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1 **TITLE**

2 Perceptions and responses of Pacific Island fishers to changing coral reefs

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45

46

47 **ABSTRACT (150 words maximum- at 149)**

48 The transformation of coral reefs has profound implications for millions of people. However,
49 the interactive effects of changing reefs and fishing remain poorly resolved. We combine
50 underwater surveys (271,000 fishes), catch data (18,000 fishes), and household surveys (351
51 households) to evaluate how reef fishes and fishers in Moorea, French Polynesia responded to a
52 landscape-scale loss of coral caused by sequential disturbances (a crown-of-thorns sea star
53 outbreak followed by a category 4 cyclone). Although local communities were aware of the
54 disturbances, less than 20% of households reported altering what fishes they caught or ate. This
55 contrasts with substantial changes in the taxonomic composition in the catch data that mirrored
56 changes in fish communities observed on the reef. Our findings highlight that resource users and
57 scientists may have very different interpretations of what constitutes 'change' in these highly
58 dynamic social-ecological systems, with broad implications for successful co-management of
59 coral reef fisheries.

60

61 **KEYWORDS**

62 Fisheries, Social-ecological feedbacks, Selectivity, Disturbance, Local knowledge, Coral reef
63 resilience

64

65 **INTRODUCTION**

66 Coral reef ecosystems are under significant anthropogenic pressures from overfishing,
67 pollution, sedimentation, ocean acidification, and rising seawater temperatures (Bellwood et al.
68 2004; Hughes et al. 2018), resulting in unprecedented levels of coral mortality (Hughes et al.
69 2017) and shifts from coral-dominated to macroalgae-dominated community states (Rogers and
70 Miller 2006). Beyond biodiversity loss, degraded reefs present challenges for millions of coastal
71 dwellers who rely on healthy reef ecosystems for food, income, and their personal and cultural
72 identities. This has prompted research examining how local communities and resource users
73 perceive, adapt to, and manage coral reefs in the Anthropocene (McClanahan and Cinner 2012;
74 McMillen et al. 2014), including a focus on adaptive co-management, whereby management is
75 implemented and adapted based on knowledge about feedbacks between resource users and
76 shifting local ecosystems (Hughes et al. 2005).

77 The Pacific Islands region represents an ideal context to investigate how local communities
78 and changing coral reefs interact. Island peoples have shown the capacity to adapt, cope, and
79 innovate in the face of social-ecological change, with positive and negative outcomes for coral
80 reef health (Johannes 2002). In some Pacific Islands, such as Fiji, Vanuatu, and the Solomon
81 Islands, marine resources have been effectively managed over long periods through periodic
82 fishing ground closures, gear restrictions, and other socially enforced constraints on harvesting
83 (Cinner et al. 2006). Elsewhere, local responses to changing conditions have had negative
84 ecological outcomes, as with poison and dynamite fishing (McManus et al. 1997). The
85 effectiveness of adaptive responses is shaped by local cultural values and power relations that
86 inform decision-making and the range of possibilities available (Cinner et al. 2018).

87 Effective adaptive management requires that resource users detect or anticipate shifts in the
88 local environment and alter their activities accordingly. Some empirical studies have
89 demonstrated that Pacific islanders can detect rapid shifts in benthic communities disrupted by
90 tsunamis (Lauer and Matera 2016), in addition to more gradual changes such as expanding
91 seagrass beds (Lauer and Aswani 2010). Numerous questions remain, however, about the
92 sensitivity of local resource users to change, and in particular whether ecosystem disturbances
93 identified by ecologists are similarly perceived by Pacific islanders.

94 We addressed these issues for a small-scale reef fishery on the island of Moorea, French
95 Polynesia. Social and ecological surveys explored how communities perceived and responded to
96 changes in fishery resources associated with a crown-of-thorns sea star (COTS) outbreak
97 followed by a destructive cyclone. In 2004, coral cover around Moorea was near the highest
98 levels observed in the past half century (Traçon et al. 2011), but an outbreak of corallivorous
99 COTS that peaked in 2009, followed by Cyclone Oli in early 2010, reduced live coral cover by >
100 95% (Adam et al. 2011; Traçon et al. 2011; Adam et al. 2014; Lamy et al. 2015). Dead coral
101 skeletons and cleared reef substrates provided substantial free space for growth of macroalgae,
102 raising the possibility that a macroalgal phase shift could occur. However, benthic community
103 changes were rapidly followed by changes in the fish assemblage, with roving herbivorous fishes
104 such as parrotfishes doubling in density and tripling in total biomass (Han et al. 2016), thus
105 preventing macroalgae from establishing. Moreover, in the years since the disturbances, coral
106 cover has increased and even exceeds pre-disturbance levels in some areas (Holbrook et al.
107 2018). Despite intensive ecological study, it is not known if these changes in the fish
108 assemblages have altered fishable resources, the activities of reef fishers, or how local people
109 perceived the changes. Because spearfishing – a highly selective method – is common in

110 Moorea, a shift in the abundances of fishable resources provides an opportunity to assess
111 whether fishers alter what they catch as their resource environment changes.

112 This study addressed four questions: 1) How did residents of Moorea perceive the shifts
113 documented in ecological studies? 2) Do they report changing their fishing behavior or seafood
114 consumption in response to the shift? 3) How did the changes in the fish assemblage affect the
115 availability and taxonomic composition of fishable biomass? 4) Is there evidence for changes in
116 fishing behavior (such as taxonomic selectivity) over time?

117 To answer these questions, we conducted 351 household surveys documenting fishers'
118 perceptions of the changes and their potential responses via alteration in fishing practices or fish
119 consumption. We analyzed a time series of catch data (~18,000 identified and measured fishes)
120 collected before and after the disturbances, spanning a nine year time period, to determine
121 changes in targeted fish species and sizes, including key groups of herbivores crucial to recovery
122 and resilience of the coral state. Finally, we compared the catch data with extensive surveys that
123 estimated abundance and biomass of fishes on the reef throughout the same time frame.

124 **METHODS**

125 *Ecological and social context*

126 Moorea (17° 32' S, 149° 50' W) is a volcanic 'high' island 60 km in perimeter with an
127 offshore barrier reef that encloses a shallow lagoon (Figure 1A). The island has three types of
128 reef habitats: within the lagoon there are fringing reefs and back reefs, while outside the barrier
129 reef crest there is a steeply sloping fore reef. Moorea has over 17,000 inhabitants (Institut de la
130 statistique de la Polynésie française 2012) residing in five *communes associées*: Afareaitu,
131 Ha'apiti, Paopao, Papetoai, and Teavaro. It has undergone substantial economic development
132 over the past half-century, including becoming a major international tourist destination.

133 Communal land has been supplanted by private land ownership and the state declared that all
134 lagoon and marine areas are public property, meaning that customary sea tenure is non-existent.

135 Reefs in Moorea continue to be the focus of widespread fishing activity, although major
136 economic and social changes have shifted household livelihoods away from direct dependence
137 on marine resources for food or income towards wage-earning employment. Over half of
138 households fish, with free-dive spearfishing as the preferred method (Leenhardt et al. 2016).
139 Most people fish so they can eat and share fresh reef fishes, a fundamental marker of Polynesian
140 life. Reef fishes constitute the bulk of the catch and are prized as symbols of Polynesian identity
141 and cultural pride. It is notable that Moorea's households are less dependent on marine resources
142 for food security or income than is common in other regions in the Pacific. As citizens of France
143 they have access to state-subsidized healthcare, education, and social services, so poverty levels
144 are lower than in most of Oceania. Although most households contain fishers, only a small
145 number of fishers fish full-time solely for income.

146 *Household surveys and key informant interviews*

147 In 2014-15, we interviewed 351 (approximately 20%) households in the communes of
148 Afareaitu, Papetoai and Haapiti. In each commune, we identified village boundaries, within
149 which we conducted a blend of random and convenience sampling. The 60 to 80 min survey
150 interviews were conducted in French or Tahitian, with local Tahitians assisting in the surveys
151 and translating for household heads more comfortable speaking in Tahitian. Interview topics
152 included basic demographic information, fishing effort, livelihoods, catch preferences,
153 consumption patterns, and perceptions of resource conditions. Standardized questions allowed
154 for later comparison, but more open-ended questions were used to discuss important issues and
155 perceptions. Sample size for the standardized questions varied, since not every question was

156 relevant for all respondents. We also conducted 15 semi-structured interviews with fishers from
157 around the island who were considered highly knowledgeable local experts. In 2018, follow-up
158 interviews were carried out with nine key informants to whom results from this paper were
159 presented. Questions explored respondents' perceptions of post-disturbance changes in the fish
160 assemblages.

161 *Fish-seller surveys*

162 The sale of most reef fishes takes place from small roadside stands along the perimeter road
163 of the island (which has no fish markets). Fresh reef fishes are strung through the gills and hung
164 from racks (Figure 1B, S1). Each string of fish is sold as a unit, known in Tahitian as a *tui*. A
165 seller, often the fisher, assembles each *tui* and 10 or more may be hung for sale. Any single *tui*
166 may contain a few larger fishes or many small ones of different species. Most fish stands are
167 active early in the morning and by mid-morning most have sold their catch.

168 To sample the fishes being sold at these roadside stands, a researcher drove Moorea's ring
169 road early in the morning on weekends, typically the busiest times for fish sales. At each stand,
170 the rack of *tui* was photographed with a scale bar of known size (0.5m) and the seller was briefly
171 interviewed. Photographed fishes were later identified to the lowest taxonomic level possible and
172 the length of each was estimated by comparison with the scale bar (Schneider et al. 2012).

173 Catch surveys were conducted in 5 different years during 2007-15 (2007, 2008, 2012, 2014,
174 2015; Table 1). Three of the five *communes associées* were sampled in all five years (Afareaitu,
175 Paopao, and Teavaro), and so only data from these regions were analyzed to maintain consistent
176 geographical coverage through time, with data pooled across regions in all analyses.

177 ***Reef surveys***

178 We assessed reef fish populations using data from the NSF-funded Moorea Coral Reef Long
179 Term Ecological Research (MCR LTER) project that collects time series data at 18 locations
180 around Moorea (Brooks 2017), and the SO CORAIL-PGEM monitoring program that collects
181 data from 13 locations around the island (Lamy et al. 2015). Here we used data collected
182 annually from 2007 to 2015 (Table 1), and included data only from transects located on reefs
183 offshore of the three focal *communes* (Afareaitu, Paopao, Teavaro) as most targeted fishes are
184 territorial and most fishers fish near where they live.

185 The MCR LTER surveys are conducted by SCUBA divers between 0900 and 1600 hours
186 during late July or early August. Abundances of all mobile taxa of fishes observed are recorded
187 on fixed 5 m x 50 m transects that extend from the surface of the reef through the water column.
188 The abundances of all non-mobile or semi-cryptic taxa of fishes are also counted along the same
189 transect lines in a 1 m wide transect. The total length of each fish observed is estimated to the
190 nearest 0.5 cm. The SO CORAIL-PGEM monitoring program has sampled similar habitats in
191 each of these years, counting and estimating sizes of all fishes within 5 m x 25 m transects. Fish
192 biomass (kg) is calculated based on species-specific scaling parameters (Brooks 2011).

193 ***Fishing selectivity and fishable biomass***

194 Spearfishing is a highly selective fishing method in which the size and species of targets can
195 be observed before they are harvested. We tested for selectivity in size by comparing the fishes
196 being sold by the roadside to the sizes of fishes observed during reef surveys (pooling data across
197 the five years for which we have catch data). We defined a minimum fishable size (15 cm) across
198 all species based on sizes observed in the catch (<2% of fishes were below this size).

199 We determined which taxa were targeted based on the relative abundances of each genus
200 observed in the catch and on the reef. We defined fished taxa as genera making up more than
201 0.1% of the total catch, which included 23 genera, constituting 99% of all fishes and 95% of all
202 biomass being sold. Parrotfishes from the genera *Scarus* and *Chlorurus* were combined in all
203 analyses because species from these genera often could not be reliably distinguished in our
204 photographs of *tuis*. We note that some excluded species may be highly prized but rare in the
205 catch because they are rare on the reef. Subsetting the ecological survey data based on our list of
206 23 targeted genera and the minimum fishable size, we calculated how the total fishable biomass
207 and the fishable biomass of different targeted groups changed from 2007 to 2015.

208 ***Taxonomic composition of the catch***

209 We evaluated the degree to which variation in the biomass of each taxon on the reef predicts
210 variation in the taxonomic composition of the catch by comparing the relative biomass of the
211 seven most common taxa in the catch with their relative biomass on the reef. We excluded
212 soldierfishes (*Myripristis spp.*) from this analysis because they are nocturnal and were poorly
213 sampled in our (diurnal) reef surveys, when they shelter within reef structures. Other species may
214 shift habitats on a daily cycle, but any such movements are well within the spatial scale of our
215 sampling. Because sampling effort of the catch (during roadside surveys) was not consistent over
216 time, we cannot determine how total catch changed.

217 **RESULTS**

218 ***Household surveys and interviews***

219 The household surveys revealed that a substantial majority of households reported regular
220 consumption of fish, with 67% reporting that they eat fish at least three times per week, and
221 more than half of those eating fish six to seven times per week. Most households (76%) reported

222 at least one member who actively participated in the local reef fishery. There was great
223 consistency in the species that households preferred to eat and preferred to catch (Table 2). All of
224 these species are commonly caught and highly prized for the taste and texture of their meat. An
225 exception to the focus on reef fishes is tuna (*thon* in French), which has become an increasingly
226 important component of diets in Moorea but which is caught by a small number of pelagic
227 fishers operating with specialized boats offshore.

228 There was considerably more variability in how households reported any changes in their
229 behavior in response to the outbreak of COTS (*taramea* in Tahitian) and the cyclone (Table 3).
230 Although 40% remembered the COTS outbreak and 100% remembered Cyclone Oli, few
231 reported modifying the kinds of fishes they ate or bought (1.5% and 10% respectively). Of those
232 that reported responding to the COTS outbreak, responses included removing COTS from the
233 reefs (30%), avoiding fishing in COTS-dominated areas (18%), or changing their fishing areas
234 (6%). Of those that reported responding to Cyclone Oli, responses included waiting until the
235 lagoon was clean from runoff before resuming fishing (30%), fishing in different locations
236 because the fishes moved to different areas of the lagoon (16%), fishing less in the lagoon than
237 prior to the cyclone (13%), or fishing less overall after the cyclone (10%).

238 In-depth interviews with expert fishers revealed that they are aware of COTS outbreaks and
239 they recognize that COTS kill coral. Two expert fishers described how in the past, parts of the
240 seastars' bodies were applied as garden pesticide. Other expert fishers mentioned that the
241 Papetoai school and local fisher organizations (in Haapiti and Afareaitu) organized outings
242 where local people removed COTS from the reefs. One fisher noted that this practice was "a new
243 thing" and that "the oldtimers never mentioned this kind of practice happening in the past." Most
244 fishers acknowledged a relationship between live coral cover and reef fish abundance. However,

245 few indicated that the dramatic loss of live coral cover caused by the COTS outbreak or Cyclone
246 Oli had an impact on the composition of fish assemblages or the relative abundance of the main
247 targeted taxonomic groups.

248 ***Fishing selectivity***

249 Roadside fish sellers mostly caught fishes on the reef (77%), largely from the lagoon (69%),
250 and the most common gear used was the spear gun (83%), followed by fishing with nets (11%)
251 and hook and line (5%). Fishes sold in the morning were mostly caught at night (90% between
252 1800 and 0600 hrs), so our surveys of fishes sold by the roadside (hereafter, “the catch”) may not
253 be representative of fishing activities undertaken at other times.

254 Fishes in the catch represent a nonrandom distribution of sizes relative to those observed on
255 the reef (Figure 2). Harvested fishes were significantly larger on average than fishes on the reef
256 (23 cm vs. 8 cm; $P < 0.0001$, Wilcoxon rank-sum test). More than 98% of fishes in the catch
257 were at least 15 cm in length, suggesting this is a minimum bound on the size of fishes that are
258 targeted. The relative abundance of taxa observed in the catch also diverged substantially from
259 the community found on the reef, even when only individuals of fishable size were considered.
260 More than 99% of the fishes in the catch were from 23 genera (Table 4) with almost 60% of the
261 catch made up of unicornfishes (*Naso spp.*), parrotfishes (*Scarus* and *Chlorurus spp.*),
262 soldierfishes (*Myripristis spp.*), and rabbitfishes (*Siganus spp.*). The composition of the catch
263 contrasted with the most abundant taxa on the reef (based on fishable sized individuals; Tables 4,
264 S1). In particular, while *Scarids* and *Naso* were both abundant on the reef, *Myripristis* and
265 *Siganus* were rarely observed in the reef surveys (the 38th and 29th most abundant taxa,
266 respectively; Table S1). Furthermore, several of the most abundant taxa on the reef were

267 completely absent from the catch, most notably surgeonfishes from the genus *Ctenochaetus*
268 (25% of fishes on the reef).

269 ***Fishable biomass***

270 The amount of fishable biomass (fishes >15 cm in length from 23 targeted genera) on the reef
271 was relatively stable from 2007-2015. Although there was some variation from year to year
272 (Figure 3), including a spike in 2010, there was no sustained shift in fishable biomass coinciding
273 with the disturbances that occurred in 2009-2010. By contrast, there was substantial change in
274 the abundance of some taxonomic groups on the reef over the time period. Most dramatically,
275 *Naso* biomass fell from 21 kg ha⁻¹ to about 4 kg ha⁻¹. This decline was offset to some degree by
276 an increase in the biomass of parrotfishes of the genus *Scarus*. While the biomass of other taxa
277 varied substantially from year to year, there was no apparent secular trend in their abundances.

278 ***Taxonomic composition of the catch***

279 The changes in the taxonomic composition on the reef were roughly mirrored by trends in the
280 catch (Figure 4). For example, *Naso* comprised more than a third of the catch prior to the
281 disturbances, and less than 10% after. By contrast, the proportion of the catch composed of
282 parrotfishes from the genera *Chlorurus* and *Scarus* increased over time from 56% to 66%. *Naso*,
283 *Chlorurus* and *Scarus* collectively composed the bulk of the fishable biomass on the reef (48-
284 66%) and a roughly similar total proportion of the catch (43-65%).

285 For the taxa that were well-sampled in our reef surveys, there was a surprisingly high
286 correlation between the biomass of each taxon on the reef and its annual contribution to the
287 catch, with high correlations observed for the most common taxa (Figure 5). Indeed, the
288 correlation for unicornfishes is above 0.99, which suggests both that our reef surveys captured

289 variation in their abundance over time and that the variation in abundance within the ecological
290 community may explain the observed pattern of variation in catch.

291 **DISCUSSION**

292 In this study we couple data from intensive sampling of both the ecological community and
293 human resource users to provide new insights on how fishes and Pacific Island fishing
294 communities interact during periods of substantial ecological change, and how the fishing
295 communities perceive the changes. Each method provided a different view on these feedbacks.
296 Household surveys confirmed that residents of Moorea were aware of the major disturbances that
297 occurred on the reef, but revealed that little explicit change occurred in fishing behavior or
298 perceptions of resources harvested. This contrasts with the marked shifts in the taxonomic
299 composition of the catch that we observed, particularly the significant decrease of *Naso spp.*, one
300 of the most highly prized fishes due to its palatability. Those taxonomic shifts mirrored changes
301 we observed in fish communities on the reef, implying that the composition of the catch is highly
302 dependent on reef state despite the high selectivity of the fishery and local perceptions that
303 fishing and fished resources had not changed.

304 ***Fishing selectivity***

305 Our results revealed high selectivity in the Moorea reef fishery, both in terms of body size and
306 taxonomy, consistent with observations of other spearfishing-focused fisheries in the Pacific
307 (Dalzell et al. 1996). Fishers showed a preference for fishes that are larger on average than those
308 encountered on the reef. Even when size selectivity was accounted for, we found strong
309 taxonomic selectivity for a handful of taxa, with some being disproportionately abundant in the
310 catch relative to their abundance on the reef (e.g., *Naso spp.* and *Myripristis spp.*) while others
311 were greatly under-represented in the catch (e.g., *Ctenochaetus spp.*). This high degree of size

312 and taxonomic selectivity is not surprising given the prevalence of spearfishing on the island.
313 Spearfishers visually identify and evaluate each fish before it is harvested (Frisch et al. 2008).
314 The resultant selectivity affords them greater latitude for adapting to ecological shifts than other
315 capture techniques, such as hook and line or gill netting, in which the fishes are invisible to the
316 fisher before capture.

317 The suite of preferred species on Moorea is not limited to larger-bodied species. Soldierfishes
318 (*Myripristis*), for example, are relatively small-bodied but represent the third most fished genus
319 (in terms of numbers and biomass in the catch), as they are prized for the taste and the texture of
320 their meat rather than their large filets. In commercially-oriented fisheries, size selectivity can be
321 linked to higher market demand or value for fishes of particular sizes, e.g., large enough to filet
322 or sized to fit on a dinner plate (Reddy et al. 2013). In Moorea spearfishers commonly describe
323 their fishing decisions through idioms of cooking and eating, and will seek out certain species
324 based on how they want to cook their meal that day, underscoring the non-economic nature of
325 the fishery.

326 Elsewhere, Pacific Islanders commonly target piscivores, such as emperors and groupers, but
327 in fisheries where spearfishing is the primary mode of capture, herbivorous fishes such as
328 unicornfishes and parrotfishes often dominate the catch (Jennings and Polunin 1995; Gillett and
329 Moy 2006). Contemporary reef fish preferences in Moorea may be the result of the gear type
330 used or an outcome of overfishing and fishing down the food web (Pauly et al. 1998) from
331 piscivores to herbivores. More historical work could shed light on this possibility by detailing the
332 trajectory of taxonomic selectivity over the last several centuries. We also note that Moorea
333 fishers show a strong selectivity against harvesting *Ctenochaetus* and *Acanthurus* (*maito* in
334 Tahitian) even though they are some of the most abundant species on the reef. These fish are

335 known to be ciguatoxic, and the sale of *Ctenochaetus* was banned by the territorial government
336 in the 1960s (Walter 1968).

337 ***Taxonomic composition on the reef and in the catch over time***

338 Our roadside surveys indicate that the taxonomic composition of the catch shifted
339 substantially after the disturbance (Figure 4). Changes in the catch largely correlated with shifts
340 in the taxonomic composition of the reef community, particularly for species that made up a
341 substantial proportion of the catch (Figure 5). However, there is wide variation in the strength of
342 this relationship. The unexplained variation may stem from analyzing catch at the genus level,
343 likely combining species of different desirability within the same category. For example,
344 dynamics on the reef and in the catch were poorly correlated for *Acanthurus*. There are 5 species
345 commonly observed in the catch within this genus; if some of these are targeted and some are not
346 (possibly based on ciguatera risk), then trends in the biomass of the genus on the reef may not
347 represent trends in the preferred species within that genus, obscuring a tighter relationship at the
348 species level. By contrast, one species (*Naso lituratus*) makes up more than 90% of the fishable-
349 size individuals of that genus on the reef, so variation in the abundance of that species translates
350 more directly to our genus-level analyses.

351 The composition of the catch is a joint product of the availability of resources and the demand
352 for each from the fishing communities. If the catch primarily reflects demand for different
353 species, we might expect to see little change in the composition of the catch as the ecosystem
354 changes, particularly in such a highly selective fishery. Instead, the high correlations between
355 biomass on the reef and in the catch for unicornfishes (*Naso spp.*) and parrotfishes (*Scarus*
356 *spp./Chlorurus spp.*) indicate that shifting relative abundances result in different compositions of
357 the catch, and suggest that there is considerable flexibility in harvest and consumption behavior.

358 *Perceptions of change*

359 Our household surveys and key informant interviews suggest that Moorea's fishers generally
360 were aware of the COTS outbreak and Cyclone Oli and that they understood the ecological
361 impacts of these disturbances. This in-depth understanding is not surprising given most engage in
362 fishing on a regular basis and thus have frequent experiential contact with the marine
363 environment. It is widely acknowledged that in Pacific Island contexts where communities
364 depend on marine resources, islanders maintain rich, site-specific knowledge of the marine
365 environment as well as sophisticated understanding of ecological processes (Johannes 1981;
366 Lauer 2017). Despite their awareness of the disturbances, few households saw these as a change
367 that warranted modification of their fishing strategies, or altering what species of fish they ate.
368 This narrative is in striking contrast to the shifts we documented with our roadside surveys
369 conducted before and after the disturbances. Most surprisingly, the significant decrease of *Naso*
370 *spp.* in the reef counts, while reflected in the catch, was not expressed in informants' responses.
371 There are several possible explanations for this apparent discrepancy. For one, the relative
372 abundances of species shifted after the disturbances but the suite of species caught did not, with
373 the same top five species caught before and after the disturbances. It may be that Moorea fishers
374 would only report a more radical shift (e.g., the complete disappearance of a targeted fish) in the
375 taxonomic composition of their diet and catch. Furthermore, fishers speak less of shifts in
376 abundance *per se* but rather about changes in fishes' behavior and their habitat choices. When
377 asked about the decline in abundance of *Naso spp.* in the catch surveys, several fishers stated that
378 unicornfishes have learned, as a result of heavy fishing pressure, to swim into deeper waters. Yet
379 these behavioral changes of *Naso spp.* do not necessarily result in fewer fish caught for the best
380 spearfishers. As one fisher stated, "a good spearfisher will find and catch the fish he desires."

381 The discrepancy between what constitutes noteworthy changes for Moorean fishers and
382 western scientists could also be related to the different ways each group conceptualizes marine
383 environments (Johannes 1981; Hviding 1996). Ethnographic material indicates that Pacific
384 Islanders cognize marine and terrestrial environments holistically, with more attention focused
385 on the components and interactions of an integrated whole, than on discrete ecological attributes.
386 The most vivid Islander expressions of this ecosystem-like understanding are the wedge-shaped,
387 ridge-to-reef resource management units that have been described across Oceania (Ruddle et al.
388 1992; Lauer 2016). These land-sea concepts emphasize the intrinsic entangling of physical and
389 biological components with the social and cultural world.

390 In addition to a holistic worldview of coral reef social-ecological systems, island societies like
391 Moorea also emphasize the unpredictability and unknowability of these systems. In fact, many
392 non-western societies, including those in Oceania, grasp the nature of ecosystems in ways similar
393 to non-equilibrium ecosystem science, a framework that emphasizes surprise and non-linearity,
394 threshold effects, and systems flips instead of predictability, stable states, and homeostasis. The
395 magnitude of ecological and fishing changes we observed likely fall within the bounds of Pacific
396 Islanders' cultural expectations for normal fluctuations in their diets and catch. In other words,
397 the disturbances deemed dramatic from a Western scientific perspective, and perceived as
398 significant events to fishers, are also inscribed for Pacific Islanders within a 'normal' cyclical
399 pattern of disturbances and recoveries. Indeed, the ecological observations of the COTS outbreak
400 and Cyclone Oli span relatively short timeframes (barely a decade) relative to individuals' own
401 lifespans. In addition, the fore reef of Moorea has proven very resilient to disturbances that
402 reduce coral cover, with several major disturbance events and subsequent recovery of the reef
403 since the 1970s (Adam et al. 2011; Trapon et al. 2011). In the case of the most recent

404 disturbances considered here, many areas of the fore reef regained their pre-disturbance levels of
405 live coral within 5 years (Holbrook et al. 2018). The resilience of the reef ecosystem, when
406 considered at the scale of the individuals' lifespans, may contribute to the perceptions of our
407 informants (whose mean age = 47 y) of the limited impacts the disturbances had on their fishing
408 behavior and dietary choices. Future archeological research, similar to that carried out on Hawaii
409 and Rapa Nui (Kirch and Hunt 1997), exploring the long-term socio-ecological dynamics on
410 Moorea, could shed light on the scale and intensity of social-ecological changes on Moorea in
411 the context of disturbance frequency.

412 *Conclusions*

413 Although this study focuses on fisher-fish interactions in Moorea, our results are of general
414 relevance for coral reef ecosystems. Coral reefs globally are experiencing increasing
415 disturbances, in many cases causing major changes in benthic and fish communities (Holbrook et
416 al. 2008). Understanding how fishers conceive and respond to these ecological changes is crucial
417 to predicting how social-ecological feedbacks might enhance or erode ecosystem resilience
418 (Leenhardt et al. 2016; Leenhardt et al. 2017). Such feedbacks are particularly likely in places
419 like Moorea where the most commonly targeted fishes are herbivores, which control macroalgae
420 and confer resilience on the coral dominated reef state (Mumby et al. 2007; Holbrook et al.
421 2016). Fishing on such species has often been linked to switches between coral and algal
422 community states (Hughes et al. 2007; Rasher and Hay 2010), and thus the details of fishing
423 behavior may be critical for understanding the resilience of these alterative states.

424 More broadly, our analysis has implications about researching knowledge production and
425 formulating management initiatives in socio-ecological systems. The disconnect between
426 Moorea's fishers' reporting of change, those apparent in the catch data, and the characterizations

427 of reef change offered by ecologists, highlights a critical issue - western scientists and other
428 stakeholders may produce knowledge grounded in different epistemological and ontological
429 assumptions about the world and what constitutes 'change' (Barnes et al. 2013). In complex
430 social-ecological systems like the one studied here, we should not expect singular,
431 incontrovertible knowledge about the system, and there will be significant differences between
432 and gaps within both local and ecological knowledge that may only widen with the uncertainty
433 of the Anthropocene era. Thus, it is likely to be increasingly useful to understand how all
434 stakeholders (e.g., scientists, conservation practitioners, fishers, tourist operators, etc.) produce *in*
435 *situ* site-specific knowledge and form social-ecological relations. Scientist-resource user
436 collaborations for research and resource monitoring can increase trust between stakeholders,
437 improve adaptive management strategies, and help keep pace with unforeseen social-ecological
438 transformations of the Anthropocene.

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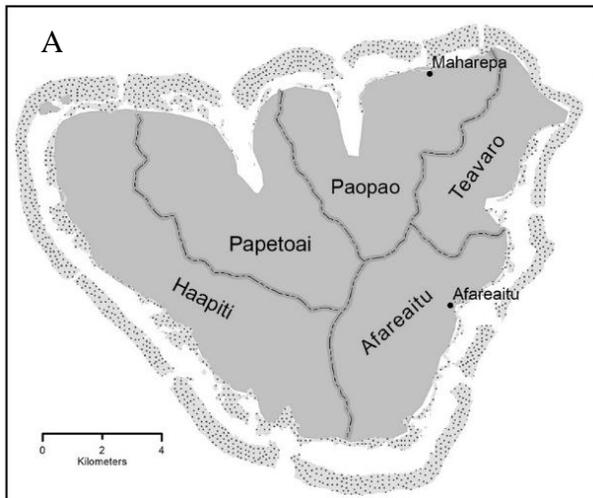
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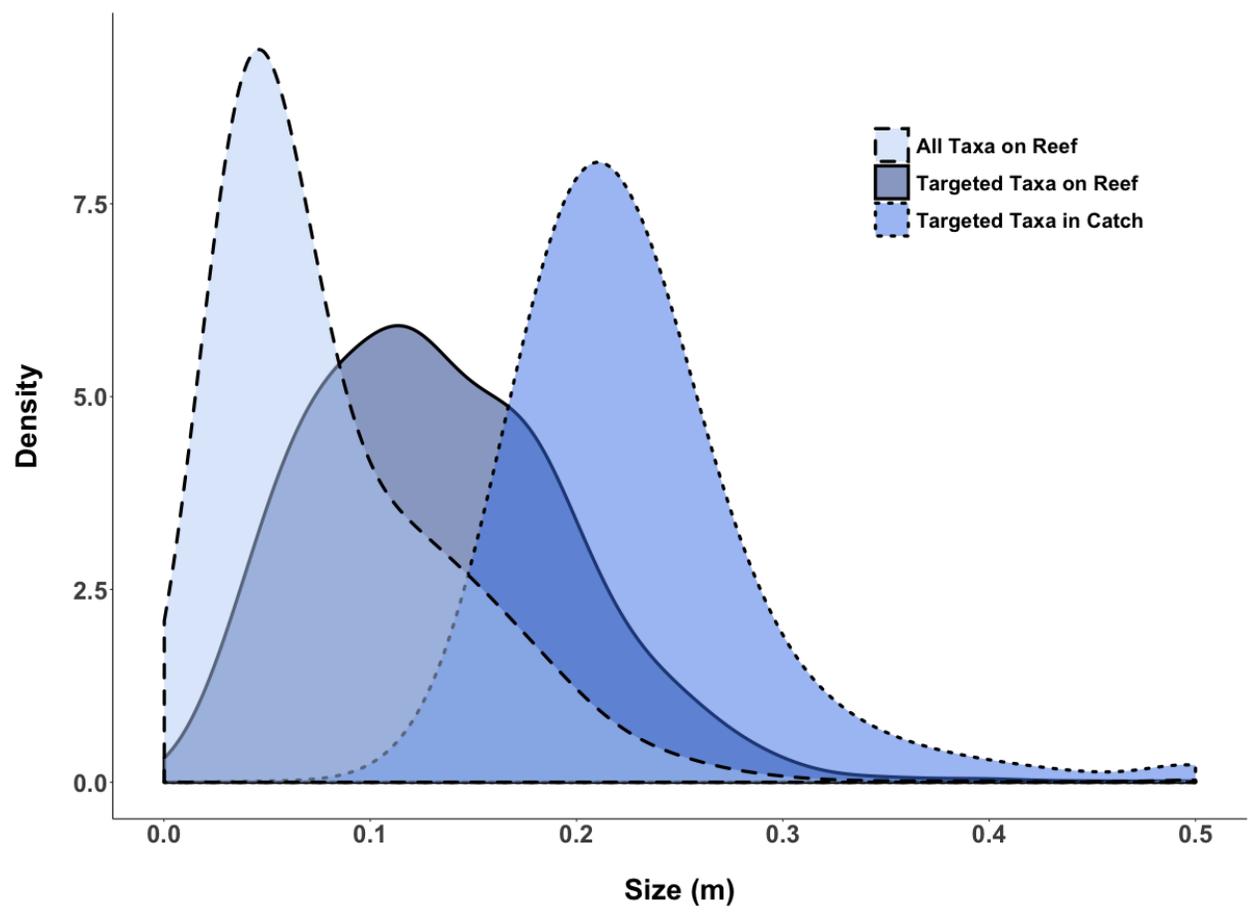
552 **FIGURES**

553 Figure 1. (A) Map of the island with the focal regions of Afareaitu, PaoPao and Teavaro
554 marked. (B) Photo of fish being sold by the roadside (note 0.5 m sizing bar).



557 Figure 2. Size distributions of all fish taxa observed on the reef, the subset of targeted taxa on the reef,
558 and the taxa found in the catch. Curves are kernel density estimations produced with the geom_density
559 function of the ggplot package in R (bandwidth smoothing parameter = 0.02).

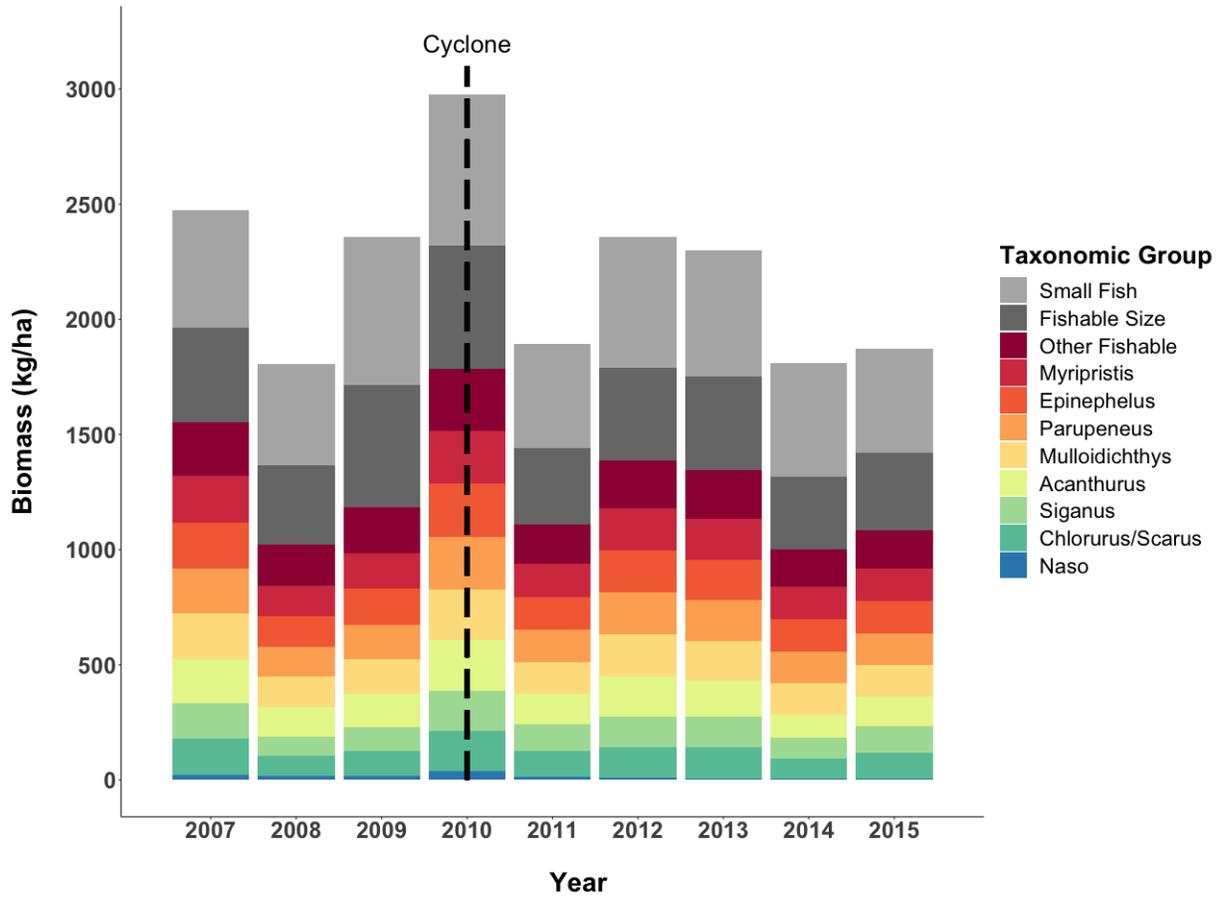
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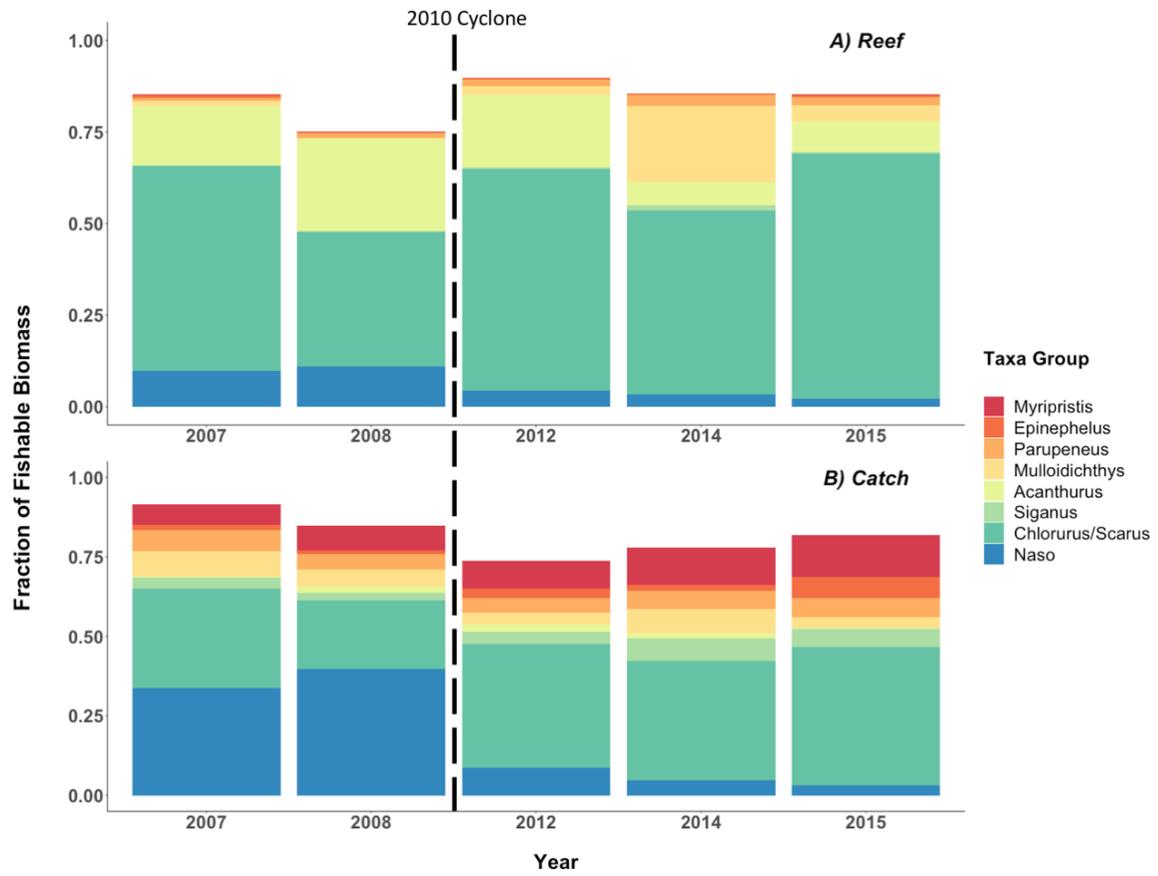
563 Figure 3. Fish biomass on the reef through the time period spanning the 2009-2010 disturbances. The
 564 “Small Fish” indicates biomass of fish smaller than 0.15 m, “Fishable Size” represent larger (> 0.15 m)
 565 fish from non-targeted taxa. The remaining areas represents biomass of fish > 0.15 m which are
 566 commonly found in the catch (Table 4), with 8 taxa broken out, and the remainder combined into “Other
 567 Fishable.” The timing of the peak disturbance is indicated with a dashed line.



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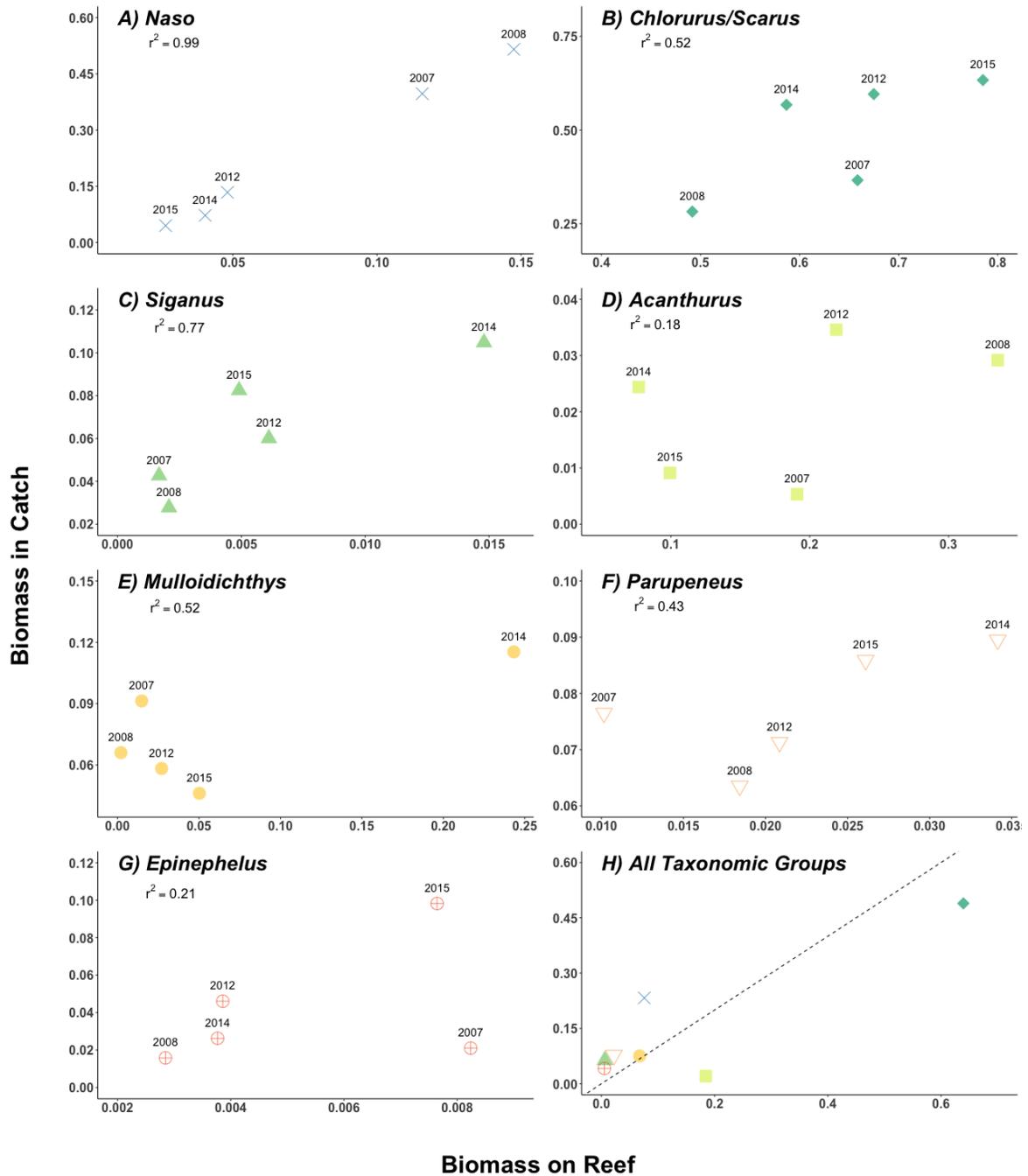
569

570 Figure 4. The relative biomass of fishable taxa (including only individuals > 15 cm) on the reef (A) and
 571 in the catch (B). The timing of the peak disturbance is indicated with a dashed line.



572

573 Figure 5. The relationship between the relative biomass of each taxonomic group on the reef and the
 574 relative biomass of that group in the catch plotted by year. The time-averaged biomass in the catch and on
 575 the reef for each taxon are also plotted (H). In this latter panel, the symbols for each species match those
 576 in A-G and the 1:1 line is plotted.



578 **TABLES**

579 Table 1. Number of fish observed in the reef surveys and in the catch, by year.

Year	Fish counted on reef	Fish sampled in catch
2007	32131	1878
2008	34255	4309
2009	41538	-
2010	30013	-
2011	24231	-
2012	25963	2435
2013	29330	-
2014	30430	4319
2015	23995	4836

580

581 Table 2. Fish most frequently reported eaten or caught in household surveys (N = 326 surveys).

Tahitian name	Scientific name	Reported commonly eaten	Reported commonly caught
Thon (French)	<i>Thunnus spp.</i>	17%	4%
Pa'ati*	<i>Scarus/Chlorurus spp.</i>	15%	12%
Pahoro	<i>Scarus/Chlorurus spp.</i>	11%	6%
I'ihī	<i>Myripristis spp.</i>	8%	13%
Tarao	<i>Epinephelus spp.</i>	8%	8%
Pa'aihere	<i>Caranx spp.</i>	6%	9%
Ume	<i>Naso spp.</i>	6%	6%
Maito	<i>Acanthurus/ Ctenochaetus spp.</i>	4%	3%
Ature	<i>Selar crumenophthalmus</i>	3%	4%
Roi	<i>Cephalopholis spp.</i>	2%	4%
To'au	<i>Lutjanus fulvus</i>	2%	4%

582 * This term denotes terminal phase fish

583

584 Table 3. Percentage of households who responded affirmatively to the questions related to the COTS
585 outbreak and Cyclone Oli.

	Answered 'Yes'
Do you remember any taramea (COTS) outbreaks? (N = 348)	40%
Did taramea outbreaks change how, what, or where you fished? (N = 339)	13%
Did it change what fish you ate or bought to eat? (N = 194)	1.5%
Do you remember Cyclone Oli? (N = 348)	100%
Did Cyclone Oli change how, what, or where you fished? (N = 310)	19%
Did Cyclone Oli change what fish you ate or bought to eat? (N = 350)	10%

586

587 Table 4. Relative abundance of taxa observed in the catch and their corresponding % contribution to
588 abundance on the reef (considering only fish of targetable size, > 0.15 m). The top 23 genera observed in
589 the catch are listed, representing more than 99% of the catch. The genera *Chlorurus* and *Scarus* have been
590 combined in this table because they can be difficult to distinguish in the photos of the catch. Stars (*)
591 indicate taxa reported commonly eaten in more than 5% of household surveys.
592

Genus	% abundance in catch	% biomass in catch	% fishable size abundance on reef	% fishable size biomass on reef
<i>Chlorurus-Scarus*</i>	26.5	35	20.9	22.8
<i>Naso*</i>	18.5	16.1	5.5	4.2
<i>Myripristis*</i>	15.5	10	0.2	0.1
<i>Siganus</i>	8.9	4.5	0.4	0.2
<i>Mulloidichthys</i>	6.4	5.1	3.4	2.1
<i>Parupeneus</i>	5.4	5.4	1.5	0.9
<i>Epinephelus*</i>	3.2	3.1	0.4	0.3
<i>Selar</i>	2.9	1.2	0	0
<i>Cypselurus</i>	2.2	0.9	0	0
<i>Acanthurus</i>	1.8	1.6	10.1	8.5
<i>Cephalopholis</i>	1.4	1.8	3.8	3.3
<i>Cheilopogon</i>	1.4	0.5	0	0
<i>Sargocentron</i>	1.1	0.9	0.6	0.3
<i>Lutjanus</i>	0.8	0.9	0.3	0.2
<i>Monotaxis</i>	0.7	1.4	0.4	0.5
<i>Caranx*</i>	0.5	3.1	0.2	1.1
<i>Lethrinus</i>	0.4	1.3	0.1	1
<i>Calotomus</i>	0.3	0.5	0	0
<i>Heteropriacanthus</i>	0.3	0.2	0	0
<i>Cheilinus</i>	0.2	0.4	0.5	0.8
<i>Gnathodentex</i>	0.2	0.1	2.5	1.5
<i>Kyphosus</i>	0.2	0.4	0	0