters, meanwhile adults occur in deeper waters away from the coast (Acuña-Marrero et al., 2018; Kohler, Casey, & Turner, 1998; Wetherbee et al., 1996). Areas used by early life stages are vital for population stability and recovery (Bonfil, 1997), and therefore, their protection is necessary.

Additionally, several initiatives have proposed other strategies to protect marine coastal and offshore ecosystems at Easter Island. Notably, a local initiative promoted by the Rapa Nui chamber of tourism suggested the creation of a marine reserve at Hanga Roa Bay (west side of the island); however, local conflicts hindered its creation (Gaymer et al., 2011). An effort has been made in the last seven years to raise awareness and capacity building in the Rapanui community (Aburto, Gaymer, & Cundill, 2017; Gaymer et al., 2013). These efforts ultimately resulted in a participatory process that lead to the creation of a multiple uses coastal marine protected area, MUMPA, around the entire EEZ of Easter and Salas and Gómez islands, completing the protection initially provided by the Motu Motiro Hiva Marine Park in 2010. In order to implement this large-scale MPA, a participatory management plan has to be built, which includes the zoning of the MUMPA in both the coastal and offshore areas. Zoning will include establishing fully no-take coastal areas that could allow recovery of some over-exploited target fishes, but also to protect areas were top predators (such as the Galapagos sharks) are concentrated. Top predators play a crucial role in ecosystem function (Friedlander & De Martini, 2002), thus their protection is necessary for maintaining ecological processes and ecosystem services. The current study is an important contribution for planning the management and conservation strategies to be implemented in the newly created Rapa Nui MUMPA. A Marine Council, with a majority of Rapanui-elected members, will place the administration of this area under a co-management strategy, in which is an unprecedented model of MPA administration in Chile (Aburto et al. 2017)

Over the last decades, there has been an increasing awareness of the added value that ecosystem services and sustainable management can offer to small human communities that inhabit coastal areas (Arkema, Abramson, & Dewsbury, 2015). Biodiversity has been recently recognized as an economic resource (Admiraal, Wossink, de Groot, & de Snoo, 2013), enhancing ecotourism and helping local inhabitants shift from non-sustainable practices (overfishing) to a broader array of sustainable activities with added value such as community-based ecotourism. In this sense, the year-round occurrence of the Galapagos shark in one specific area of the island could be considered a shark-based ecotourism spot, where local operators benefit from long-lived animals ensuring decades of incomes. Thus, not only the protection of the Galapagos shark, but also its potential for ecotourism (e.g. shark-watching by SCUBA divers), should be key elements for taking into account for the zoning of the Rapa Nui MUMPA, that will allow activities such as traditional fishing practices, ecotourism, scientific research and others that should be defined in the management plan.

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Tables

Table 1. List of the 15 species recorded using BRUVS at Easter Island.

Species	Rapa Nui name	Trophic level	Target
Carcharhinidae			
Carcharhinus galapagensis	Mango	Top predator	Yes
Aulostomidae			
Aulostomus chinensis	Toto amo	Top predator	No
Fistulariidae			
Fistularia commersonii	Toto amo hiku kio´e	Top predator	No
Carangidae			
Pseudocaranx cheilio	Po´opo´o	Top predator	Yes
Caranx lugubris	Ruhi	Top predator	Yes
Seriola lalandi	Toremo	Top predator	Yes
Decapterus muroadsi	ature	Planktivores	Yes
Kyphosidae			
Kyphosus sandwicensis	Nanue	Herbivorous	Yes
Chaetodontidae			
Chaetodon litus	Tipi tipi uri	Secondary consumer	No
Pomacentridae			
Chromis randalli	Mamata	Planktivores	No
Sphyraenidae			
Sphyraena helleri	Barracuda	Top predator	Yes
Scombridae			
Thunnus albacares	Kahi	Top predator	Yes
Katsuwonus pelamis	Bonito	Top predator	Yes
Balistidae			
Xanthichthys mento	Kokiri	Planktivores	No
Monacanthidae			
Aluterus scriptus	Paoa	Secondary consumer	No

Table 2. Summary of fish sightings and relative abundance recorded by Baited Remote Underwater Video systems (BRUVS) at Easter Island. *cMaxN*: corrected MaxN.

Trophic level	**Total no. Individuals**	**% of total**	**Highest *cMaxN***
Top predator	**685**	**8.12**	
Carcharhinus galapagensis	112	1.33	21
Aulostomus chinensis	27	0.32	2
Fistularia commersonii	147	1.74	4
Caranx lugubris	12	0.14	4
Pseudocaranx cheilio	78	0.92	12
Seriola lalandi	108	1.28	5
Sphyraena helleri	25	0.30	25
Katsuwonus pelamis	1	0.01	1
Thunnus albacares	175	2.07	133
Sec. Cons	**97**	**1.15**	
Chaetodon litus	47	0.56	9
Aluterus scriptis	50	0.59	3
Planktivore	**6227**	**73.80**	
Chromis randalli	2838	33.63	163
Xanthichthys mento	3279	38.86	140
Decapterus muroadsi	110	1.30	43
Herbivore	**1429**	**16.94**	
Kyphosus sandwicensis	1429	16.94	241
Total	**8438**	**100**	

Figure legend

Figure 1. (a) Map of Easter Island and Salas y Gómez Island in relation to South America. Dark lines represent the exclusive economic zone. (b) Sampling locations around Easter Island for seasonal variability (yellow dots). Purple dots represent the 3 extra sites used for assessing spatial variability during summer and autumn.

Figure 2. Canonical analysis of principal coordinates (CAP) ordination of the variation in fish assemblage among (a) sites and (c) seasons. (b) and (d) CAP loadings shown graphically.

Supporting Information

Table S1. Mean wave energy values (kW/m) and percentage of occurrence from every (360° degree) direction.

Direction (degree)	Mean Power	Percentage occurrence	Mean Power	Percentage occurrence	Mean Power	Percentage occurrence	Mean Power	Percentage occurrence
Long-term Wave Energy (2005-2015)								
	Autumn		**Winter**		**Spring**		**Summer**	
0	45.996	0.1	49.817	0.08	29.23	0.08	15.169	0.03
22.5	0	0.01	47.896	0.18	51.586	0.16	0	0
45	0	0	30.633	0.87	32.205	0.87	20.171	0.15
67.5	22.668	0.3	38.359	2.08	29.567	2.34	18.31	1.4
90	41.308	1.34	64.37	1.8	29.915	1.68	19.312	0.61
112.5	41.924	0.78	59.407	2.02	51.097	0.6	26.563	0.55
135	80.406	1	48.923	2.2	38.107	0.34	26.459	0.44
157.5	68.59	1.15	60.981	5.15	39.376	1.24	60.248	0.19
180	68.195	18.65	68.696	14.95	53.093	9.01	37.128	4.34
202.5	61.698	53.63	77.077	44.38	54.84	52.7	36.6	41.38
225	59.686	15.53	70.942	23.24	47.086	22.07	32.513	20.93
247.5	38.733	3.16	56.676	1.55	31.134	2.9	30.431	6.21
270	36.067	1.55	44.103	0.69	32.888	1.21	32.583	5
292.5	43.165	2.07	52.508	0.54	26.892	2.34	34.588	12.62
315	42.979	0.73	54.927	0.28	35.519	2.46	38.798	6.14
337.5	0	0	0	0	0	0	0	0
Recent Wave Energy (2016-2017)								
	Autumn		**Winter**		**Spring**		**Summer**	
0	0	0	0	0.42	0	0	0	0
22.5	0	0	15.471	2.51	0	0	0	0
45	0	0	14.976	1.26	0	0	0	0
67.5	18.433	15.83	0	0	0	0	0	0
90	0	0	0	0	0	0	0	0
112.5	0	0.42	0	0	0	0	0	0
135	67.318	9.17	14.243	3.35	0	0	0	0
157.5	70.302	7.92	0	0.42	0	0	0	0
180	58.7	12.92	28.605	10.04	15.983	6.05	26.789	7.66
202.5	40.651	45.42	48.94	76.99	28.868	51.21	32.747	72.18
225	32.686	8.33	50.62	3.77	29.566	16.13	31.654	16.53
247.5	0	0	0	0	24.626	7.66	26.55	1.21
270	0	0	0	0	24.761	6.45	22.706	0.81
292.5	0	0	20.776	0.84	19.917	7.66	25.284	1.61
315	0	0	0	0.42	31.161	4.84	0	0
337.5	0	0	0	0	0	0	0	0

Table S2. Environmental variables used in the DistaLM analysis for every site and season.

Season/ Site	Temperature (°C)	Historical wave energy (kW/m)	Specific wave energy (kW/m)	Distance from shore (m)	Shelf width (m)
Winter					
Ana hukahu	-	-	-	-	-
Ovahe	20.669	30.633	14.976	392.875	250
Omohi	-	-	-	-	-
Kari Kari	20.69	56.676	0	324.25	250
Motu tautara	19.285	44.103	20.776	202.5	0
Poike		22.668	18.433	395.5	250
Vaihu	20	60.981	28.605	463.75	1000
Vinapu	20	77.077	48.94	311.75	750
Spring					
Ana hukahu	-	-	-	-	-
Ovahe	23.746	32.205	0	392.875	250
Omohi	-	-	-	-	-
Kari Kari	23.463	31.134	24.626	324.25	250
Motu tautara	23.149	32.888	19.917	202.5	0
Poike	-	-	-	-	-
Vaihu	22	39.376	15.963	463.75	1000
Vinapu	22	54.84	28.868	311.75	750
Summer					
Ana hukahu	26	26.563	0	386.5	1000
Ovahe	26.758	20.171	0	392.875	250
Omohi	26.247	38.798	0	255.25	0
Kari Kari	26.59	30.431	26.55	324.25	250
Motu tautara	26.38	32.583	25.284	202.5	0
Poike	26.43	18.31	0	395.5	250
Vaihu	26	60.248	26.789	463.75	1000
Vinapu	26	36.6	32.747	311.75	750
Autumn					
Ana hukahu	22.683	0	0	392.875	250
Ovahe	22.708	42.979	0	255.25	0
Omohi	22.84	38.733	0	324.25	250
Kari Kari	22.773	36.067	0	202.5	0
Motu tautara	22	22.668	18.433	395.5	250
Poike	22	68.59	58.7	463.75	1000
Vaihu	22	61.698	40.651	311.75	750
Vinapu	22	41.924	67.318	386.5	1000

Table S3. PERMANOVA test for all the pelagic fish species. Figures in bold indicate significant results.

	Level	Type	Pseudo-F	P(perm)	Unique perms
MAIN TEST					
Site	**5**	**Fixed**	**4.9648**	**0.0001**	**9943**
Season	**4**	**Fixed**	**8.274**	**0.0001**	**9924**
Season x Site			1.3362	0.0881	9887
PAIR-WISE TEST					
Sites					
Ovahe. Kari Kari				0.1441	9964
Ovahe. Motu Tautara				0.0978	9977
Ovahe. Vaihu				**0.0001**	**9951**
Ovahe. Vinapu				0.0158	9956
Kari Kari. Motu Tautara				0.2019	9947
Kari Kari. Vaihu				**0.0001**	**9948**
Kari Kari. Vinapu				**0.0047**	**9956**
Motu Tautara. Vaihu				**0.0001**	**9956**
Motu Tautara. Vinapu				**0.0005**	**9954**
Vaihu. Vinapu				**0.001**	**9943**
Season					
Autumn. Spring				0.4036	9960
Autumn. Summer				0.1654	9954
Autumn. Winter				**0.0001**	**9956**
Spring. Summer				0.1402	9952
Spring. Winter				**0.0001**	**9945**
Summer. Winter				**0.0001**	**9965**

Table S4. DistaLM test for all the pelagic fish species. Figures in bold indicate significant results.

Variable	**SS(trace)**	**Pseudo-F**	**P**	**Prop.**
Site				
Temperature (ºC)	913.69	1.9302	0.085	0.12117
Historical WE (kW/m)	1008.9	2.1624	0.052	0.13379
Specific WE (kW/m)	**1162.3**	**2.5512**	**0.032**	**0.15414**
Distance from shore (m)	**1093.5**	**2.3746**	**0.043**	**0.14502**
Shelf width (m)	**2004.5**	**5.0691**	**0.001**	**0.26583**
Season				
Temperature (ºC)	639.58	1.1143	0.3476	0.058295
Historical WE (kW/m)	**1887**	**3.7986**	**0.0308**	**0.17199**
Specific WE (kW/m)	462.36	0.92675	0.437	0.042142