

1 A 10-Year Comparison of the Pohnpei, Micronesia, Commercial Inshore Fishery Reveals
2 an Increasingly Unsustainable Fishery

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19 **Abstract**

20 In Pohnpei, Micronesia, a 10-year (2006 – 2015) follow-up market survey was conducted
21 to provide the basis for a comparative assessment of the status of the commercial inshore
22 fishery, to inform management and to identify the most relevant management options.
23 Within this timeframe, marketed coral reef fish volumes declined by 50 mt (*ca.* 20%), the
24 use of unsustainable fishing methods (nighttime spearfishing and small-mesh gillnets)
25 increased by 75.5% to 81.9%, and catch-per-unit-effort decreased from 3.4 ± 0.1 to $3.2 \pm$
26 $0.4 \text{ kg hr}^{-1} \text{ fisher}^{-1}$. Simultaneously, the economic return as price per unit effort was nearly
27 halved for all gear types. Trip volumes increased, however, this was paralleled by a rise
28 in the average number of fishers per trip, particularly for nighttime spearfishing. Effort
29 shifted from inner to outer reef areas and further away from high fisher density
30 communities. At the family level, increases in the percentage of lower trophic level catch
31 were observed, with herbivores and planktivores increasing in frequency in catch more
32 than other trophic level fishes. The only weight increase among top carnivores was for
33 epinephelids, however this was accompanied by a greater contribution by juveniles for
34 the most commonly targeted grouper, Camouflage grouper, *Epinephelus polyphekadion*.
35 Among fish families, eight epinephelids were absent in catch in 2015 compared to 2006,
36 with additional species observed in speared catch in 2015 that were absent in 2006. To
37 reverse continuing declines and prevent the potential for fisheries collapse, government
38 needs to institute rights-based management, ban the use of nighttime spearfishing and
39 small-mesh gillnets, and improve existing enforcement within marine protected areas and
40 markets.

41

42 **Keywords:** Coral reef fisheries; Overfishing; Nighttime spearfishing; Management; Food
43 security

44

45 **Highlights**

46

47 • The Pohnpei coral reef fishery has become increasingly unsustainable.

48

49 • Catch volumes, catch-per-unit-effort and economic return were diminished.

50

51 • Unsustainable fishing gear now represents 82% of the fishery.

52

53 • Effort shifts from depauperate inner reefs to outer reef areas increased by 20%.

54

55 • An increased reliance on lower trophic level species was identified.

56

57 • Mean size reductions were observed among major target species.

58

59 **1. Introduction**

60

61 Coastal communities in developing Pacific Island countries and territories (PICTs) are
62 highly dependent on inshore coral reef resources for food and income (Bell et al., 2009),
63 however rarely are they properly managed, in part due to a lack of information on their
64 status and trends. In many PICT fisheries, anecdotal reports of declines in catch volumes
65 and mean species size and abundance are common, and there are a number of
66 documented accounts to support widespread changes to inshore fish resources (e.g.,
67 Hensley and Sherwood, 1993; Friedlander and DeMartini, 2002). Throughout the central
68 and western Pacific coral reef communities are becoming increasingly devoid of once-
69 common fish species important to ecosystem maintenance, e.g., Green humphead
70 parrotfish (*Bolbometopon muricatum*) and iconic species that contribute to local
71 economies through eco-tourism, e.g., Humphead wrasse (*Cheilinus undulatus*) (e.g.,
72 Hensley and Sherwood, 1993; Dalzell et al., 1996; Houk et al., 2012). Perhaps more
73 troubling is the demise throughout the region of fish spawning aggregations for some of
74 the main target species of coastal commercial fisheries (e.g., Rhodes et al., 2014a). The
75 causes for these impacts are typically broad and often interconnected, and include natural,
76 economic and anthropogenic effects, such as under-valued target species (e.g., Rhodes et
77 al., 2011a), human population increase, common (open) access or proximity to fishing
78 grounds (e.g., Kaunda-Arara et al., 2003), fishing (DeMartini et al., 2008),
79 commercialization (e.g., Brewer et al., 2009), sedimentation from terrestrial activities
80 (e.g., Edinger et al., 1998, Victor et al., 2006), destruction of nursery habits (e.g.,
81 nearshore corals, seagrass beds and mangroves) (e.g., Hamilton et al., 2017), targeting of

82 spawning aggregations (e.g., Sadovy et al., 2008; Rhodes et al., 2011b) and extreme
83 weather events and climate change (Knowlton and Jackson, 2008).

84

85 In the Federated States of Micronesia (FSM), there is increasing evidence that these
86 various impacts are having dire effects on coral reef fisheries (e.g., Rhodes and Tupper,
87 2007; Rhodes et al. 2008; Rhodes et al. 2011b; Houk et al. 2012; Bejarano et al., 2013;
88 Rhodes et al., 2014b; McLean et al., 2016), with a potential concomitant loss to fisheries
89 income and longevity. Specifically, Houk et al. (2012) (for all of Micronesia) and Rhodes
90 and Tupper (2008) and Bejarano et al. (2013) (for Pohnpei) reported the harvest of a
91 number of species below the size-at-sexual maturity, with a diminution of many top
92 carnivores and a reliance on unsustainable nighttime spearfishing. McLean et al. (2016)
93 (in Kosrae) identified shifting baselines in the fishery with a greater reliance on lower
94 trophic level species and a paucity of top carnivores among catch that were reportedly
95 reducing coral reef resilience and reef decline. In Pohnpei, Rhodes et al. (2014b) used
96 socio-economic and market data to show that Pohnpei's inshore fishery is well above
97 biocapacity (i.e. consumption is outstripping production), while Rhodes et al. (2014a)
98 show year-over-year declines in spawning aggregations of some of the most important
99 target species. Thus, there are clear indications throughout much of the FSM of a
100 troubling trend in fisheries that will undoubtedly impact future socio-economic and food
101 security.

102

103 In Pohnpei, a 2006-2007 (2006, hereafter) market-based inshore commercial fishery
104 survey identified more than 153 species among 15 fish families that contributed to the

105 fishery, with nighttime spearfishing overshadowing all other fishing methods (71.3% of
106 the total) (Rhodes et al., 2008). Acanthurids (surgeonfish and unicornfish) comprised
107 more than a quarter of total catch volume with Epinephelids (groupers, hinds and
108 lyretails) and Scarids (parrotfishes) each contributing an additional 15% of caught
109 volumes. Substantial variations were observed in species composition among speared,
110 lined and netted fish. Ten species that included Bluespine unicornfish (*Naso unicornis*),
111 Orangespine unicornfish (*Naso lituratus*), Paddletail snapper (*Lutjanus gibbus*) and
112 Pacific steephead parrotfish (*Hipposcarus longiceps*) were common to two or more gear
113 types, while nearly 2/3 of species were represented by only a few individuals over the 12-
114 month survey. Overall catch-per-unit-effort varied across gears, with gillnets yielding the
115 highest volumes (3.9 kg hr⁻¹ fisher⁻¹), followed by nighttime spearfishing (3.6 kg hr⁻¹
116 fisher⁻¹) and line (2.6 kg hr⁻¹ fisher⁻¹). For combined gears, juveniles and small adults
117 dominated catch. The 2006 survey also focused on epinephelids, which showed juveniles
118 comprising between 34 and 100% of the catch by species, including nearly 50% of the
119 most commercially targeted species, Camouflage grouper, *Epinephelus polyphekadion*
120 (Rhodes and Tupper, 2007).

121

122 The objectives of the current study were (1) to procure additional data from the Pohnpei,
123 Micronesia, inshore commercial fishery and compare it to 2006 data in order to (2)
124 examine possible changes within fished populations and the fishery over a 10-year
125 timeframe and (3) provide recommendations to the Pohnpei State Government for
126 management decision-making. Pohnpei State, as with many other PICTs, has no
127 comprehensive fisheries management plan and has not responded to evidence showing

128 long-term declines over at least a 20-year timeframe. Existing management in the state is
129 piecemeal and outdated, while enforcement efforts are relatively poor and conducted in
130 lieu of a strategic plan, which is directly contributing to fisheries decline. Finally, there
131 has been anecdotal evidence of further decline in the fishery since the 2006 surveys were
132 conducted, with markets and restaurants now struggling to find fish, along with observed
133 shifts to even smaller individuals within target species.

134

135 **2. Methods**

136

137 The 2006 and 2015-2016 (2015, hereafter) market surveys were conducted in Pohnpei,
138 Micronesia (07°00'N, 158°15'E) to examine coral reef and nearshore pelagic fish
139 markets around the island (**Fig. 1**). Pohnpei is one of 8 islands and atolls within the state
140 and is the only high island (791 m), with a population of around 33,000 inhabitants living
141 on the main island. The local economy is varied, with about 1/3rd of the workforce
142 employed by government and another 1/3rd living through subsistence. The number of
143 commercial fishers on-island as well as the number and kinds of boats contributing to the
144 fishery is still unknown. Fully 27% of Pohnpeians are dependent on remittance from
145 outside the state and fishing communities are economically marginalized. The island is
146 perhaps best known for its rainfall (c. 800 cm yr⁻¹) and sakau (*Piper methisticum*), which
147 is farmed in loose soil and sold and consumed locally for its narcotic properties, and is a
148 primary source of terrestrial runoff and subsequent inshore reef sedimentation and
149 nursery habitat loss, particularly in fringing reef environments. Coral dredging, which is
150 active at 25 sites around the island, is also likely impacting fisheries through additional

151 sedimentation and loss of critical nursery habitat for some species (e.g. Hamilton et al.
152 2017).

153

154 Based on anecdotal reports, commercialized fisheries have been operating in Pohnpei
155 since the 1960s, with an expansion starting in the 1980s to the current 20+ markets
156 operating in the state. Impacts to the fishery and to individual species prior to 2006 are
157 unknown, however anecdotal reports of the abundance and distribution of marine
158 resources suggest major impacts well before the 2006 market study occurred, e.g. the loss
159 of giant clam, changes in depth distribution and abundance of Green humphead
160 parrotfish. Market surveys in both 2006 and 2015 were conducted using the same format
161 (Rhodes et al., 2008) with the exception that the latter surveys benefitted from the use of
162 a digital image capture system (DICS) to electronically document catches. We assume
163 any errors or bias associated with fisher or market owner responses are consistent
164 between surveys. Surveys were concentrated in Kolonia, the population center and
165 economic and state government hub, where most markets operate. As in 2006, additional
166 assessments and fisher interviews were conducted at market locations outside of Kolonia.
167 Marketed volumes of inshore catch were obtained daily from market owners at all
168 locations. The first surveys were conducted 10 January 2006 to 31 January 2007, while
169 the 10-year follow-up surveys were conducted from 27 January 2015 to 15 January 2016.
170 Both surveys were done from c. 0700 to 1700 hr Tuesday through Saturday when the
171 majority of markets are operational. Market surveys included the collection of daily
172 purchased volumes (nearest kg) of reef fish (and nearshore pelagics) by all markets
173 operating in the state, which were collated by month and by market. In addition,

174 individual fishes were approached at the time of sale to markets and interviewed for
175 details about the trip, including the number of participating fishers, hours fished
176 (excluding travel time), gear and vessel used, expenditures, targeted reef and fisher
177 origin. Further details were recorded on the market location, including GPS coordinates
178 **(Fig. 1)**. Each day, a number of catches were haphazardly sampled, with catch first split
179 into individual families to gather family weight (nearest 0.1 kg) and then photographed
180 using the DICS.

181

182 The DICS is a low-cost system that provides a digital record of catch. The system was
183 developed to record and store digital images on a pre-programmed SD card for
184 subsequent evaluation. The system was designed by JCB and incorporates a digital
185 pocket camera mounted to a PVC arm that allows the camera to point downward to a
186 standard fish measuring board (60- or 100-cm in length with 1-cm increments) where the
187 fish are placed. The camera is linked to a remote push-button trigger, allowing individual
188 catches to be quickly processed. A monitoring code is written on the measuring board to
189 link fishers with catch and interview data. For the current study, determinations of
190 maturity used size-at-sexual maturity information from either peer-reviewed scientific
191 life history studies from Pohnpei or Micronesia (e.g., Rhodes et al., 2011b; Rhodes et al.,
192 2013; Taylor et al., 2014; Rhodes et al., 2016), from Fishbase (www.Fishbase.org) or
193 from yet unpublished data collected locally or regionally. For both survey years, the
194 interview data was combined with available catch data (family or species) to develop a
195 species list that was used for comparison. Size data from the earlier 2006 survey included
196 only select grouper species.

197

198 **3. Results**

199

200 Using similar methodology and sample sizes between the 2006 and 2015 surveys,
201 findings reveal substantial changes in the Pohnpei commercial inshore fishery, including
202 altered catch composition and the loss of some target species, reduced catch-per-unit-
203 effort and economic return, and lower overall marketed volumes (**Table 1**). Over the 10-
204 year timeframe, overall annual marketed volumes for the combined fishery fell around 50
205 mt (*c.* 20%), trip volumes increased along with increased effort, specifically an uptick in
206 the average number of fishers per trip, a greater use of motorized boats and expanded use
207 of unsustainable fishing methods. Between survey periods, nighttime spearfishing
208 increased from 71.3% of all gears in 2006 ($n_{2006} = 607$) to 75.6% in 2015 ($n_{2015} = 1125$),
209 while the use of small-mesh (2-in) gillnets increased from 4.2% ($n_{2006} = 34$) to 6.3%
210 ($n_{2015} = 93$). Concomitantly, hook-and-line fishing declined by 6% from 24.3% in 2006
211 ($n_{2006} = 168$) to 18.1% in 2015 ($n_{2015} = 270$). Between survey periods the net economic
212 return was roughly halved for catches from all gears (**Table 1**) likely in relation to the
213 need to cover expenditures associated with increased commodity prices related to fishing,
214 particularly fuel, which in 2006 was *c.* \$1.75 gal⁻¹ (\$0.38 l⁻¹; base consumer price index,
215 CPI) and sold at *c.* \$4.50 gal (\$0.99 l⁻¹; adjusted for CPI = \$0.94 l⁻¹) in 2015, a 2.5-fold
216 increase. During the same period, the price paid to fishers went from *c.* \$1.00 lb⁻¹ (\$2.03
217 kg⁻¹; base CPI) in 2006 to *c.* \$1.40 lb⁻¹ (\$2.85 kg⁻¹; adjusted for CPI = \$2.71) in 2015, a
218 1.3-fold increase, or *c.* one-half the fuel price increase during the same period. Fishing

219 locations also shifted, with 63.8% of fishing in 2006 done inside the lagoon, which had
220 dropped to 42.9% by 2015.

221

222 3.1 Fishing locations and fisher origin

223

224 Shifts in fishing area within the Pohnpei inshore fishery were observed, with increased
225 targeting of Ant Atoll and Sokehs and Uh municipalities (**Fig. 2**) and less effort
226 associated with Kitti and Nett municipalities, which have historically had the highest
227 concentration of fishers (**Fig. 3**). Less fish was marketed in 2015 from the more distant
228 municipalities of Madelonimw and Uh municipalities. A percent change in fisher
229 contributions to the commercial fishery by municipality was also observed, with
230 contributions from Kitti municipality, with the highest concentration of commercial
231 fishers, increasing from 50.1% to 57.4% between survey periods. Additionally, fishing
232 effort increased to outer reef areas and away from inner reefs, with 55.4% of effort at
233 outer reef locations in 2015 ($n_{2015} = 793$), compared to 33.7% in 2006 ($n_{2006} = 230$).

234

235 3.2 Volumetric changes, species composition and family contributions to catch

236

237 In 2006, a total of 153 species were identified in commercial inshore catch. By 2015, the
238 number of species recorded had increased to 163 species, in part owing to the opportunity
239 to re-examine and positively identify individuals (as images) over longer time periods
240 using the DICS. More than other families, sampling improvements increased the number
241 of holocentrids identified from 1 to 14 species. Sampling in both survey periods split and

242 weighed fish at the family level to provide evidence of a changing fishery (**Fig. 4**).
243 Among top carnivores, only epinephelids increased in relative volume, however data
244 shows that this increase was supplied through an increased capture of juveniles,
245 particularly for the most commonly targeted grouper (See 3.3 Species shifts and size
246 frequency comparisons, below). Species-specific catch comparisons, as numerical totals,
247 were not possible for the current report since individuals were not counted in 2006 from
248 monitored catches aside from epinephelids, which in both years were identified, weighed
249 and measured individually to allow direct comparison.

250

251 Compared to 2006, observed declines in monthly catch volumes were noted during 7 of
252 12 months surveyed in 2015 (**Fig. 5**), however these were not statistically significant (t-
253 test; $p = 0.07$). Overall volumes directly marketed (excluding exported fish and fish that
254 went direct to business) declined 18.8%, from 271 mt in 2006 to 220 mt in 2015. In 2015,
255 catch volumes increased from February to July relative to other months, which coincides
256 with the peak spawning season identified for all coral reef fish species examined in
257 Pohnpei to date (Rhodes et al., 2014a; Rhodes et al., 2017; Taylor et al., 2014).

258

259 3.3 Species shifts and size frequency comparisons

260

261 Inter-survey comparisons identified shifts in the ranks of marketed species and the
262 absence in 2015 of eight species documented previously in 2006: Honeycomb grouper
263 (*Epinephelus merra*), Brownspotted grouper (*Epinephelus chlorostigma*), Netfin grouper
264 (*Epinephelus miliaris*), One-blotch grouper (*Epinephelus melanostigma*), Coral hind

265 (*Cephalopholis miniata*) and Tomato hind (*Cephalopholis sonnerati*), Leopard
266 coralgrouper (*Plectropomus leopardus*), and White-edged lyretail (*Variola*
267 *albomarginata*). Each of these species was found in relatively low numbers in 2006. For
268 more common species, the Squaretail coralgrouper (*Plectropomus areolatus*) increased in
269 importance within the fishery from the 6th most common grouper to 2nd, while Highfin
270 grouper (*Epinephelus maculatus*) decreased from 8th to 14th (**Table 2**). Both of the latter
271 species, along with *E. polyphkadion* are known or suspected of forming spawning
272 aggregations, where they are targeted. Two species recorded in 2015, White-streaked
273 grouper (*Epinephelus ongus*) and Snubnose grouper (*Epinephelus macrospilos*) were not
274 observed in 2006.

275

276 The mean size of *P. areolatus* was similar between surveys (2006: 42.0±4.1 cm TL;
277 2015: 42.8±2.5 cm TL), whereas the average size of *E. polyphkadion* (**Fig. 6**) declined
278 significantly (t-test, $p < 0.00$) from 35.2±0.4 cm TL in 2006 ($n = 363$) to 32.2±0.0 cm TL
279 ($n = 593$) in 2015, with only 44% of marketed individuals above the 50% size at sexual
280 maturity. For *N. unicornis*, the only other species for which local size-at-sexual maturity
281 was available (Taylor et al., 2014), 98.8% of individuals ($n = 3843$) were above the 50%
282 size at male sexual maturity. No sex-specific data were available to gauge the percent of
283 females above the 50% size-at-sexual maturity (31.2 cm FL) threshold.

284

285 3.4 Changes in species composition in speared catch

286

287 For speared catches examined, increased presence in catch was shown for 28 of 42
288 species, with the remaining species showing declines (10 species) or no substantial
289 change (Table 3). Planktivores showed the greatest average increase among trophic
290 groups with an $18.9\pm 5.0\%$ increase, while herbivores increased by $10.4\pm 2.1\%$.
291 Herbivores (16 species) that showed increased presence in catch included 5 scarids, 4
292 siganids and 2 acanthurids. The greatest shift in presence was for Dash-and-dot goatfish,
293 *Parupeneus barberinus*, which was present in 21% less catches examined in 2015 than in
294 2006. Piscivores showed an average increase of $5.1\pm 3.3\%$, with two groupers rare in
295 catch in 2006 increasing in catch by 2015, along with three carangids.

296

297 **4. Discussion**

298

299 In Pohnpei, surveys over a 10-year time span revealed troubling shifts in the commercial
300 inshore fishery. Among those were an increase in unsustainable fishing methods that
301 appears to be driving diminution of catch volumes and mean size among major
302 commercially targeted species, lowered CPUE and economic return, and shifts in catch to
303 lower trophic level species. Clearly, there is a need to eliminate nighttime spearfishing
304 and small-mesh nets, and markedly improve the manner in which inshore fisheries are
305 managed and enforced in the state.

306

307 Throughout the tropics, nighttime spearfishing use has been increasingly prevalent in
308 inshore fisheries as access to gear has become easier. The gear has been identified as a
309 major contributor to overfishing of inshore resources in part because it is used non-

310 selectively and because fishers target schools of lower trophic level species when they are
311 largely immobile (Gillett and Moy, 2006). This combined with close proximity to
312 markets and the recent shift in many PICTs from subsistence to commercial economies
313 (Cinner and McClanahan, 2006; Cinner et al., 2012) has resulted in negative outcomes
314 for many inshore stocks. While a number of factors have contributed to overfishing in the
315 region, commercialized nighttime spearfishing is perhaps the most damaging and now
316 accounts for *c.* 75% of all inshore fish captured within the Federated States of
317 Micronesia, the US territory of Guam and Commonwealth of the Northern Mariana
318 Islands (Houk et al., 2012). In Guam, nighttime spearfishing and the use of SCUBA
319 spearfishing have all but decimated populations of most higher trophic level species,
320 including epinephelids and lutjanids, while some species, including coastal sharks, *B.*
321 *muricatum* and *C. undulatus* have become increasingly scarce (e.g. Hensley and
322 Sherwood, 1993; Dalzell et al., 1996). These latter species continue to be prime targets of
323 the fishery, with *C. undulatus* still representing the highest percentage of catch by
324 SCUBA spearfishing (Lindfield et al., 2014). The same species have all but disappeared
325 from shallow reefs and passes in Pohnpei within the past two decades (Rhodes, pers.
326 observ.) A 20-year examination of Guam catch data by Lindfield et al. (2014) also
327 revealed a direct correlation between decreasing mean sizes of parrotfish and a shift to a
328 mixed fishery that included greater proportions of acanthurids, with the increased
329 prevalence of nighttime SCUBA spearfishing. The Guam snorkel spearfishery now
330 appears largely devoid of higher trophic level species and there are clear signs that a
331 similar trend is occurring in Pohnpei. Guam is now almost wholly reliant on imported
332 reef fish from Chuuk to maintain demand, with herbivores now the main fishing target

333 among Guam spearfishers (Cuetos-Bueno and Houk, 2017). In the Commonwealth of the
334 Northern Mariana Islands, nighttime spearfishing has been reported to be impacting some
335 easily accessible areas, with abundance declines among major spearfishery targets
336 ranging from 40-80%, along with CPUE (Bearden et al., 2005). Overall declines from the
337 1950s have been estimated at 39 - 73% (Cuetos-Bueno and Houk, 2014). Bejarano et al.
338 (2013) implicated spearfishing for adding ecological risk in both Pohnpei and Palau by
339 targeting low-redundancy species, such as *N. unicornis*, and targeting juveniles of several
340 species of protogynous parrotfish, including Bicolor parrotfish, *Cetoscarus bicolor*,
341 Ember parrotfish, *Scarus rubroviolaceus* and Steephead parrotfish, *Chlorurus*
342 *microrhinos*. Other moderate-risk herbivorous species were also identified, including
343 Goldspotted spinefoot, *Siganus punctatus* and *H. longiceps*. Bejarano Chavarro et al.
344 (2013) also showed an increased targeting of less-preferred herbivores by spearfishers
345 during the April-July grouper closure, highlighting the unintended consequences of
346 uninformed management decision-making that in this instance shifted fishing pressure to
347 lower trophic level species. A similar impact was shown in Pohnpei during the March-
348 April grouper closure there, whereby the targeting of lutjanids and scarids increased
349 during grouper ban periods (Rhodes and Tupper, 2007). In Solomon Islands, nighttime
350 spearfishing was reported to cause severe declines in aggregating grouper populations,
351 with a 30-fold difference in CPUE between non-aggregation and aggregation-based catch
352 of *P. areolatus* (Hamilton et al., 2012). The same practice has resulted in the elimination
353 of other species' spawning aggregations in some Solomon Island locales (e.g., Hamilton
354 et al., 2004), while a recent survey of the Gizo (Western Province) inshore fish market
355 showed around one-half of most spearfished species were below the size at sexual

356 maturity (Rhodes, unpubl. data). Similarly, fisher interviews in Gizo noted declining
357 catch and size (Sabetian and Foale, 2004). In Pohnpei, the use of nighttime spearfishing
358 is directly linked to the demise of the shallow water portion of the *P. areolatus* spawning
359 aggregation (Rhodes and Tupper, 2008; Rhodes et al. 2014a), with year-over-year
360 declines in aggregation density for all three grouper species (also Brown-marbled
361 grouper, *Epinephelus fuscoguttatus* and *E. polyphekadion*) aggregating at the site. Herein,
362 we show diminution of mean size of the most commercially targeted grouper, *E.*
363 *polyphekadion*, changes in overall catch with greater contributions by herbivores and
364 overall reductions in CPUE and catch volumes as fishing efforts increase overall and shift
365 to outer reef areas. Thus, throughout the western and central Pacific, nighttime
366 spearfishing in combination with commercialization appears to be catalyzing
367 unsustainable fisheries.

368

369 In Pohnpei, nighttime spearfishing also appears to be altering catch composition, with
370 shifts among the major target species, with the greatest increased shown for herbivores
371 and the appearance in catch of species formerly absent. Recent changes also include the
372 presence of a number of species formerly not preferred by Pohnpeians, including mullids
373 and lethrinids, the former which has shown the greatest decline in catch since the 2006
374 survey. Boxfish (Ostraciidae), angelfish (Pomacanthidae) and spadefish (Ephippidae)
375 were not found in catches in the years prior to the 2006 survey. Some species present in
376 2006 were also absent from catch in 2015, including Acute-jawed mullet (*Neomyxus*
377 *leuciscus*) and Squaretail mullet (*Ellochelon vaiigiensis*) and Kanda (*Moolgarda engeli*), a
378 reflection of small-mesh net fishing. Shifts in catch composition may well reflect declines

379 in abundance and it is unclear what impacts these reductions in abundance are having on
380 the reef ecosystem, however the diminution in herbivores from overfishing are known to
381 alter ecosystem function (e.g., Thacker et al., 2001; Hughes et al., 2007), while decreases
382 in individual species abundance can profoundly alter nutrient cycling (e.g., *B. muricatum*)
383 (Bellwood et al., 2003; Bellwood and Choat, 2011). Additionally, sedimentation from
384 upland activities and dredging are profoundly changing inshore reefs and nursery habitats
385 (Turak and Devantier, 2005; Victor et al., 2006). These combined activities, left
386 unabated, increase the potential for eventual fisheries collapse, threaten the food and
387 socio-economic security of coastal fishing communities and impede the ability for non-
388 extractive resource use, including dive tourism development (Cesar et al., 2003). Climate
389 change, whose impacts to fisheries are only beginning to be understood, will present
390 greater challenges to fisheries management, such that any measures that can be made now
391 to mitigate unsustainable fishing and build resilience into these populations should be
392 implemented.

393

394 In Pohnpei, state government has clearly shown an inability to grasp or respond to
395 fisheries decline. Rights-based management and shifts in enforcement and monitoring to
396 the municipal governments and communities may enhance a sense of ownership and
397 improve resource protection. Regionally, NGOs and outside funding sources are working
398 to empower local communities through monitoring training and development of locally
399 managed marine areas. Some, such as the Nan Wap LMMA in Pohnpei, have shown
400 success both in protecting critical habitat and improving fish population abundance.
401 Similarly, municipal governments in Pohnpei, including Pakin, U and Kitti have

402 developed fisheries management plans with provisions to restrict access through fisher
403 licensing and boat registration, with enforcement and monitoring by community
404 conservation officers. However, for these actions to be effective, greater support and
405 power sharing is needed between municipal and state governments, the latter who so far
406 appear reluctant to relinquish power or provide the needed resources. Regardless of the
407 format chosen to improve fisheries management, market-based mechanisms should be
408 used to eliminate nighttime spearfishing and small-mesh gillnets, along with strengthened
409 enforcement of existing size restrictions at markets and marine protected areas. The
410 elimination of speared fish from commercial sale during the primary reproductive season
411 in Pohnpei (January – May) and a ban on the importation and sale of small-mesh nets
412 would be a good first step. Nonetheless, a more timely response is needed given the
413 current level of decline and reduce the severity of socio-economic consequences for
414 coastal fishing communities.

415

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430

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578

579

580 Table 1: Summary table of fishery parameters in the Pohnpei commercial inshore fishery
581 between 2006 and 2015. CPUE = catch-per-unit-effort; PPUE = price per unit effort, as
582 economic return fisher⁻¹ hr⁻¹. Trip volumes represent total catch irrespective of the
583 number of fishers per trip
584

Parameter	2006	2015
No. fisher interviews	1123	1495
No. catches examined	693	418
CPUE (Combined gears)	3.4±0.1	3.2±0.4
CPUE (Spear)	3.6±0.1	3.1±0.0
CPUE (Line)	2.6±0.1	2.9±0.1
CPUE (Net)	3.9±0.3	4.8±0.4
Overall volumes (mt)	270	221
Net return PPUE (Spear)	\$6.70±0.20	\$2.95±0.07
Net return PPUE (Line)	\$4.40±0.30	\$2.48±0.18
Net return PPUE (Net)	\$7.70±0.80	\$4.1±0.35
Trip volume (All gears)	42.5±1.2	59.8±1.6
Avg. trip volume (Spear)	43.9±1.4	68.9±2.0
Avg. trip volume (Line)	26.1±1.4	27.7±1.6
Avg. trip volume (Net)	49.4±5.8	36.1±3.0
Avg. hrs fished (Spear)	5.7±0.1	7.4±0.1
Avg. hrs fished (Line)	6.0±1.2	7.5±0.1
Avg. hrs fished (Net)	4.8±0.2	4.5±0.2
Avg. no. Fishers (Spear)	2.4±0.1	3.7±0.1
Avg. no. Fishers (Line)	1.7±0.1	1.7±0.1
Avg. no. Fishers (Net)	3.1±0.3	3.3±0.2
Motorized boat use (%)	86.1	89.1
Non-motorized boat use (%)	13.9	10.1
% Spear	71.3	75.9
% Line	24.3	16.7
% Net	4.2	6.3

585

586 Table 2: Comparison of grouper catches between survey periods. Shifts in catch volume relative to other groupers (as ranks) were
 587 observed, along with the absence in 2015 of a number of minor species present in the earlier survey. na = not available; np = not
 588 present; L_m = reported length at maturity; C. = *Cephalopholis*; E. = *Epinephelus*; P. = *Plectropomus*; V. = *Variola*

589

Species	No. (2006)	No. (2015)	% of total (2006)	% of total (2015)	2006 Size range (cm)	2015 Size range (cm)	Max. length (cm)	L _m (cm TL)	Percent mature (2006)	Percent mature (2015)	Mean length (cm) (2006)	Mean length (cm) (2015)	2006 Rank	2015 Rank
<i>E. polyphkadion</i>	383	889	20.7	29.9	17-41	17-57	90	32.7	67.7	43.0	27.2±5.0	32.2±0.2	1	1
<i>P. areolatus</i>	219	561	11.9	18.9	21-51	29-60	80	36.6	75.6	86.3	35.2±5.5	42.8±0.2	6	2
<i>C. argus</i>	277	347	15.0	11.7	16-35	20-42	60	20	34.2	100	23.5±3.3	28.8±0.2	2	3
<i>E. spilotoceps</i>	224	251	13.1	8.5	17-41	19-37	35	na	***	***	20.6±1.9	24.3±0.1	4	4
<i>E. howlandi</i>	224	239	12.1	8.0	18-32	21-38	55	na	***	***	23.6±3.2	28.5±0.2	5	5
<i>E. tauvina</i>	1	157	0.1	5.3	24.0	16-45	100	61.1	0.0	0.0	***	32.2±0.4	24	6
<i>E. coeruleopunctatus</i>	244	156	13.2	5.3	14-41	22=53	76	na	***	***	26.5±5.9	38.3±0.6	3	7
<i>E. macrospilos</i>	0	153	0.0	5.2	***	23-40	51	na	***	***	***	29.9±0.5	np	8
<i>E. fuscoguttatus</i>	61	115	3.3	3.9	22-67	30-79	129	40.8	24.6	54.0	39.19.4	45.91.1	7	9
<i>P. oligacanthus</i>	11	24	0.6	0.8	21-48	37-59	75	27.0	100.0	100	36.2±7.9	50.7±1.2	15	10
<i>E. corallicola</i>	14	22	0.8	0.7	20-30	20-30	49	na	***	***	22.7±2.9	36.2±7.9	12	12
<i>E. leucogrammicus</i>	10	22	0.5	0.7	22-34	18-48	65	34	60	54.0	27.7±4.2	34.9±1.3	16	11
<i>V. louti</i>	14	11	0.8	0.4	30-48	32=51	83	na	***	***	29.1±3.6	41.2±1.8	13	13
<i>E. ongus</i>	0	6	0.0	0.2	***	24-31	40	26.1	***	75.0	***	28.8±1.6	np	14
<i>E. maculatus</i>	35	5	1.9	0.2	19-35	26-34	60	30.8	60.0	60.0	26.7±4.7	30.8±1.5	8	15
<i>Epinephelus sp.</i>	30	3	1.6	0.1	***	14-45	na	na	***	***	***	***	11	16
<i>C. rogae</i>	4	3	0.2	0.1	20-23	30-38	60	na	***	***	21.7±1.3	33.3±2.4	18	17
<i>C. sexfasciatus</i>	1	2	0.1	0.1	22.0	22	50	na	***	***	***	***	23	18
<i>P. laevis</i>	1	1	0.1	0.0	43.0	43	125	na	***	***	***	56	25	20
<i>E. melanostigma</i>	33	0	1.8	0.0	18-37	***	35	na	***	***	26.2±5.4	***	9	np
<i>E. merra</i>	27	0	1.5	0.0	18-26	***	32	na	***	***	20.9±2.1	***	10	np
<i>E. miliaris</i>	4	0	0.2	0.0	23-26	***	53	na	***	***	24.5±1.3	***	19	np

<i>C. sonnerati</i>	3	0	0.2	0.0	21-25	***	57	na	***	***	23.8±2.3	***	20	np
<i>C. miniata</i>	2	0	0.1	0.0	19-23	***	50	na	100	***	21.1±3.1	***	21	np
<i>E. chlorostigma</i>	2	0	0.1	0.0	18-34	***	80	28	50	***	26.0±1.1	***	22	np
<i>V. albimarginata</i>	1	0	0.1	0.0	31.0	***	65	na	***	***	***	***	26	np
<i>P. leopardus</i>	5	0	0.3	0.0	33-50	***	120	33.1	0	***	41.2±6.1	***	17	19

590

591

592

593 Table 3: Summary table of speared catches where changes in frequency of occurrence and relative ranks of presence in catch were observed. Tr.
594 Lev = Dominant trophic level of individual species. % Chg = percentage change in the frequency of occurrence in speared catch. D = detritivore;
595 H = herbivore; I = invertivore; PL = planktivore; P = piscivore
596

Species	Catches (2006)	Catches (2015)	Freq (2006)	Freq (2015)	Rank (2006)	Rank (2015)	Rank	Tr. Lev	% Chg
<i>Parupeneus barberinus</i>	245	141	71.0	49.6	8	5	—	D	-21.4
<i>Parupeneus indicus</i>	47	16	13.6	5.6	2	1	—	D	-8.0
<i>Acanthurus blochii</i>	10	98	2.9	34.5	1	4	+	H	31.6
<i>Siganus argenteus</i>	94	142	27.2	50.0	3	6	+	H	22.8
<i>Acanthurus nigricauda</i>	194	224	56.2	78.9	6	8	+	H	22.7
<i>Scarus rubrioviolaceus</i>	70	96	20.3	33.8	3	4	+	H	13.5
<i>Siganus punctatus</i>	228	223	66.1	78.5	7	8	+	H	12.4
<i>Chlorurus frontalis</i>	17	41	4.9	14.4	1	2	+	H	9.5
<i>Scarus frenatus</i>	6	29	1.7	10.2	1	2	+	H	8.5
<i>Scarus frontalis</i>	24	41	7.0	14.4	1	2	+	H	7.4
<i>Siganus doliatus</i>	238	208	69.0	73.2	7	8	+	H	4.2
<i>Chlorurus sordidus</i>	0	10	0.0	3.5	0	1	+	H	3.5
<i>Siganus randalli</i>	30	31	8.7	10.9	1	2	+	H	2.2
<i>Naso unicornis</i>	278	253	80.6	89.1	9	9		H	8.5
<i>Hipposcarus longiceps</i>	315	282	91.3	99.3	10	10		H	8.0
<i>Acanthurus olivaceus</i>	31	44	9.0	15.5	1	2	+	H	6.5
<i>Acanthurus xanthopterus</i>	104	102	30.1	35.9	4	4		H	5.8
<i>Naso lituratus</i>	345	284	100.0	100.0	10	10		H	0.0
<i>Caesio caeruleus</i>	33	111	9.0	39.1	1	4	+	PL	30.1
<i>Myripristis adusta</i>	102	162	29.6	57.0	3	6	+	PL	27.4
<i>Macalor macularis</i>	28	47	8.1	16.5	1	2	+	PL	8.4
<i>Pterocaesio tessellata</i>	37	3	10.7	1.1	2	1	—	PL	-9.6
<i>Lethrinus erythracanthus</i>	8	54	2.3	19.0	1	2	+	I	16.7
<i>Monotaxis grandoculis</i>	222	211	64.4	74.3	7	8	+	I	10.0
<i>Lethrinus xanthochilus</i>	77	89	21.7	31.3	3	4	+	I	9.6

<i>Lethrinus obsoletus</i>	84	93	24.3	32.7	3	4	+	I	8.4
<i>Lethrinus harak</i>	26	36	7.5	12.7	1	2	+	I	5.2
<i>Cheilinus undulatus</i>	79	3	22.9	1.1	3	1	—	I	-21.8
<i>Kyphosus vaigensis</i>	219	144	63.5	50.7	7	6	—	I	-12.8
<i>Cheilinus trilobatus</i>	36	3	10.4	1.1	2	1	—	I	-9.3
<i>Plectrorhynchus albovittatus</i>	15	29	4.3	10.2	1	2	+	I/P	5.9
<i>Caranx melampygus</i>	0	75	0.0	26.4	0	3	+	P	26.4
<i>Epinephelus tauvina</i>	1	66	0.3	23.2	1	3	+	P	22.9
<i>Epinephelus macrospilos</i>	1	55	0.3	19.4	1	2	+	P	19.1
<i>Lutjanus monostigma</i>	96	101	27.8	35.6	3	4	+	P	7.8
<i>Lutjanus gibbus</i>	238	203	69.0	71.5	7	8	+	P	2.5
<i>Carangoides plagiotaenia</i>	0	11	0.0	3.9	0	1	+	P	3.9
<i>Caranx papuensis</i>	0	7	0.0	2.5	0	1	+	P	2.5
<i>Lutjanus semicinctus</i>	106	60	30.7	21.1	4	3	—	P	-9.6
<i>Epinephelus coeruleopunctatus</i>	126	81	36.5	28.5	4	3	—	P	-8.0
<i>Lutjanus fulvus</i>	42	13	12.2	4.6	2	1	—	P	-7.6
<i>Lutjanus bohar</i>	35	19	10.1	6.7	2	1	—	P	-3.4

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