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A 10-year comparison of the Pohnpei, Micronesia, commercial inshore fishery reveals an increasingly unsustainable fishery

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A R T I C L E I N F O

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A B S T R A C T

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

1. Introduction

Coastal communities in developing Pacific Island countries and territories (PICTs) are highly dependent on inshore coral reef resources for food and income (Bell et al., 2009), however rarely are they properly managed, in part due to a lack of information on their status and trends. In many PICT fisheries, anecdotal reports of declines in catch volumes and mean species size and abundance are common, and there are a number of documented accounts to support widespread changes to inshore fish resources (*e.g.*, Hensley and Sherwood, 1993; Friedlander and DeMartini, 2002). Throughout the central and western Pacific coral reef communities are becoming increasingly devoid of once-common fish species important to ecosystem maintenance, *e.g.*, Green humphead parrotfish (*Bolbometopon muricatum*) and iconic species that contribute to local economies through eco-tourism, *e.g.*, Humphead wrasse (*Cheilinus undulatus*) (*e.g.*, Hensley and Sherwood, 1993; Dalzell et al., 1996; Houk et al., 2012). Perhaps more troubling is the demise throughout the region of fish spawning aggregations for some of the main target species of coastal commercial fisheries (*e.g.*, Rhodes et al., 2014a). The causes for these impacts are typically broad and often interconnected, and include natural, economic and anthropogenic effects, such as under-valued target species (*e.g.*, Rhodes et al., 2011a), human population increase, common (open) access or proximity to fishing grounds (*e.g.*, Kaunda-Arara et al., 2003), fishing (Jennings and Polunin, 1997; DeMartini et al., 2008), commercialization (*e.g.*, Brewer et al., 2009), sedimentation from terrestrial activities (*e.g.*, Edinger et al., 1998; Victor et al., 2006), destruction of nursery habits (*e.g.*, nearshore corals, seagrass beds and mangroves) (*e.g.*, Hamilton et al., 2017), targeting of spawning aggregations (*e.g.*, Sadovy de Mitcheson et al., 2008; Rhodes et al., 2011b) and extreme weather

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events and climate change (Knowlton and Jackson, 2008).

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

In Pohnpei, a 2006–2007 (2006, hereafter) market-based inshore commercial fishery survey identified more than 153 species among 15 fish families that contributed to the fishery, with nighttime spearfishing overshadowing all other fishing methods (71.3% of the total) (Rhodes et al., 2008). Acanthurids (surgeonfish and unicornfish) comprised more than a quarter of total catch volume with Epinephelids (groupers, hinds and lyretails) and Scarids (parrotfishes) each contributing an additional 15% of caught volumes. Substantial variations were observed in species composition among speared, lined and netted fish. Ten species that included Bluespine unicornfish (*Naso unicornis*), Orangespine unicornfish (*Naso lituratus*), Paddletail snapper (*Lutjanus gibbus*) and Pacific steephead parrotfish (*Hipposcarus longiceps*) were common to two or more gear types, while nearly 2/3 of species were represented by only a few individuals over the 12-month survey. Overall catch-per-unit-effort varied across gears, with gillnets yielding the highest volumes (3.9 $\mathrm{kg\,h^{-1}\,fisher^{-1}}$), followed by nighttime spearfishing (3.6 $\mathrm{kg\,h^{-1}\,fisher^{-1}}$) and line (2.6 $\mathrm{kg\,h^{-1}\,fisher^{-1}}$). For combined gears, juveniles and small adults dominated catch. The 2006 survey also focused on epinephelids, which showed juveniles comprising between 34 and 100% of the catch by species, including nearly 50% of the most commercially targeted species, Camouflage grouper, *Epinephelus polyphekadion* (Rhodes and Tupper, 2007).

The objectives of the current study were (1) to procure additional data from the Pohnpei, Micronesia, inshore commercial fishery and compare it to 2006 data in order to (2) examine possible changes within fished populations and the fishery over a 10-year timeframe and (3) provide recommendations to the Pohnpei State Government for management decision-making. Pohnpei State, as with many other PICTs, has no comprehensive fisheries management plan and has not responded to evidence showing long-term declines over at least a 20-year timeframe. Existing management in the state is piecemeal and outdated, while enforcement efforts are relatively poor and conducted in lieu of a strategic plan, which is directly contributing to fisheries decline. Finally, there has been anecdotal evidence of further decline in the fishery since the 2006 surveys were conducted, with markets and restaurants now struggling to find fish, along with observed shifts to even smaller individuals within target species.

2. Methods

The 2006 and 2015–2016 (2015, hereafter) market surveys were conducted in Pohnpei, Micronesia (07°00′N, 158°15′E) to examine coral reef and nearshore pelagic fish markets around the island (Fig. 1). Pohnpei is one of 8 islands and atolls within the state and is the only high island (791 m), with a population of around 33,000 inhabitants

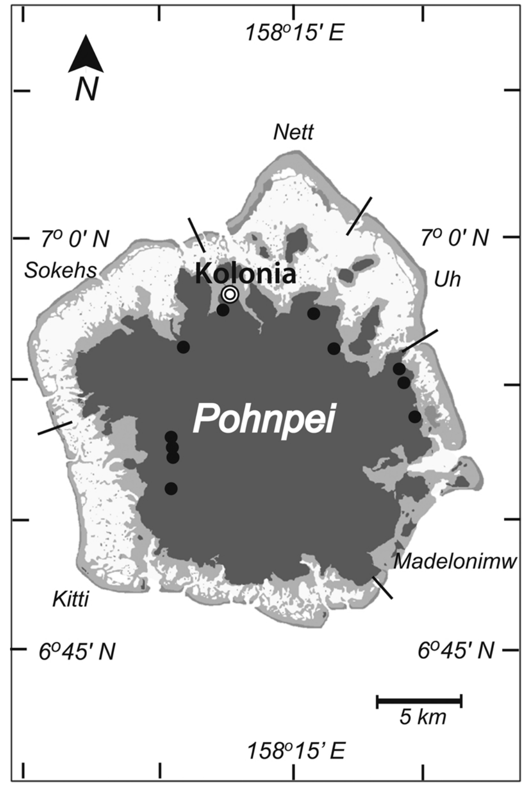

Fig. 1. Map of Pohnpei, Micronesia. The population center of Kolonia (open circle) is where approximately one-half of markets occur, whereas minor and outlying markets (closed circle) are dispersed among each of Pohnpei's five municipalities (italicized text).

living on the main island. The local economy is varied, with about 1/3rd of the workforce employed by government and another 1/3rd living through subsistence. The number of commercial fishers on-island as well as the number and kinds of boats contributing to the fishery is still unknown. Fully 27% of Pohnpeians are dependent on remittance from outside the state and fishing communities are economically marginalized. The island is perhaps best known for its rainfall (*c.* 800 $\mathrm{cm\,yr^{-1}}$) and sakau (*Piper methisticum*), which is farmed in loose soil and sold and consumed locally for its narcotic properties, and is a primary source of terrestrial runoff and subsequent inshore reef sedimentation and nursery habitat loss, particularly in fringing reef environments. Coral dredging, which is active at 25 sites around the island, is also likely impacting fisheries through additional sedimentation and loss of critical nursery habitat for some species (*e.g.* Hamilton et al., 2017).

Based on anecdotal reports, commercialized fisheries have been operating in Pohnpei since the 1960s, with an expansion starting in the 1980s to the current 20 + markets operating in the state. Impacts to the fishery and to individual species prior to 2006 are unknown, however anecdotal reports of the abundance and distribution of marine resources suggest major impacts well before the 2006 market study occurred, *e.g.* the loss of giant clam, changes in depth distribution and abundance of Green humphead parrotfish. Market surveys in both 2006 and 2015 were conducted using the same format (Rhodes et al., 2008) with the exception that the latter surveys benefitted from the use of a digital image capture system (DICS) to electronically document catches. We assume any errors or bias associated with fisher or market owner responses are consistent between surveys. Surveys were concentrated in Kolonia, the population center and economic and state government hub, where most markets operate. As in 2006, additional assessments and fisher interviews were conducted at market locations outside of Kolonia. Marketed volumes of inshore catch were obtained daily from market owners at all locations. The first surveys were conducted 10 January 2006–31 January 2007, while the 10-year follow-up surveys were conducted from 27 January 2015 to 15 January 2016. Both surveys were done from *c.* 0700 to 1700 h Tuesday through Saturday when the majority of markets are operational. Market surveys included the collection of daily purchased volumes (nearest kg) of reef fish (and nearshore pelagics) by all markets operating in the state, which were collated by month and by market. In addition, individual fishers were approached at the time of sale to markets and interviewed for details about the trip, including the number of participating fishers, hours fished (excluding travel time), gear and vessel used, expenditures, targeted reef and fisher origin. Further details were recorded on the market location, including GPS coordinates (Fig. 1). Each day, a number of catches were haphazardly sampled, with catch first split into individual families to gather family weight (nearest 0.1 kg) and then photographed using the DICS.

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

3. Results

Using similar methodology and sample sizes between the 2006 and 2015 surveys, findings reveal substantial changes in the Pohnpei commercial inshore fishery, including altered catch composition and the loss of some target species, reduced catch-per-unit-effort and economic return, and lower overall marketed volumes (Table 1). Over the 10-year timeframe, overall annual marketed volumes for the combined fishery fell around 50 mt (*c.* 20%), trip volumes increased along with increased effort, specifically an uptick in the average number of fishers per trip, a greater use of motorized boats and expanded use of unsustainable fishing methods. Between survey periods, nighttime spearfishing increased from 71.3% of all gears in 2006 (n_{2006} = 607) to 75.6% in 2015 (n_{2015} = 1125), while the use of small-mesh (2-in) gillnets increased from 4.2% (n_{2006} = 34) to 6.3% (n_{2015} = 93). Concomitantly, hook-and-line fishing declined by 6% from 24.3% in 2006 (n_{2006} = 168) to 18.1% in 2015 (n_{2015} = 270). Between survey periods the net economic return was roughly halved for catches from all gears (Table 1) likely in relation to the need to cover expenditures associated with increased commodity prices related to fishing, particularly fuel, which in 2006 was *c.* \$1.75 gal^{-1} (\$0.38 l^{-1}; base consumer price index, 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 increase. During the same period, the price paid to fishers went from *c.* \$1.00 lb^{-1} (\$2.03 kg^{-1}; base CPI) in 2006 to *c.* \$1.40 lb^{-1} (\$2.85 kg^{-1}; adjusted for CPI = \$2.71) in 2015, a 1.3-fold increase, or *c.* one-half the fuel price increase during the same period. Fishing locations also shifted, with 63.8% of fishing in 2006 done inside the lagoon, which had dropped to 42.9% by 2015.

3.1. Fishing locations and fisher origin

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

Table 1
Summary table of fishery parameters in the Pohnpei commercial inshore fishery between 2006 and 2015. CPUE = catch-per-unit-effort; PPUE = price per unit effort, as economic return $fisher^{-1}\,h^{-1}$. Trip volumes represent total catch irrespective of the number of fishers per trip.

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

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

In 2006, a total of 153 species were identified in commercial inshore catch. By 2015, the number of species recorded had increased to 163 species, in part owing to the opportunity to re-examine and positively identify individuals (as images) over longer time periods using the DICS. More than other families, sampling improvements increased the number of holocentrids identified from 1 to 14 species. Sampling in both survey periods split and weighed fish at the family level to provide evidence of a changing fishery (Fig. 4). Among top carnivores, only epinephelids increased in relative volume, however data shows that this increase was supplied through an increased capture of juveniles, particularly for the most commonly targeted grouper (See 3.3 Species shifts and size frequency comparisons, below). Species-specific catch comparisons, as numerical totals, were not possible for the current report since individuals were not counted in 2006 from monitored catches aside from epinephelids, which in both years were identified, weighed and measured individually to allow direct comparison.

Compared to 2006, observed declines in monthly catch volumes were noted during 7 of 12 months surveyed in 2015 (Fig. 5), however these were not statistically significant (*t*-test; $p = .07$). Overall volumes directly marketed (excluding exported fish and fish that went direct to business) declined 18.8%, from 271 mt in 2006 to 220 mt in 2015. In 2015, catch volumes increased from February to July relative to other

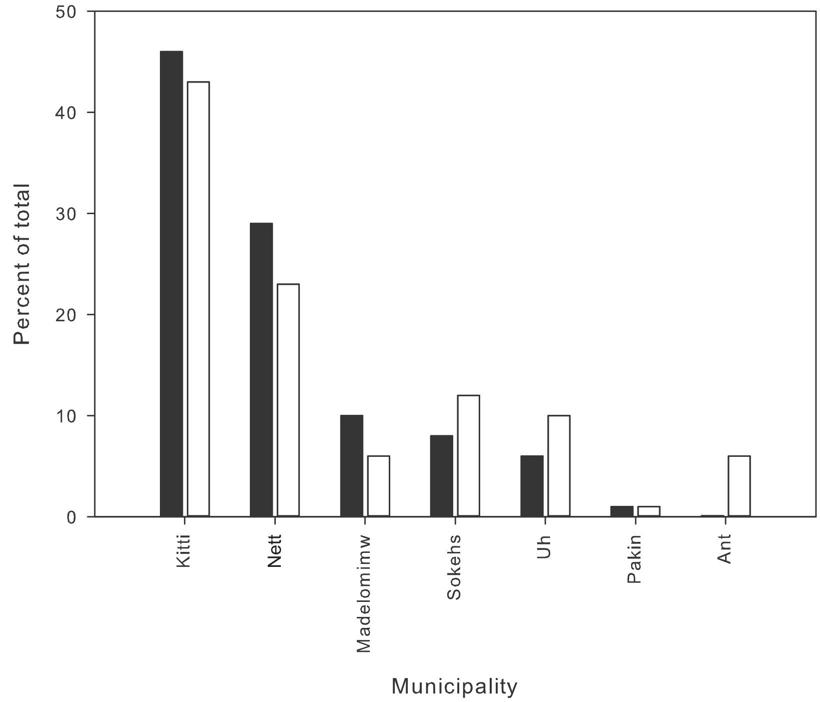

Fig. 2. Fishing locations in 2006 (black) and 2015 (white) showing shifts in targeted fishing areas, as municipalities and atolls (Pakin, Ant). Both Kitti and Nett dominated in terms of commercial fishing pressure, however shifts in fishing pressure were observed in areas previously receiving less fishing pressure, particularly Ant Atoll.

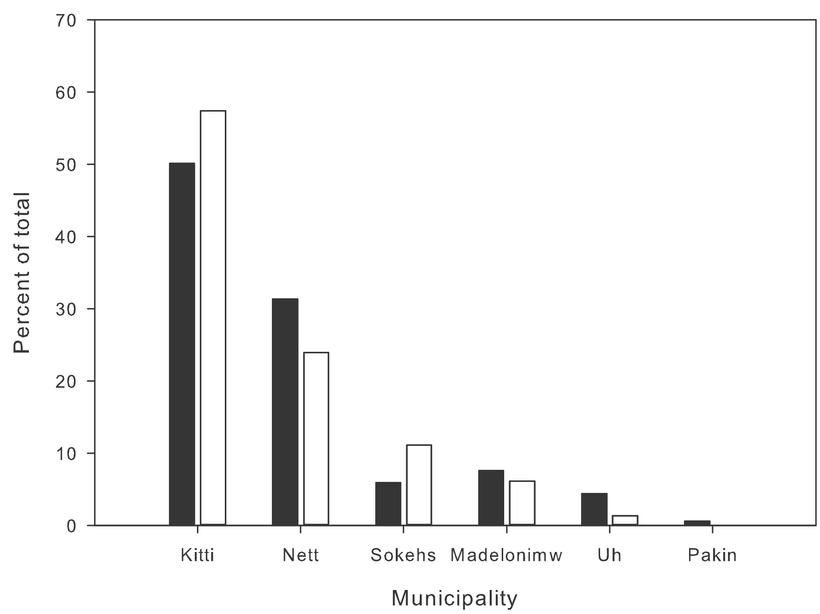

Fig. 3. Fisher origin in 2006 (black) and 2015 (white) showing shifts in the percentage of fisher contributions to commercial catch by area or municipality.

months, which coincides with the peak spawning season identified for all coral reef fish species examined in Pohnpei to date (Rhodes et al., 2014a, 2017; Taylor et al., 2014).

3.3. Species shifts and size frequency comparisons

Inter-survey comparisons identified shifts in the ranks of marketed species and the absence in 2015 of eight species documented previously in 2006: Honeycomb grouper (*Epinephelus merra*), Brownspotted grouper (*Epinephelus chlorostigma*), Netfin grouper (*Epinephelus miliaris*), One-blotch grouper (*Epinephelus melanostigma*), Coral hind (*Cephalopholis miniata*) and Tomato hind (*Cephalopholis sonnerati*), Leopard coralgrouper (*Plectropomus leopardus*), and White-edged lyretail (*Variola albomarginata*). Each of these species was found in relatively low numbers in 2006. For more common species, the Squaretail coralgrouper (*Plectropomus areolatus*) increased in importance within the fishery from the 6th most common grouper to 2nd, while Highfin grouper (*Epinephelus maculatus*) decreased from 8th to 14th (Table 2). Both of the latter species, along with *E. polyphekadion* are known or suspected of forming spawning aggregations, where they are targeted. Two species recorded in 2015, White-streaked grouper (*Epinephelus ongus*) and Snubnose grouper (*Epinephelus macrospilos)* were not observed in 2006.

The mean size of *P. areolatus* was similar between surveys (2006: 42.0 ± 4.1 cm TL; 2015: 42.8 ± 2.5 cm TL), whereas the average size of *E. polyphekadion* (Fig. 6) declined significantly (*t*-test, p < 0.00)

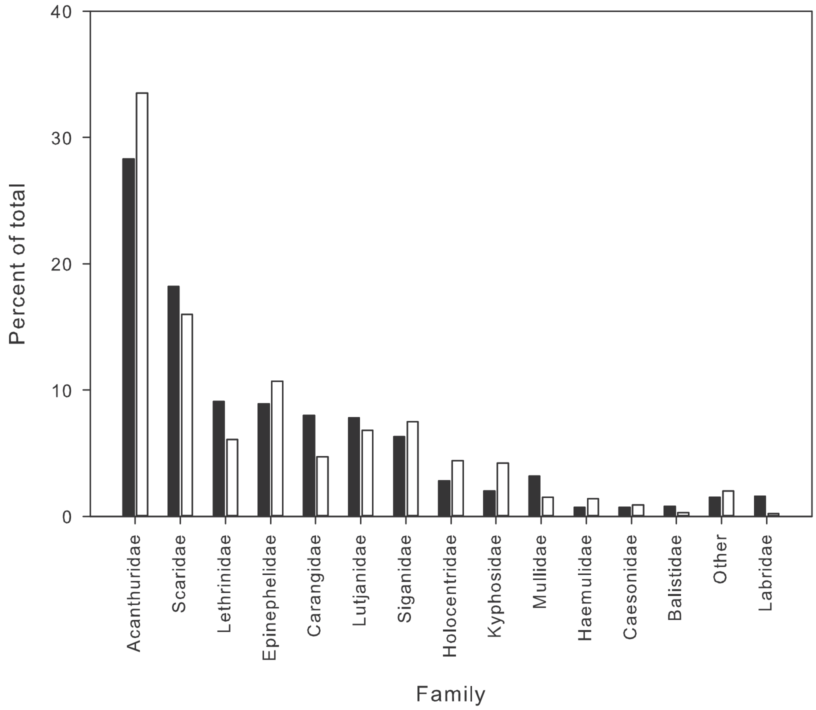

Fig. 4. Fish family volumetric contributions to catch in 2006 and 2015. An overall increase in some lower trophic level families (*i.e.* Acanthuridae, Siganidae) is apparent between survey periods.

from 35.2 ± 0.4 cm TL in 2006 (n = 363) to 32.2 ± 0.0 cm TL (n = 593) in 2015, with only 44% of marketed individuals above the 50% size at sexual maturity. For *N. unicornis*, the only other species for which local size-at-sexual maturity was available (Taylor et al., 2014), 98.8% of individuals (n = 3843) were above the 50% size at male sexual maturity. No sex-specific data were available to gauge the percent of females above the 50% size-at-sexual maturity (31.2 cm FL) threshold.

3.4. Changes in species composition in speared catch

For speared catches examined, increased presence in catch was shown for 28 of 42 species, with the remaining species showing declines (10 species) or no substantial change (Table 3). Planktivores showed the greatest average increase among trophic groups with an 18.9 ± 5.0% increase, while herbivores increased by 10.4 ± 2.1%. Herbivores (16 species) that showed increased presence in catch included 5 scarids, 4 siganids and 2 acanthurids. The greatest shift in presence was for Dash-and-dot goatfish, *Parupeneus barberinus*, which

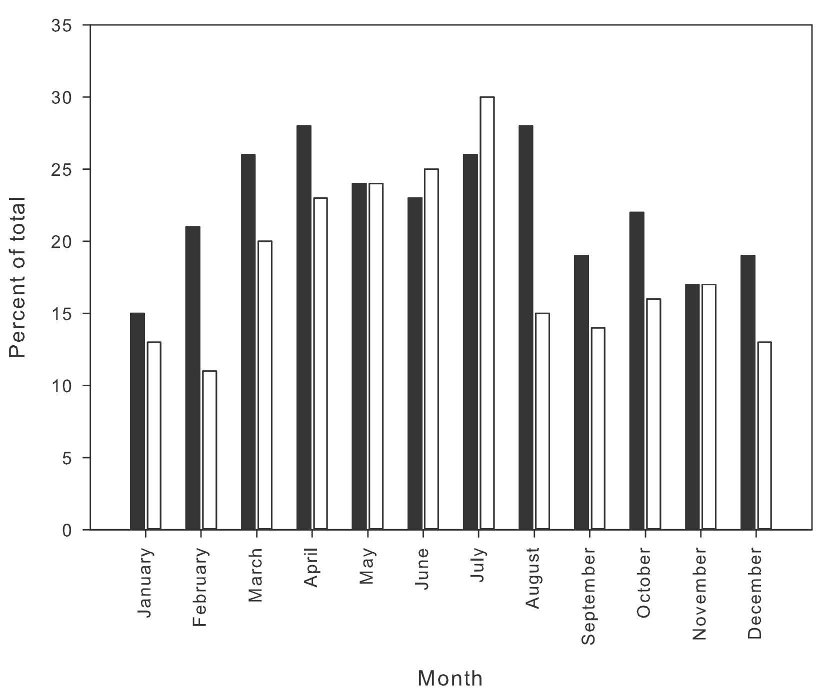

Fig. 5. Monthly volumes of reef fish sold in 2006 (black) and 2015 (white). Although 2006 catch was greater in most months, volume differences were not significant (*t*-test, p = 0.57).

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

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
E. polyphekadion	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
P. areolatus	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
C. argus	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
E. spilotoceps	224	251	13.1	8.5	17–41	19–37	35	na	***	***	20.6 ± 1.9	24.3 ± 0.1	4	4
E. howlandi	224	239	12.1	8.0	18–32	21–38	55	na	***	***	23.6 ± 3.2	28.5 ± 0.2	5	5
E. tauvina	1	157	0.1	5.3	24.0	16–45	100	61.1	0.0	0.0	***	32.2 ± 0.4	24	6
E. coeruleopunctatus	244	156	13.2	5.3	14–41	22 = 53	76	na	***	***	26.5 ± 5.9	38.3 ± 0.6	3	7
E. macrospilos	0	153	0.0	5.2	***	23–40	51	na	***	***	***	29.9 ± 0.5	np	8
E. fuscoguttatus	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
P. oligacanthus	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
E. corallicola	14	22	0.8	0.7	20–30	20–30	49	na	***	***	22.7 ± 2.9	36.2 ± 7.9	12	12
E. leucogrammicus	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
V. louti	14	11	0.8	0.4	30–48	32 = 51	83	na	***	***	29.1 ± 3.6	41.2 ± 1.8	13	13
E. ongus	0	6	0.0	0.2	***	24–31	40	26.1	***	75.0	***	28.8 ± 1.6	np	14
E. maculatus	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
Epinephelus sp.	30	3	1.6	0.1	***	14–45	na	na	***	***	***	***	11	16
C. rogaa	4	3	0.2	0.1	20–23	30–38	60	na	***	***	21.7 ± 1.3	33.3 ± 2.4	18	17
C. sexfasciatus	1	2	0.1	0.1	22.0	22	50	na	***	***	***	***	23	18
P. laevis	1	1	0.1	0.0	43.0	43	125	na	***	***	***	56	25	20
E. melanostigma	33	0	1.8	0.0	18–37	***	35	na	***	***	26.2 ± 5.4	***	9	np
E. merra	27	0	1.5	0.0	18–26	***	32	na	***	***	20.9 ± 2.1	***	10	np
E. miliaris	4	0	0.2	0.0	23–26	***	53	na	***	***	24.5 ± 1.3	***	19	np
C. sonnerati	3	0	0.2	0.0	21–25	***	57	na	***	***	23.8 ± 2.3	***	20	np
C. miniata	2	0	0.1	0.0	19–23	***	50	na	100	***	21.1 ± 3.1	***	21	np
E. chlorostigma	2	0	0.1	0.0	18–34	***	80	28	50	***	26.0 ± 1.1	***	22	np
V. albimarginata	1	0	0.1	0.0	31.0	***	65	na	***	***	***	***	26	np
P. leopardus	5	0	0.3	0.0	33–50	***	120	33.1	0	***	41.2 ± 6.1	***	17	19

was present in 21% less catches examined in 2015 than in 2006. Piscivores showed an average increase of 5.1 ± 3.3%, with two groupers rare in catch in 2006 increasing in catch by 2015, along with three carangids.

4. Discussion

In Pohnpei, surveys over a 10-year time span revealed troubling shifts in the commercial inshore fishery. Among those were an increase in unsustainable fishing methods that appears to be driving diminution of catch volumes and mean size among major commercially targeted species, lowered CPUE and economic return, and shifts in catch to

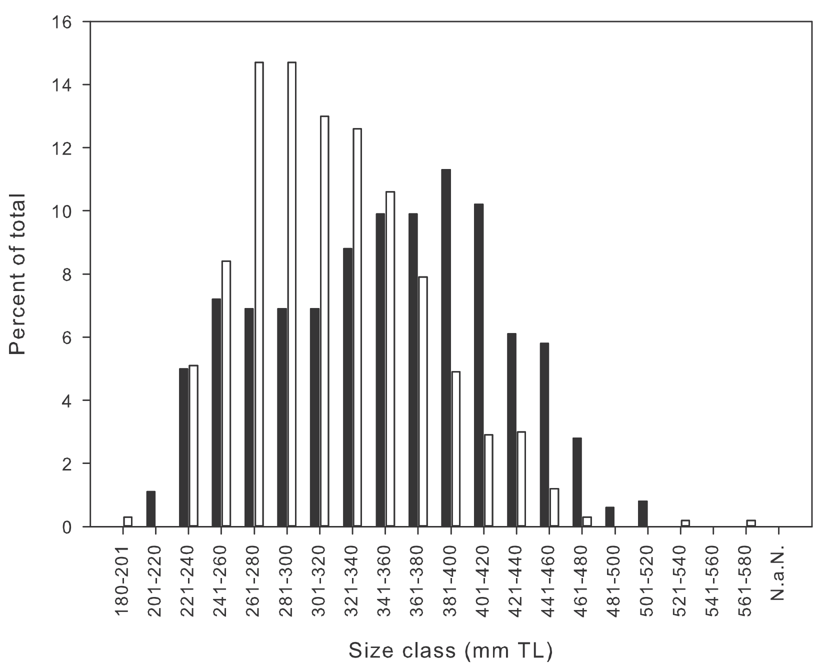

Fig. 6. Size frequency distributions of Camouflage grouper, *Epinephelus polyphekadion* in 2006 (n = 383) (black) and 2015 (n = 889) (white) showing a significant ($p < 0.00$) downward shift in mean size from 35.2 ± 0.4 cm TL to 32.0 ± 0.2 cm TL in 2016–2017 and an increase in the percentage of juveniles in catch.

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

Species	Catches (2006)	Catches (2015)	Freq (2006)	Freq (2015)	Rank (2006)	Rank (2015)	Δ Rank	Tr. Lev	% Chg
Parupeneus barberinus	245	141	71.0	49.6	8	5	–	D	−21.4
Parupeneus indicus	47	16	13.6	5.6	2	1	–	D	−8.0
Acanthurus blochii	10	98	2.9	34.5	1	4	+	H	31.6
Siganus argenteus	94	142	27.2	50.0	3	6	+	H	22.8
Acanthurus nigricauda	194	224	56.2	78.9	6	8	+	H	22.7
Scarus rubrioviolaceus	70	96	20.3	33.8	3	4	+	H	13.5
Siganus punctatus	228	223	66.1	78.5	7	8	+	H	12.4
Chlorurus frontalis	17	41	4.9	14.4	1	2	+	H	9.5
Scarus frenatus	6	29	1.7	10.2	1	2	+	H	8.5
Scarus frontalis	24	41	7.0	14.4	1	2	+	H	7.4
Siganus doliatus	238	208	69.0	73.2	7	8	+	H	4.2
Chlorurus sordidus	0	10	0.0	3.5	0	1	+	H	3.5
Siganus randalli	30	31	8.7	10.9	1	2	+	H	2.2
Naso unicornis	278	253	80.6	89.1	9	9		H	8.5
Hipposcarus longiceps	315	282	91.3	99.3	10	10		H	8.0
Acanthurus olivaceus	31	44	9.0	15.5	1	2	+	H	6.5
Acanthurus xanthopterus	104	102	30.1	35.9	4	4		H	5.8
Naso lituratus	345	284	100.0	100.0	10	10		H	0.0
Caesio caerulaureus	33	111	9.0	39.1	1	4	+	PL	30.1
Myripristis adusta	102	162	29.6	57.0	3	6	+	PL	27.4
Macalor macularis	28	47	8.1	16.5	1	2	+	PL	8.4
Pterocaesio tesselata	37	3	10.7	1.1	2	1	–	PL	−9.6
Lethrinus erythracanthus	8	54	2.3	19.0	1	2	+	I	16.7
Monotaxis grandoculis	222	211	64.4	74.3	7	8	+	I	10.0
Lethrinus xanthochilus	77	89	21.7	31.3	3	4	+	I	9.6
Lethrinus obsoletus	84	93	24.3	32.7	3	4	+	I	8.4
Lethrinus harak	26	36	7.5	12.7	1	2	+	I	5.2
Cheilinus undulatus	79	3	22.9	1.1	3	1	–	I	−21.8
Kyphosus vaigensis	219	144	63.5	50.7	7	6	–	I	−12.8
Cheilinus trilobatus	36	3	10.4	1.1	2	1	–	I	−9.3
Plectrorhinchus albovittatus	15	29	4.3	10.2	1	2	+	I/P	5.9
Caranx melampygus	0	75	0.0	26.4	0	3	+	P	26.4
Epinephelus tauvina	1	66	0.3	23.2	1	3	+	P	22.9
Epinephelus macrospilos	1	55	0.3	19.4	1	2	+	P	19.1
Lutjanus monostigma	96	101	27.8	35.6	3	4	+	P	7.8
Lutjanus gibbus	238	203	69.0	71.5	7	8	+	P	2.5
Carangoides plagiotaenia	0	11	0.0	3.9	0	1	+	P	3.9
Caranx papuensis	0	7	0.0	2.5	0	1	+	P	2.5
Lutjanus semicinctus	106	60	30.7	21.1	4	3	–	P	−9.6
Epinephelus coeruleopunctatus	126	81	36.5	28.5	4	3	–	P	−8.0
Lutjanus fulvus	42	13	12.2	4.6	2	1	–	P	−7.6
Lutjanus bohar	35	19	10.1	6.7	2	1	–	P	−3.4

lower trophic level species. Clearly, there is a need to eliminate nighttime spearfishing and small-mesh nets, and markedly improve the manner in which inshore fisheries are managed and enforced in the state.

Throughout the tropics, nighttime spearfishing use has been increasingly prevalent in inshore fisheries as access to gear has become easier. The gear has been identified as a major contributor to overfishing of inshore resources in part because it is used non-selectively and because fishers target schools of lower trophic level species when they are largely immobile (Gillett and Moy, 2006). This combined with close proximity to markets and the recent shift in many PICTs from subsistence to commercial economies (Cinner and McClanahan, 2006; Cinner et al., 2012) has resulted in negative outcomes for many inshore stocks. While a number of factors have contributed to overfishing in the region, commercialized nighttime spearfishing is perhaps the most damaging and now accounts for *c.* 75% of all inshore fish captured within the Federated States of Micronesia, the US territory of Guam and Commonwealth of the Northern Mariana Islands (Houk et al., 2012). In Guam, nighttime spearfishing and the use of SCUBA spearfishing have all but decimated populations of most higher trophic level species, including epinephelids and lutjanids, while some species, including coastal sharks, *B. muricatum* and *C. undulatus* have become increasingly scarce (*e.g.* Hensley and Sherwood, 1993; Dalzell et al., 1996). These latter species continue to be prime targets of the fishery, with *C. undulatus* still representing the highest percentage of catch by SCUBA spearfishing (Lindfield et al., 2014). The same species have all but disappeared from shallow reefs and passes in Pohnpei within the past two decades (Rhodes, pers. observ.) A 20-year examination of Guam catch data by Lindfield et al. (2014) also revealed a direct correlation between decreasing mean sizes of parrotfish and a shift to a mixed fishery that included greater proportions of acanthurids, with the increased prevalence of nighttime SCUBA spearfishing. The Guam snorkel spearfishery now appears largely devoid of higher trophic level species and there are clear signs that a similar trend is occurring in Pohnpei. Guam is now almost wholly reliant on imported reef fish from Chuuk to maintain demand, with herbivores now the main fishing target among Guam spearfishers (Cuetos-Bueno and Houk, 2018). In the Commonwealth of the Northern Mariana Islands, nighttime spearfishing has been reported to be impacting some easily accessible areas, with abundance declines among major spearfishery targets ranging from 40 to 80%, along with CPUE (Bearden et al., 2005). Overall declines from the 1950s have been estimated at 39–73% (Cuetos-Bueno and Houk, 2015). Bejarano et al. (2013) implicated spearfishing for adding ecological risk in both Pohnpei and Palau by targeting low-redundancy species, such as *N. unicornis*, and targeting juveniles of several species of protogynous parrotfish, including Bicolor parrotfish, *Cetoscarus bicolor,* Ember parrotfish, *Scarus rubroviolaceus* and Steephead parrotfish, *Chlorurus microrhinos*. Other moderate-risk herbivorous species were also identified, including Goldspotted spinefoot, *Siganus punctatus* and *H. longiceps*. Bejarano Chavarro et al. (2013) also showed an increased targeting of less-preferred herbivores by spearfishers during the April-July grouper closure, highlighting the unintended consequences of uninformed management decision-making that in this instance shifted fishing pressure to lower trophic level species. A similar impact was shown in Pohnpei during the March-April grouper closure there, whereby the targeting of lutjanids and scarids increased during grouper ban periods (Rhodes and Tupper, 2007). In Solomon Islands, nighttime spearfishing was reported to cause severe declines in aggregating grouper populations, with a 30-fold difference in CPUE between non-aggregation and aggregation-based catch of *P. areolatus* (Hamilton et al., 2012). The same practice has resulted in the elimination of other species' spawning aggregations in some Solomon Island locales (*e.g.*, Hamilton et al., 2004), while a recent survey of the Gizo (Western Province) inshore fish market showed around one-half of most spearfished species were below the size at sexual maturity (Rhodes, unpubl. data). Similarly, fisher interviews in Gizo noted declining catch and size (Sabetian and Foale, 2006). In Pohnpei, the use of nighttime spearfishing is directly linked to the demise of the shallow water portion of the *P. areolatus* spawning aggregation (Rhodes and Tupper, 2007; Rhodes et al., 2014a), with year-over-year declines in aggregation density for all three grouper species (also Brown-marbled grouper, *Epinephelus fuscoguttatus* and *E. polyphekadion*) aggregating at the site. Herein, we show diminution of mean size of the most commercially targeted grouper, *E. polyphekadion*, changes in overall catch with greater contributions by herbivores and overall reductions in CPUE and catch volumes as fishing efforts increase overall and shift to outer reef areas. Thus, throughout the western and central Pacific, nighttime spearfishing in combination with commercialization appears to be catalyzing unsustainable fisheries.

In Pohnpei, nighttime spearfishing also appears to be altering catch composition, with shifts among the major target species, with the greatest increase shown for herbivores and the appearance in catch of species formerly absent. Recent changes also include the presence of a number of species formerly not preferred by Pohnpeians, including mullids and lethrinids, the former which has shown the greatest decline in catch since the 2006 survey. Boxfish (Ostraciidae), angelfish (Pomacanthidae) and spadefish (Ephippidae) were not found in catches in the years prior to the 2006 survey. Some species present in 2006 were also absent from catch in 2015, including Acute-jawed mullet (*Neomyxus leuciscus*) and Squaretail mullet (*Ellochelon vaigiensis*) and Kanda (*Moolgarda engeli*), a reflection of small-mesh net fishing. Shifts in catch composition may well reflect declines in abundance and it is unclear what impacts these reductions in abundance are having on the reef ecosystem, however the diminution in herbivores from overfishing are known to alter ecosystem function (*e.g.*, Thacker et al., 2001; Hughes et al., 2007), while decreases in individual species abundance can profoundly alter nutrient cycling (*e.g.*, *B. muricatum*) (Bellwood et al., 2003; Bellwood and Choat, 2011). Additionally, sedimentation from upland activities and dredging are profoundly changing inshore reefs and nursery habitats (Turak and Devantier, 2005; Victor et al., 2006). These combined activities, left unabated, increase the potential for eventual fisheries collapse, threaten the food and socio-economic security of coastal fishing communities and impede the ability for non-extractive resource use, including dive tourism development (Cesar et al., 2003). Climate change, whose impacts to fisheries are only beginning to be understood, will present greater challenges to fisheries management, such that any measures that can be made now to mitigate unsustainable fishing and build resilience into these populations should be implemented.

In Pohnpei, state government has clearly shown an inability to grasp or respond to fisheries decline. Rights-based management and shifts in enforcement and monitoring to the municipal governments and communities may enhance a sense of ownership and improve resource protection. Regionally, NGOs and outside funding sources are working to empower local communities through monitoring training and development of locally managed marine areas. Some, such as the Nan Wap LMMA in Pohnpei, have shown success both in protecting critical habitat and improving fish population abundance. Similarly, municipal governments in Pohnpei, including Pakin, U and Kitti have developed fisheries management plans with provisions to restrict access through fisher licensing and boat registration, with enforcement and monitoring by community conservation officers. However, for these actions to be effective, greater support and power sharing is needed between municipal and state governments, the latter who so far appear reluctant to relinquish power or provide the needed resources. Regardless of the format chosen to improve fisheries management, market-based mechanisms should be used to eliminate nighttime spearfishing and small-mesh gillnets, along with strengthened enforcement of existing size restrictions at markets and marine protected areas. The elimination of speared fish from commercial sale during the primary reproductive season in Pohnpei (January–May) and a ban on the importation and sale of small-mesh nets would be a good first step. Nonetheless, a more timely response is needed given the current level of decline to reduce the severity of socio-economic consequences for coastal fishing communities.

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