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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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1 Spatial and seasonal differences in the top predators of Easter Island:
2 essential data for implementing the new Rapa Nui multiple-uses
3 MPA
4

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17
18 **Abstract**

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

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

40 **Keywords**

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

43

44 **Introduction**

45 Reef fishes play an important role in ecosystem function (Stevens, Bonfil, Dulvy, & Walker,
46 2000), and are the target of recreational, commercial, and subsistence fisheries in many
47 coastal locations (Henry & Lyle, 2003; Kingsford, Underwood, & Kennelly, 1991). Precise
48 and accurate information on the diversity and abundance of fish populations is important for
49 understanding their ecology, and is critical for developing effective management and
50 conservation strategies (Andrew & Mapstone, 1987; Pita, Fernández-Márquez, & Freire,
51 2014). Changes in the fish assemblage composition usually indicate alteration in the
52 community structure in response to ecological, climatic, or anthropogenic drivers (Jeppesen
53 et al., 2010; Schlosser, 1990; Westera, Lavery, & Hyndes, 2003).

54 Reef fish assemblages vary spatially and temporally in response to biotic variables, such as
55 food availability (Tickler, Letessier, Koldewey, & Meeuwig, 2017), predation or competition
56 (Almany, 2004), and abiotic variables, such as habitat complexity and environmental
57 characteristics like wave exposure and temperature (Anderson & Millar, 2004; Coles & Tarr,
58 1990; Curley, Kingsford, & Gillanders, 2003; Friedlander & Parrish, 1998). For example,
59 spatial variation in reef fish assemblages can occur on scales of metres to kilometres (Connell
60 & Jones, 1991; Curley et al., 2003; Malcolm, Gladstone, Lindfield, Wraith, & Lynch, 2007),
61 and are usually associated with habitat complexity and the environmental conditions that
62 structure that habitat (Asher, Williams, & Harvey, 2017; Coles & Tarr, 1990; Friedlander &
63 Parrish, 1998). Seasonal changes are more evident in reef ecosystems from sub-tropical
64 latitudes because of greater environmental variability (Coles & Tarr, 1990; Friedlander &
65 Parrish, 1998). However, these influences differ by location. For example, Coles and Tarr

66 (1990) found that the large variation in temperature between winter and summer (about 20°C)
67 in the Western Arabian Gulf determines the richness and abundance of inshore species. In
68 Hawaii, Friedlander and Parrish (1998) observed that fish assemblages responded to high
69 wind and wave energy during winter by taking refuge at deeper depths and in more complex
70 habitats. Understanding the natural variations in the fish assemblage provides essential
71 baseline information for designing and evaluating the effectiveness of marine protected areas
72 (MPA) (Charton et al., 2000). Having accurate information of where to protect is especially
73 valuable in highly urbanized areas, where area protection is constrained owing to conflicts
74 among multiple users (Curley et al., 2003).

75 Marine Protected Areas (MPAs) have been shown to be a highly effective means of
76 conserving biodiversity and managing fisheries, while also restoring and preserving overall
77 ecosystem functions (Gaines, White, Carr, & Palumbi, 2010; Lubchenco & Grorud-Colvert,
78 2015). Through the establishment of fishing regulations such as minimum size, effort control
79 and/or regulation of total catches (Botsford, Micheli, & Hastings, 2003; Hilborn, Micheli, &
80 De Leo, 2006), MPAs are usually associated with the increase of abundance, biomass and
81 size of focal species (Micheli, Halpern, Botsford, & Warner, 2004) as well as catch-per-unit-
82 effort (CPUE) in adjacent areas (Roberts, Bohnsack, Gell, Hawkins, & Goodridge, 2001). In
83 Chile, 23 MPAs have been created in the last decade, protecting over 41% of its economic
84 exclusive zone (EEZ) (Petit, Campoy, Hevia, Gaymer, & Squeo, 2017). The most recent
85 three MPAs were announced during the 2017 International Marine Protected Areas Congress
86 (IMPAC4 2017): Islas Diego Ramirez-Paso Drake, Juan Fernandez archipelago and Rapa
87 Nui. The Rapa Nui Multiple Uses Coastal Marine Protected Area (MUMPA) covers the
88 entire Easter Island Ecoregion and extends from the Easter Island coastline to the limit of the
89 EEZ, embracing ~579,000 km².

90 Easter Island, also known by its Polynesian name Rapa Nui, is the most south-eastern coral
91 reef ecosystem in the Pacific Ocean and harbours a unique fish assemblage with a high level
92 of endemism (Randall & Cea, 2010). Easter Island is one of the most isolated inhabited
93 islands in the Pacific Ocean; yet, long-term overfishing has dramatically reduced the
94 abundance of targeted species (Aburto, Gaymer, Haoa, & Gonzales, 2015; Friedlander et al.,
95 2013; Randall & Cea, 2010; Zyllich et al., 2014). Modern fishing equipment and the demand

106 for local fish from increasing tourism has compounded the effects of overfishing (Randall &
107 Cea, 2010; Zyllich et al., 2014). There have been a limited number of surveys of fishes around
108 Easter Island (e.g. Easton, Gaymer, Friedlander, & Herlan, 2018; Fernández, Pappalardo,
109 Rodríguez-Ruiz, & Castilla, 2014; Friedlander et al., 2013), with most of these studies
110 focusing on reef fishes, rather than pelagic species. Using underwater visual census (UVC),
111 Friedlander et al. (2013) found contrasting reef fish assemblages between Easter Island and
112 its nearest neighbour, Salas y Gómez, a small island located ~390 km to the east. Salas y
113 Gómez is one of the most isolated islands in the Pacific Ocean and is fully protected from
114 fishing as part of the Motu Motiro Hiva Marine Park. Sharks, primarily the Galapagos shark
115 (*Carcharhinus galapagensis*), and jacks account for more than 40% of the fish biomass
116 around Salas y Gómez, whereas Easter Island is dominated by smaller planktivorous species,
117 with top predators virtually absent (Friedlander et al. 2013).

118 In the past, ecological studies of fishes at Easter Island have relied on fishery-dependent data
119 from commercial fisheries and UVC, performed by scuba divers (Acuña et al., 2018). The
120 use of fishery-dependent sampling is destructive (Skomal, 2007) and inefficient due to
121 sampling biases from gear selectivity and different fishing effort between species, habitats,
122 seasons, and vessels (Bishop, 2006; Murphy & Jenkins, 2010; Thorson & Simpfendorfer;
123 2009). Additionally, this technique is less effective in locations with insufficient and
124 inaccurate landing information, like Easter Island (Aburto & Gaymer, 2018). UVC is the
125 most-used observational technique for reef ecosystems (Medley, Gaudian, & Wells, 1993;
126 Samoilys & Carlos, 2000). However, it also has several well-documented limitations and
127 problems, including intra- and inter-observer variability (Thompson & Mapstone, 1997) and
128 the effect of divers on the species behaviour (Chapman, Johnston, Dunn, & Creasey, 1974;
129 Cole, 1994; Kulbicki, 1998; Gray et al., 2016; Emslie, Cheal, MacNeil, Miller, & Sweatman,
130 2018; Lindfield, Harvey, McIlwain, & Halford, 2014). In contrast, remote underwater video
131 systems, such as Baited Remote Underwater Video Systems (BRUVs), are effective, non-
132 destructive fishery-independent techniques used to sample fish assemblages without these
133 diver-associated problems.

134 BRUVs attract a wide range of marine species from different trophic groups into the field of
135 view of a camera so that they can be identified and counted (Dorman, Harvey, & Newman,

126 2012; Hardinge, Harvey, Saunders, & Newman, 2013). BRUVs increase the number of
127 sampled species (Stobart et al., 2007; Willis & Babcock, 2000), and are especially effective in
128 the detection of cryptic and rare predators, such as sharks and fishery-targeted species, that
129 are not well sampled using UVC (Brooks, Sloman, Sims, Danylchuk 2011; Harvey et al.
130 2012; Malcolm et al., 2007; Watson, Harvey, Anderson, & Kendrick, 2005). Pelagic BRUVs
131 are even more novel than traditional BRUVs, allowing the study of species that inhabit the
132 water column, including highly mobile species (Santana-Garcon, Newman & Harvey, 2014;
133 Santana-Garcon et al., 2014b). Pelagic species are ecologically important to marine
134 ecosystems (Freon , Cury, Shannon, Roy, 2005) and highly valuable for the fishing industry
135 (Pauly 2002; Worm et al. 2006). Despite their importance and that they are constantly
136 threatened by multiple factors, such as pollution, climate change, and overfishing (see Game
137 et al. 2009), the pelagic ecosystems, at a community scale, are still data poor worldwide.

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

145

146 **Material and Methods**

147 *Study area*

148 Easter Island (27°13'S and 109°37'W) has a land area of 166 km² and ~5600 inhabitants.
149 Located 2250 km east from Pitcairn Island and 3760 km south-west from mainland Chile, it
150 is one of the most isolated places on earth. The nearest island is Salas y Gomez Island
151 (26°28'S and 105°21'W), which is an uninhabited volcanic island with a total area of 0.15
152 km². Both islands and more than several dozen seamounts are part of the Salas y Gómez
153 Ridge, which extends 2232 km before reaching the Nazca Ridge in the south-eastern Pacific
154 Ocean (Randall & Cea, 2010; Friedlander et al., 2013).

155 *Sample collection*

156 Mid-water BRUVs were constructed according to Santana-Garcon et al., (2014a). Each
157 BRUVs was constructed using a single GoPro Hero 4 camera (mono-camera) held in their
158 own underwater housing. GoPros were set to record a wide-angle of view and 1080p. A mix
159 of fresh local fishes (~300 gr) and one can of Chilean jack mackerel (*Trachurus murphyi*)
160 were used as bait. Deployments were carried out during daylight hours, avoiding dusk and
161 dawn. Four simultaneous 1-h deployments (replicates), having a minimum separation of 500
162 m to avoid plume dispersion overlap (Santana-Garcon et al., 2014a), were conducted at a
163 depth of ~25 m at each site; a minimum of six deployments were conducted per site. Local
164 knowledge, previous studies and limitations related to weather conditions were used to guide
165 the spatial coverage of sites. Date, hour and location (latitude and longitude) were recorded
166 during every deployment. To study spatial differences around Easter Island, eight sites were
167 sampled during autumn and summer 2017 (Figure 1). To determine seasonal changes in the
168 fish assemblage, quarterly seasonal sampling was undertaken at five of those sites during
169 2016-2017.

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

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

193 *Data analyses*

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

207 *Environmental data collection and analysis*

208 To determine the role of seasonal and spatial environmental variation on the fish assemblage
209 structure, sea surface temperature (SST), long-term and recent wave energy, distance of each
210 deployment site from the shore, and shelf width were considered. For each site, SST MUR
211 (Multi-scale Sea Surface Temperature) satellite data at a 1 km spatial resolution
212 (<https://mur.jpl.nasa.gov>) were used after we verified the accuracy of these satellite data with
213 in situ SST data collected at Omohi, Motu Tautara, Ovahe and Kari Kari sites by Evie Wieters
214 (Pers. Comm., unpublished data) from deployed temperature sensors (Onset, tidbit) set to
215 record SST every ten minutes at 12-15 m depth. Long-term and recent wave energy, were

216 computed from NOAA's Wave Watch III (WWIII; <http://polar.ncep.noaa.gov/waves>), were
217 binned into 16 discrete sectors each spanning 22.5 degrees. The long-term wave energy
218 ranged from Jan 2010 to Jul 2015, meanwhile recent wave energy was calculated using mean
219 values corresponding to the month each deployment was made. Distance from shore and
220 shelf width were calculated for each site using Google Earth Pro (<http://earth.google.com>)
221 (Table 1S). For seasonal analysis, only wave energy, long-term wave energy, and SST were
222 considered. Environmental and biological data were analysed using distance-based linear
223 modelling (DistLM) and a distance-based redundancy analysis (*dbRDA*). DistLM is a routine
224 for analysing and modelling the relationship between a multivariate data cloud, as described
225 by a resemblance matrix, and one or more predictor variables. The *dbRDA* analysis was used
226 to visualize the given model in a multi-dimensional space (Anderson et al., 2008).
227 Environmental values used in the DistLM-*dbRDA* are shown in Table S2.

228

229 **Results**

230 Fifteen species were recorded during the study (Table 1). Planktivores and herbivores were
231 the largest components of the pelagic fish assemblage at Easter Island, accounting for 73.8%
232 and 16.9%, respectively (Table 2). The most abundant species around Easter Island were
233 *Xanthichthys mento* (Jordan & Gilbert, 1882) and *Chromis randalli* (Greenfield & Hensley,
234 1970). Both occurred at every site-season combination, except at Vaihu during spring. Top
235 predators, while having the highest species richness (9 species), were not well represented in
236 abundance except at Vaihu. *Fistularia commersonii* (Rüppell, 1838) was the most abundant
237 species among top predators, followed by *Seriola lalandi* (Valenciennes, 1833) (Table 2).
238 Some species such as *Aulostomus chinensis* (Linnaeus, 1766) and *Caranx lugubris* (Poey,
239 1860) showed seasonal occurrence and other species such as *C. galapagensis* (Snodgrass &
240 Heller, 1905) and *Pseudocaranx cheilio* (Bloch & Schneider, 1801) displayed more site-
241 specific occurrences. Nine target species were recorded, seven of which were top predators.
242 The most abundant and well distributed was *Kyphosus sandwicensis* (Sauvage, 1880), which
243 was abundant along the east and west coasts of Easter Island year-round; however, low
244 abundances were reported at Vinapu, and it was absent at Vaihu. The black trevally *C.*
245 *lugubris* was rare during the entire study.

246 *Spatial differences*

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

262 *Seasonal differences*

263 Highest richness and abundances were found in autumn and summer. Fish assemblages
264 during winter significantly differed from the other seasons (Pseudo-F = 3.366, $p < 0.001$,
265 Table S3). Principal axes values from CAP were $\delta_1 = 0.909$ and $\delta_2 = 0.546$, over $m = 3$
266 principal coordinate axes (Figure 2b). The overall estimation of misclassification error
267 showed an allocation success of only 60%. Winter had the highest allocation success with
268 80%, while success for autumn (60%), summer (60%), and spring (40%) were lower. In
269 general, the occurrence and abundance of species such as *X. mento*, *A. chinensis* and *S.*
270 *lalandi*, were associated with winter, while *Aluterus scriptus* and *C. lugubris* were associated
271 with the summer season.

272 *Environmental analysis*

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

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

278 **Discussion**

279 This study is the first on spatial and temporal patterns of the pelagic fish assemblage at Easter
280 Island, highlighting the importance of specific areas of occurrence and abundance. We found
281 the pelagic fish assemblage at Easter Island to be dominated numerically by two small
282 planktivore species, *C. randalli* and *X. mento*, followed by the herbivorous *K. sandwicensis*.
283 The numerical dominance of planktivorous and herbivorous species observed in our study is
284 consistent with Friedlander et al. (2013) findings that these two trophic groups accounted for
285 40% and 31% of the total reef fish biomass, respectively. Top predator species, although less
286 abundant, constituted the richest trophic group in our study (nine species). In contrast,
287 Friedlander et al. (2013) only observed six species of this trophic group, and with lower
288 abundances. These differences in richness and abundance of top predators species might be
289 explained by differences in sampling methods. UVCs is a reliable observational technique
290 (Medley et al., 1993; Samoilys & Carlos, 2000), and it is widely used for sampling reef-
291 associated species at shallow, nearshore habitats. However, the effect of divers on animal
292 behaviour has led to the underestimation of some species abundance, such is the case of
293 cryptic and fishery-target species within fishing areas (Chapman et al., 1974; Cole, 1994;
294 Gray et al., 2016; Kulbicki, 1998; Lindfield et al., 2014), especially pelagic species (De
295 Girolamo & Mazzoldi, 2001; Stanley & Wilson, 1995). The higher occurrence of rare species
296 and species undersampled by UVCs, such as *C. galapagensis*, *K. pelamis*, *T. albacare* and
297 *C. lugubris*, during our study proved the effectiveness of BRUVs in studying the pelagic fish
298 assemblages at Easter Island, especially top predators.

299 Top predators play an important role in the top-down ecosystem regulation (Stevens et al.,
300 2000), yet these species are the most vulnerable to overfishing and their removal could lead
301 to environmental changes affecting ecosystem function in fragile ecosystems (Hughes,
302 Graham, Jackson, Mumby, & Steneck, 2010; Shears & Babcock, 2002). The continued
303 decline of top-predator populations at Easter Island has likely caused a phase shift from a
304 healthy community dominated by large top predators, such as at Salas y Gómez, to a
305 disturbed community dominated by smaller planktivorous species (Friedlander et al., 2013).

306 Seven of the nine species of top predators recorded in this study are targeted by fishermen
307 at Easter Island. Together with the herbivorous Pacific rudderfish, *K. sandwicensis*, top
308 predators like *S. lalandi*, *S. helleri* and *T. albacares* are the most targeted pelagic fishes at
309 Easter Island (Zylich et al., 2014). Subsistence catches are also dominated by *K. sandwicensis*
310 and other jacks such as *C. lugubris* and *P. cheilio* (Zylich et al., 2014). According to local
311 residents, *C. lugubris* was abundant in the past, but now is uncommon. Similarly, the
312 Galapagos shark, which is currently classified as Near Threatened on the IUCN Red List, has
313 been reported by local residents to have declined considerably around Easter Island, possibly
314 as a result of direct and indirect fishing impacts (Zylich et al., 2014; N. Morales, pers. obs),
315 although the overfishing of prey may also be contributing to this decline (DiSalvo, Randall,
316 & Cea, 1988). Even though fishermen on Easter Island do not directly target the Galapagos
317 shark, they seem to be susceptible to bycatch in coastal and offshore fisheries. Likewise, their
318 population has declined considerably in Central America (Bennett et al., 2003), where the
319 major threat comes from bait-fishing activities around islands and seamounts (Bennett et al.,
320 2003; Zylich et al., 2014).

321 The Galapagos shark is the most common coastal shark around Easter Island (Randall & Cea,
322 2010; Zylich et al., 2014), and it was the only species of shark observed during the current
323 study. A similar BRUVs study in the Galapagos Archipelago found that the Galapagos shark
324 was also the most abundant among 12 species of sharks in the area (Acuña-Marrero et al.
325 2018). In that study, the Galapagos shark showed a similar mean cMaxN (0.52) per
326 deployment to our observations (0.58), despite the fact that the highest cMaxN found in the
327 Galapagos (8) was almost three times lower than in the current study (21). Total number of
328 individuals observed was 334 in the Galapagos Archipelago, and 112 in the current study.
329 These contrasting numbers could be a result of a higher local (i.e., site) concentration of this
330 species but a lower regional (i.e., island) abundance at Easter Island than at the Galapagos
331 Archipelago.

332 Spatial and seasonal differences in the composition of pelagic fish species were found during
333 this study. Species composition along the south coast (Ana hukahu, Vaihu and Vinapu) was
334 significantly different from the east and west coasts of the island. Spatial differences in
335 assemblage structure were driven by the occurrence and abundance of the top predators such

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

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

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

376 Seasonal variability in pelagic fish assemblage structure was evident during this study, with
377 winter been significantly different from the other seasons. Autumn and spring are transition
378 seasons, as has been described from other subtropical areas (Friedlander & Parrish, 1998).
379 Sites located along the coasts most exposed to winter swells and winds (Ana hukahu, Vaihu
380 and Vinapu) showed higher variability among seasons in comparison with more protected
381 sites. Similar results were found by Coles and Tarr (1990) in the western Arabian Gulf, and
382 by Friedlander and Parrish (1998) in the Hawaiian Archipelago. In both cases, the authors
383 noticed that some mobile fishes seem to migrate from exposed to more protected and deeper
384 locations that provide refuge from high wave energy during winter. In contrast, more
385 protected sites seem to have more stable assemblages throughout the year. Asher et al. (2017)
386 also found an increase in abundance of jacks and sharks in shallow and mesophotic reefs in
387 the Hawaiian Archipelago with increasing depth, due probably to the avoidance of
388 environmental (e.g. wave energy) and anthropogenic factors (e.g. fishing) in shallow waters.
389 Easter Island has been understudied in comparison to other islands in the Pacific Ocean, and
390 studies at deeper depths are even more limited (Easton et al., 2017). *Seriola lalandi* and *P.*
391 *cheilio* were recorded at ~280 m and ~170 m, respectively, using ROV (remotely-operated
392 vehicle) and Drop-Cams around Easter Island and the surrounding seamounts (Easton et al.,
393 2017). The occurrence of inshore species at deeper depths could also suggest that deeper
394 habitats are being used as a refuge from natural and anthropogenic influences. The presence
395 of particular species during certain seasons and at certain sites could be explored by

396 expanding the survey area in order to include mesophotic zones and incorporate surrounding
397 seamounts in future designs.

398 *Conservation actions*

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

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

426 management and conservation strategies to be implemented in the newly created Rapa Nui
427 MUMPA. A Marine Council, with a majority of Rapanui-elected members, will place the
428 administration of this area under a co-management strategy, in which is an unprecedented
429 model of MPA administration in Chile (Aburto et al. 2017)

430 Over the last decades, there has been an increasing awareness of the added value that
431 ecosystem services and sustainable management can offer to small human communities that
432 inhabit coastal areas (Arkema, Abramson, & Dewsbury, 2015). Biodiversity has been
433 recently recognized as an economic resource (Admiraal, Wossink, de Groot, & de Snoo,
434 2013), enhancing ecotourism and helping local inhabitants shift from non-sustainable
435 practices (overfishing) to a broader array of sustainable activities with added value such as
436 community-based ecotourism. In this sense, the year-round occurrence of the Galapagos
437 shark in one specific area of the island could be considered a shark-based ecotourism spot,
438 where local operators benefit from long-lived animals ensuring decades of incomes. Thus,
439 not only the protection of the Galapagos shark, but also its potential for ecotourism (e.g.
440 shark-watching by SCUBA divers), should be key elements for taking into account for the
441 zoning of the Rapa Nui MUMPA, that will allow activities such as traditional fishing
442 practices, ecotourism, scientific research and others that should be defined in the
443 management plan.

444

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459

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

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

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

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700 **Figure legend**

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

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

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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

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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)
<i>Winter</i>					
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
<i>Spring</i>					
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
<i>Summer</i>					
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
<i>Autumn</i>					
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

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727 **Table S3.** PERMANOVA test for all the pelagic fish species. Figures in bold indicate significant
 728 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					
<i>Sites</i>					
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
<i>Season</i>					
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

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

Variable	SS(trace)	Pseudo-F	P	Prop.
Site				
Temperature (°C)	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 (°C)	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

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