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A framework for adaptive gear and ecosystem-based management in the artisanal coral reef fishery of Papua New Guinea

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ABSTRACT

1. Artisanal fishing on coral reefs in Papua New Guinea is an important livelihood activity that is managed primarily at the level of local communities. Pockets of overexploitation exist and are expected to increase with plans for increased commercialization.

2. This paper provides a current assessment of the artisanal multi-species coral reef fishery by examining selectivity of the dominant gear, namely line fishing, spearguns, and gill nets. Each gear has its own strengths and weaknesses in terms of use and conservation of resources, with no clear problem gear.

3. The three gears utilize different resources but there was moderate overlap in the species caught, particularly between gill nets and line fishing and marginally between lines and spearguns. Gill nets have the disadvantage of being destructive to coral and the advantage of catching commercial species. Line fishing catches an intermediate number of species but mostly large-bodied and predatory species that could potentially reduce predation and the mean trophic level of the fishery. Spearguns catch the highest numbers of species, including many non-commercial and herbivorous fish and could reduce the diversity of fish and encourage algal growth.

4. This information could be used in combination with scientific monitoring and traditional ecological knowledge to develop an adaptive management framework that uses local restrictions on the various gears to restore or balance the fishery and ecosystem. Restrictions could be selectively imposed: on gill nets when coral cover is low, line fishing when large-bodied predators are depleted, and spearguns when biodiversity is reduced and algal abundance high.

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KEY WORDS: adaptive management; catch composition; ecosystem-based management; gear selectivity; gill nets; hook and line; speargun; Melanesia

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INTRODUCTION

Coral reefs in Papua New Guinea (PNG) are among the most diverse marine ecosystems on the Earth (Hughes *et al*., 2002) and constitute a large area and resource comprising 40 000 km^2 above a water depth of 30 m (Frielink, 1983). They also remain one of the more underexploited coral reefs in the region, with reported harvests in the mid-1990s being less than 20% of the maximum sustainable yield on a national level (Huber, 1994). Fishing is an important economic and subsistence activity for most coastal people (Huber, 1994) but, like most of Melanesia, is currently exploited almost exclusively by small-scale artisanal and subsistence fishers (Johannes, 1978; Hviding, 1996; Cinner *et al*., 2006). Efforts to increase fisheries exploitation is being planned and intensive fishing effort of over 200 fishing trips km^{-2} day^{-1} already occurs in select areas near fish markets (Cinner and McClanahan, 2006). Consequently, there is a need to consider management options and potential guidelines before these pressures increase and the problems of overfishing develop.

PNG has government fisheries regulations, but they are seldom enforced (Huber, 1994). The fishery is small scale and dispersed; multiple gears catch a high variety of species and management is based on highly decentralized marine tenure institutions that are seldom coordinated over large scales (McClanahan *et al*., 2006). These problems and constraints make it difficult to expect successful top-down enforcement of fisheries regulations by government and create a need to develop simple management heuristics that can be utilized by local leaders that know the state of their society, ecosystem, and fishery (Prince, 2003). This is recognized by the PNG Government, which provides legal recognition of rights to customary management by local communities (Hyndman, 1993), which include local practices, such as taboos, that regulate the use of and access to resources. Customary resource management is usually informed by indigenous ecological knowledge and relies on community leaders and resource owners who negotiate access to resources based on local politics, community needs, and knowledge of the environment. Consequently, to improve the chances of sustainable resource use in PNG, there is a need to develop fisheries management guidelines that are amenable to local customary management and that reflect existing customary management regimes and can easily be understood, justified, and enforced at the local level (Drew, 2005).

Gear-based management is a potentially easy and low-cost means to manage tropical coral reef fisheries (McClanahan and Mangi, 2004) and is particularly practical in PNG, where many communities already use customary practices to adaptively restrict gears and spatial areas as ecological and social conditions require (Cinner *et al*., 2005b; 2006). In parts of coastal PNG and wider Melanesia, the use of fishing gears is regulated by cultural traditions such as user rights and the need to pass through initiation ceremonies before using a certain gear (Johannes, 2002a,b; Quinn, 2004). Documented traditional gear restrictions in Melanesia exist on derris root, gill nets, spearguns, and night diving and communities generally ban a particular gear because it is perceived to be too effective (Johannes, 1980; 2002b; Zann, 1985; Hviding, 1996), destructive to the coral habitat, or because it results in extensive juvenile fish mortality (Johannes, 1981). Gear restrictions are sometimes applied to non-owners who want to fish in owned fishing grounds, and they may be banned from using gill nets, spearguns, and night diving (Johannes, 1981; Ruddle, 1998).

Customary gear restrictions in PNG have been shown to have high compliance and significant effects on improving reef fish biomass (Cinner *et al*., 2005a; McClanahan *et al*., 2006) and may prove a valuable tool for local-level management of coral reef fisheries in PNG. The decentralized control of marine resource management present in PNG means that communities can adopt and change resource management measures, such as gear restrictions, as social or ecological conditions require without administrative and legal processes (Cinner *et al*., 2006). This paper presents a framework for developing a local and adaptive gear-based management system that is based on principles of local control and ecosystem assessment that has been promoted by critics of top-down management systems (Prince, 2003; Hughes *et al*., 2005). It provides an alternative or supplement to other management methods, such as space and time closures, that

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are currently used (McClanahan *et al.*, 2006) or species and size limitations (Johannes, 1981; Aswani and Hamilton, 2004).

This paper examines aspects of gear selectivity in the fishery and considers the potential for competition among gears and potential effects on ecology and biodiversity of the fishery to determine whether and how this management option might be valuable in PNG. Fishers in PNG use a range of technology and techniques, such as spearguns, 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 and Wright, 1990; Huber, 1994; Quinn, 2004). Although the literature on artisanal and subsistence fisheries in PNG is lacking in both quantity and depth, there are a few published studies of catch composition in local markets, including the Huron (Anas, 2000) and Tigak Islands regions (Wright and Richards, 1985; Dalzell and Wright, 1990); however, catch is often reported from fish buyers and is not based on species by gear. Cinner and McClanahan (2006) examine how socioeconomic factors are related to the condition of fish catch in six landing areas throughout PNG. While these papers provide information on the species removed from the reef fishery as a whole, they do not compare the catch selectivity by different gear types and the potential for competition and management of gears.

In this context, this study presents the first thorough analysis of fish catch by the major gear types to determine (1) if there were aspects of the catch that would assign some gears to the categories of being too effective or competitive and therefore amenable to management by communities, and (2) whether there were specific gear bans that may be useful in rectifying ecological changes hypothesized to be caused by fishing (McClanahan, 1995b) or the interaction between fishing and environmental change (McClanahan *et al.*, 2002).

METHODS

Study sites

This study covers ten fishing sites in PNG that were studied and described by Cinner and McClanahan (2006) in an investigation of socioeconomic influences on fish catch (Figure 1). The ten sites included Ahus and Andra Islands in the Manus Province, Enuk, Nusa, Sivasat, and Mongol near Kavieng in the New Ireland Province, Riwo and Kranget Islands in the Madang Province and Tubusereia and Gabagaba in the Central Province on the southern mainland. Fish traders at the Kranget fish market (in Madang) and fishers who brought their catch to a buyer in Kavieng were also sampled. Villages were purposely selected to encompass a wide range of social, economic, and demographic conditions rather than a random or haphazard selection. Nonetheless, the fisheries were typical shallow-water tropical artisanal fisheries dominated by coral reef and seagrass ecosystems.

Data were collected over 2–3 weeks per village, during a period between October 2001 and June 2002. Sampling of fish was done as time permitted and where sample sizes were <250 individuals per site the samples were pooled by gear into nearby landings sites. Consequently, the sites of Ahus and Andra were pooled into Manus, and Enuk, Nusa, Sivasat and Mongol were pooled into Kavieng, such that there were six sites with >250 individuals sampled. The data were further pooled by gear and therefore the data as presented are representative of general use in PNG and not specific sites (Table 1). The second author participated in a number of fishing trips to evaluate the usage of the various gears.

Gear and analyses

Data are based on 2612 fish specimens collected from landing sites or sold to local buyers and markets where fish sellers knew the fishers and the gear they used. At the landing sites, fish landings were opportunistically examined at all times of the day and night by approaching and asking permission from

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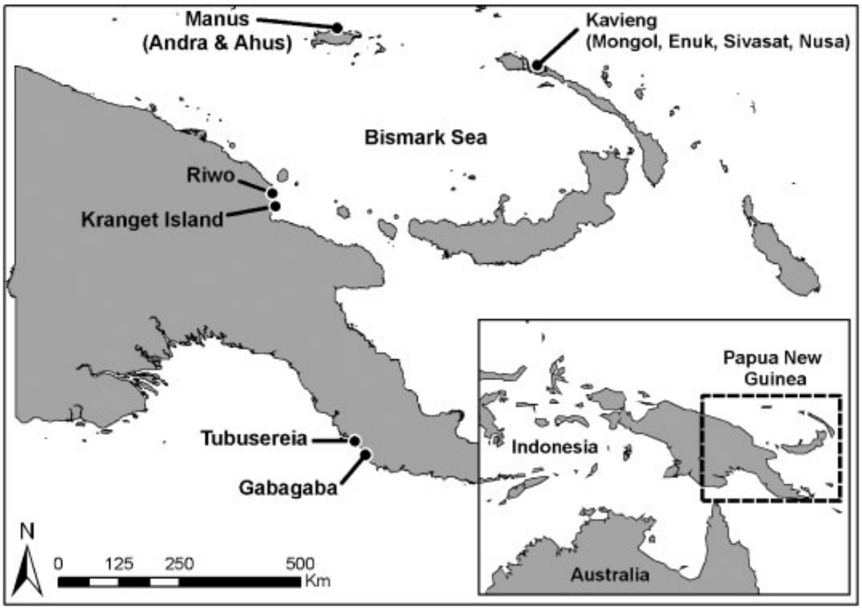

Figure 1. Map of major fisheries areas that were studied in Papua New Guinea.

Table 1. Proportion (%) of fish from the main study sites caught with the main gear types based on a total of 2154 sampled fish. Data from sites with small sample sizes were pooled into neighbouring sites

Study site	Line fishing	Net	Spear–gun
Gabagaba	63	0	37
Kavieng (Enuk, Nusa, Sivasat, Mongol)	9	42	52
Kranget	1	46	53
Manus (Andra and Ahus)	54	6	40
Riwo	26	25	49
Tubuseria	18	36	46
Total	22	31	47

fishers as they returned from fishing activities. The fish were photographed with a digital camera (Sony^{TM} DSC P-1, 3.3 megapixel) using the methods of Cinner and McClanahan (2006) and a record taken of the gear used to capture each fish. When multiple gears were used in a single trip, catch was separated by gear type. The length, abundance, and composition of catch were recorded. Fish were identified to family and species (Randall *et al*., 1997). Although a variety of fishing gears and techniques were used throughout PNG, three main gear types were widespread and used in sufficient numbers that they can be compared quantitatively and their management would have a significant influence on catch, namely line fishing, gill nets, and spearguns. The infrequency of use of other fishing methods (including weirs, traps, and derris root) made comparison among these gears across study sites difficult. By eliminating other gear types and fish that were unidentifiable, this reduced the number of fish to 2154.

To test for differences in the selectivity of the three gears Detrended Correspondence Analysis (DCA) based on the untransformed catch as individuals for the 80 most abundant species and pooled into families was used (Sall *et al*., 2001). Correspondence analysis is a multivariate ordination method that separates

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groups, such as catch by gear, based on the numbers caught for each species. Pair-wise Pearson-Product moment correlations were also performed and the Bray–Curtis measure of similarity for pair-wise comparisons of the total catch by individuals pooled into gear. The cumulative number of species caught by each gear as a function of the number of fish recorded was plotted.

RESULTS

Fish were recorded from nearly every gear type at each village (Table 1). The majority of fish sampled were caught with spearguns at all sites except Gabagaba and Manus, where the majority were sampled from hook and line. Hook and line fishing occurred at all times of day and night, frequently from outrigger canoes or motorized fiberglass dinghies. A variety of hook sizes were used, but smaller hooks (<2.5 cm) were most common. Gill nets ranged in gauge from 1.2–8.5 cm, with most fishers using 2.5–4.0 cm mesh. Nets were typically purchased in 50–100 m segments, but were strung together to form nets up to 1 km long, particularly in Tubuseria and Gabagaba. Gill nets were frequently set early in the morning or in the evening. When gill netting, it was common for 3–10 fishers to splash in the water, throw rocks, and break coral with sticks or other instruments to drive the fish into the net. Gill nets frequently became entangled in the coral and damaged branching or plate corals when removed. Hand spears were used in the shallow seagrass beds or from canoes but were not common enough to collect a sample size sufficient for comparison with other gear. Speargun handles were frequently made from wood and the spear from a sharpened bicycle spoke or metal rod that was propelled by a bicycle inner tube. Spearfishing occurred at all hours, with night-time spear fishers targeting parrotfish.

A total of 273 species in 43 families was observed in the fish catch. A large number of species were caught by the three dominant gears, with little evidence for dominance of any single species (Figure 2(a)). For example, the most dominant species caught was *Siganus argenteus* comprising 17% of the catches by spearguns, whereas the dominant catches by the net and line were *Lethrinus harak* and *Lutjanus gibbus* at 12% and 11% of the catch, respectively. The net did, however, catch a smaller number of families and species and there was higher dominance in the catch with the dominant 5, 10, and 20 species representing 43, 62, and 81% of the total catch, compared to around 35, 50, and 64% of the total catch for lines and spearguns (Figure 2(b)). Spearguns caught the greatest number of species (169), followed by lines (109) and nets (81) (Figure 3).

Overall analyses of the species-level gear selectivity by correlations, percentage similarity and DCA plots based on the number of individuals caught suggest that there were not strong overlaps in selectivity among the gears (Table 2, Figure 4). The maximum percentage similarity in the catch was between nets and line at 30% with a significant correlation in the pooled catch ($r = 0.57$) between these two gears. These two gears caught a greater abundance of carnivorous taxa including various Belonidae, Mullidae, Carangidae, Lethrinidae, Bothidae, and Lutjanidae. Correlations and percentage similarity for the other pair-wise comparisons were weak with a marginal correlation between spearguns and lines, exhibiting some overlap in species of Mullidae, Lethrinidae, Lutjanidae and Serranidae.

DISCUSSION

Hypothesized gear effects

This study suggests that the common gears used in the near-shore coral reef habitats of PNG catch a high diversity of fish. Additionally, the three main gears used — nets, spearguns, and line fishing — tend to target specific families and species of fish. This suggests that there is currently moderate partitioning of

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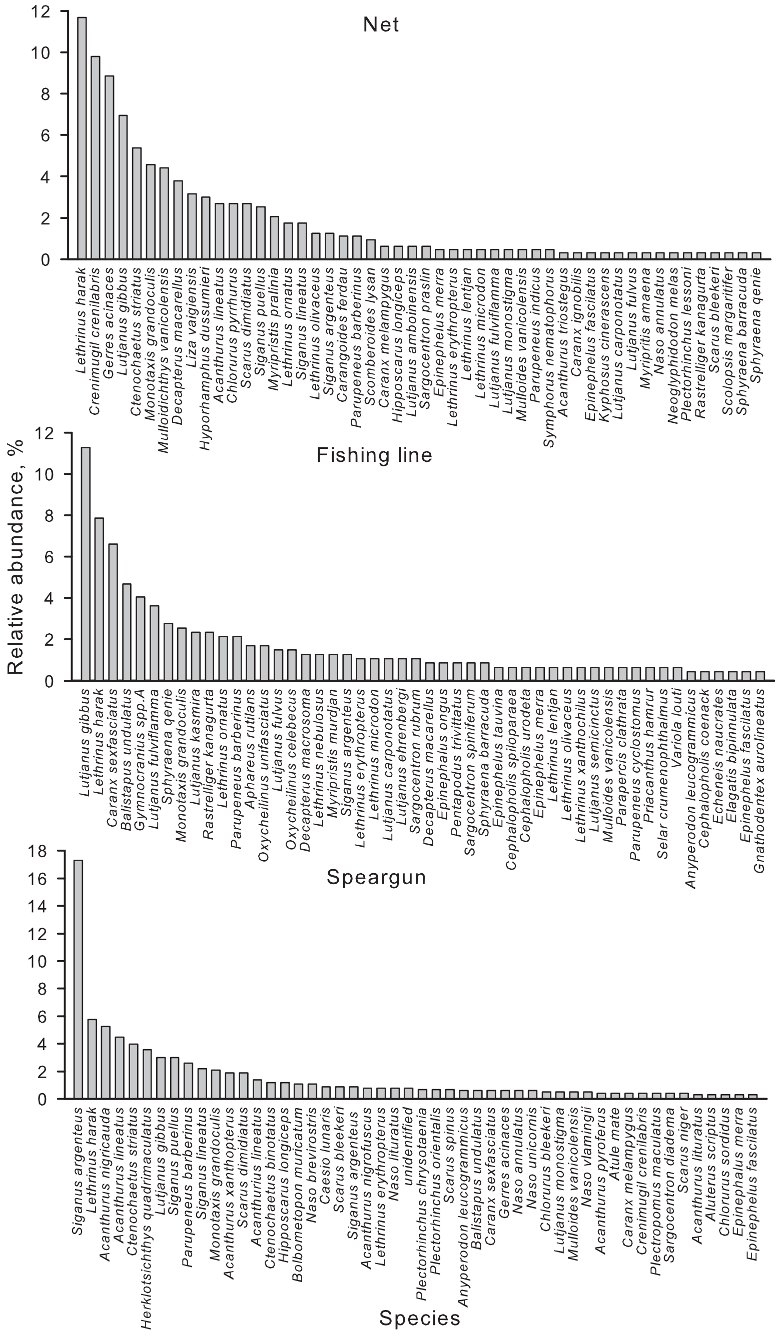

Figure 2. Relative abundance of the dominant (a) species and (b) families targeted by each gear type.

resources among gear, but some evidence for competition among lines and nets that could potentially increase with increasing fishing effort, the addition of other novel gear, or more advanced technologies (i.e. scuba diving with spearguns).

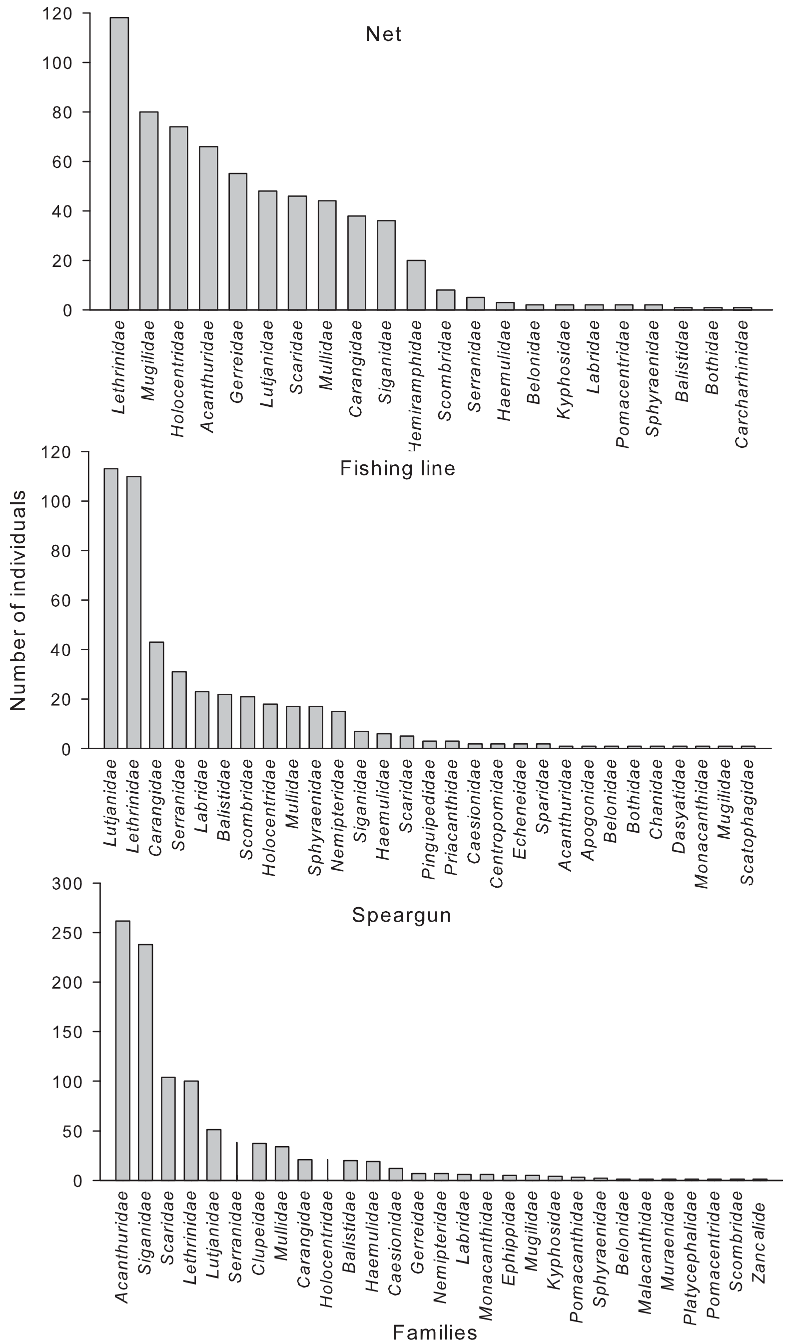

Figure 2. *continued*

Nets and line fishing had a significant similarity in the species they captured and, given the high diversity of species, the significant correlation between catch by these two gears indicates the potential for gear competition. Net and line fishing target some similar families, particularly Belonidae, Mullidae,

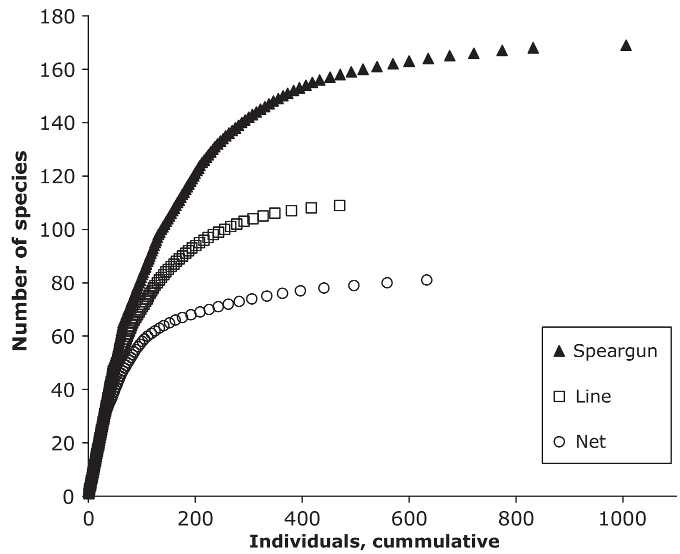

Figure 3. Cumulative number of species caught as a function of the number of individuals caught per gear type.

Table 2. Pair-wise comparisons by Pearson Product Correlations and Bray–Curtis similarity of the fish catch for the three dominant gears

Variable	by Variable	Correlation	Count	$P<$	Similarity
Net	Line	0.57	34	0.0001	0.30
Speargun	Line	0.26	51	0.068	0.23
Speargun	Net	0.26	42	0.099	0.24

Carangidae, Lethrinidae, Bothidae, and Lutjanidae. Since four of these families represented almost 30% of the fish caught in the PNG reef fishery (Belonidae and Bothidae combined only account for <0.4%), this overlap is of concern and an area for potential management. Line fishing also has the attribute of catching more species of fish and fish with higher trophic levels and larger maximum body sizes than gill nets (Cinner and McClanahan, 2006) and possibly greater potential for influencing trophic cascades. Gill nets have the attribute of being more destructive to corals as they become entangled during placement and because fishers often break coral while chasing fish into the nets. Spearguns remove a high diversity of species, which could significantly reduce the diversity of fish on a reef if caught beyond their potential for replacement. Spearguns also captured smaller and many herbivorous fish (Cinner and McClanahan, 2006) and could potentially reduce rates of herbivory and lead to dominance of the benthos by algae (McClanahan, 1995b; Bellwood *et al*., 2004; Mumby, 2006; Mumby *et al*., 2006). This gear–ecosystem model implies that gear and associated fishing mortality are the strongest factors influencing these reef communities as opposed to strong trophic cascades or environmental disturbances, such as coral bleaching and mortality. More sophisticated models will need to include these factors, where relevant, and determine the relative importance of the various fishing and environmental factors.

Consequently, this study of the three main gear types indicates that each of the gears has its attributes and detriments in terms of their potential effect on the fishery and ecosystem, with no excessively competitive gear that can be singled out for restrictive management based on overlap in gear selectivity (McClanahan and Mangi, 2004). There are, however, other aspects of gear apart from selectivity, such as damage to corals or selecting small individuals that were not fully considered by this study, but are an

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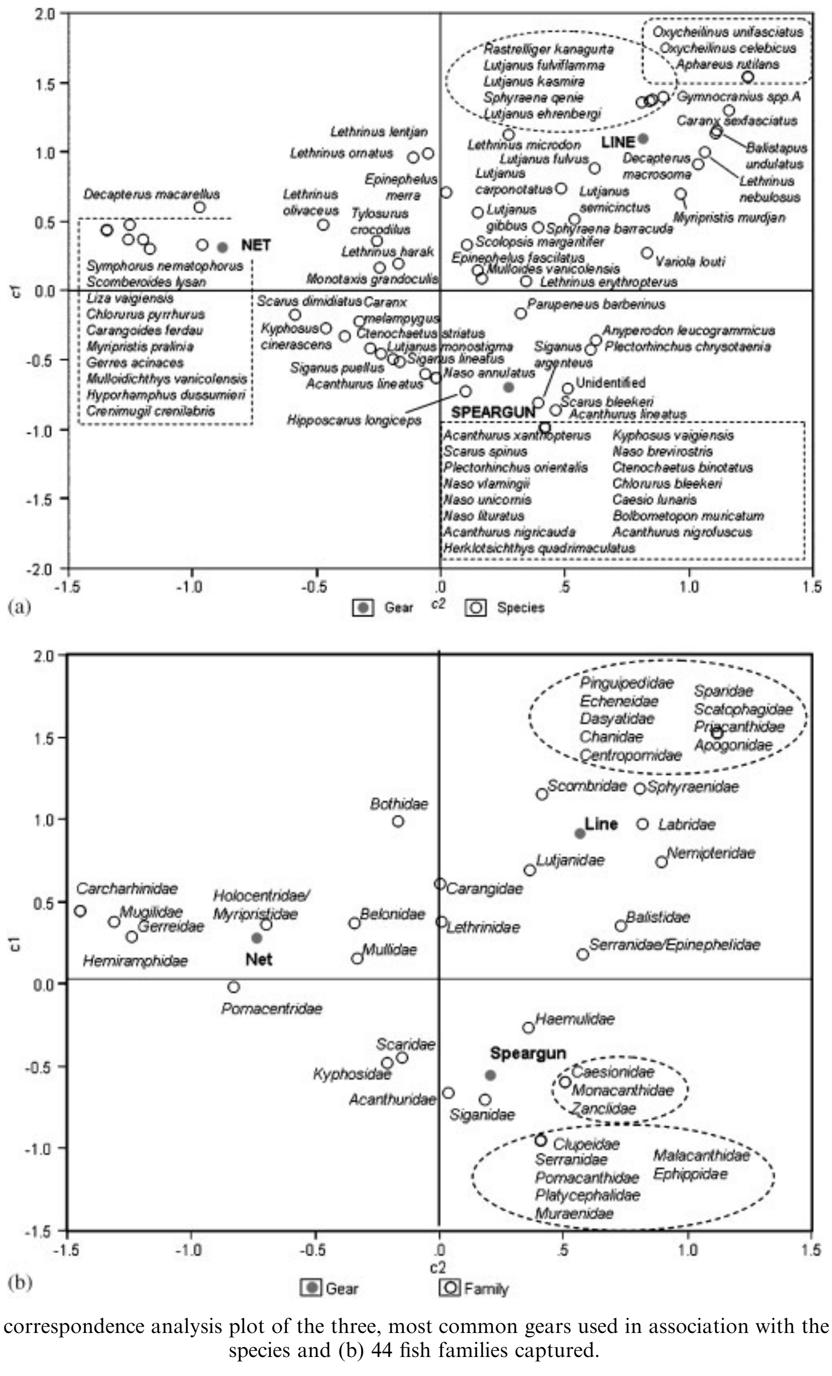

Figure 4. Detrended correspondence analysis plot of the three, most common gears used in association with the dominant (a) 80 fish species and (b) 44 fish families captured.

important part of decisions concerning gear use (McClanahan and Mangi, 2004). The low overlap in gear selectivity suggests that national-level guidelines for fisheries management based on gear need to consider other factors, such as maintaining coral reef ecosystem attributes of habitat, coral cover, body size, trophic

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levels, and the diversity of species. Gear may need to be adapted according to local circumstances of the fishery and the ecological factors that are most in need of management and restoration. This will require fisheries-independent methods of stock and ecosystem assessment.

The resilience of social–ecological systems is expected to increase as managers have a higher diversity of potential responses to disturbances that they can adaptively implement (Walker *et al*., 2006). Synthesizing and combining results of gear selectivity with the current understandings of ecosystem function and sociocultural governance of marine resources leads to a framework by which communities, managers, and scientists can adaptively manage coral reef ecosystems with gear restrictions (Figure 5). Where coral and associated habitat is in need of protection or restoration, managers should consider reducing or banning the use of nets. Low coral cover can be associated with destructive gear, such as nets, but may also be associated with other environmental factors, such coral bleaching and diseases (McClanahan *et al*., 2002). Regardless, restricted use of nets is likely to have beneficial effects on corals and their use might also be restricted after bleaching or disease events. Alternatives would include increasing the size of the mesh, using mesh characters that do not easily entangle with corals, or restricting nets to non-coral reef habitat.

Changing net-mesh size at the national level may be unrealistic because the smaller mesh nets are allegedly sold and used primarily for freshwater fisheries. However, community leaders and provincial authorities should encourage local-level restrictions on the use of small mesh nets in coral reef habitats. Further research is needed in designing nets that entangle less and therefore are less destructive to corals. Conservation, development, and donor organizations should consider supporting these efforts through programmes such as gear or mesh exchanges, whereby smaller-gauge nets can be exchanged for larger-gauge nets or traps with large gauge and biodegradable material (Al-Masroori *et al*., 2004). Additionally, some local restrictions on net use to noncoral-dominated areas could also potentially reduce their effects on corals.

Limiting the use of spearguns may also be appropriate in certain areas or during certain times. In combination with scuba diving, spearguns have the potential to eliminate populations in deep water that may be breeding refuges. One clear detriment of spearguns evident in the data presented here is that they capture many and mostly herbivorous species, and may have the greatest potential to reduce the diversity of reef fish. They have the potential benefit of utilizing species that might not otherwise be captured by other gear, namely herbivorous surgeonfish, parrotfish, and rabbitfish, and generally capturing larger individuals (McClanahan and Mangi, 2004). Nevertheless, when algae is increasing or common, it may be beneficial to reduce the use of spearguns and the subsequent capture of herbivorous fish in

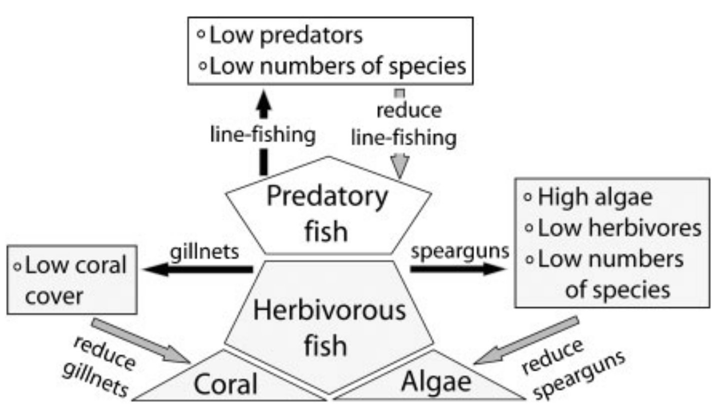

Figure 5. Conceptual model of the potential effects of the three main gears used in PNG on the coral reef and suggested management decisions to restore the ecosystem. Effects can also be caused by other environmental and anthropogenic factors but, for simplicity, are not listed here.

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order to help maintain the balance between corals and algae (McClanahan, 1995b; Mumby *et al.*, 2006). Algal dominance may also occur due to non-fishing effects, such as coral mortality (Williams and Polunin, 2001) or an interaction between reduced herbivory and increased inorganic nutrients (Lapointe *et al.*, 2004; Burkepile and Hay 2006). Additionally, where there is evidence for reduced numbers of species in a fishery, restrictions on spearguns may be effective at restoring numbers. In order to reduce the effects of spearguns, limits to the types of species caught and the depth to which they are used can also be recommended.

Line fishing has the advantage of not being destructive to habitat, but it also has potential detriments of catching species with large maximum body sizes and that feed at the highest trophic levels, resulting in low maximum sustained yields (McClanahan, 1995b). Consequently, in fisheries where large bodied and predatory fish are reduced to low levels, restrictions on line fishing is expected to have the greatest influence in the recovery of these species. Again, rather than an outright ban on line fishing, some effort to return fish below some size limit or specific taxa with keystone effects (McClanahan, 2006) could have a similar effect, although this is not currently part of most PNG resource users' management concepts (Cinner, J. personal observation).

Gear restrictions in coral reefs and their long-term effects on the ecosystem remain largely untested (but see McClanahan *et al.*, 1997). Nonetheless, the recommendations here are based on a current understanding of ecological interactions in coral reefs, simulation, and conceptual models (McClanahan, 1995a; McClanahan *et al.*, 2002; Bellwood *et al.*, 2004; Mumby, 2006) and, therefore, are a best guess or working hypothesis for guiding management. The catch by gear in PNG is similar to catch reports from Kenya (McClanahan and Mangi, 2004) and may, therefore, be applicable to other coral reef fisheries. The recommendations offer a starting point for ecosystem-based management that is not solely dependent on closures but also allows adaptive resource use that considers the diversity and status of the ecosystem.

Because there is some overlap in gear selectivity and because of the potential for changes and compensation in selectivity to occur with the frequency of gear use at sites, there is a need to test the efficacy of these recommendations with field studies. Similarly, environmental effects or the interaction between fishing and the environment can cause some of the ecological changes, such as reductions in coral or increases in algae (McClanahan *et al.*, 2002). Consequently, these environmental effects may at times override the suggested management and hypothesized ecological effects.

Although the status of fisheries in PNG at a national level is in a fair state (Cinner and McClanahan, 2006), particularly in the context of the poor state in neighbouring countries (Pauly *et al.*, 1989; White *et al.*, 2000, 2007; Pet-Soede *et al.*, 2001), the early and site-specific implementation of management could greatly improve the chances of avoiding overfishing and associated problems that are currently evident in some locations (Cinner and McClanahan, 2006). At the national scale, there is considerable potential for increased yields but where localized overfishing occurs, such as is found in Riwo and Kranget where close proximity to markets has resulted in overfishing of the higher value and high trophic-level species, gear management can help to alleviate overfishing problems in conjunction with other methods, such as effort restrictions and closures. Most of the fisheries studied here did not have access to ice or commercial markets outside the local area at the time of the study. However, as proposed infrastructure improves and markets develop, there is a considerable potential for increasing the demand on these fisheries and, unless isolation or other social forces limit effort (Kuster *et al.*, 2005), these fisheries could soon face the consequences of overexploitation.

Social and cultural management context

In the context of Melanesia, where national-level rules and regulations are difficult to enforce, management of reef resources could be aided by building upon the wide range of area, species, gear, and time restrictions as well as social controls such as age, sex, totem, and community-wide practices that exist and limit or

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prohibit consumption of certain marine species (Hviding, 1996; Colding and Folke, 1997, 2001). These practices generally rely on an underlying system of customary marine tenure, whereby complicated systems of use rights determine whether and how individuals and communities can access marine resources (Carrier and Carrier, 1983; Carrier, 1987; Hviding, 1996; Aswani and Hamilton, 2004). These marine tenure and customary management systems are often dynamic and adaptive in nature and are enforced reactively or proactively to deal with changes in social, economic, and ecological systems (Berkes *et al*., 2000). Consequently, there is a precedent for adaptive gear restrictions (Cinner *et al*., 2005a).

Cinner *et al*. (2006) developed a conceptual model of the phases in which communities use customary taboos on resource use to implement adaptive management. These were: (1) placing the taboo, which requires marine tenure systems that facilitate a flexible governance structure; (2) observing the taboo, which requires strong social capital, appropriate sanctions for violations, and social mechanisms that embed taboos in the local culture; (3) evaluating the system, requiring traditional ecological knowledge to observe and make sense of environmental and social conditions; and (4) lifting the taboo, requiring low-to-moderate population density and the use of low-tech gears so that recently opened areas do not become intensively overfished, as has been reported in other locations (Russ and Alcala, 1998; White *et al*., 2007). Such phases and conditions are relevant to communities using adaptive gear-based management, but scientific information could greatly complement traditional ecological knowledge in the evaluation phase (Drew, 2005).

Although traditional gear restrictions are frequently documented in Pacific societies (Colding and Folke, 2001) and local restrictions on spearguns and nets have been shown to significantly increase the biomass of fish (Cinner *et al*., 2006; McClanahan *et al*., 2006), this does not imply that those placing these restrictions necessarily do so because of an understanding or belief in a relationship between resource use and ecological effects (Carrier, 1987). In many cases the restrictions have a spiritual, social access, or resource availability reasoning that is independent of ecological causation (McClanahan *et al*., 1997). For the community, understanding and confirming ecological causation may be less important to compliance than the perceived legitimacy of the process and authorities behind the regulations (Sutinen and Kuperan, 1999). However, for scientists and conservationists working with these communities, understanding that conservation is often an unintended by-product or secondary function of utilitarian social or economic goals will be important to tempering expectations about conservation and resource management projects.

CONCLUSIONS

Managers of fisheries and other resources are increasingly being asked by critics of western-style technological resource management to develop more bottom-up (Prince, 2003; Hughes *et al*., 2005), adaptive (Walters, 1997), and ecosystem-based management (National Research Council, 2006) approaches. In many cases customary management is seen as adaptive management (Berkes *et al*., 2000), even if the conservation or resilience effect is unintentional (Berkes *et al*., 2003). PNG fisheries appear conducive to some of these suggested forms of fisheries management because of the bottom-up nature of resource management, the potential for local adaptation, and a considerable indigenous ecological knowledge (Quinn, 2004). Thus, a simple heuristic model of management, based on a current understanding of coral reefs and the effects of dominant gears on the fish assemblages, has the potential to achieve some ecosystem management goals without the use of large closed areas, which have previously failed in PNG.

The gear management proposed, however, is not traditional knowledge; it is based on hypothesized cause-and-effect relationships in the fishery and ecosystem, which Carrier (1987), has argued as not being the basis for PNG indigenous fisheries knowledge. Nevertheless, because indigenous knowledge is flexible and adapts with time and circumstances, it has the potential to become part of the knowledge systems in

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these fisheries, if presented in a way that will facilitate adoption (Drew, 2005). There are precedents for this type of integration of knowledge in the region (Aswani and Hamilton, 2004) and, given the tradition of various restrictions on fishing, there is considerable opportunity to incorporate adaptive gear-based management into local management. Efforts to assist this process should begin before the projected increase in fishing effort has the opportunity to threaten these remaining Indo-Pacific biodiversity hotspots.

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