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REPORT

Characterization and management of the commercial sector of the Pohnpei coral reef fishery, Micronesia

K. L. Rhodes · M. H. Tupper · C. B. Wichilmel

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Abstract Commercial coral reef fisheries in Pohnpei (Micronesia) extract approximately 1,521 kg of reef fish daily (~500 MT year^{-1}) from 152 km^2 of surrounding reef. More than 153 species were represented during surveys, with 25 species very common or common within combined-gear catch. Acanthurids contributed the greatest to catch volume, with bluespine unicornfish, *Naso unicornis*, and orangespine unicornfish, *Naso lituratus*, among the most frequently observed herbivores. Nighttime spearfishing was the dominant fishing method and inner lagoon areas were primarily targeted. A seasonal sales ban (March–April), intended to reduce pressure on reproductively active serranids, significantly increased the capture volume of other families. Catch was significantly greater during periods of low lunar illumination, suggesting higher fishing success or greater effort, or both. The marketed catch was dominated by juveniles and small adults, based on fishes of known size at sexual maturity. Artificially depressed market prices appear to be catalyzing (potential or realized) overfishing by increasing the volume of fish needed to offset rising fuel prices. These results support the need for comprehensive fisheries management that produces sustainable fishing and marketing practices and promotes shared management and enforced responsibilities between communities and the state. To be effective, management should prohibit nighttime spearfishing.

Keywords Coral reef fishery · Precautionary management · Spearfishing · Marine protected areas · Micronesia

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Introduction

Many tropical Pacific communities are dependent on marine resources from coral reef and nearshore environments as a primary source of protein and income (Munro 1996), with the loss of these resources substantially impacting food security and socio-economic structure (Sadovy 2004). While the main impact typically attributed to coral reef environments is human disturbance from fishing (Polunin and Roberts 1996), sedimentation, pollution, and global climate change are also playing increasing roles (Hughes et al. 2003; Victor et al. 2006; Wilson et al. 2006). Unfortunately, the pace of our understanding of human effects on coral reef habitats and associated organisms is considerably slower than the rate of disturbance, thereby creating a dilemma for marine resource managers and biologists tasked with offsetting or preventing resource loss. To further complicate matters, most developing Pacific tropical communities are resource limited, thereby reducing their ability to document, monitor, manage or enforce marine resources and the impacts to them (Adams et al. 1997; Zeller et al. 2006b), which often occur along substantial expanses of coastline. In many Pacific island communities, including Micronesia, the negative impacts to reefs have also been accelerated by the move from a barter system to a cash economy, greater access and improvements to gear, and a post-colonial shift from traditionally managed to openly accessed reefs (Ruddle 1996; Gillet and Moy 2006). Finally, there are inherent complexities within many tropical communities between state authorities and local clan- or tribal-based communities, and even among clans, for ownership, management, and enforcement rights (Dahl 1997). To effectively protect the vital marine resources that these communities depend upon, there is a need to assist marine resource agencies in documenting and monitoring impacts to coral reef ecosystems and facilitate, through observations and recommendations, workable management solutions.

In Pohnpei (Federated States of Micronesia), ongoing efforts over the past decade to document the life history strategies and impacts of fishing on locally and regionally important coral reef fish species have resulted in improved management (Rhodes and Sadovy 2002a). Recent studies in Pohnpei have included investigations of the reproductive dynamics and life history of squaretail coralgrouper (*Plectropomus areolatus*) and camouflage grouper (*Epinephelus polyphekadion*) at (fish) spawning aggregation sites (FSA) to determine the effectiveness of an existing FSA-based marine protected area (MPA) and a seasonal serranid sales ban that covers a portion of the known spawning season (Rhodes and Sadovy 2002a, b). More recently, a market analysis of impacts to locally fished serranids was performed as a sub-component of the current study to further analyze life history component of squaretail coralgrouper and examine the effects of the serranid sales ban on other species (Rhodes and Tupper 2007). Recent rapid environmental assessments of corals and coral reef fishes have also been conducted to assist conservation efforts and two general resource inventories were completed in the 1980s. While each of these has provided general insight into the composition of the coral reef community, and some have resulted in specific management improvements, there has been no detailed investigation of the commercial or subsistence sectors of the coral reef fishery that could be used to improve fisheries management, a common problem among Pacific island communities (e.g., Sadovy 2004; Gillett and Moy 2006; Zeller et al. 2006b).

The objectives of the current study were to document aspects of the Pohnpei coral reef fishery that could serve as a baseline inventory of commercially targeted coral reef fishes and provide insights into the relative volumes of families and species contributing to the fishery. The project was also developed to assess the fishing methods and areas affected by fishing, and include data on the demography of the commercial fishing community. The project provided a detailed examination of the effects of a 2-month serranid sales ban from a market perspective and its relative impacts on serranids and other families within the coral reef fishery, since market-based management has been touted as an effective management strategy in the state (e.g., Rhodes et al. 2005). All of the above objectives were conducted to identify potential problems that are or could threaten the fishery and assess whether improvements to management or changes from within the fishery were needed.

Materials and methods

Pohnpei (07°00′ N, 158°15′ E) is part of the Caroline Islands Archipelago and is the second most populous of four states in the Federated States of Micronesia. The state is comprised of the high island (791 m) of Pohnpei Island (hereafter, Pohnpei) and eight surrounding, and widely distributed atolls within the central Pacific Ocean that combine for 345.2 km^2 of total land area and 858.2 km^2 of lagoon. In contrast to the outer atolls, several rivers and steams emanate from Pohnpei's higher elevations to distribute ~800 cm $year^{-1}$ of precipitation into the mangrove-lined and barrier reef-surrounded lagoon (Fig. 1).

Within Pohnpei, Kolonia (Nett Municipality) serves as the economic and transportation hub for the state, the seat of the local and state government and a center of coral reef fish market activities. Approximately 94% of the state's 35,000 residents live on Pohnpei and are distributed among five municipalities (Pohnpei State Government 1996; Federated States of Micronesia 2002). Fifty-four percent of the population is unemployed, while 11.1% of the total workforce (15+ years of age) is dedicated to agriculture or fishing, including a combined total of 756 commercial and 1,408 subsistence farmers and fishers.[1] Forty-seven percent of the state's commercial farmers/fishers and 19.1% of all subsistence farmers/fishers reside in Kitti Municipality, followed by 16.5% each of commercial and subsistence farmers/fishers in Uh, with lesser proportions elsewhere in Pohnpei.

Fisheries management in Pohnpei currently includes a March–April sales ban on all serranids and nine permanent marine protected areas, including the Kehpara Marine Sanctuary (Fig. 1) that protects the largest recorded spawning aggregations of squaretail coralgrouper, *P. areolatus*, camouflage grouper, *E. polyphekadion*, and brown-marbled

[1] State and federal statistics combine farmers and fishers into one statistic, such that the total number of subsistence fishers is unknown.

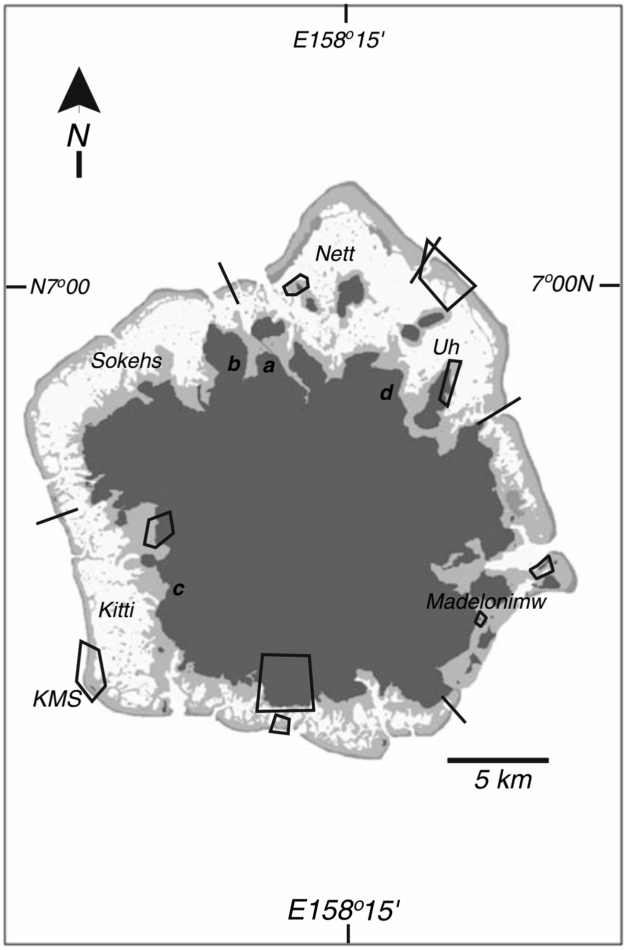

Fig. 1 Map of Pohnpei showing municipal reef boundaries (*lines*) and approximate locations of sampled markets. *a* Kolonia, Nett Municipality; *b* Sokehs Municipality; *c* Seinwar, Kitti Municipality; *d* Uh Municipality. Marine protected area (MPA) boundaries are represented as *black polygons* (areas approximate); *KMS* Kehpara marine sanctuary

grouper, *Epinephelus fuscoguttatus*, in the Indo-Pacific. Other management measures include bans on fishing with chemicals, explosives and SCUBA. No licensing measures are in place for boats or fishers in the state and fishing within Pohnpei is currently open access, with a pre-colonial history of marine tenureship. Markets set prices for fish purchases from fishers and public sale, and no fishing cooperatives are currently active in the state.

Between 10 January 2006 and 31 January 2007, individual coral reef fish markets were surveyed daily for the total fish purchase weight in four of five municipalities (Nett, Uh, Sokehs and Kitti, excluding Madelonimw). As a sub-component of the larger 13-month survey, individual catch evaluations and fisher interviews (see below) were also conducted over 7 months between 10 January and 31 July 2006, including a detailed assessment of serranids from 10 January to 31 May 2006 (see below). Markets chosen for sampling were based on an initial island-wide survey of the number and distribution of markets, with selected markets, representing ~75% of all markets operating, sampled 5–7 days per week between 0700 and 1200 hours when fishers typically land catch. Sample times were based on observations of peak fisher and market activity during prior research (1998–2005) and interviews with marine resource personnel. All major markets were sampled, while smaller or infrequently operating outlying markets were sampled rarely or not at all. For outlying markets that were sampled, daily fish purchase volumes were obtained through phone surveys or through datasheets supplied to markets monthly. Market purchases (as total weight) made after 1200 hours were recorded separately at approximately 1700 hours and compared to morning purchases to verify that selected sampling times sufficiently characterized the fishery. Few fishers and few of the approximately 30 markets operated on Sunday (i.e., the main fishing periods are Monday–Friday, with sale primarily Tuesday–Saturday). Thus, data collection on Sunday was rare and Monday records were typically limited to total weights purchased.

To provide a more accurate estimate of reef fish volume extracted from local reefs, the survey combined a small-scale investigation of reef fish exported and consumed by the local hospital, college, private school and major restaurants and hotels. For fish export estimates, airport surveys were conducted over a 6-day period and included recording total weight, type of marine product exported (i.e., reef fish, crab, eel, pelagic, etc.) and destination from haphazardly selected individuals. Exports were included in the analysis if they contained only reef fish and were not mixed with other marine products. Thus, volumes may underestimate the total daily volume of reef fish exported, since a number of samples were mixed unit marine products. A business survey that included major academic institutes, hospitals, hotels and restaurants was conducted in May 2007 to determine the volume, frequency and source of fish purchases (e.g., fishers, markets). Lacking in the current study to complete the estimated total daily and annual extracted volumes of reef fish is the volume of fish extracted by Pohnpeian subsistence fishers (i.e., non-commercial) that could add considerably to total daily consumption.

From January through July 2006, fishes were separated into family from haphazardly selected catches, and weighed (nearest 0.1 kg), with the total number of surveyed catches varying daily according to availability. Catches were coded to link them to the fisher and details of fishing effort (see below). As a sub-component of catch assessment, all serranids were separated from catch, counted, identified to species or next highest taxonomic level, weighed to the nearest 100 g and measured to the nearest total length (TL) and standard length (SL) in mm. Major findings from the serranid survey are found herein, while additional details may be found in Rhodes and Tupper (2007). All other non-serranid fishes were identified to species or highest taxonomic level but neither quantified nor weighed (as individual species).

In addition to evaluation of catch and to provide a more specific characterization of the fishery, fisher interviews were conducted between January and July 2006, focusing primarily, but not exclusively, on fishers whose catch was examined. Fishers were queried on the total number of fishers per boat, time spent fishing, gear use, total catch weight (divided into sold and kept weights), costs of fuel and supplies, fisher origin and fishing location, both as site (e.g., Peleng Channel) and general reef area (inner or outer reef). From these interviews and to establish a baseline for future comparison, determinations were made for catch-per-unit-effort (CPUE) overall and by reef area, gear and boat type. Additional parameters included average (±SE), fuel and supply costs, and hourly gross and net economic return.

To determine species-specific gear vulnerabilities and the relative importance of species within the fishery, a frequency (of occurrence) index (FI) was developed. For individual species and gears, the FI_{GEAR} represents the frequency of occurrence of a species within all catches examined, normalized to 100%.

Equation 1:

$$FI_{GEAR} = 1/\text{highest frequency of occurrence (FO) of a species gear}^{-1} \times FO \times 100,$$

where FO is the frequency of occurrence.

An overall FI (FI_{ALL}) was also constructed to illustrate the relative importance of (and likely impact to) individual species within the combined-gear fishery. FI_{ALL} is a normalized additive index, based on the relative percent contribution of each gear type to the fishery for the combined survey period and the gear-specific relative contribution of each species. FI_{ALL} is calculated using the formula: Equation 2:

$$FI_{ALL} = 0.713 \times FI_{SPEAR} + 0.243 \times \text{line } FI_{LINE} + 0.042 \times FI_{NET},$$

where 0.713 is the relative contribution of spearfishing to the fishery overall, 0.243 is the contribution of linefishing, and 0.042 is the contribution from netfishing.

Scalar FI rankings for both FI_{GEAR} and FI_{ALL} were arbitrarily assigned to each species, based on observations, as follows: very common (V) = 100–60.1; common = 60–30.1; moderately common (M) = 30–10.1; uncommon (U) = 10–0.

To determine the effect of seasonal sales bans on target families and examine possible changes in fishing habits during those periods, family-specific weight comparisons (as monthly total purchase weight and kg catch^{-1}) were made between open sales and closed sales periods. A Student's *t* test was used to compare open and closed periods for individual family catch weights and square root-transformed monthly percentages of the total volume. Changes in catch volume (as fish sold daily to markets by fishers) were also examined by lunar cycle, based on the fraction of daily lunar illumination, e.g., where 1.00 equals full moon, 0.50 represents last and first quarter moon and 0.00 equals new moon. Lunar standards were set to Chamorro Standard Time (http://aa.usno.navy.mil/cgi-bin/aa_moonill.pl) to simulate Pohnpei lunar cycles. For *t* test comparisons of daily marketed volumes relative to lunar illumination, illumination periods were divided into high (0.500–1.000) and low (0.000–0.499).

Results

Between 10 January 2006 and 31 January 2007, market data (as total purchased weight) was collected during 300 of 387 possible sample days, with individual catches examined on 166 of 202 possible sample days (10 January–31 July 2006). Of the approximately 30 markets operating island-wide, 21.0 ± 0.14 (SE) were sampled daily from four of five municipalities, with combined purchases of 962.2 ± 24.6 (SE) kg reef fish day^{-1} (mean = 46.1 ± 1.8 kg market^{-1} day^{-1}; range 22.2–2,478.5 kg day^{-1}). In addition to the total volume sold, fishers kept an estimated 14.8% (144.2 kg of fish day^{-1}) of catch for home consumption (n = 852 catches). By including unsampled markets and kept weights in estimated totals, the total daily reef fish volume from commercial fishing equals approximately 1,521 kg day^{-1} and roughly 475 MT year^{-1}. Subsistence catch, which was excluded during this survey, could add considerably to total volumes.

Exported volumes from the airport equaled 3.8–25.5% of the total weight of fish marketed in Pohnpei (n = 6). However, it is unclear whether these exports were market-derived or exported directly following capture. Export destinations in order of occurrence were Hawaii, US mainland, Guam, other FSM states, and the Marshall Islands (n = 47). By using a conservative export estimate of 10% of marketed weight, the total volume of reef fish increases to 521 MT year^{-1}. The business survey showed that among major academic institutions, hospitals and hotel/restaurants (n = 13), only two (hotels) purchased fish directly from fishers and that too only in small volumes (~200 kg month^{-1}). Thus, additional inputs from businesses are considered minor.

Within the survey period, 693 individual catches (~30 MT of reef fish) were assessed during morning survey periods for total and family weight and species composition. Morning purchases represented 88.0% of the daily totals, thereby confirming that catch assessments during morning only adequately characterized the coral reef fishery. Acanthurids accounted for 28.6 ± 1.7% of the total weight overall (range 24.6–32.2%) and 10.4 ± 0.7 kg catch^{-1}, while scarids contributed 16.4 ± 1.7% (range 11.4–23.1%) and 5.6 ± 0.5 kg catch^{-1} (Fig. 2a). Serranids represented 14.3% of catch, with 5.5 ± 0.4 kg catch^{-1} and exceeded scarids in both percent of overall volume and catch weight if sales ban months are removed, signifying their true importance to Pohnpei fisheries. Other major families include the Lutjanidae, Carangidae and Lethrinidae, in decreasing order of overall weight, volume, and weight contribution to individual catches.

During the March–April serranid sales ban, the per catch volume (mean ± SE kg) of scarids ($t_{0.05\ (2),\ 745}$, $P = 0.009$), lethrinids ($t_{0.05\ (2),\ 745}$, $P = 0.000$) and mullids ($t_{0.05\ (2),\ 745}$, $P = 0.008$) increased significantly over open sales periods, suggesting a shift in target species during the ban (Fig. 2b). This shift is presumed to maintain overall catch volume and, therefore, income. Monthly variations in mean (±SE) individual catch weight for all species combined and for serranids were observed both outside and during the serranid sales ban (1 March–31 April) (Fig. 3) to show that monthly volumetric trends were not responding solely to the ban.

While the sales ban affected the species of fish targeted, the lunar cycle affected capture volumes. An analysis of daily purchases relative to lunar illumination showed a significantly higher volume of reef fish purchased (as total daily marketed fish weight) during low illumination

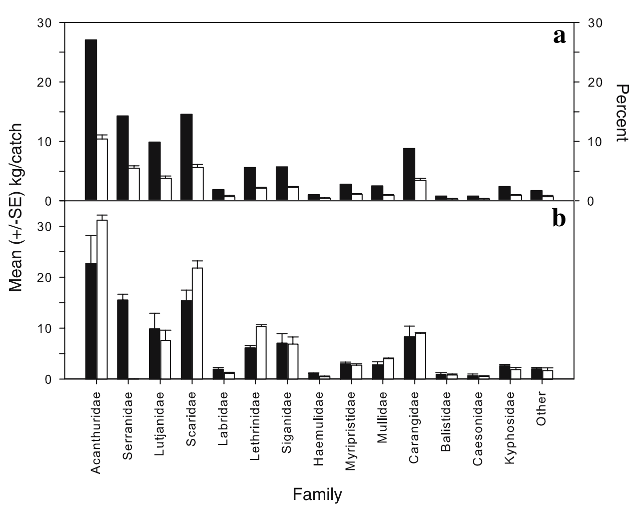

Fig. 2 **a** Percent contribution to total catch volume (*black*) and mean (±SE) kg catch^{-1} (*grey*) of major fish families within the Pohnpei coral reef fishery in 2006; **b** mean (±SE) kg catch^{-1} by family for combined catches within the open (*black*) and closed (*white*) serranid sales ban period

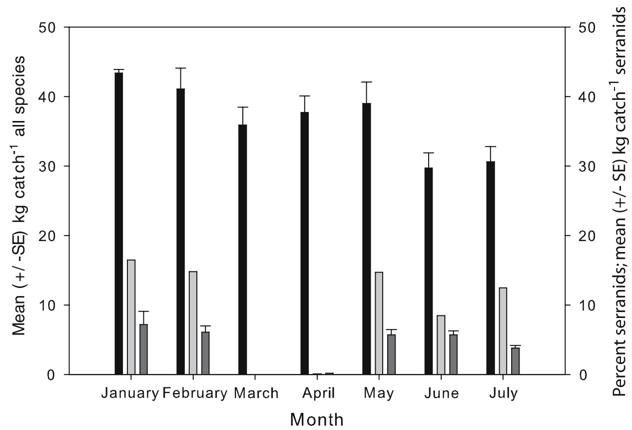

Fig. 3 Monthly mean (±SE) kg catch^{-1} for all species (*black*) and for serranids (*dark grey*). The monthly percent contribution of serranids to overall catch volume is shown in *light grey*

(<50%) periods associated with new moon [1,096.7 ± 35.1 (SE) kg day^{-1}], compared to high illumination (≥50%) periods (836.3 ± 31.2 kg day^{-1}) ($t_{0.05\ (2),\ 298}$, $P < 0.0001$) (Fig. 4) to suggest greater effort and/or greater fishing success during periods of low light. Fishing during low light periods is a known strategy used by spearfishers to reduce backlighting and fish avoidance.

Within the 693 catches examined, 153 species were identified, with unidentified fishes distributed among 15 families and 5 genera (Table 1). Based on the overall frequency index (FI_{ALL}), 25 species were very common (V) or common (C) in combined catch, with an additional 34 species ranked as moderately common (M). Uncommon species (U) were represented by 97 species and a number of unidentified species (Electronic Supplementary Material, Table 1). Only one species, the brassy trevally, *Caranx papuensis*, received a very common ranking for an

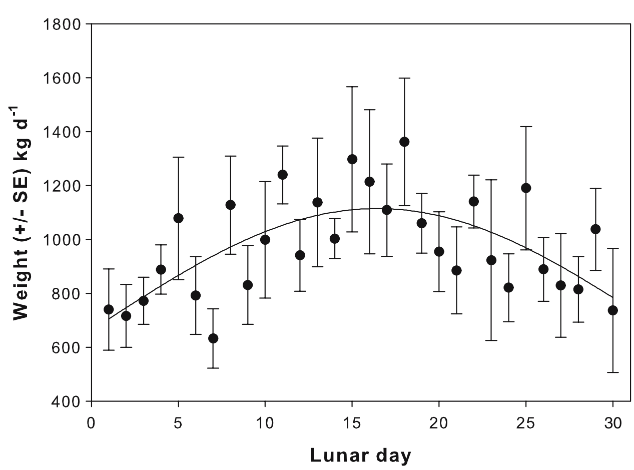

Fig. 4 Daily values (mean ± SE in kg day^{-1}) of catch volumes by lunar day illustrate the significantly higher average yield (as volume of fish purchased by markets) observed during periods of low illumination (lunar days 7–21)

Table 1 The frequency of occurrence and rank (*R*) of very common to moderately common species taken by the coral reef fishery, January–June 2006

Species	No. S	% S	FI S	*R*	No. L	% L	FI L	*R*	No. N	% N	FI N	*R*	CP	FI A	OR
Naso lituratus	345	77.7	100.0	V					5	18.5	35.7	C	56.2	100.0	V
Lutjanus gibbus	238	53.6	69.0	V	96	57.8	100.0	V	7	25.9	50.0	C	53.4	94.9	V
Hipposcarus longiceps	315	70.9	91.3	V	2	1.2	2.1	U	7	25.9	50.0	C	52.0	92.5	V
Myripristidae	256	57.7	74.2	V	53	31.9	55.2	C	4	14.8	28.5	M	49.5	88.1	V
Naso unicornis	278	62.6	80.6	V					6	22.2	42.8	C	45.6	81.1	V
Parupeneus barberinus	245	55.2	71.0	V	1	0.6	1.0	U	4	14.8	28.5	M	40.1	71.4	V
Siganus doliatus	238	53.6	69.0	V					6	22.2	42.8	C	39.2	69.7	V
Siganus punctatus	228	51.4	66.1	V					7	25.9	50.0	C	37.7	67.1	V
Monotaxis grandoculis	222	50.0	64.4	V	7	4.2	7.3	U	5	18.5	35.7	C	37.5	66.6	V
Kyphosus vaigensis	219	49.3	63.5	V	5	3.0	5.2	U	5	18.5	35.7	C	36.7	65.3	V
Lethrinus erythropterus	181	40.8	52.5	C	22	13.3	22.9	M	8	29.6	57.1	C	33.5	59.7	V
Acanthurus nigricauda	194	43.7	56.2	C					4	14.8	28.5	M	31.8	56.5	C
Acanthurus lineatus	167	37.6	48.4	C					5	18.5	35.7	C	27.6	49.1	C
E. polyphekadion	134	30.2	38.8	C	35	21.1	36.5	C	3	11.1	21.4	M	27.1	48.2	C
Scarus rivulatus	163	36.7	47.2	C					3	11.1	21.4	M	26.6	47.4	C
Siganus puellus	158	35.6	45.8	C					8	29.6	57.1	C	26.6	47.4	C
Lutjanus semicinctus	106	23.9	30.7	C	39	23.5	40.6	C	8	29.6	57.1	C	24.0	42.7	C
Lutjanus monostigma	96	21.6	27.8	M	45	27.1	46.9	C	8	29.6	57.1	C	23.2	41.4	C
E. coeruleopunctatus	126	28.4	36.5	C	14	8.4	14.6	M	1	3.7	7.1	U	22.4	39.9	C
Chlorurus microrhinos	129	29.1	37.4	C					6	22.2	42.8	C	21.6	38.5	C
Cephalopholis argus	116	26.1	33.6	C	5	3.0	5.2	U	1	3.7	7.1	U	19.5	34.7	C
E. howlandi	109	24.5	31.6	C	9	5.4	9.4	U	2	7.4	14.3	M	19.1	34.0	C
Lutjanus bohar	35	7.9	10.1	M	76	45.8	79.2	V	8	29.6	57.1	C	18.0	32.0	C
Plectropomus areolatus	108	24.3	31.3	C	1	0.6	1.0	U	1	3.7	7.1	U	17.6	31.4	C
Lethrinus xanthochilus	77	16.9	21.7	M	28	16.9	29.2	M	8	29.6	57.1	C	17.4	30.9	C
Acanthurus xanthopterus	104	23.4	30.1	M									16.7	29.7	M
Myripristis adusta	102	23.0	29.6	M					1	3.7	7.1	U	16.5	29.4	M
Cetoscarus bicolor	96	21.6	27.8	M					2	7.4	14.3	M	15.7	28.0	M
E. spilotoceps	92	20.7	26.7	M	6	3.6	6.3	U					15.7	27.8	M
Siganus argenteus	94	21.2	27.2	M					3	11.1	21.4	M	15.6	27.7	M
Caranx sexfasciatus					87	52.4	90.7	V	8	29.6	57.1	C	14.0	24.9	M
Scarus dimidiatus	86	19.4	24.9	M					1	3.7	7.1	U	14.0	24.8	M
Lethrinus obsoletus	84	18.9	24.3	M	3	1.8	3.1	U					13.9	24.8	M
Lutjanus fulvus	42	9.5	12.2	M	39	23.5	40.6	C	4	14.8	28.5	M	13.1	23.3	M
Parupeneus bifasciatus	83	18.7	24.1	M					1	3.7	7.1	U	13.5	24.0	M
Scarus ghobban	78	17.6	22.6	M					5	18.5	35.7	C	13.3	23.7	M
Parupeneus cyclostomus	79	17.8	22.9	M					3	11.1	21.4	M	13.2	23.4	M
Cheilinus undulatus	79	17.8	22.9	M					1	3.7	7.1	U	12.8	22.8	M
Scarus rubrioviolaceus	70	15.8	20.3	M					2	7.4	14.3	M	11.6	20.6	M
Siganus vulpinis	69	15.5	20.0	M					2	7.4	14.3	M	11.4	20.3	M
Chlorurus bleekeri	66	14.9	19.1	M					3	11.1	21.4	M	11.1	19.7	M
Scarus oviceps	63	14.2	18.3	M					1	3.7	7.1	U	10.3	18.3	M
Scarus tricolor	63	14.2	18.3	M					1	3.7	7.1	M	10.3	18.3	M
Selar crumenopthalmus	2	0.5	0.6	U	66	39.8	68.8	V					10.0	17.8	M
E. fuscoguttatus	48	10.8	13.9	M	8	4.8	8.3	U					8.9	15.8	M
Plectorhinchus lineatus	52	11.7	15.1	M									8.4	14.9	M
Caranx melampygus					45	27.1	46.9	C	10	37.0	71.4	V	8.1	14.5	M
Parupeneus indicus	47	10.6	13.6	M					3	11.1	21.4	M	8.0	14.3	M

Table 1 continued

Species	No. S	% S	FI S	*R*	No. L	% L	FI L	*R*	No. N	% N	FI N	*R*	CP	FI A	OR
Scarus niger	47	10.6	13.6	M					2	7.4	14.3	M	7.9	14.0	M
E. maculatus	27	6.1	7.8	U	24	14.5	25.0	M					7.8	14.0	M
Siganus randalli	30	6.8	8.7	U					14	51.9	100.0	V	7.0	12.4	M
Cheilinus trilobatus	36	8.1	10.4	M	2	1.2	2.1	U	2	7.4	14.3	M	6.4	11.4	M
Lethrinus ornatus	34	7.7	9.9	U	4	2.4	4.2	U	2	7.4	14.3	M	6.4	11.3	M
Lethrinus harak	26	5.9	7.5	U	5	3.0	5.2	U	8	29.6	57.1	C	6.2	10.9	M
Pterocaesio tesselata	37	8.3	10.7	M	1	0.6	1.0	U					6.1	10.8	M
Scarus altipinnis	35	7.9	10.1	M					2	7.4	14.3	M	5.9	10.6	M
Mulloidichthys vanicolensis	29	6.5	8.4	U	1	0.6	1.0	U	6	22.2	42.8	C	5.7	10.2	M
Macalor macularis	28	6.3	8.1	U	8	4.8	8.3	U					5.7	10.1	M
Lethrinus olivaceus	13	2.9	3.8	U	23	13.9	24.0	M					5.5	9.7	M

Shown are the number (no.), percent (%) and frequency index (FI) for speared (S), line (L) and net (N) caught fishes in Pohnpei during the survey, along with a cumulative FI (FI A), cumulative percent (CP), and overall rank (OR). Formulas for calculating the FI are found in "Materials and methods"

E. Epinephelus

individual gear type (i.e., net), yet was listed as uncommon overall. Among very common species in combined catch were the orangespine unicornfish (*Naso lituratus*) and bluespine unicornfish (*Naso unicornis*) that along with the lined surgeonfish (*Acanthurus lineatus*) and epaulette surgeonfish (*Acanthurus nigricauda*) were dominant among acanthurids. Paddletail snapper, *Lutjanus gibbus*, was the most commonly caught species among all gear types, while several species were common within combined spear and net catches, including Pacific longnose parrotfish, *Hipposcarus longiceps*, and longfin emperor, *Lethrinus erythropterus*. Both carangids (*Caranx sexfasciatus, Selar crumenopthalmus*) and lutjanids (*L. gibbus, Lutjanus bohar*) dominated line catch, while the most common netted species was Randall's rabbitfish, *Siganus randalli*. The goldspotted spinefoot, *Siganus punctatus* and the barred spinefoot, *Siganus doliatus* were the most commonly speared and highly FI-ranked siganids. Except for the shadowfin soldierfish (*Myripristis adusta*), all myripristids were lumped together, resulting in a high FI rating for the family. Species richness was highest for speared catch (148 identified species, 11 identified to family), followed by netted (73 identified species, 1 unidentified) and line caught species (69 species, 5 identified to family) (Table 1).

A comparison of frequently occurring species showed that 26 combined species contributed to the top-20 ranked species for lagoon or outer reef areas (Table 2). The greatest disparities among ranks for individual species were for *Epinephelus spilotoceps*, which occurred predominantly in catch from outer reef areas, while *Lethrinus obsoletus* and *Scarus dimidiatus* were substantially more common to catches made inside the lagoon. Species richness was

Table 2 Frequency of occurrence (FO) and rank (*R*) of species in combined catches captured inside (I) and outside (O) reef areas and the rank difference (*Diff*)

Species	FO I	*R* I	*R* O	FO O	*Diff*
Naso lituratus	67.2	2	1	83.7	1
Naso unicornis	56.8	4	5	63.4	1
Siganus doliatus	54.4	7	8	51.5	1
Lutjanus gibbus	54.1	8	9	49.5	1
Scarus rivulatus	35.5	14	15	37.1	1
Hipposcarus longiceps	73.0	1	3	69.3	2
Myripristidae	49.4	9	4	64.4	5
Monotaxis grandoculis	41.7	12	7	57.4	5
Acanthurus nigricauda	55.6	5	10	49.0	5
Siganus punctatus	54.8	6	12	43.6	6
Kyphosus vaigensis	37.8	13	6	59.9	7
Cephalopholis argus	35.1	23	16	35.1	7
Chlororus microrhinos	39.6	21	13	39.6	8
Parupeneus barbarinus	62.5	3	11	43.6	8
Cetoscarus bicolor	29.7	28	19	29.7	9
Epinephelus polyphekadion	26.6	17	26	24.8	9
Lethrinus erythropterus	47.5	10	20	29.7	10
Acanthurus lineatus	27.8	15	2	69.3	13
Siganus puellus	43.2	11	24	26.7	13
Acanthurus xanthopterus	27.8	16	29	21.8	13
Lutjanus monostigma	23.2	19	33	20.8	14
Epinephelus howlandi	31.7	32	17	31.7	15
Epinephelus coeruleopunctatus	37.1	31	14	37.1	17
Scarus dimidiatus	22.8	20	40	13.9	20
Lethrinus obsoletus	26.3	18	39	16.3	21
Epinephelus spilotoceps	30.2	44	18	30.2	26

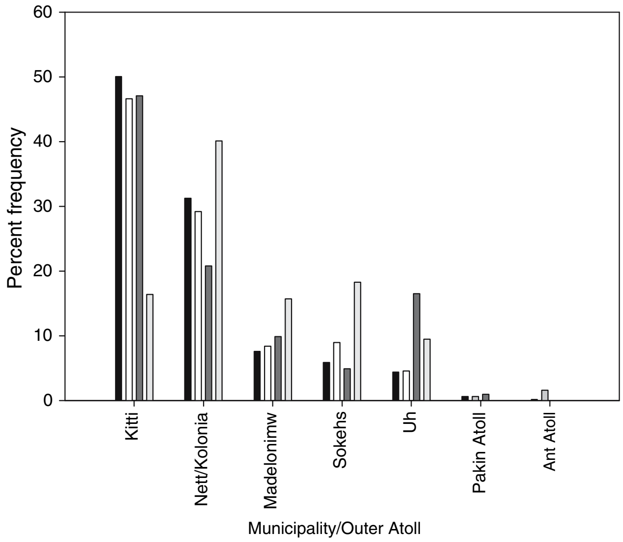

Fig. 5 Fisher origin (*black*) and fishing locale (*white*) by municipality as reported during fisher interviews in 2006. The percent of the total population of Pohnpei Island (*light grey*) and resident commercial fishers and farmers (*dark grey*) by municipality, are also shown for comparison (Pohnpei State Government 1996)

highest from outer reef locations ($n = 136$) compared to the lagoon ($n = 129$) and several uncommon species were unique to inner or outer reef areas.

During the survey, 1,123 fisher interviews were conducted, representing at least 514 (of 756) commercial fishers (Pohnpei State Government 1996), to provide data on CPUE, fisher origin, catch location and gear preference. Spear was the overwhelmingly preferred gear type, accounting for 71.3% of catch, followed by line (24.3%), net (4.2%) or a combination of gears (0.3%) ($N = 943$). Motorized boats were the most common fishing vessel, with 86.1% of fishers using motor, 12.2% using canoe and the remainder swimming from shore (1.7%). More than half (50.1%) of all fishers interviewed originated from Kitti followed by fishers from Nett (31.3%) (Fig. 5). Kitti was also the focus of the most fishing activity, with 46.6% of reported fishing occurring there, although only 16.4% of the Pohnpei (Island) total population are Kitti residents. In general, fishing locations mirrored trends for fisher origin, with the exception of Sokehs, which hosts a preferred line-fishing locale (ship moorings) and, therefore, a higher percentage of effort by fishers from other municipalities. The nearby uninhabited Ant Atoll received only 1.6% of the total reported fishing effort, with 0.6% at the more distant Pakin Atoll. Just over 65% of fishers targeted inside reef locations, while 33.7% fished either in outer reef locales or a combination of both (1.1%) ($n = 979$).

Overall CPUE was 3.4 ± 0.1 (SE) kg hr^{-1}, with an average of 13.8 ± 0.4 fisher h $trip^{-1}$ among all gear types (Table 3). The net return per fisher was US$ 6.19 ± 0.18 h^{-1}. Netfishers recorded the highest CPUE and hourly income, owing to lower expenditures for gas and supplies. Perhaps not surprisingly, fishers who did not use a vessel ($n = 16$) had a higher hourly return than practically all other fishers and a relatively higher CPUE. Cost outputs for fuel and supplies was highest among spearfishers, particularly those using 40 hp motors. The average catch volume per trip was 42.5 ± 1.2 kg.

Among serranids, six species dominated in terms of catch abundance: camouflage grouper, peacock hind, *Cephalopholis argus*, whitespotted grouper, *Epinephelus coeruleopunctatus*, foursaddle grouper, *E. spilotoceps.*

Table 3 Trip values by gear, vessel type/horsepower (h.p.) for Pohnpeian fishers in 2006

		N	Fisher hours		CPUE		Total costs		Gross trip		Net trip		Hourly	
			Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Gear	*Spear*	673	14.6	0.4	3.6	0.1	23.8	0.6	100.0	3.0	72.2	2.7	6.7	0.2
	Line	230	10.9	0.5	2.6	0.1	15.4	0.6	59.1	3.0	43.7	2.9	4.4	0.3
	Net	40	13.1	1.3	3.9	0.3	15.2	2.6	106.5	12.4	91.3	11.5	7.7	0.8
	Overall	946	13.8	0.4	3.4	0.1	21.5	0.5	90.8	2.4	69.2	2.2	6.2	0.2
Vessel/ h.p.	6	2	3	0.0	4.3	2.9	6.9	2.7	33.3	24.2	26.4	21.6	8.8	7.2
	15	27	13.1	2.3	3.4	0.4	17.1	1.7	74.5	9.6	57.4	9.4	5.7	0.9
	25	15	13.8	2.4	2.5	0.5	15.7	1.0	68.3	12.2	52.6	11.7	4.4	0.9
	30	146	12.2	0.8	2.7	0.1	18.1	0.9	70.6	4.1	52.5	3.6	5.0	0.3
	40	647	14.9	0.5	3.6	0.1	26.0	0.6	103.6	3.3	77.6	3.0	6.5	0.2
	Canoe	118	11.4	0.7	2.8	0.2	5.6	0.5	60.2	3.3	54.6	3.2	6.2	0.4
	None	16	4.1	1.0	4.2	0.5	3.6	0.9	32.0	3.8	28.4	3.4	9.3	1.3

All values for costs or income (gross and net trip, hourly return) are in US dollars, rounded up to the nearest 0.1 dollar. Cost values represent items used specifically for fishing, e.g., line, boat motor parts, spear heads, etc

CPUE catch-per-unit-effort

blacksaddle grouper, *E. howlandi*, and squaretail coralgrouper. Both camouflage grouper and highfin grouper, *Epinephelus maculatus*, dominated line catch, while several species were common to spear catch, including the most common species, camouflage grouper and peacock hind. Curiously, camouflage grouper and squaretail coralgrouper, which form large spawning aggregations on the outer reef, dominated the catch inside the lagoon, while peacock hind (*C. argus*) and four-saddle grouper (*E. spilotoceps*) were the most commonly reported serranids captured at outer reef locations. Among serranids with known sizes of sexual maturity, the catch was dominated by small adults and juveniles, with some species, such as squaretail coralgrouper, represented in marketed catch by more than one-third juveniles and >97% below the mean size of sexual maturity for males. Details of the serranid survey are provided in Rhodes and Tupper (2007).

Discussion

Anthropogenic impacts on coral and associated fish populations are becoming an increasing threat to biodiversity throughout the Pacific (Waddell 2005). In Pohnpei, overfishing, sedimentation, pollution, coral mining, dredging, deforestation and mangrove loss have all combined to negatively impact the coral reef ecosystem, home to 330 species of hermatypic corals and 470 recorded coral reef fish species (664 estimated species). Anecdotal reports of fisheries-induced reductions in size and abundance of some large-bodied species (humphead wrasse, *Cheilinus undulatus*, and bumphead parrotfish, *Bolbometopon muricatum*), impacts on spawning aggregations and migrations (e.g., siganids, serranids) (Rhodes and Sadovy 2002a) and accounts of increasing crown-of-thorns starfish outbreaks (*Acanthaster planci*) suggest that significant impacts to the reef ecosystem are occurring (*B. muricatum* is currently banned for sale, owing to large-scale reductions in size and abundance from historic levels; thus, bumphead parrotfish were rare in the observed catch). Unfortunately, Pohnpei is faced with limits in its ability to document, manage and monitor local marine resource depletions and reduce impacts to them, similar to other regional locales (e.g., Zeller et al. 2006b), and must often rely on outside government assistance. This project was undertaken to assist Pohnpei with a comprehensive quantification of the species, locales, methods, and capture efficiency (as CPUE) of the coral reef fishery, and provide an informational baseline to assist current and future management and research efforts. In doing so, the investigation highlights evidence of unsustainable fishing practices, including the use of nighttime spearfishing (Gillet and Moy 2006) and targeting of juveniles and juvenile habitat that may be catalyzing overfishing (Rhodes and Tupper 2007). The findings also show that a substantial volume of reef fish is being removed from the reef daily, particularly herbivores that, ironically, received greater pressure as a result of management attempts to control overfishing of serranids. It is noteworthy that the volumes documented herein do not include subsistence fisheries, which for some Pacific locales are up to 10 times greater that that of the commercial fishery sector (Zeller et al. 2006a). Therefore, catch estimates provided herein may substantially underestimate actual catch volumes. While it is unknown whether contemporary fishing levels are unsustainable, it is likely that a continuation of current fishing and marketing practices will lead to overfishing, as observed elsewhere in the Pacific where similar conditions exist (e.g., Guam, American Samoa, Fiji) (Craig et al. 1993; Hensley and Sherwood 1993; Zeller et al. 2006b).

Perhaps, most troubling among the findings is the degree of reliance on nighttime spearfishing that, as practiced, is a non-selective, highly destructive fishing method characterized by no fish discards and the targeting of practically all life history stages of commercial species encountered (Gillet and Moy 2006). Evidence for non-selectivity is reflected in the large number of species in speared catch and a relatively high volume of juveniles (with serranids serving as a proxy for other species) (Rhodes and Tupper 2007). While it is clear that spearfishing should be eliminated as an acceptable fishing practice for commercial purposes, it (in Pohnpei) is now considered traditional, which will make eradication extremely difficult, particularly using top-down management strategies. Based on the number of individual fishers identified during interviews, at least 514 fisher families (excluding market and service-related industries) depend on commercial fishing, with at least 70% of those reliant on spearfishing. One management option recently offered for Pohnpei (Rhodes and Tupper 2007) is a phase-out ban that increasingly prohibits spearfishing for commercial purposes by one month per year, e.g., a 12-year phase out. The enforcement potential of a commercial spearfishing ban is high since (1) markets are centralized, (2) marine resource enforcement agencies are proximate to markets, and (3) speared fish are readily identified. However, even the concept of a spearfishing ban is receiving resistance among fishers and a compromise measure will likely be needed (e.g., seasonal closures on spearfishing) to strike a balance between management and fishing interests. For any such legislation to pass, however, extensive community outreach and consultation will be required that directly involves fisher input (e.g., Dahl 1997).

Among those fishes most heavily targeted by spearfishers and other gear types in Pohnpei are herbivores, whose importance in structuring reef communities is widely known, as are the effects of overfishing them (Hughes 1996; Littler and Littler 1997; McCook et al. 2001; Bellwood et al. 2004). In Pohnpei, as elsewhere, herbivores are a dominant, diverse species assemblage within the reef fish community. This assemblage clearly receives the brunt of fishing efforts, particularly acanthurids that contribute nearly 30% of the total catch volume and include some of the most heavily targeted species, the orangespine unicornfish (*N. lituratus*), and the bluespine unicornfish (*N. unicornis*). It is likely that management of these and other herbivorous (e.g., siganids) and bioeroder species (e.g., scarids) is needed; yet little is known of their life histories, particularly reproductive habits, spatial and resource requirements, and patterns of movement (but see Meyer and Holland 2005, for *N. unicornis*). However, many small-bodied herbivores are probably early maturing, fast growing species that are likely to recover rapidly following management protection (e.g., Jennings et al. 1999). In contrast, under continued fishing pressure and without management improvement, recovery is unlikely regardless of growth and reproductive potential. In Pohnpei, such is the case for siganids and mugilids, which according to anecdotal reports have been dramatically reduced from historic levels by targeting spawning migrations outside existing MPAs. Therefore, for these and similar species whose life history details are and will likely remain unknown for the near future, a precautionary management approach is warranted, with broader marine protected area coverage and greater strategies to reduce fishing effort. While past creation of MPAs in Pohnpei is laudable, the small size of most current MPAs inherently precludes the combination of essential habitat types needed for many species during ontogenetic development and do not take feeding or reproductive migrations into account. Moreover, few of the current MPAs include shallow water habitats where current fishing efforts appear to be focused. Therefore, larger scale MPAs that link essential habitats for a broad range of species are recommended, using community input in design, monitoring, and enforcement. While effective co-management is rare in the Pacific, in Pohnpei, such a condition will be necessary for MPA function.

The use of MPAs in protecting essential fish habitat was first implemented in Pohnpei in 1995, preceded by a seasonal serranid sales ban introduced in 1987. Both the ban and the MPA were intended to protect reproductively active serranids at and away from spawning sites, including squaretail coralgrouper, *P. areolatus*, camouflage grouper, *E. polyphekadion*, and brown-marbled grouper, *E. fuscoguttatus*. Both measures have shown positive effects, for example, by significantly reducing serranid catch during the March–April ban period and at the Kehpara Marine Sanctuary spawning site (Rhodes and Sadovy 2002a; Rhodes and Tupper 2007). However, both the ban and the MPA have shortcomings and highlight the difficulties associated with single-species (or family) management and small-scale MPAs in lieu of biological data. Specifically, the ban covers only a portion of the reproductive season for all target species, e.g., two of five months for squaretail coralgrouper (Rhodes and Tupper 2007), and may not protect other species known to form spawning aggregations (e.g., highfin grouper, *E. maculatus*), or those that spawn seasonally outside the ban period. The Kehpara MPA, by comparison, is highly effective at protecting spawners at the aggregation site, but appears not to protect them along reproductive migratory pathways or other areas where fish congregate prior to or after spawning (i.e., staging areas). Similar to herbivores, serranids (and a number of other piscivores) would also benefit from larger marine protected areas that specifically include spawning aggregation sites, reproductive migratory pathways and juvenile habitat.

Findings also highlight the need for additional resource protection both in shallow water habitats, which receive 2/3rd of fishing effort statewide, and in Kitti Municipality, where more than 50% of total commercial fishing pressure is focused. Currently, four (of nine) marine protected areas exist in Kitti, including the Kehpara Marine Sanctuary (Fig. 1). However, there is currently limited protection for either central or inner lagoon areas, particularly seagrass and mangrove habitats that are known to be important to a number of coral reef species for feeding, reproduction and ontogenetic development. One possible solution for reducing fishing pressure in Kitti is to expand the KMS to include reproductive migratory pathways and provide greater coverage to adjacent inner reef and central lagoon habitat, where fishing is most commonly observed. Similar improvements could be made to the two existing MPAs that border mangrove areas within Kitti, although it is unclear whether these expansions would shift effort to other areas. The current fishing pressure and observed degradation to reef habitats may already be affecting productivity and signals a need for greater protected area coverage together with a reduction in overall effort and/or volume of fish captured (e.g., Sadovy 2004).

One measure that may be useful in reducing overall catch volume is an increase in market prices paid to fishers that, in turn, would raise prices for consumers, possibly driving down demand. Over the past decade, market prices paid to fishers have remained relatively stagnant, while fuel prices have steadily increased. Specifically, in 1997, fish were sold to markets at US$ 0.85 lb^{-1} (US$ 1.87 kg^{-1}), with a marginal increase to US$ 1.00–1.20 lb^{-1} (US$ 2.20–2.64 kg^{-1}) by 2006, a 41% rise. Simultaneously, fuel prices increased from US$ 1.75 gal^{-1} (US$ 0.46 l^{-1}) to more than US$ 4.00 gal^{-1} (US$ 1.06 l^{-1}) for mixed fuel, or 228%. This 5-fold discrepancy between commodity prices is suspected of driving up catch volumes to cover basic supplies and fuel costs and still maintain a living wage. While further investigation is needed, the price stagnation for fish is undoubtedly creating an undue burden on fishers while maintaining artificially depressed prices for consumers. One alternative to accomplish a market price increase is for Pohnpei fishers to establish fishery cooperatives that help set prices and provide greater power and involvement over marketing decisions, fishing areas, and resource usage. While there is no guarantee for the success of cooperatives in Pohnpei, these have been used effectively in some areas of the Indo-Pacific, particularly where long-term educational support and awareness training was provided to fishers outside the cooperative structure, and improvements to catch followed management implementation (e.g., Baticados 2004). Alternatively, cooperatives will fail if fisher participation is not unanimous or the state allows unlicensed markets to operate that undercut cooperative pricing. Another alternative worth mentioning is a price increase through a state-imposed conservation tax, which would funnel proceeds toward additional marine resource monitoring and enforcement efforts. Regardless, if and when price changes occur, and whether by the state or through the fishing community, a close, thorough a priori and a posteriori examination of both commercial and non-commercial fishing sectors are necessary to ensure that fishing efforts and, therefore, volumes and sales of fish are simply not displaced elsewhere. The likelihood of a profit-driven increase in fishing effort (and, therefore, volume) is low, since (1) consumers are cash-limited and likely to buy less, not more, fish following a price increase, and (2) markets are already approaching (and often exceed) saturation levels in terms of the volume of fresh fish that can be sold daily. These conditions suggest that volumes of marketed fish are more likely to decrease than increase as a result of a price hike. The possible reduction in fish consumption from a price hike is not expected to affect local health (as protein intake), since Pohnpeians currently consume substantially higher volumes of protein than required for daily nutritional needs.

Like many other island nations, Pohnpei is subject to a thriving coral reef fishery that is poorly documented, infrequently monitored, marginally managed and possibly experiencing unsustainable levels of fishing. Clearly, a comprehensive coral reef fisheries management plan is needed that takes into account the current pressures being exerted on individual fish families and species, areas most being affected, and the drivers that are creating the volume, types and life history stage(s) of fishes being targeted (e.g., spearfishing, market pricing, lack of impact and conservation awareness). For Pohnpei, comprehensive management should include a reduction and eventual ban on nighttime spearfishing, some method to reduce juveniles entering the market (i.e., size limits), a market pricing scheme that accounts for costs to fishers and larger, more biologically meaningful and co-managed marine protected areas that encompass mangrove, lagoon and outer reef areas. Past experience has shown that the national and state governments throughout the Pacific are rarely fitted with sufficient revenue and resources to fully and properly manage coastal marine fisheries (e.g., Zeller et al. 2006b). While some market-based management, such as size limits and gear restrictions can be effectively introduced and enforced through state marine resource management agencies (in Pohnpei), others, such as marine protected area management, will require greater cooperative assistance from fishing communities, municipal governments, and clan leaders (e.g., Dahl 1997; Johannes 1998; Walmsley and White 2003). To develop a comprehensive fisheries strategy, state and community leaders, market owners, and members of the fishing community must initiate and coordinate the development and implementation of workable management solutions (see Bellwood et al. 2004). These solutions should include both market-based and area-based initiatives and introduce innovative solutions that reduce overall fishing effort. In the case of Pohnpei, consumers of marine products should share the burden of increasing fuel prices that are already being experienced in other sectors of the food industry. The proactive management and enforcement steps Pohnpei has shown in the past demonstrates the potential for development of an effective management strategy, while market findings (similar to those of other regionally overfished island nations) illustrate the urgency with which such a strategy should be developed.

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