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Socioeconomic factors that lead to overfishing in small-scale coral reef fisheries of Papua New Guinea

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SUMMARY

The coral reefs of Papua New Guinea are among the most species diverse in the world, support an important artisanal fishery, but lack an effective national conservation programme. Increased commercialization, population growth, promotion of fisheries development projects, and the live reef food fish trade are expected to increase demand for the country's reef fish. This paper examines how socioeconomic factors affect the condition of the artisanal multi-species coral reef fishery in six sites in Papua New Guinea. Catch characteristics such as diversity, trophic level and body size by landing site were examined along a fishing pressure gradient. Both exogenous factors such as markets and endogenous factors such as fishing pressure were related to the condition of fish catch. In general, the trophic level and lengths of fish captured in Papua New Guinea were relatively high, but were reduced on reefs with high fishing effort near fish markets. Fisheries showed signs of depletion above *c*. 25 fishing trips per km^2 per day and the proximity of markets was a better indicator of overfishing than human population size. A cross-scale approach to fisheries management is required in Papua New Guinea to coordinate decentralized local management, limit the intrusion of extractive enterprises, and develop policies that seek to minimize exogenous pressures on marine resources.

Keywords: coral reefs, fishing effort, gear selectivity, overfishing, Papua New Guinea, socioeconomic

INTRODUCTION

The region of South-east Asia and Melanesia, which includes the nations of Indonesia, Philippines, Malaysia and Papua New Guinea (PNG), harbours the highest marine diversity on Earth (Hughes *et al*. 2002). Poor fisheries management threatens the natural resources and biodiversity of much of this region (Bryant *et al*. 1998). This situation is particularly acute in Indonesia, Malaysia and the Philippines, where overfishing has reduced fish stocks in many areas to well below their maximum sustainable yields (ICLARM [The International Center for Living Aquatic Resources Management] 1997; Tomascik *et al*. 1997) and destructive fishing is common (Pauly *et al*. 1989; Edinger 1998; White *et al*. 2000). The least exploited marine resources in this region are found in PNG, where 40 000 km^2 of coral reefs above a water depth of 30 m (Frielink 1983) constitute an extensive resource, with harvests estimated at less than 20% of the maximum sustainable yield on a national level (Huber 1994).

Currently, the reefs in PNG are exploited almost exclusively by small-scale artisanal and subsistence fishers that use a range of techniques such as spear guns, hook and line, hand spears, kite fishing, gill nets, hand traps, derris root, dynamite, weirs and bamboo traps to harvest reef and reef-associated fish (Dalzell & Wright 1990; Huber 1994; Quinn 2004). Despite the overall health of the PNG fishery, local overexploitation has been noted, particularly in fisheries with access to cash markets (Huber 1994). Human population density, technological efficiency and market pressure have been cited as probable causes of overfishing (McClanahan 2006), but few studies have directly examined how socioeconomic factors may affect the catch in small-scale artisanal fisheries (Dalzell & Wright 1990).

PNG provided a good site for our study of the factors leading to overfishing in artisanal reef fisheries because: (1) it is the only place in the centre of marine biodiversity where sites with low fishing pressure are widespread, but pockets of overfishing are present, and (2) determining fishing pressure for a particular area was facilitated by the presence of customary marine tenure regimes that exclude outsiders from accessing marine resources (Cinner 2005). In this paper, we explore how the condition of the artisanal and subsistence fishery is related to socioeconomic factors along a gradient of fishing pressure. To accomplish this, we (1) examined catch characteristics (namely fish diversity, length and trophic level) and socioeconomic conditions (namely population size, dependence on the fishery, distance to market, size of fishing ground and fishing pressure) in six PNG fisheries, (2) determined whether fish catch characteristics were related to socioeconomic conditions in the fisheries sites, and (3) determined the level of fishing pressure at which the effects of overfishing might become apparent. By relating the catch and fishing data to effort and the socioeconomic conditions at the study sites, we aimed to determine what specific socioeconomic factors might be responsible for overfishing.

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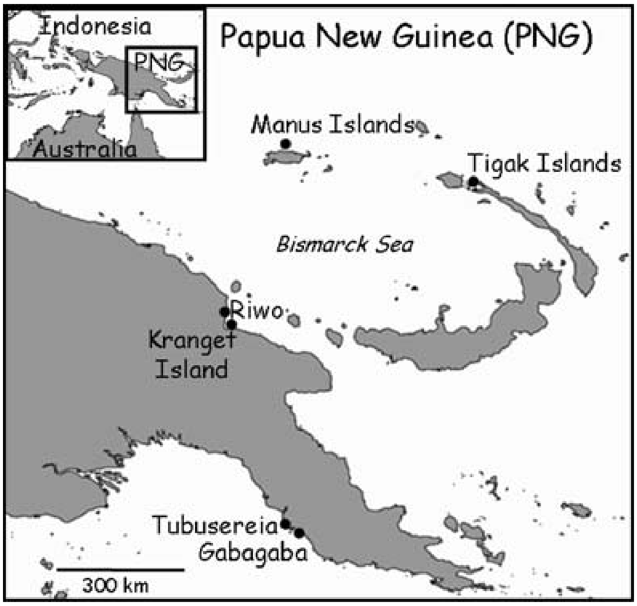

Figure 1 Map of fisheries study sites in Papua New Guinea.

METHODS

Study sites

Study sites were purposively selected to encompass a wide range of social, economic, demographic, and resource governance conditions (for example varying degrees of remoteness, marine tenure, market influence and dependence on marine resources; Agrawal 2001). This present study covers the six sites (Fig. 1) where we were able to sample >250 fish from local landing sites and markets. In some instances a site consisted of a single village and, in others, it consisted of several villages combined. We combined neighbouring villages into a single site when our sampling of fish catches produced <250 fish per village so there would be adequate catch data. In particular, the Manus Islands site encompasses the communities of Ahus and Andra, and the Tigak Islands site encompasses the communities of Mongol, Nusa Lik, Sivasat and Enuk; thus this study covers a total of 10 coastal communities. Initially our socioeconomic research included an additional four communities from Kimbe Bay (West New Britain province) and Karkar Island (Madang province) (Cinner 2005; Cinner *et al.* 2003, 2006), but fishing pressure in these communities was so light that an inadequate catch sample was obtained. A modified study was later conducted at two sites in the New Ireland province, but fish catch were not sampled. We also studied sites in Indonesia (Cinner 2005; Cinner *et al.* 2006), but chose to limit this study to PNG because aerial images compatible with the aerial photos we used to calculate fishing ground area for PNG could not be obtained for the Indonesian sites. We felt that the potential bias introduced by using inconsistent estimates of fishing area would outweigh the potential benefits of including more sites. Since the study sites were not randomly selected, these villages cannot be considered a statistically representative sample of coastal communities in PNG. Therefore, it is not possible to extrapolate the findings from this site-limited study more widely.

Socioeconomic indicators

At each site, we examined the human population, their dependence on fishing, distance to market, percentage of fish bartered or sold, the size of fishing grounds and fishing effort. We conducted research over one to three weeks per village using up to two trained local assistants to aid in data collection. In each community, we used household surveys to elicit information on fishing pressure, dependence on the fishery and the percentage of fish going to market. We triangulated information obtained through surveys with key informant interviews and participation in fishing activities at each site.

We conducted between 33 and 51 household surveys in each village, making a combined total of 373 surveys throughout the study. Household sampling was based on a systematic sample design, where a sampling fraction of every i^{th} house (for example 2nd, 3rd, 4th) was determined by dividing the total number of households in the village by the sample size (Henry 1990; de Vaus 1991). The time and resources available (such as number of assistants and number of days available to conduct the surveys) determined the number of households surveyed in each village. The head of each household was interviewed unless unavailable, when another adult from the household was interviewed. Interviews generally took 25–40 minutes per household.

We determined the household's dependence on the fishery by asking respondents to list the occupations their household engaged in and rank these occupations from most important to least important (Pollnac & Crawford 2000). We estimated fishing pressure by asking household respondents to estimate the average number of days per week that each member of the household typically engaged in fishing. Respondents reported the proportion of time spent using different gear types. We averaged seasonal variations to obtain a general estimate for the entire year. We extrapolated these data to estimate the total fishing pressure on reef resources for the entire community and divided this by the area of fishing grounds (see below) to obtain fishing pressure per km^2. We determined human population density by dividing the human population at each site by the area of fishing grounds. We determined the percentage of fish sold or bartered by asking respondents how many fish they would catch in a typical fishing trip and the number of fish that would be sold in the market. On Kranket Island we used key informants rather than household surveys to determine the percentage of fish sold at the market. We pooled survey data for sites that consisted of one or more communities (such as the Manus and Tigak Islands) and averaged village-level indicators, such as distance to markets and the size of fishing ground.

We conducted structured interviews with key informants (such as community leaders and fishers) to examine selected

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issues in more detail, such as seasonality of fishing activities, market activities and the borders of fishing grounds. We selected key informants using non-probability sampling techniques, including convenience sampling (for example approaching a respondent during resource-use activities) or snowball sampling (where community members suggest appropriate respondents) (Henry 1990). We conducted 3–15 key informant interviews in each village. Distance to the nearest market was measured on a map or nautical chart. J. Cinner participated in 1–10 fishing trips per site to acquire detailed information about specific gear use.

Due to the largely artisanal nature of the fishery that we studied and because observations of most fishing practices occurred on shallow reefs or the reef edges, we used our own method for calculating the size of shallow-water fishing grounds. Key informants provided us with easily discernable landmarks and sea features that acted as or approximated the borders of their fishing grounds. We analysed 1:100 000 aerial photographs with the UTHSCSA (University of Texas Health and Science Centre, San Antonio, USA) Image Tool 2.0 for Windows™. We used the image analysis software to digitally trace the area of all shallow-water habitats (seagrass, sand and reef) above approximately 10 m depth within the borders that we were shown for each village. Therefore, the fishing pressure indices we use include only shallow-water areas and should not be directly compared with estimates that may also include substantial deep-water areas. None of the photographs contained fixed geodetic points, so we calibrated the digital images by measuring the distance between two easily discernable points near the centre of the actual photograph and extrapolating the distance based on the 1:100 000 scale of the photograph. We did not correct for edge distortion in the photographs.

Gear and landing studies

We also collected data on the abundance, composition and length structure of fish landings in the six sites. We examined a total of 2621 fish obtained from landing sites, fish displayed in local markets and fish being sold to local fish buyers. The communities and landing sites were small enough for us to be confident that we did not double-count fish (i.e. record them on the beach and then later at the market). At the landing sites, we approached fishers as they returned from fishing activities and asked if their catch could be examined. We opportunistically examined fish landings at all times of the day and night. We used the methodology of Cinner *et al.* (2005*a*) to examine fish catch, whereby all fish catch data were photographed using a digital camera (Sony™ DSC P-1, 3.3 megapixel). We included a scale in all photographs for the purpose of size calibration. We measured the standard length, total length and fork length for each fish from the digital photographs with the UTHSCSA Image Tool 2.0 for Windows™. Occasionally the scale was missing from the photograph, or a particular fish was at an angle at which its length could not be determined, thus we had lengths for a total of 1935 fish. Benthic reef fisheries show low seasonality in some locations (McClanahan & Mangi 2000), but since only 2–3 weeks were spent in each community, the fish landing data for each community were not necessarily representative of local fish catch throughout the year and comparative results between sites should be interpreted with caution.

Catch analyses

We analysed the following fish catch characteristics for each site: a mean modified Simpson's index of diversity ($D = 1 - \sum n_i/N_t$), the mean standard length, the mean infinite length (i.e. the mean length the fish captured could potentially reach if they were to grow indefinitely) and the mean trophic level. In order to estimate trophic level, we obtained the mean trophic level for each species from FishBase (Froese & Pauly 2000), where compiled diet composition data and the trophic level of each fraction of the diet of the fish were used to calculate the mean trophic level (Pauly *et al.* 2000). In the few cases where species were absent from FishBase, we used the trophic level of closely-related species in the same genus. When a fish could not be identified to species level, we used the average trophic level for all other species in our sample of that family. In order to determine if fishing was preferentially influencing species with large body sizes, we took the infinite length (*Linf*) from FishBase for each species caught, and used it to calculate an average *Linf* for the catch at each landing site (Jennings *et al.* 1999). This was done by multiplying *Linf* by the density of the individual species in the catch, summing, and dividing by the number of species in the sample.

We also examined these characteristics for the dominant fishing gears used. Although a variety of gears and techniques were used throughout PNG, three main gear types were comparable across study sites, namely hook-and-line fishing, gill nets and spear guns. We used the following formula to calculate the mean trophic level of the catch for each gear:

$$TL_k = \frac{\sum_{i=1}^{m} y TL}{\sum y}$$

where Y_{ik} is the catch of species i in gear k and TL is the trophic level of species i for m (number) sampled fish species (Pauly *et al.* 2001).

We used one-way ANOVA comparisons to test for differences in the above variables for the catch by gear. When we found overall significance, we used the Tukey-Kramer honest significant differences (HSD) to conduct pairwise comparisons to determine which of the gears differed (Sall *et al.* 2001).

Examining how socioeconomic factors are related to catch characteristics

We used a Spearman's rank correlation to examine whether socioeconomic conditions at each site (population,

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dependence on fishing, distance to market, per cent of fish bartered or sold, size of fishing grounds, population density and fishing pressure) were related to catch characteristics (trophic level, diversity, mean length and *Linf* of fish). The six sites could be divided into three high and three low fishing pressure sites and, therefore, we divided them into two groups (low pressure <25 trips day^{-1} km^{-2} and high pressure >25 trips day^{-1} km^{-2}) and used a nested ANOVA to test for statistical significance in catch characteristics between the two groups. We also used a two-way ANOVA to test whether the interaction of gear and fishing effort was significantly related to fish length and trophic level.

RESULTS

Coastal communities in PNG were very heterogeneous with regard to their use of reef fisheries. Dependence on fishing, distance to market, area of fishing grounds (sand/reef/seagrass), percentage of fish catch sold or used for subsistence and fishing pressure varied considerably across study sites (Table 1). Between 55 and 72% of the fish caught were reportedly bartered or sold (Table 1). Respondents suggested that the larger and more preferential fish were typically sold at the market. The Tigak, Riwo and Kranket Islands had fish buyers <10 km away and access to local and export fish markets.

Both the overall intensity and the effort allocated to specific gear types varied considerably from community to community (Table 1). Fishing pressure ranged from 16 trips day^{-1} km^{-2} in Gabagaba to 209 trips day^{-1} km^{-2} in Kranget Island. A grouping based on fishing pressure among the sites was evident; the Gabagaba, Tigak Islands and Manus Islands sites had relatively low fishing pressure (with 16, 17 and 21 trips day^{-1} km^{-2}, respectively) and the Tubusereia, Riwo Island and Kranget Island sites had high fishing pressure (with 59, 167, 209 trips day^{-1} km^{-2}, respectively).

There were considerable differences in mean, infinite lengths and trophic level of catches between study sites (Table 2). Length ranged from a mean of 142 mm (± 3.5 SE) in Riwo to 226 mm (± 5.9) in Gabagaba. Trophic levels also ranged from a mean of 2.7 (± 0.04) in Kranget to 3.54 (± 0.04) in Gabagaba. The Simpson's diversity index of the catches was high, but the range was small (from 0.86 in Tubusereia to 0.95 in Gabagaba). We examined the correlations among the fish catch indicators (mean length, diversity and trophic level) at the site level to ensure that each was relatively independent. The variables did not manifest statistically significant levels of intercorrelation at a 0.05 significance level, and thus can be considered to represent independent indicators.

Standard length, infinite length and trophic level of the catch were related to several socioeconomic characteristics, including fishing pressure, distance to markets and the size of fishing grounds (Table 3). The catches in the three sites with lower fishing pressure (Gabagaba, Tigak Islands and Manus Islands) had significantly higher mean trophic levels (ANOVA, $F = 53.5$, $df = 5$, $p < 0.001$) and fish lengths (ANOVA, $F = 57.0$, $df = 5$, $p < 0.001$) than the sites with higher fishing pressure (Tubusereia, Riwo and Kranget). The mean trophic level of fish catch was negatively related to fishing pressure and positively related to the size of fishing

Table 1 Socioeconomic characteristics of the study sites organized from left to right as lowest to highest fishing pressure. [a]Includes the communities of Enuk, Nusa Lik, Sivasat and Mongol. [b]Includes the communities of Ahus and Andra. NA = not available.

Factor	*Gabagaba*	*Tigak*[a]	*Manus*[b]	*Tubusereia*	*Riwo*	*Kranget*
Human population size	1707	1073	1021	5000	1136	2127
Human population density (people km^{-2} of fishing ground)	114.6	98.4	92.0	490	111.4	2363
Fishing ranked as most important livelihood strategy (% of community)	51.4	24.2	65.5	17.7	24.3	35.1
Distance to market (km)	58	5	26	25	7	1
Fish sold or bartered (%)	66.3	55.6	71.8	NA	56.4	66.5
Size of fishing ground	14.9	10.9	11.1	10.2	0.7	0.9
Total fishing pressure/area (trips day^{-1} km^{-2})	15.7	17.3	21.4	58.9	164.4	208.6
Line fishing (trips day^{-1} km^{-2})	8.7	8.3	10.7	27.6	75.3	120.3
Net fishing (trips day^{-1} km^{-2})	2.0	2.9	0.7	27.4	15.3	18.7
Spear fishing (trips day^{-1} km^{-2})	1.1	5.6	10.0	2.6	45.9	49.9
Marine tenure	strong	moderate	strong	weak	moderate	weak

Table 2 Diversity, size and trophic level of fish caught by region organized from left to right as lowest to highest fishing pressure.

Fish catch characteristic	*Gabagaba*	*Tigak*	*Manus*	*Tubusereia*	*Riwo*	*Kranget*
Diversity	0.97	0.95	0.89	0.86	0.91	0.91
Mean length (mm ± SE)	226 (± 5.9)	219 (± 7.8)	202 (± 7.6)	172 (± 4.5)	142 (± 3.5)	152 (± 5.0)
Mean infinite length (mm ± SE)	636.6 (± 25.0)	486.1 (± 8.9)	567.7 (± 42.5)	417.9 (± 7.4)	452.4 (± 17.2)	483.2 (± 14.8)
Mean trophic level	3.5 (± 0.04)	3.0 (± 0.08)	3.2 (± 0.05)	3.1 (± 0.03)	2.8 (± 0.04)	2.7 (± 0.03)

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Table 3 Results of Spearman's rank correlations between socioeconomic conditions and catch characteristics (*$p < 0.05$, **$p < 0.01$).

Socioeconomic conditions	*Length*	*Linf*	*Trophic level*
Total fishing pressure (trips day^{-1} km^{-2})	−0.943**	−0.714	−0.829*
Line fishing pressure (trips day^{-1} km^{-2})	−0.943**	−0.600	−0.657
Net fishing pressure (trips day^{-1} km^{-2})	−0.600	−0.886*	−0.600
Spear fishing pressure (trips day^{-1} km^{-2})	−0.771	−0.314	−0.829*
Distance to markets	−0.543	0.486	0.943**
Size of fishing grounds (km^2)	0.943**	0.829*	0.886*
Human population	−0.257	−0.543	−0.200
Human population density	−0.314	−0.429	−0.371
% Fish sold/bartered	−0.100	0.300	0.100
% Community that ranked fishing as the primary occupation	0.257	0.771	0.371

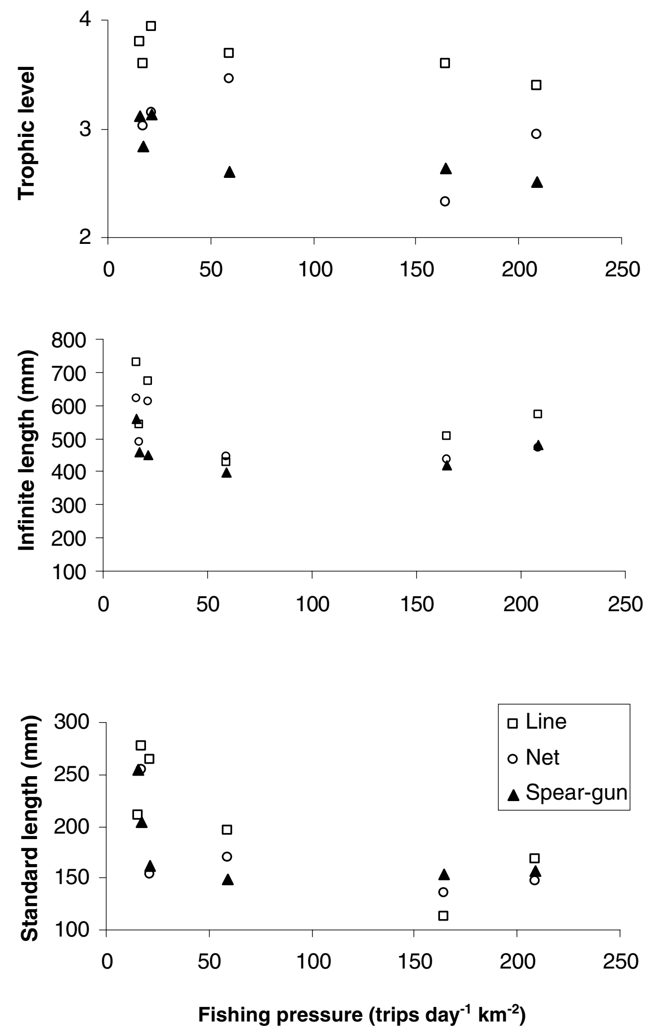

Figure 2 Relationship between fishing pressure by gear type and (*a*) trophic level, (*b*) infinite length and (*c*) standard length.

grounds and the distance to markets (Table 3). When fishing pressure values from specific gears were analysed separately, spear fishing pressure was negatively correlated to mean trophic level of catch (Table 3). Mean and infinite length of catch was negatively related to fishing pressure (Fig. 2). When gear types were analysed separately, hook-and-line fishing pressure was negatively related to the mean length of the catch and net fishing was negatively related to *Linf*. Both *Linf* and mean length were positively related to the size of fishing grounds. Diversity of the catch was not significantly correlated to any of the socioeconomic characteristics. Human population size and density, the percentage of households within a community that ranked fishing as a primary livelihood strategy and the percentage of fish sold or bartered were not significantly correlated to any catch characteristics.

There were significant differences in the mean trophic level of the catch among gears with hook and lines catching fish at the highest trophic level, followed by nets and spear guns (Table 4). The average size of fish caught was ≤ 20 cm and both nets and lines caught larger fish than the spear guns.

Table 4 The families, species, diversity (Simpson's index), mean trophic level, standard and infinite length (mm) of the fish caught by each of the dominant gears. n = number, SEM = standard error of mean.

	Line fishing			*Gill net*			*Spear gun*			*One way comparison*		*All pair comparison*
	n	*Mean*	*SEM*	*n*	*Mean*	*SEM*	*n*	*Mean*	*SEM*	*F*	*p*	*Tukey test*
Count of families		29			22			30				
Count of species		109			84			169				
Diversity, *D*		0.96			0.95			0.95				
Mean trophic level	470	3.7	0.02	655	3.1	0.03	1022	2.8	0.02	451.9	0.001	Line>net>spear gun
Mean standard length (mm)	488	226	5.6	537	215.5	3.8	906	188	2.9	7.1	0.001	Net>spear gun Line>spear gun
Mean *Linf* (mm)	448	568.2	1.8	631	4830	1	978	449.5	0.7	27	0.001	Line>net Line>spear gun

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We also found that fishing effort and gear had significant interaction effects between fish length (MANOVA: $F = 17.6$, $df = 9$, $p < 0.001$) and trophic levels (MANOVA: $F = 14.9$, $df = 10$, $p < 0.001$) (Fig. 2).

DISCUSSION

We found the fishery of PNG generally contained moderately large fish with high trophic levels compared to published studies of other reef fisheries (Dalzell 1996). For example, when compared to a similar study in the heavily-exploited reef fishery of Kenya (McClanahan & Mangi 2004), the mean length by gears was between 13 and 18 cm compared to 14–22 cm for PNG. Similarly, the mean trophic level by gear for Kenya was 2.6–2.9, with the exception of 3.5 for hook and line, compared to 2.8–3.7 for PNG, where hook and line was 3.7. Specific locales, however, showed signs of overexploitation, particularly Kranget, Riwo and Tubusereia, the sites with the highest fishing effort. Our data suggests that the mean fish lengths and trophic levels of catches were strongly related to socioeconomic characteristics such as fishing pressure, distance to markets and size of fishing grounds. Despite the presumed subsistence nature of many Melanesian fisheries (Quinn 2004), we found that more than half of the caught fish were bartered or sold, which suggests susceptibility to market forces.

The mean trophic level of fish caught in different locations varied predictably with differences in fishing pressure, distance to markets and the size of fishing grounds. The heavily-fished reefs of Kranget and Riwo produced catches with particularly low trophic level fish, suggesting that these fisheries are in poor condition. Despite extremely high hook-and-line fishing pressure in these communities (which targets high trophic levels), the low trophic levels of fish captured suggest that the higher trophic level species had been overfished (Pauly *et al.* 1998).

The strong negative correlation between fishing trips per day per km^2 and fish length, and the significant interaction effect between gear types and effort suggests that the size of fish caught was strongly affected by fishing pressure. Overall, hook-and-line fishing was not removing fish of a different size from those taken with nets or spear guns, but both total fishing pressure and line fishing pressure were negatively correlated with the mean length of fish. The infinite length of fish was also negatively related to net fishing pressure, which suggests that large-bodied species were most affected. Consequently, it appears that increasing fishing pressure, even when the gears were catching fish of similar size, could reduce fish size.

Resource use in Melanesia can be driven by factors such as subsistence and market demand, resource-use rights and the prestige associated with livelihood activities (Smith 2004; Bird & Smith 2005; Cinner *et al.* 2005*b*). Although this study did not investigate the specific factors that lead people to engage in fishing as a livelihood strategy, we found that distance to markets was positively correlated to the mean trophic level of the fish caught, suggesting that communities in close proximity to markets had likely overfished the higher value and high trophic level species. Most of the sites did not have access to ice or commercial markets outside the local area. However, as infrastructure improves and markets open up, there is potential for extra demand to be placed on the reef fishery. Also, at the time of the study, there were no live reef food fish operations exporting from any of the study sites. However, live reef food fish operations have since opened in Kavieng (the Tigak Islands) and are planned for the Manus Province, which may significantly increase demand for reef fish in these areas.

In contrast to other studies in Melanesia that found a negative relationship between resource conditions and human population density (Jennings & Polunin 1995, 1996; Dulvy *et al.* 2004), we found that human population size and density relative to the fishing area were not significantly related to catch characteristics. These contrasting results may be explained by several methodological factors, namely (1) we used catch characteristics rather than underwater visual censuses of resource conditions, (2) we used population per area of shallow water fishing ground rather than population per length of barrier reef front used in these other studies and (3) we may not have been able to detect weak effects (Dulvy *et al.* 2004) with the smaller sample size used in this study. Our results do suggest that for short-term research with a limited number of study sites, survey-based measures of fishing pressure may provide a better metric of fishing intensity than those based solely on human population density (Dulvy *et al.* 2004). Results also suggest that markets may be more important in determining the condition of a fishery than human population density, thus controls on marketing at the regional and global level may have more influence in achieving sustainability than efforts to control the local human population size.

Fishing ground size was positively related to the length, *Linf* and trophic level of the fish catch. The size of fishing ground was expected to be closely related to fishing pressure because it was used to estimate fishing pressure. However, marine tenure institutions are dynamic institutions that can change over time (Carrier & Carrier 1989; Aswani 2002). Therefore, local social or political decisions that affect the size of a community's marine tenure may increase local fishing pressure and have implications for the condition of the local fishery.

Thus far, we have examined the factors that may contribute to overfishing, but it is also important to examine whether there is a point at which the effects of overfishing start to become evident in the fishery. The mean length of fish caught in Riwo, Kranget and Tubusereia were considerably smaller than the other sites, suggesting that the effects of overfishing on length may start to become apparent in the catch at > 22 trips day^{-1} km^{-2}. The mean trophic level of fish caught in the Riwo and Kranget sites were considerably smaller than the other sites, suggesting that the effect of fishing pressure on trophic levels may become apparent at > 60 trips day^{-1} km^{-2}. Additionally, the three sites with trophic levels of ≤ 3 were < 10 km from markets.

In PNG, government fisheries regulations such as size restrictions, gear restrictions and harvest bans exist, but are not thoroughly enforced (Huber 1994). Successful top-down enforcement of fisheries regulations by the government is particularly complicated because (1) fishers typically work on a small and dispersed scale, which makes monitoring and enforcement costly and complicated, (2) highly decentralized customary marine tenure regimes make coordinated management of resources over large areas difficult (Foale & Manele 2004), (3) catches are multi-species which can make single-species management methods such as monitoring effort, growth and mortality expensive, and (4) national and provincial governments often lack adequate personnel and funding to monitor catch or enforce regulations. Therefore, there is compelling evidence for the need for specific communities to take local action to manage their fishery, particularly when fishing effort exceeds *c*. 22 trips day^{-1} km^{-2} and/or if local markets are <10 km away.

In PNG, local communities have the legal rights to regulate nearshore resources through customary marine tenure regimes (Hyndman 1993; Asafu-Adjaye 2000). Throughout PNG and wider Melanesia, there are also cultural traditions (i.e. taboos) that regulate access to fisheries, the use of fishing gears, the species that can be consumed and other aspects of the fishery (Hyndman 1993; Hviding 1996; Colding & Folke 2001; Quinn 2004). There is limited evidence that marine tenure and customary management practices may improve aspects of local fisheries (see Ruttan 1998; Cinner *et al*. 2005*a*, 2006). The applicability of these practices has been examined in the context of modern marine resource management in the Pacific (Johannes 1978, 1980, 2002; Polunin 1984; Carrier 1987; Hoffmann 2002). Yet by suggesting that exogenous forces such as markets may profoundly affect the fishery, this study questions whether local management will be enough to safeguard PNG's marine resources. Local overexploitation is likely to increase in range and intensity as fishing and market pressures increase, fisheries development projects are instituted, the live reef food fish market develops, and fisheries markets become overexploited (as in Indonesia; Pet-Soede *et al*. 2001) and search for additional resources. Furthermore, it has been suggested that exogenous forces such as proximity to markets and migration may weaken the marine tenure institutions that form the foundation for many of these traditional management practices (Polunin 1984; Cinner 2005).

Profound social, economic, and cultural changes will continue to redefine Melanesians' relationship with natural resources, making it unlikely that customary practices alone will be able to maintain a sustainable fishery on a national or regional level. This paper suggests the need for a cross-scale approach to fisheries management in PNG; communities should use the highly decentralized management options available to them to use resources sustainably, non-governmental organizations and other stakeholders should attempt to coordinate these community efforts on a broad-scale to limit the intrusion of resource extraction enterprises such as the live reef food fish trade and the development of regional markets, while the national and provincial governments must also make policy decisions that limit rather than encourage the exogenous pressures communities face in managing their resources.

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