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Changes in a coral reef fishery along a gradient of fishing pressure in an Indonesian marine protected area

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ABSTRACT

1. Human population growth, rising incomes, and increased commercialization of marine resources promote demand for reef fish, yet few studies in Indonesia have examined how artisanal fisheries are influenced by the socio-cultural conditions that contribute to their exploitation. This study examined artisanal fisheries of Karimunjawa National Park, Java, to understand how the condition of an artisanal fishery was related to socio-cultural factors, along a gradient in fishing pressure.

2. A total of 8674 fishes landed in Karimunjawa by fishers using four artisanal fishing gears were examined to understand how the condition of the artisanal fishery (standard and infinite fish length, trophic level and weight) related to fishing gear use, village fishing grounds, management, human population size, human population density and estimated fishing pressure.

3. Depletion in fish lengths and trophic structure were found at or above 46 fishing trips day^{-1} km^{-2}, suggesting that fishing pressure is a key factor driving fishery catch structure. When catch characteristics were examined in relation to the fishing pressure estimates from each village, negative correlations were found between inshore fishing pressure (no. trips day^{-1} km^{-2}) and all four fish catch characteristics, but owing to small sample sizes ($n = 5$), only the effects on trophic level were significant.

4. Fishery closures had limited impact on fish characteristics, and lack of any effect of spatial controls on fishing also supports the notion that fishing pressure and the types of fishing gears used, most likely driven by human population densities, are the greatest drivers of reef fish catch characteristics in the Karimunjawa fishery.

5. In the absence of support for fishery closures from local fishing communities or adequate enforcement of fishery closures, targeted gear or species management strategies that limit impacts on large-bodied fish and aim to conserve key species may be more effective in improving the size and trophic structure of fish populations.
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KEY WORDS: coral reefs; marine protected area; spatial restriction; fishing; Karimunjawa; resource dependency

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INTRODUCTION

Coral reefs and seagrass habitats of the Indo-Pacific represent some of the most diverse marine ecosystems in the world (Unsworth and Cullen, 2010; Burke *et al*., 2011). Reef fish are not only critical in maintaining the ecological function of coral reefs (McClanahan *et al*., 2011), but also provide food security for coastal communities in many developing countries (Donner and Potere, 2007; McClanahan, 2010; Hughes *et al*., 2012). However, reef and seagrass fishery stocks are under increasing threat from factors such as climate-related habitat degradation, land-use practices, and resource extraction related to human population growth, direct consumption and increasing connectivity between *in situ* fisheries and fish markets (Fabricius, 2005; Graham *et al*., 2007; Unsworth and Cullen, 2010; Cinner *et al*., 2013).

Structural features of reef fish populations such as changes in biomass, length and trophic level provide clear indicators of fishing intensity and overfishing (Pet-Soede *et al*., 2001; Campbell and Pardede, 2006; Lokrantz *et al*., 2009). Even at low fishing pressures, exploitation of fish populations may occur and lead to shifts in species composition and fish population structure and the dominance of fish from lower trophic levels (Jennings and Polunin, 1996, 1997; McClanahan, 1997; Dulvy *et al*., 2004). Fishing pressure can influence the size and trophic levels of fish populations (Coté *et al*., 2001; Dulvy *et al*., 2004; Lokrantz *et al*., 2009), as has been demonstrated by comparing fish community structure along a gradient of fishing intensity (Pet-Soede *et al*., 2001; McClanahan and Graham, 2005; Campbell and Pardede, 2006; Cinner and McClanahan, 2006; Lokrantz *et al*., 2009). Effects of fishing pressure on trophic structure, especially with regard to piscivores and planktivores (Pet-Soede *et al*., 2001) have been reported, while biomass and trophic structure can increase when controls on fishing pressure are effective (McClanahan *et al*., 2007).

Human societies on the coast of Indonesia and other Coral Triangle countries remain heavily reliant on small-scale artisanal and subsistence fisheries that employ a wide range of fishing methods (Pet-Soede *et al*., 2001; Campbell and Pardede, 2006; Aswani and Sabetian, 2010; Varkey *et al*., 2010; Brewer *et al*., 2012; Ferse *et al*., 2013). Overfishing is particularly serious in Indonesia, yet few studies have examined the condition of artisanal fisheries (Pet-Soede *et al*., 2001; Ferse *et al*., 2013). Some studies have found that protected areas are poorly complied with (McClanahan *et al*., 2006), but there has been little research examining fishery exploitation rates inside marine protected areas (Clifton, 2003; Glaser *et al*., 2010).

To date, few studies have examined how the condition of the artisanal fishery is related to fishing pressure and gear use in the absence of variations in market pressures. Here, we compare catch data on trophic level and fish length along a gradient of fishing intensity in Karimunjawa Marine National Park (KNP) in Indonesia. KNP is a medium sized (111 625 ha) marine protected area, with mutiple no-take, fisheries utilization, and other zoning types (Campbell *et al*., 2013). It provided an excellent study site for examining how fishing intensity influenced catch characteristics because: (1) it is a site where a gradient in fishing pressure among five coastal communities can be examined; (2) fishing communities are relatively homogenous in ethnicity and use a range of common fishing techniques; (3) fishing grounds are close to villages where all landing sites provide the means to sell or barter fish for local and distant consumption, thereby eliminating market distance as a factor influencing fishing pressure; and (4) laws on fishing restrictions are weakly enforced.

METHODS

Site details

Karimunjawa National Park (KNP) was first legislated in 1988 and covers 111 625 ha (Figure 1). The Karimunjawa Islands are made up of 25 individual islands (five of which are inhabited) with 8842 people living in four villages (Karimunjawa, Kemujan, Parang, Nyamuk) inside the park and one community (Genting) outside the park. Each village has a different number of sub-villages and each village has local fishing grounds, where fishers work and bring their daily catch to the main landing sites on Karimunjawa Island for distribution to

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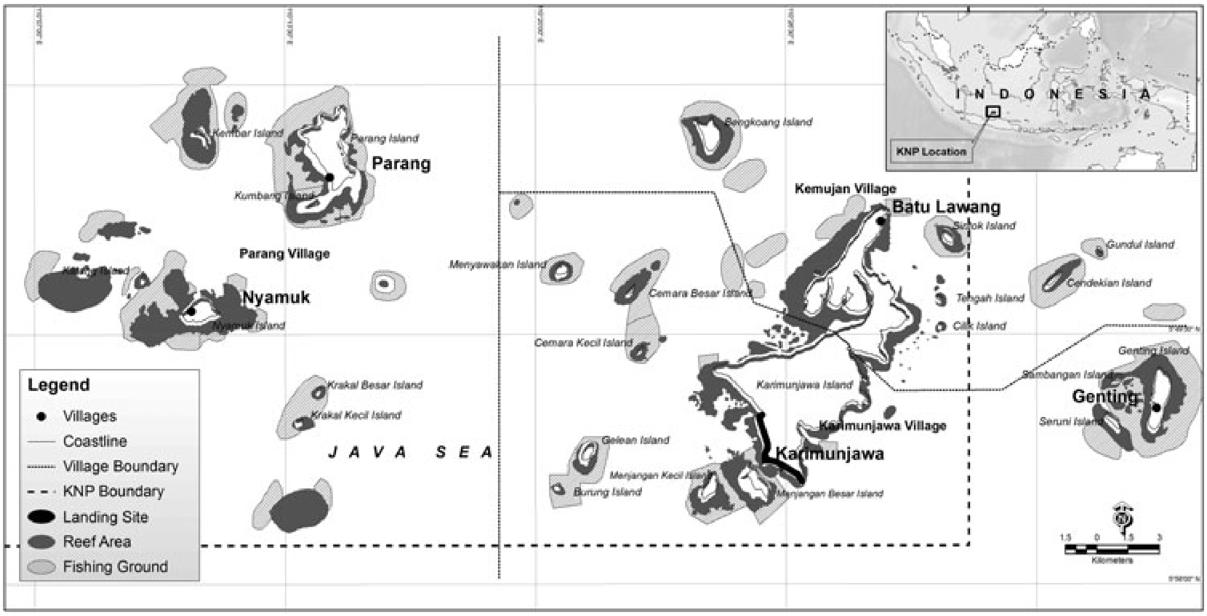

Figure 1. Map of the study area showing locations of fishing grounds and the fish landing sites sampled in the Karimunjawa Islands, Indonesia.

markets inside and outside the national park. Fishing grounds included areas of nearshore coral reef to maximum depths of 30 m and areas of nearshore mixed reef–seagrass and seagrass habitats (Campbell *et al.*, 2011). The surveys of fish harvested in the present study included fish caught for market distribution and does not include the 5–10% of catch used for direct household consumption. The five villages represented a gradient in fishing pressure among fishing communities in the Karimunjawa Islands, with relatively homogenous ethnic, social, economic and resource governance characteristics, and relatively homogenous reef topography and benthic composition throughout the five fishing grounds (Marnane *et al.*, 2004).

Fish catch surveys (dependent variables)

Fish catch surveys were conducted at landing sites on Karimunjawa Island. Generally fish were caught by fishers at their local fishing grounds located in proximity to the five village communities and then transported to the Karimunjawa landing sites. Therefore the surveys were able to assign the location of fish capture from one of five village fishing grounds. If fishers could not identify the exact location or gears used to capture fish, or if the catch was from more than one village's fishing ground, these catches were not included for anlaysis.

At the fish landing sites on Karimunjawa, 8674 fish from 895 fishing trips were examined, sampled every 1–2 months from January 2004 to December 2005. Two observers averaged 15.6 ($\pm$1.4SE) days of sampling per month for a total of 219 days of sampling effort on Karimunjawa Island. Fish landings were opportunistically sampled at day and at night time using methodology reported in Cinner *et al.* (2005). Observers recorded the gear that was used to catch the fish by asking fishers the gear used and verifying this through direct observation.

All fish were photographed using a digital camera (Sony TM DSCP-1, 3.3 Megapixel) with a scale in all photographs for size calibration. Digital photos were later analysed to examine four catch characteristics. (1) Fish lengths were measured (in mm) on digital photographs using the UTHSCSA Image tool for Windows 2.0 to calculate the length of a fish measured from the tip of the snout to the posterior end of the last vertebra, excluding the length of the caudal fin. This way of measuring length is usually referred to as 'standard length (SL)'. (2) The wet weight (in g) of each fish was determined by applying length–weight conversion factors from Fishbase (Froese and Pauly, 2006). (3) In order to assess if fishing was preferentially influencing species with large body sizes we took the infinite length ($L\infty$ in mm) (i.e. the mean length the fish

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could potentially reach if it were to grow to an infinite age), from Fishbase (Froese and Pauly, 2006) for each species caught. (4) Trophic levels for each species were also obtained from Fishbase. In some cases where species were not available in Fishbase the trophic level of closely related species from the same genus was used. For the four different gear types and the five fishing grounds the mean (±SE) values of all four catch characteristics were derived by summing all values and dividing this by the total number of fish recorded (Pauly *et al.*, 2001).

Independent variables

Six independent variables were examined: (1) gear, (2) village, (3) management, (4) human population size, (5) human population density, and (6) fishing pressure. The first three (the gear used to capture the fish, the village adjacent to the ground where the fish were captured, and the respective management zone) were recorded at the landing site, as described above, by asking fishers which fishing grounds they were fishing in and what gear they used. Catches from the most commonly used gear types (e.g. handlines, traps, nets, muroami) were measured. Fishing by nets included all nets (e.g. purse, gill) (Campbell and Pardede, 2006) except for muroami net fishing which was analysed separately. For the zoning, the marine waters included zones designated for fishing use and zones where fishing was prohibited by national laws. Fishing was reported during the study from both fishing use zones and fishery closures, within the three village fishing grounds of Karimunjawa, Nyamuk and Parang where both management zones were in place.

Data on human population size were derived from village government statistics (District of Karimunjawa, 2002). To calculate human population density per reef area, the coral reef area (km^2) of each fishing ground was determined. The size of fishing grounds was calculated using Landsat TM imagery (2002) (1:30 000) and ArcView 3.2 based on easily discernable landmarks and sea features provided by key informants and fishers. The areas of fishing grounds that included seagrass, reef and sand habitat to 30 m depth were digitally traced. Human population density as a function of fishing ground area was determined by dividing the human population size of each of the five villages by the area (km^2) of their fishing grounds.

To gather information on fishing pressure from local communities in the five villages 119 household surveys were conducted from January to March 2003, in Karimunjawa (n = 46), Parang (n = 20), Kemujan (n = 18) and Nyamuk (n = 20) (all inside the Park), and Genting (n = 15) (outside the Park) (Figure 1). Maps of the communities were created and households were systematically sampled using methods described in Henry (1990). The surveys targeted the head of each household; however, in some situations, more than one respondent may have provided information about the household. For example, in some situations where a female headed the household, her son may have answered fishing-specific questions if he was most knowledgeable about the household's fishing activities.

Total fishing pressure at each village (no. trips day^{-1} km^{-2}) was obtained from household survey data on the mean number of daily fishing trips of households, separated by gear type, based on data on the number of fishing households per community from local government statistics (District of Karimunjawa, 2002). The mean number of fishing trips per household per day in each village was multiplied by the number of fisher houses in each village, and then divided by the fishing ground size (Table 1). Not all household

Table 1. Socio-cultural characteristics of the five village communities organized from left to right as the highest to lowest population size

Social and fishery characteristics	K'jawa	Kemujan	Parang	Genting	Nyamuk
Number of households	1141	750	573	102	87
Population size	4137	2689	2007	365	313
Number of fisher houses	504	284	239	45	36
Size of fishing ground (km^2)	31.3	10.9	23.1	5.1	9.7
Population density (people km^{-2} of fishing ground)	132.1	245.6	86.9	71.6	32.3
Total fishing pressure/area (trips day^{-1} km^{-2})	46	58	23	20	12

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fishing is conducted in nearshore waters where coral reefs occur, as fishers sometimes fish in offshore pelagic waters. From village household responses on the number of fishing trips per week in nearshore or pelagic waters, it was possible to calculate the proportion of fishing trips in nearshore waters (Karimunjawa = 76.5%, Kemujan = 31.9%, Parang = 51.9%, Nynamuk = 46.3% and Genting = 75.7%). For each village this value was multiplied by total fishing pressure to derive the mean inshore fishing pressure (no. household trips $day^{-1} km^{-2}$). The percentage of all household fishing trips km^{-2} for each of the four gears within each village was determined to examine the proportional use of gear throughout the park.

Statistical treatment

All four dependent variables, standard length, infinite length, trophic level and the weight of fishes, were $\log_{10}(x+1)$ transformed before analyses to meet conditions of normality and analyses were performed in SPSS. ANOVA analyses were used to test for differences in mean catch characteristics (standard length, infinite length, trophic level and weight of fishes) among the four fishing gears and the five village fishing grounds. Post-hoc comparisons (LSD) were used to determine significant ($P < 0.05$) mean differences among gear and villages. Spearman rank correlation was used to test for relationships between the three independent variables, human population size, human population density and fishing pressure (no. trips $day^{-1} km^{-2}$) at each village (n = 5). All three independent variables were significantly correlated (r = 0.9, $P < 0.05$), so only relationships between fishing pressure (no. trips $day^{-1} km^{-2}$) and fish catch characteristics (standard and infinite length, trophic level, weight) at each village (n = 5) were examined.

Finally, a two-way ANOVA was used to test for differences in means of each of the four fish catch characteristics associated with village fishing grounds (fixed; n = 3; Karimunjawa, Nyamuk, Parang) and management zones (fixed; n = 2; fishing closure zones, fishing zones). Post-hoc comparisons (LSD) were used to determine if mean catch characteristics varied between management zones and among village fishing grounds.

RESULTS

The human population differed between villages, ranging from 313 people in Nyamuk to over 4137 people in Karimunjawa (Table 1). The size of fishing ground also differed considerably, resulting in an eight-fold variation in human density per km^2 of reef fishing ground among villages with highest densities in Kemujan and Karimunjawa and lowest in Nyamuk (Table 1). The overall fishing pressure (no. trips $day^{-1} km^{-2}$) was highest in Kemujan (58 trips $day^{-1} km^{-2}$) and lowest in Nyamuk (12 trips $day^{-1} km^{-2}$) (Table 1). The 100 most commonly fished species (21 families) in the Karimunjawa fishery and the fishing gears commonly employed to catch each species is presented in Table 2.

Fish caught in fishing grounds adjacent to Nyamuk and Parang had higher standard lengths (mean = 341.9 mm ± 6.8SE and 332.1 ± 5.5SE) than those caught at Karimunjawa, Kemujan, and Genting (ANOVA, $F_{4,8668} = 84.66$, $P < 0.001$) (Table 3). Fish caught at fishing grounds near Nyamuk and Parang had higher infinite lengths than those from the other three villages (ANOVA, $F_{4,8668} = 27.38$, $P < 0.001$) (Table 3). The mean trophic level of fish was higher at Nyamuk, Parang and Genting (3.53 ± 0.03SE and 0.02SE for Genting) than at Karimunjawa (3.42 ± 0.01SE) (ANOVA, $F_{4,8668} = 7.25$, $P < 0.001$), but all these villages did not differ in terms of mean trophic level compared with Kemujan (Table 3). The fish caught at fishing grounds near Parang and Nyamuk had higher (ANOVA, $F_{4,8668} = 99.37$, $P < 0.001$) mean weight than at fishing grounds at Genting, which in turn were higher than at Karimunjawa and Kemujan (Table 3).

When catch characteristics were examined in relation to the fishing pressure estimates from each village, negative correlations were found between nearshore fishing pressure (no. trips $day^{-1} km^{-2}$) and standard length (r = –0.8), infinite length (r = –0.3), trophic level (r = –0.9) and weight (r = –0.8) of fish catches, but because of small sample sizes (n = 5), only the effects on trophic level were significant. The results for trophic level, however, are unlikely to have any biological significance as the mean trophic levels among villages differed only by a

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Table 2. Common reef fish families and species of the nearshore coral reef fishery in Karimunjawa and fishing gears most commonly used to catch each species: 1 = handline, 2 = muroami, 3 = net, 4 = trap

Reef fish	Gear
Acanthuridae	
Acanthurus bariene	2 3
Acanthurus mata	2 3
Acanthurus nigricauda	3 4
Balistidae	
Balistoides viridescens	3 4
Caesionidae	
Caesio caerulaurea	2 3
Caesio cuning	2 3 4
Pterocaesio chrysozona	2 3
Pterocaesio diagramma	2 3
Pterocaesio lativittata	2
Pterocaesio pisang	2 3
Pterocaesio tessellata	2
Pterocaesio tile	2
Scomber japonicus	2
Carangidae	
Alectis ciliaris	2 3
Atule mate	1 2
Carangoides bajad	2 3
Carangoides caeruleopinnatus	3
Carangoides equula	2 3
Carangoides ferdau	2
Carangoides fulvoguttatus	2
Carangoides gymnostethus	2
Caranx ignobilis	2
Carangoides orthogrammus	2
Carangoides plagiotaenia	2
Ephippidae	
Platax boersii	2 3
Platax pinnatus	2 3
Platax teira	1 2 3
Haemulidae	
Diagramma pictum	3
Plectorhinchus chaetodonoides	2 3
Plectorhinchus flavomaculatus	2 3 4
Plectorhinchus picus	1 3
Kyphosidae	
Kyphosus biggibus	2
Kyphosus vaigiensis	3
Labridae	
Cheilinus fasciatus	2 3 4
Chelio inermis	2
Choerodon anchorago	1 3
Choerodon monostigma	2 4
Cirrhilabrus cyanopleura	2
Epibulus insidiator	2 3
Hemigymnus melapterus	2 3
Lethrinidae	
Gymnocranius euanus	2
Lethrinus erythropterus	2 3 4
Lethrinus harak	3
Lethrinus lentjan	1 3 4
Lethrinus microdon	2 3 4
Lethrinus olivaceus	2 3
Lethrinus ornatus	1 2 4
Lutjanidae	
Lutjanus argentimaculatus	1
Lutjanus bohar	2
Lutjanus carponotatus	2 3 4
Lutjanus fulviflammus	3
Lutjanidae	
Lutjanus monostigma	2 3
Lutjanus rivulatus	2
Lutjanus sebae	3
Lutjanus decussatus	1 2 3 4
Mullidae	
Parupeneus barberinus	2 3 4
Parupeneus multifasciatus	3
Nemipteridae	
Nemipterus peronii	1
Pentapodus caninus	2 3
Scolopsis margaritifer	2 3 4
Scolopsis monogramma	2 3 4
Pomacanthidae	
Pomacanthus annularis	2 4
Pomacanthus sexstriatus	2 3 4
Pygoplites diacanthus	2
Pomacentridae	
Chromis analis	2 3
Chromis weberi	3
Scaridae	
Bolbometopon muricatum	1 2 3 4
Cetoscarus bicolor	1 2 3
Chlorurus bleekeri	2 3
Chlorurus bowersi	2 3
Chlorurus microrhinos	2 3
Chlorurus sordidus	2 3
Scarus dimidiatus	2 3
Scarus flavipectoralis	2 3
Scarus ghobban	2 3 4
Scarus prasiognathos	2 3
Scarus rivulatus	2 3
Scarus schlegeli	2
Scarus tricolor	2
Scombridae	
Euthynnus affinis	1
Rastrelliger kanagurta	1 3
Scomberoides commersonnianus	2 3
Thunnus tonggol	1
Serranidae	
Anyperodon leucogrammicus	2 3 4
Cephalopolis cyanostigma	1 3
Epinephelus areolatus	1
Epinephelus melanostigma	2
Epinephelus merra	1 2
Plectropomus areolatus	1 2 3 4
Plectropomus leopardus	2 4
Plectropomus maculatus	4
Plectropomus oligacanthus	1 2 3 4
Sphyraenidae	
Sphyraena barracuda	1
Sphyraena jello	2 3
Siganidae	
Siganus canaliculatus	2 3
Siganus corallinus	2 3
Siganus guttatus	3
Siganus virgatus	2 3 4
Siganus vulpinus	2 3
Zanclidae	
Zanclus cornutus	2

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Table 3. Mean (±1SE) standard and infinite lengths, trophic level and weight of fish caught in both fishing closures and fishing areas by five village communities, organized from left to right as the highest to lowest population size. Different superscript letters denote significant differences ($P < 0.05$) among villages for standard length, infinite length, trophic level and wet weight of fish catches

Fish catch characteristics	Karimunjawa	Kemujan	Parang	Genting	Nyamuk
Standard length (mm)	271.6 ± 1.7^{a}	278.8 ± 3.02^{a}	332.1 ± 5.5^{b}	297.5 ± 4.1^{c}	341.9 ± 6.8^{b}
Infinite length (mm)	550.5 ± 5.4^{a}	586.9 ± 7.9^{b}	649.1 ± 16.5^{c}	569.1 ± 7.8^{ab}	643.5 ± 15.5^{c}
Trophic level	3.42 ± 0.01^{a}	3.46 ± 0.01^{ab}	3.53 ± 0.03^{b}	3.53 ± 0.02^{b}	3.53 ± 0.03^{b}
Wet weight (g)	430.9 ± 12.7^{a}	493.1 ± 29.2^{ab}	788.2 ± 52.9^{c}	560 ± 40.6^{b}	849 ± 82.03^{c}

maximum of 0.11 (Table 3), suggesting a previous depletion of higher trophic levels among all villages.

The proportion of fishing grounds in fishery closure zones in Nyamuk (69%), was more than double that of areas where fishing was allowed (31%). The proportion of fishing grounds where fishing was prohibited in Karimunjawa (27%) and Parang (22%) was about 3 times lower than that of areas where fishing was permitted (73% and 78% respectively).

The characteristics of the fish catch also varied significantly among the fishing gears used (Table 3). Differences among fishing gears for mean standard length (mm) (ANOVA, $F_{3,8668} = 105.1$, $P < 0.001$) and trophic level (ANOVA, $F_{3,8669} = 547.3$, $P < 0.001$) occurred in the following order; handline > trap > muroami > net (purse seine and gill nets) (Table 4). The mean infinite length of fish caught by handline (mean = 637.8 mm ± 10.3SE) was higher (ANOVA, $F_{3,8669} = 3.89$, $P < 0.009$) than the mean infinite length of fish caught by the three other fishing gears tested (Table 4). The mean weight of fish was also higher for handline (mean = 783.1 g ± 38.0SE) than the mean weights of fish caught by muroami and trap, which in turn, were higher than the mean weight of fish caught by nets (ANOVA, $F_{4,8669} = 52.79$, $P < 0.001$) (Table 4).

Management zones from which the fishes were caught appeared to have little effect on fish sizes. An interaction of management and village fishing ground on infinite length ($F_{2,7520} = 8.42$, $P < 0.001$) and standard length of fish ($F_{2,7520} = 29.06$, $P < 0.001$) was due to greater mean fish lengths in Parang and Nyamuk compared with Karimunjawa, for both fishery closures and fishing zones. In Nyamuk standard and infinite lengths differed between management zones, with larger mean fish sizes recorded in fishing use zones than in fishery closures (Figure 2).

The significant interaction between management and village fishing ground ($F_{2,7520} = 28.95$, $P < 0.001$) on fish weights was explained by significantly higher mean weights of fish in Karimunjawa fishery closures than in fishing use zones, but not in the other two villages. Mean fish weights in both Parang and Nyamuk were higher than in Karimunjawa. For trophic levels, the interaction of management and village fishing ground ($F_{2,7520} = 3.38$, $P < 0.034$) was explained by higher trophic levels in fishing use zones in Parang and Nyamuk than in Karimunjawa, while in fishery closures, trophic levels were higher in Parang than Karimunjawa (Figure 2). Mean trophic levels did not differ between fishery closures and fishing use zones in any of the three villages.

For all catch variables tested, the variance explained by F ratios was higher for village fishing grounds (weights: 77.2%, trophic level: 92.6%, infinite lengths: 60.1%, and standard lengths: 74.2%)

Table 4. Differences in key catch characteristics among fishing gears. Mean (±1SE) standard and infinite length (mm), trophic level and wet weight (g) of fish caught by each fishing gear. Different superscript letters denote significant differences ($P < 0.05$) among gears for standard length, infinite length, trophic level and wet weight of fish catches

Fish catch characteristics	Handline	Muroami	Net	Trap
Standard length (mm)	336.3 ± 4.2^{a}	270.8 ± 2.1^{b}	258.5 ± 1.4^{c}	283.9 ± 2.3^{d}
Infinite length (mm)	637.8 ± 10.3^{a}	555.6 ± 5.2^{b}	546.8 ± 5.8^{b}	562.3 ± 3.1^{b}
Trophic level	3.96 ± 0.01^{a}	3.33 ± 0.01^{b}	3.23 ± 0.01^{c}	3.39 ± 0.02^{d}
Wet weight (g)	783.1 ± 38.0^{a}	466.3 ± 24.3^{b}	372.0 ± 12.7^{c}	459.5 ± 17.5^{b}

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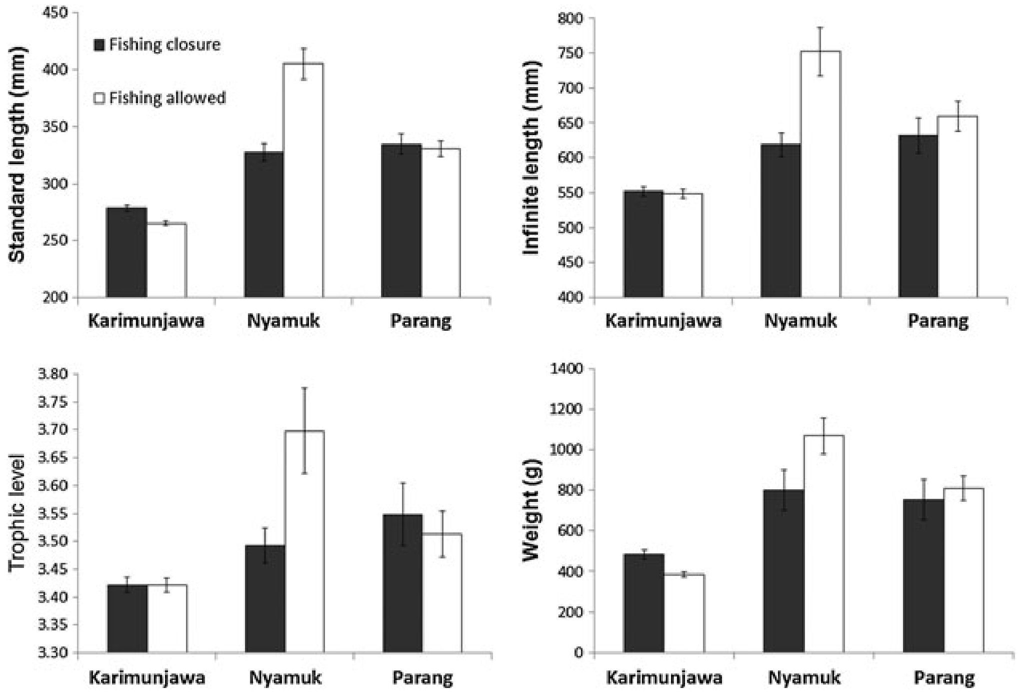

Figure 2. Mean (±1SE) fish catch characteristics of all fish catches in each of three villages and two management zones.

than management zones (weights: 5.7%, trophic level: 3.1%, infinite lengths: 25.4%, and standard lengths:7.4%).

As catch composition may vary according to the effort or use of different gears in different village locations, the proportional use of gears across all village fishing grounds was also examined to determine any marked differences in use of gears among fishing grounds, and therefore highlight any potential disproportional representation of gear use throughout the park. Fishing by handline was proportionally the highest used gear at each village fishing ground and varied two-fold from 34% of all fishing trips in Kemujan to 69% in Nyamuk (Figure 3). In Kemujan and Parang villages the use of muroami and nets exceeded 40% and this was offset by the lowest use of handlines. At villages where handline use was highest (Nyamuk, Genting), in general the proportional use of nets and/or traps was lowest.

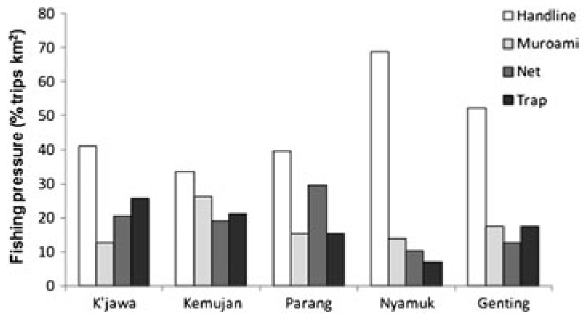

Figure 3. Percentage total fishing pressure (% household trips km^{-2}) in each village, by fishing gear.

DISCUSSION

The study found that the key catch characteristics differed across the fishing grounds and by gear type, but despite strong correlations, it was not possible to demonstrate a statistically significant relationship between this variation and fishing pressure owing to the small sample size. The artisanal fisheries in Karimunjawa contained larger reef fishes compared with published studies of other exploited reef fisheries (Dalzell and Wright, 1990; Pet-Soede *et al*., 2001; McClanahan and Mangi, 2004; Cinner and McClanahan, 2006). Likewise, the mean trophic level of fishes in Karimunjawa was slightly higher than fisheries using comparable gears (e.g. handline, nets, traps) elsewhere (McClanahan and Mangi, 2004; Cinner

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and McClanahan, 2006). Yet the larger fish sizes in Karimunjawa may be partially explained by some differences in fishing gears examined. For example in PNG, catches were reported only from gill nets, spear guns, and line fishing (Cinner and McClanahan, 2006; McClanahan and Cinner, 2008), while in Karimunjawa traps are capable of catching large-bodied species.

A closer examination of the ways in which different fishing gears in Karimunjawa selectively target different lengths and trophic levels suggests that some gears are more capable of affecting fisheries than others. For example, handline and trap fisheries tended to remove large-bodied species, and therefore may have a greater impact on fishery structure than muroami nets and other nets. Although muroami and net use was above 40% at both Kemujan and Parang, the mean length of fishes caught at Kemujan was lower than at Parang, suggesting that overall higher fishing pressure at Kemujan may be more influential in reducing average lengths of fish populations than differences in the use of fishing gears. Handline fishing is known to reduce the infinite length of fishes, and therefore large-bodied fishes are most affected by this gear (Cinner and McClanahan, 2006). In Genting where fishing pressure was comparable with Parang, fishes were overall smaller in length. A likely explanation is that depletions of large-bodied species occurred in Genting before this study owing to the frequent use of handlines. The combined proportional use of handline and traps was highest in Nyamuk, Genting and Karimunjwa. At Nyamuk, where fishing pressure was 2–4-fold lower than at Genting and Karimunjawa, the standard and infinite lengths of fish were greater, suggesting that when gear use is proportionally equivalent among fishing grounds, fishing pressure may drive changes in catch characteristics, such as reducing the mean lengths of fishes. The higher levels of fishing pressure in Karimunjawa and Kemujan also coincided with lowest fish lengths, suggesting that larger sized species may have been removed preferentially (Pauly *et al.*, 1998; Pet-Soede *et al.*, 2001), although statistical relationships between fishing pressure and body size were not significant.

Fishing pressure was negatively related to trophic level in Karimunjawa, but the range of trophic level variation was very small, suggesting an overall depletion in the trophic structure across all villages. In villages where fishes are generally smaller and from lower trophic levels, management strategies that reduce or modify fishing effort of gears that select for large-bodied species may provide the best option to improve fish sizes and trophic levels (Johnson *et al.*, 2013). Muroami catches were also generally smaller in size and at lower trophic levels than handlines and traps, as this activity non-selectively catches a range of species from different trophic groups, competing with other fisheries and damaging coral reefs (Tomascik *et al.*, 1997; Campbell and Pardede, 2006). Although muroami fishing is illegal according to national fishing laws in Indonesia, stronger enforcement of its prohibition by district governments and local communities is required. Only then will damage to coral habitats and exploitation of smaller bodied fishes be reduced, thereby promoting recovery of ecosystem function through protection of herbivores (Mumby *et al.*, 2006) and fishery sustainability by protection of planktivores (e.g. *Caesio cuning*).

Information on thresholds of overall fishing pressure, at which fishing practices start to functionally affect fish populations, can be useful for identifying the level of fishing effort for individual gears that may allow sizes and trophic levels of fisheries to be sustained or improved (McClanahan *et al.*, 2011). For example, the overall mean length and trophic level of fishes was found to be lowest at Karimunjawa and Kemujan, where fishing pressure was equal to or greater than 46 fishing trips day^{-1} km^{-2}. For trophic level, these reductions were likely to be insignificant biologically as they were very small. The levels of fishing pressure in Karimunjawa are comparable with those reported for an exploited fishery in Kenya, which was able to support up to 30 fishers km^{-2} day^{-1} without declines in the total catch (McClanahan *et al.*, 2008). As human population densities in Karimunjawa were up to 10-fold lower than in other artisinal fisheries (Cinner and McClanahan, 2006) and maximum fishing pressures approximated the lower range of fishing pressure in comparable artisinal fisheries elsewhere (Lokrantz *et al.*, 2009),

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these findings suggest that even at relatively low fishing pressures the sizes and trophic levels of fisheries can decline, as reported elsewhere for lightly exploited fisheries (Dulvy *et al*., 2004).

Effective no-take areas as a fisheries management tool can benefit biodiversity and improve fisheries (Gaines *et al*., 2010) but effectiveness may be highly dependent on the effect that closure of an area will have on the user groups and the surrounding environment (Boncoeur *et al*., 2002). Fisheries closures are rarely implemented with buy-back, incentive programmes or other measures that would result in reduced fishing effort, and the resultant fishing boat displacement will sometimes lead to effort becoming concentrated in smaller areas, causing conflict and ecological harm (Shipp, 2003). The weak compliance with no-take areas in all village fishing grounds of Karimunjawa (Campbell *et al*., 2012) suggests that proximity to more highly populated villages has little influence on compliance within no-take areas. It also suggests that fishers were unlikely to have suffered widespread displacement from these no-take areas, but displacement of fishing effort from areas which received greater enforcement than others (e.g. inside tourism zones) may have occurred. Certainly weak compliance with no-take areas, lack of targeted fishing gear based controls, and use of muroami fishing which is a non-traditional form of fishing banned by national legislation, yet permitted by district fishery laws in Karimunjawa during the 2000s, could promote competition and conflict among fishers and lack of equitable access to fishery resources (Hauck and Kroese, 2006; Campbell *et al*., 2012). In this study it was found that the consequences of these factors led to largely comparable catch characteristics among no-take areas and fishing areas.

In recognition that existing protected area governance has failed to deliver fishery and conservation benefits, the Karimunjawa National Park Authority are presently seeking to strengthen stakeholder support and compliance for fishing regulations by adopting co-management approaches that meet community goals and offset fisheries impacts on marine biodiversity (Campbell *et al*., 2013). Such approaches can avoid the costs associated with weak compliance and can involve regulating fishing gear use, development of alternative livelihoods (e.g. mariculture) or compensation measures for lost rights (Agardy *et al*., 2011). Incentives for fishing communities to comply with spatial controls on fishing and adopt gear restrictions could provide the most effective way to improve the size and density of fish populations (McClanahan and Cinner, 2008) and reduce habitat damage in Karimunjawa. In 2010 in Karimujawa, community support for muroami bans, stronger enforcement by the national park agency and economic drivers led to a cessation of muroami fishing (Campbell *et al*., 2013). Because muroami fishing uniquely involves a patron–client relationship, its cessation will probably lead to reduction in the ratio of investors to self-employed people, and shifts to more traditional gears such as handlines and spear guns (Campbell *et al*., 2012). In 2012 a subsequent recovery in reef fish biomass in Karimunjawa was reported (Pardede *et al*., 2012) and co-management approaches that view fisheries as linked social–ecological systems (Allison *et al*., 2011; Ferse *et al*., 2013) may have the potential to drive even longer-term improvements in social capital and ecological stewardship. Through securing the livelihoods of communities depending on them (Cinner and Aswani, 2007; Gutiérrez *et al*., 2011; Cinner *et al*., 2012; Ferse *et al*., 2013), such approaches are also more likely to find acceptance with fishing communities than ‘top-down’ controls that prohibit fishing altogether (Aswani *et al*., 2007; Gelcich *et al*., 2008; Agardy *et al*., 2011).

CONCLUSION

By examining fisheries characteristics across a gradient in fishing pressure it was shown that even fisheries in a relatively small geographical area can be shaped by gear use and possibly fishing pressure. Village fishing grounds subject to highest fishing pressures showed lower average fish lengths, trophic levels and fish weights. Fishers who have limited mobility, such as those who use handlines and traps from non-motorized boats, may also affect reef fisheries by catching large sized and large-bodied species. Adoption of strategies that restrict the use of such gears may allow recovery in

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areas where large-bodied fish are in decline and improvement in fishery targets (e.g. piscivores) are required. In other areas, bans on nets may be required to promote trophic diversity which can help maintain ecosystem function (e.g. herbivores) and fishery sustainability (e.g. planktivores). Spatial management controls aimed at achieving conservation objectives and a benefit to local fisheries had little influence on fish characteristics. Investments in co-management organizations that regulate sustainable gear-based fishing practices, manage fishery allocations based on fishers traditional rights and establish alternative income sources, are evolving in Karimunjawa as the key approaches to improve social well-being of communities and alleviate fishing pressure where human population densities are high. These fisheries management strategies have direct relevance to improving artisanal fisheries management in the broader Coral Triangle region.

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