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Avoiding conflicts and protecting coral reefs: Customary management benefits marine habitats and fish biomass

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Abstract One of the major goals of coral reef conservation is to determine the most effective means of managing marine resources in regions where economic conditions often limit the options available. For example, no-take fishing areas can be impractical in regions where people rely heavily on reef fish for food. In this study, we test whether coral reef health differed among areas with varying management practices and socioeconomic conditions on Pulau Weh, in the Indonesia province of Aceh. Our results show that gear restrictions, in particular, prohibiting the use of nets, were remarkably successful in minimizing habitat degradation and maintaining fish biomass despite ongoing access to the fishery. Reef fish biomass and hard-coral cover were two to eight-fold higher at sites where fishing nets were prohibited. Most interestingly, the guiding principle of the local customary management system, *Panglima Laot,* is to reduce conflict among community members over access to marine resources. Consequently, conservation benefits in Aceh have arisen from a customary system which lacks a specific environmental ethic or the means for strong resource based management. *Panglima Laot* includes many of the features of successful institutions, such as clearly defined membership rights and the opportunity of resource users to be involved in making, enforcing, and changing the rules. Such mechanisms to reduce conflict are the key to success of marine resource management, particularly, in settings which lack resources for enforcement.

Keywords: Aceh, coral reefs, gear restrictions, Indonesia, marine protected areas, fisheries, *Panglima Laot*

Introduction

Across the Indo-Pacific, marine resources are often managed by common property arrangements that limit access through closures of fishing grounds and gear restrictions (Thornburn, 2001; Harkes & Novascek, 2002; Cinner & Aswani, 2007). Benefits of these customary practices include increases in fisheries yields (McClanahan et al., 1997), target species biomass (Cinner et al., 2005a, b) and abundance (Aswani & Sabetian, 2010). Important ecosystem processes, such as herbivory (Aswani et al., 2007), and metrics of ecosystem health, such as coral cover are often higher in areas under customary management (Baird et al., 2005), Integrating these customary systems with contemporary management practices (e.g., spatially defined marine protected areas) continues to be an area of active research (Johannes, 2002; Aswani et al., 2007) with these alternate forms of marine resource management increasingly being advocated (Graham et al., 2008).

Customary management systems are frequently motivated by utilitarian social and economic goals, rather than any conservation ethic (Polunin, 1984; Pannell, 1996; Cinner & Aswani, 2007). The ability of customary systems to meet community needs such as providing fish for harvest, reducing conflict among resources users and improving yields can lead to higher levels of compliance, and ultimately better ecological outcomes than externally imposed biodiversity conservation (McClanahan et al., 2006a; Cinner & Aswani, 2007). One of the critical challenges for marine conservation in developing countries, where food security often takes priority over intrinsic conservation goals, is how to make conservation more compatible with community needs (Drew 2005; Cinner et al., 2007). Governance systems that respect customary knowledge, rules and decision-making processes are more likely to be supported by local communities (Aswani, 2005; Hoffman, 2006; Tiraa, 2006), and are commonplace in many Pacific societies (Cinner & McClanahan, 2006; Aswani et al., 2007; Cinner & Aswani, 2007).

Compared with marine customary management in central and eastern Pacific societies, there are relatively few examples of community involvement with marine resource management or marine customary law in Indonesia (Cinner & Aswani, 2007; Cinner et al., 2012). Community governance structures in Indonesia have often been modified, eroded or overruled by Provincial or National legal institutions (Novascek et al., 2001; Patlis, 2003), restricted or prejudiced by centralized conservation policies and laws with respect to marine resource access (Thornburn, 2000; Lowe, 2003), incentives for destructive fishing practices (Thornburn, 2001; Varkey et al., 2010) or disincentives for community participation in management (Novascek et al., 2001; Lowe, 2003). However, as part of the decentralisation of governance in many countries, including Indonesia (Thornburn 2001; Patlis 2003), customary practises are becoming enshrined in legislation of district and local authorities (Janssen, 2005; Gelcich et al., 2008).

Documenting the successes or failures of customary practices improves understanding of the governance frameworks within which marine environments and their resources are most effectively managed (McCleod et al., 2009). Here, we present a case study from Aceh, Indonesia, that examines the socioeconomic and ecological conditions of six coastal communities in which a customary management system operates. Our objectives were to examine if aspects of coral reef condition, specifically hard coral cover, fish biomass and fish assemblage structure, differed between reefs that were influenced by varying management practice, in particular the types of fishing gears restricted. To support our analysis, we also investigated whether ecological variation was related to socioeconomic variables including village population size, the number of fishing households, the mean number of occupations, distance to markets, distance to villages and the number of fishing gear types prohibited.

Methods

Study sites and the *Panglima Laot* system of customary management

This study was conducted on Pulau Weh, a high continental island located approximately 20 km off the northern tip of Sumatra (Fig. 1). Pulau Weh has diverse coral communities that grow primarily on bedrock and in unconsolidated sediments. The coastline of Pulau Weh is divided into several *lhoks* (*lhok* is the Acehnese term for harbour and is the unit of management in the marine realm). Within six of these *lhoks* we examined 1-4 sites (15 sites in total; Fig. 1), each with its own set of restrictions on fishing gears (Table 1). One of the *lhoks*, Iboih, was divided into two separate areas for analysis because some sites within this *lhok* are managed as a special tourist reserve, *Kawasan Wisata* (Iboih-KW), while the others are managed by a *Panglima Laot* (Iboih-PL). Sites with both high (6-9) and low (2-5) numbers of restrictions on types of fishing gear were located in *lhoks* on the north, east and west coasts of Pulau Weh.

In Aceh, fishing communities employ a customary management system known locally as *Panglima Laot*. The system was first introduced in the 17th Century by Sultan Iskandar Muda (Nurdin et al., 2004). Fishers in each *lhok* elect an individual, usually an elder fisherman, the *Panglima Laot* (literally ‘Commander of the Sea’) who meets with fishers every Friday to adjudicate disputes. The *Panglima*

Laot has the authority to adjudicate provincial laws concerning fishing rights except in cases where provincial or national criminal law is violated. The *Panglima Laot* decides who is entitled to the catch at sea and what fishing gears can be used. He enforces prohibitions on fishing on religious days, initiates searches for lost fishermen, decides compensation in the event of boat collisions and arbitrates general disputes over access to the fisheries (Janssen, 2005). The *Panglima Laot* can also enforce measures to protect the marine environment from land based threats such as poorly placed development and agriculture. Should a fisherman violate the code of conduct for a given *lhok*, the *Panglima Laot* has the authority to ground a boat for a week at a time, and if the fisherman continues to disobey the rules, the *Panglima Laot* can banish boats from the *lhok* (Wilson et al., this issue). Other sanctions include monetary fines, and preventing fisherman from attending community events. Sanctions or punishments are administered through community meetings and ceremonies to reach consensus among parties (Nurdin et al., 2004; Wilson et al., this issue). Fishers must pay a fee to enter the *Panglima Laot* system, which is used as insurance to cover the cost of rescues (Wilson et al., this issue). Importantly, the role of the *Panglima Laot* is not to manage fishery resources *per se*, but rather to promote social harmony by minimizing conflict among fishers (Nurdin et al., 2004). This lack of a conservation ethic is summed up by the Acehnese proverb mentioned by Nurdin et al., (2004) to describe the philosophy behind *Panglima Laot* "*Uleu bak matee, ranteng bek patah*". This saying is translated by Collier et al., (2010) as "killing a snake without breaking tree branches" or, in other words, to solve one problem without creating a new one. The role of the *Panglima Laot* system in marine resource management has most recently been recognized in

2008 in Provincial Laws No. 9 and 10 which give the *Panglima Laot* authority to arbitrate customary laws in relation to the sea (Adli-Abdullah & Muttaqin, 2009).

Coral cover and fish biomass

In March 2006, coral cover and fish biomass were estimated along two replicate 50 m transects at two depths (3-4 m and 6-8 m) at each of the 15 sites (Fig. 1). Coral cover was recorded at 100 points along each transect, spaced at 0.5 m intervals. Any hard coral (i.e. scleractinian or hydrozoan coral) underlying each survey point was recorded to genus.

The fish assemblages were surveyed along the same 50 m transects used for estimating hard coral cover. One diver recorded all visually apparent reef fish (i.e., excluding cryptobenthic families Blenniidae, Gobiidae, and Tripterygiidae) > 10 cm total length (TL) in a 5 m wide belt, and a second diver recorded all fish < 10 cm TL in a 2 m wide belt that extended from the reef substratum to the surface of the water. Individual fishes were identified to species and placed into one of nine size classes (0-5 cm, 5-10 cm, 10-15 cm, 15-20 cm, 20-25 cm, 25-30 cm, 30-35 cm, 35-40 cm and >40 cm). Density estimates were converted to biomass using known length-weight relationships; $W = aL^b$, where W is weight (kg), L is total length (cm) and a, b are the indices for a given species (Froese & Pauly, 2008). To examine variation in fish assemblage structure, individual species were allocated to six trophic groups (corallivores, herbivores, invertivores, ominivores, piscivores, and planktivores) following Froese & Pauly (2008).

Fishing gears of Pulau Weh

Eight main fishing gears are used on Pulau Weh, namely reef nets, gill nets, mosquito nets, muroami, hookah, spearguns, handlines, and trolling. Reef nets are modified seine nets, not more than 60 m in length with a height of 8-10 m (mesh size: 6 cm). They are deployed after dusk from two canoes in calm waters. Gill nets target reef fish including triggerfish (f. Balistidae), snapper (f. Lutjanidae) and emperor (f. Lethrinidae), and consist of single nylon nets that are either small (length: 300-400 m; height: 2-5 m) or large (length: 800-1000 m; height: up to 15 m). Mesh sizes vary from 4-11 cm and nets are set passively at the surface or at mid-water. Mosquito nets are monofilament nets of between 200-300 m in length with a mesh size of less than 3 mm that mostly target anchovies and other small pelagic fishes. Muroami is a technique that primarily targets fusiliers (f. Caesionidae) but is non-selective and can catch many reef fish species. The technique involves the use of divers and surface-supplied air (hookah) to chase fish along the reef into a large drive-net or purse net (mesh size: 2-5 cm), set on reef slopes at depths of 7-30 m. The crew of a muroami operation on Pulau Weh usually consists of 8-10 people. Reef nets and muroami are relatively non-selective catching fish from many different families. Hookah gear consists of an air compressor with several air hoses of 50-100 m length. Hooker divers use their hands to collect sea cucumber, lobster and troches, and occasionally spears to target grouper (f. Serranidae) and gill nets to target aquarium fishes. Spearguns are made from wood with spears 1.2-2.0 m in length and are used by fishers on snorkel to target a wide variety of reef fish species including snapper and grouper. Hook and line fishing is employed from many boat types including canoes and motorized boats, while trolling consist of a single fisher with a hook and line deployed from the rear of a motorized boat.

Socio-economic variables

In December 2006, 143 household surveys were conducted by AM and YH in the six *lhoks*. All respondents were asked to list and rank the occupations of members of the household, from which the mean number of occupations per lhok was calculated. Concurrent with these surveys, demographic data were sourced from the *Panglima Laot* and government records. Data available for each *lhoks* included the population size, number of households, number of households involved in fishing, and mean number of occupations per household (Table 1). At the site level, data were available on the distance (m) from survey site to the nearest village (a proxy variable for the likelihood of restrictions being enforced), the distance to the nearest fish market and the number and types of fishing gears prohibited (Table 2).

Statistical analysis

Variation in hard coral cover and total fish biomass among *lhoks* and sites were tested with two nested ANOVAs. Assumptions of the ANOVA were examined using residual analysis. Subsequently, total fish biomass was $\log_{10}(x + 1)$ transformed to improve normality and homoscedasticity. Fisher's LSD tests were used to identify which means contributed to any significant differences among sites or *lhoks*.

Variation in the functional composition of the fish assemblages among *lhoks* was analysed using a one-factor multivariate analysis of variance (MANOVA). The analysis was based on the biomass of each of the six functional groups, and was $\log_{10}(x + 1)$ transformed to improve multivariate normality. A canonical discriminant analysis (CDA) was then used to examine how the *lhoks* differed in fish assemblage composition. Ninety-five percent confidence ellipses were plotted around the group centroids (Seber 1984).

The relationships among the socioeconomic variables and hard coral cover and total fish biomass were examined using bivariate correlations and stepwise multiple regressions. The correlations provided an indication of the relationships between hard coral cover and total fish biomass and each of the socioeconomic variables independently, while the multiple regressions examined the combined effects of all socioeconomic variables and determined the relative importance of each variable in determining coral cover and total fish biomass. All analyses were performed using STATISTICA v. 7.0.

Results

Coral cover and fish biomass

The cover of hard corals varied significantly among *lhoks* ($F_{6,8}$ = 4.22, P= 0.033) and sites within *lhoks* ($F_{8,42}$ = 2.53, P = 0.02), ranging from 10.8 ± 4.2 % (mean ± SE) at Paya to 59.6 ± 5.2 % at Ie Meulee (Fig. 2a). Overall, coral cover was highest at Ie Meulee and Anoi Itam (54.5 - 59.6 %), intermediate at Iboih - KW (41.9 %) and lowest at Iboih (*Panglima Laot*), Keunekai and Paya (10.8 – 30.8 %; Fig. 2a).

Total reef fish biomass varied significantly among *lhoks* ($F_{6,8}$ = 3.67, P = 0.047), but displayed no significant variation among sites ($F_{8,45}$ = 1.56, P = 0.165). Reef fish biomass was significantly greater at Ie Meulee and Anoi Itam (1090.4 – 1729.4 kg.ha^{-1}) than at Kota, Iboih-PL, Keunekai and Paya (241.5 – 444.6 kg.ha^{-1}; Fig. 2b). The composition of the reef fish assemblages also varied significantly among *lhoks* on Pulau Weh (MANOVA, $F_{5,85}$ = 2.45, P < 0.001). The CDA revealed two distinct groups of *lhoks* along the first canonical variate, which explained 47.4 % of the total variation (Fig. 3). Anoi Itam, Ie Meulee and Iboih-KW were characterized by a greater biomass of corallivores, omnivores, herbivores, and to a lesser extent piscivores and planktivores, than Iboih-*PL*, Keunekei, Kota and Paya (Fig. 3).

Relationships between ecological and socio-economic variables

The cover of live hard corals was positively related to the number of fishing gears prohibited and *lhok* population size, and negatively related to distance to village and distance to market (Table 3). The multiple regression analysis suggested that the number of fishing gear types *prohibited*, population size and the mean number of occupations were the best combination of predictors of hard coral cover, with the overall model explaining 53 % of the variation in coral cover among sites (Table 3). Similarly, total reef fish biomass was positively related to coral cover, the number of gear types *prohibited,* and negatively related to distance to nearest village and market (Table 4). The multiple regression indicated that coral cover and the number of fishing gears prohibited were the best combination of predictors of reef fish biomass explaining 32.9 and 6.2 % of the variation in fish biomass among sites, respectively (Table 4).

Discussion

Customary marine resource management practices in the Indo-Pacific are often focused on social goals such as minimizing conflict among coastal communities, rather than western ideals of conservation or fisheries management (Polunin, 1984; Pannell, 1996; Aswani et al., 2007). Although the primary aim of the *Panglima Laot* is to minimise conflict among fishers, our findings indicate that controls on fishing gears indirectly yield conservation benefits including, healthier coral reefs that support a greater biomass of reef fish, including important trophic groups, such as herbivores that are essential for promoting reef resilience.

Coral cover was positively correlated with the number of gears restricted and the population number and inversely correlated with distance to the nearest village and distance to market (Table 3). The correlation with the number of gears prohibited is most likely a result of the banning of fishing gears, in particular the various types of nets that cause direct mechanical damage to corals and indirect damage by trampling due to high numbers of fishermen in the water to set the nets and/or scare fish into the nets. The reasons for the gear restrictions, are not, however, based on potential damage to the reef rather some fishing gears are more likely to create conflict among fishers. Reef nets and muroami in particular, compete with handlines and spears for many species (e.g. surgeonfish, grouper, parrotfish, trevally and pelagic species) and return relatively high rates of catch. The perception among most fishers is that nets deplete local fish stocks, with the profit mostly going to wealthy boat owners (WCS unpublished data). Controls enforced by the *Panglima Laot* on the use of nets therefore limit the perceived inequity by reducing competition among fishers of different economic status.

Many different socioeconomic factors influence the ability of customary institutions to limit overexploitation of fishery resources. Generally, customary management systems operate best when population is low and distance to markets is great (Cinner & Aswani, 2007; Aswani & Sabetian, 2010) Our findings suggest an opposite trend on Pulau Weh, where the proximity of a fishing location to a village and the number of people in the *Lhok* most likely assists the *Panglima Laot* to enforce compliance with fishing rules, because fishing activities are in line of sight of local communities and there are more people to watch over the resource (Crawford et al., 2004; McClanahan et al., 2006b).

Reef fish biomass was positively correlated with coral cover and the number of gears prohibited and negatively correlated with distance to market and distance to the nearest village (Table 4). The strong relationship between reef fish biomass and coral cover is not surprising because many reef fish rely on corals for shelter and food (Jones et al., 2004; Graham et al., 2007). Numerous studies have reported declines in reef fish diversity and abundance following declines in coral cover and structural complexity (Jones et al., 2004, Pratchett et al., 2008, Messmer et al., 2011). This result suggests that one of the most effective means of protecting fish biomass is to protect the habitat. However, the positive correlation between fish biomass and the number of fishing gears prohibited also suggests that gear restrictions are having a direct effect by reducing fishing pressure. Reef fish biomass can be ten-fold greater in marine protected areas within ten years of closure when compared to adjacent heavily fished areas (McClanahan and Graham, 2005; Russ et al., 2005; Aburto-Oropeza et al., 2011). Similarly, in a reef fishery in Tanzania, the banning of dynamite, cyanide and the use of small-mesh seine nets that are deployed in a similar manner to muroami nets on Pulau Weh, also resulted in an increased abundance of reef fish and biomass of some fish families (Tyler et al., 2011). While banning destructive fishing gears appear to be improving fish biomass both on Pulau Weh and elsewhere (Tyler et al., 2011) effort may need to be limited further to facilitate greater improvements in fish biomass. The *Panglima Laot* on the east coast of Pulau Weh have recently achieved this through the establishment of strict no-take areas within their marine waters. The proximity of a site to a village can shape reef fish biomass due to market driven demands (Brewer et al., 2009) and through increased fishing pressure (Cinner &

McClanahan, 2006). In contrast, our findings suggest the proximity of a fishing location to a village most likely assists the *Panglima Laot* to enforce compliance with fishing rules as described above.

Reef fish populations also vary in response to environmental factors such as wave exposure, currents and primary productivity (Halford et al., 2004; Pratchett et al., 2008). While we did not specifically control for these environmental factors, the variation in reef fish biomass was much greater (up to 8-fold) than we would predict on the basis of environmental differences alone. Furthermore, adjacent *lhoks* (which therefore have similar environments) with different levels of gear restriction (i.e., Ie Meulee vs Kota; Iboih-KW vs Iboih-*Panglima Laot* and Anoi Itam vs Keunekai) followed the general trend of greater fish biomass where the number of gears restricted was high.

Poor enforcement of controls on destructive fishing, including blast and cyanide fishing, may also be responsible for some of the differences in coral cover and fish biomass. According to local fishers, while blast fishing ceased in the 1990s, sporadic cyanide fishing continues in some *lhoks* such as Paya and Keunekai and may be contributing to consistently low coral cover and reef fish biomass at these sites.

The relative abundance of the different trophic groups was also linked to gear restrictions. The three *lhoks* where the most types of gears were prohibited (i.e. Anoi Itam, Ie Meulee and Iboih-KW) were characterized by a greater biomass of corallivores, omnivores, herbivores, and to a lesser extent piscivores and planktivores, than *lhoks* where the number or gears prohibited was low (i.e., Iboih-*Panglima Laot*, Keunekei, Kota and Paya; Fig. 3). Similar responses following spatial closures on fishing of herbivorous parrot fish, has been reported in the Indo-Pacific (Aswani & Sabetian, 2010).

The customary system of *Panglima Laot* has a number of the design principles identified by Ostrom (2009), and more recently examined by Gutierrez et al. (2011), associated with successful fisheries management institutions, including clearly defined membership rights; rules that limit resource use; the right of resource users to make, enforce, and change the rules; graduated sanctions and mechanism for conflict resolution (Cinner et al., 2012). These principles are the key to the ability of the institution to reduce conflict among communities, provide sustainable access to marine resources and limit the destruction of marine habitats. However, the institution has not been uniformly successful. In particular, reef condition in the adjacent island group of Pulau Aceh was very poor in 2005, possibly due to destructive fishing and poor coastal management (Baird et al., 2005; Campbell et al., 2007). The precise causes of this breakdown in *Panglima Laot* in Pulau Aceh are the focus of current research efforts in the region. Finally, investing a single individual with authority to make all decisions poses some risk of abuse.

Conclusion

Motivated by the aim of producing social harmony, restrictions on gear use by the *Panglima Laot* in Aceh have direct conservation benefits such as high coral cover and enhanced fish biomass. Additional surveys over a wider geographic scale and over a longer period are required to reveal whether these findings also apply at larger spatial and temporal scales.

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Biographical Sketches

STUART CAMPBELL research interests include conservation biology.

JOSHUA CINNER’s research explores how social, economic, and cultural factors influence the ways in which people use, perceive, and govern natural resources, with a particular emphasis on using applied social science to inform coral reef management.

RIZYA ARDIWIJAYA designs and applies monitoring programs to provide the ecological information necessary for the effective management of marine protected areas.

SHINTA PARDEDE research interests include coral reef fish ecology.

TASRIF KARTAWIJAYA research interests include the management of coral reef fisheries.

AHMAD MUKMUNIN works to encourage dialogue between government and communities to promote coral reef conservation. He has been managing the WCS research programme in Aceh from Pulau Weh for five years.

YUDI HERDIANA research interests include the ornamental fish trade.

ANDREW HOEY’s research interests include the functional importance of herbivorous fishes on coral reefs.

MORGAN PRATCHETT research interest include the role of disturbance on coral reefs and the effect of climate change on fisheries

ANDREW BAIRD research interests include the evolution of life histories in corals. He has been engaging with the reefs of Aceh since 1984.

TABLE 1. Population size, number of fisher households, mean number of occupations and reef area in six *lhoks* on Pulau Weh.

Lhok	Population size	No. fisher households	Mean no. occupations	Reef Area (Ha)
Anoi Itam	693	56	3.1	120.55
Iboih	766	52	2.5	158.65
Ie Meulee	3574	60	2.5	177.9
Paya	731	71	2.8	111.3
Kota	2623	170	2.6	112.31
Keunekai	532	21	3.2	32.51

TABLE 2. Distances from ecological sites to markets and village and the fishing gears prohibited in each of the 15 sites on Pulau Weh.

* indicates a gear is prohibited.

								Nets						
Lhok	Site	Distance to market (m)	Distance to village (m)	Trolling	Handline	Hookah	Spear	Gill net	Reef net	Mosquito net	Muro-ami	Bomb	Cyanide	Total gears prohibited
Anoi Hitam	Anoi Hitam	12292	1392			*		*	*	*	*	*	*	7
	Benteng	8704	1033		*	*	*	*	*	*	*	*	*	9
	Ujung Seuke	4556	3278			*		*	*	*	*	*	*	7
Iboih-KW	Batee Meuronon	7338	907				*	*	*	*	*	*	*	7
	Rubiah Channel	7286	1271		*		*	*	*	*	*	*	*	8
	Rubiah Sea Garden	6679	1110				*	*	*	*	*	*	*	7
	Ujung Seurawan	9291	3445				*	*	*	*	*	*	*	7
Iboih-PL	Ba Kopra	40086	11487			*		*	*	*	*	*	*	7
	Lhong Angin 1	24455	10167							*	*	*	*	4
	Lhong Angin 2	22809	8823							*	*	*	*	4
Ie Meulee	Sumur Tiga	3907	1127				*	*	*		*	*	*	6
	Ujung Kareung	4728	2890					*	*		*	*	*	5
Keunekei	Beurawang	5820	2710									*	*	2
Kota/Pasiran	Pulau Klah	2363	1570									*	*	2
Paya	Lhong Angin 3	17534	7036									*	*	2

TABLE 3. Relationship between live coral cover and six socioeconomic variables across 15 sites on Pulau Weh. Pearsons correlation coefficient and the results of a stepwise multiple regression are given.

	Bivariate correlation		Multiple regression				
	r	p	Multiple R^2	β	S.E. of β	$t_{(56)}$	p
Number of gears prohibited	**0.555**	**< 0.001**	**0.308**	**0.662**	**0.094**	**7.072**	**< 0.001**
Population	**0.306**	**0.017**	**0.487**	**0.516**	**0.100**	**5.163**	**< 0.001**
Mean occupations	0.032	0.806	**0.533**	**0.229**	**0.098**	**2.345**	**0.023**
Fishing households	-0.035	0.792					
Distance to village	**-0.448**	**< 0.001**					
Distance to market	**-0.337**	**0.008**					

TABLE 4. Relationship between total fish biomass and the six socioeconomic variables and live hard coral cover across 15 sites on Pulau Weh. Pearsons correlation coefficient and the results of a stepwise multiple regression are given. Total fish biomass was log-transformed. Significant effects are shown in bold.

	Bivariate correlation		Multiple regression				
	r	p	Multiple R^2	β	S.E. of β	$t_{(57)}$	p
Coral cover	**0.574**	**< 0.001**	**0.329**	**0.347**	**0.131**	**5.338**	**< 0.001**
Number of gears prohibited	**0.525**	**< 0.001**	**0.391**	**0.257**	**0.131**	**2.401**	**0.020**
Population	0.087	0.511					
Mean occupations	0.065	0.622					
Fishing households	-0.248	0.056					
Distance to village	**-0.431**	**0.001**					
Distance to market	**-0.313**	**0.015**					

Figure Legends

FIG. 1 Map of Pulau Weh showing the boundaries of each of the six *lhoks* on Pulau Weh and the 15 study sites located within these *lhoks.*

FIG. 2 Variation in a) mean coral cover and b) mean total fish biomass among the seven management areas (6 *lhoks*) on Pulau Weh. Letters above each bar indicate homogenous groups identified by Fisher's LSD post hoc analyses.

FIG. 3 Canonical discriminant analysis showing the relationship among reef fish assemblages across seven management areas (6 *lhoks*) on Pulau Weh. Ellipses represent 95% confidence limits around the centroids for each *lhok*. Vectors are structural coefficients of response variables, indicating the relative contributions of each of the fish functional groups to the observed differences in assemblage composition. pl = planktvore; ps = piscivore. Dashed ellipses indicate *lhoks* where nets are allowed, solid ellipses are *lhoks* where nets are prohibited.

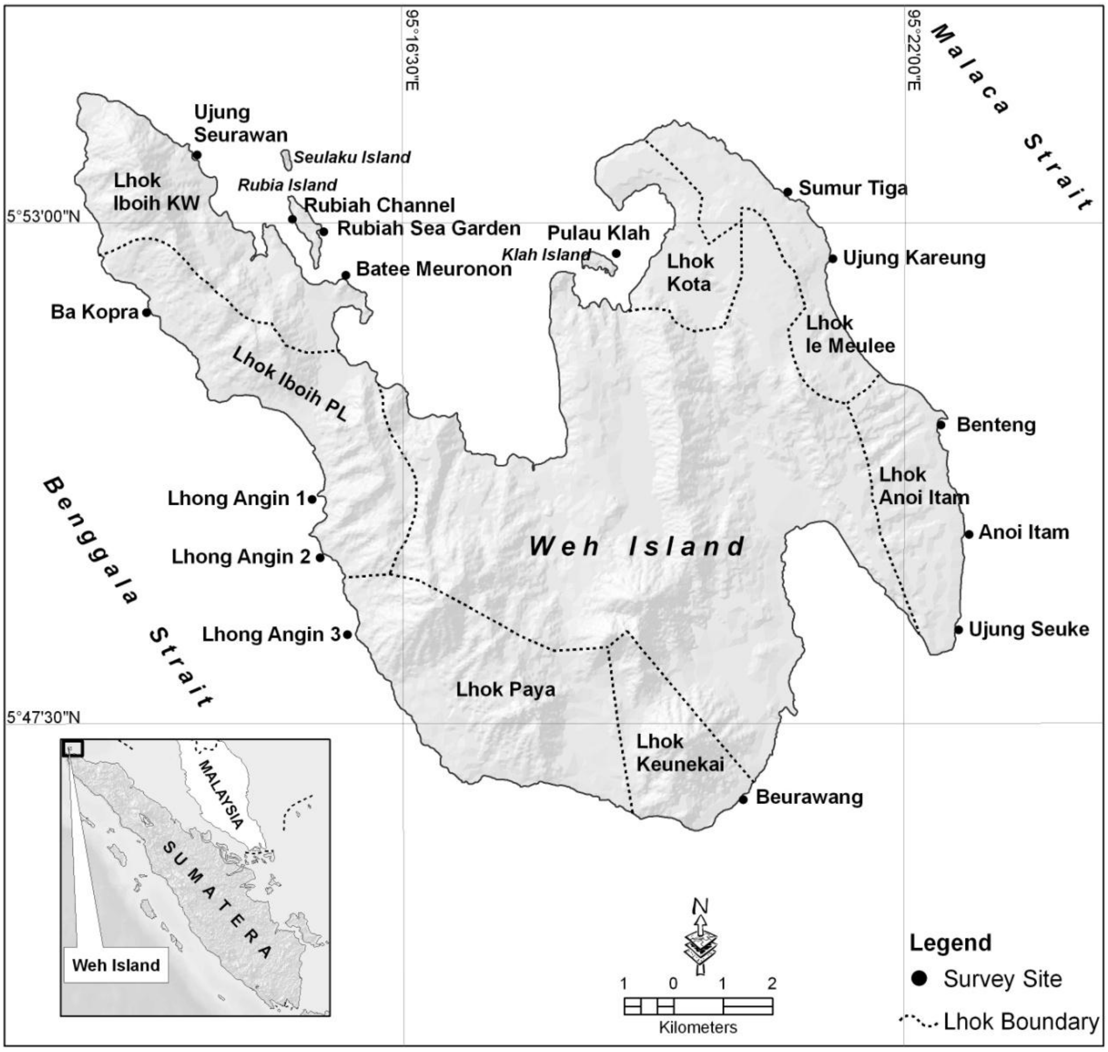

95°16'30"E
95°22'00"E
5°53'00"N
5°47'30"N
Malaca Strait
Benggala Strait
Ujung Seurawan
Seulaku Island
Lhok Iboih KW
Rubia Island
Rubiah Channel
Rubiah Sea Garden
Batee Meuronon
Pulau Klah
Klah Island
Sumur Tiga
Ujung Kareung
Lhok Kota
Lhok Ie Meulee
Ba Kopra
Lhok Iboih PL
Benteng
Lhok Anoi Itam
Anoi Itam
Lhong Angin 1
Lhong Angin 2
Weh Island
Ujung Seuke
Lhong Angin 3
Lhok Paya
Lhok Keunekai
Beurawang
MALAYSIA
SUMATERA
Weh Island
N
1 0 1 2
Kilometers
Legend
Survey Site
Lhok Boundary

FIG. 1

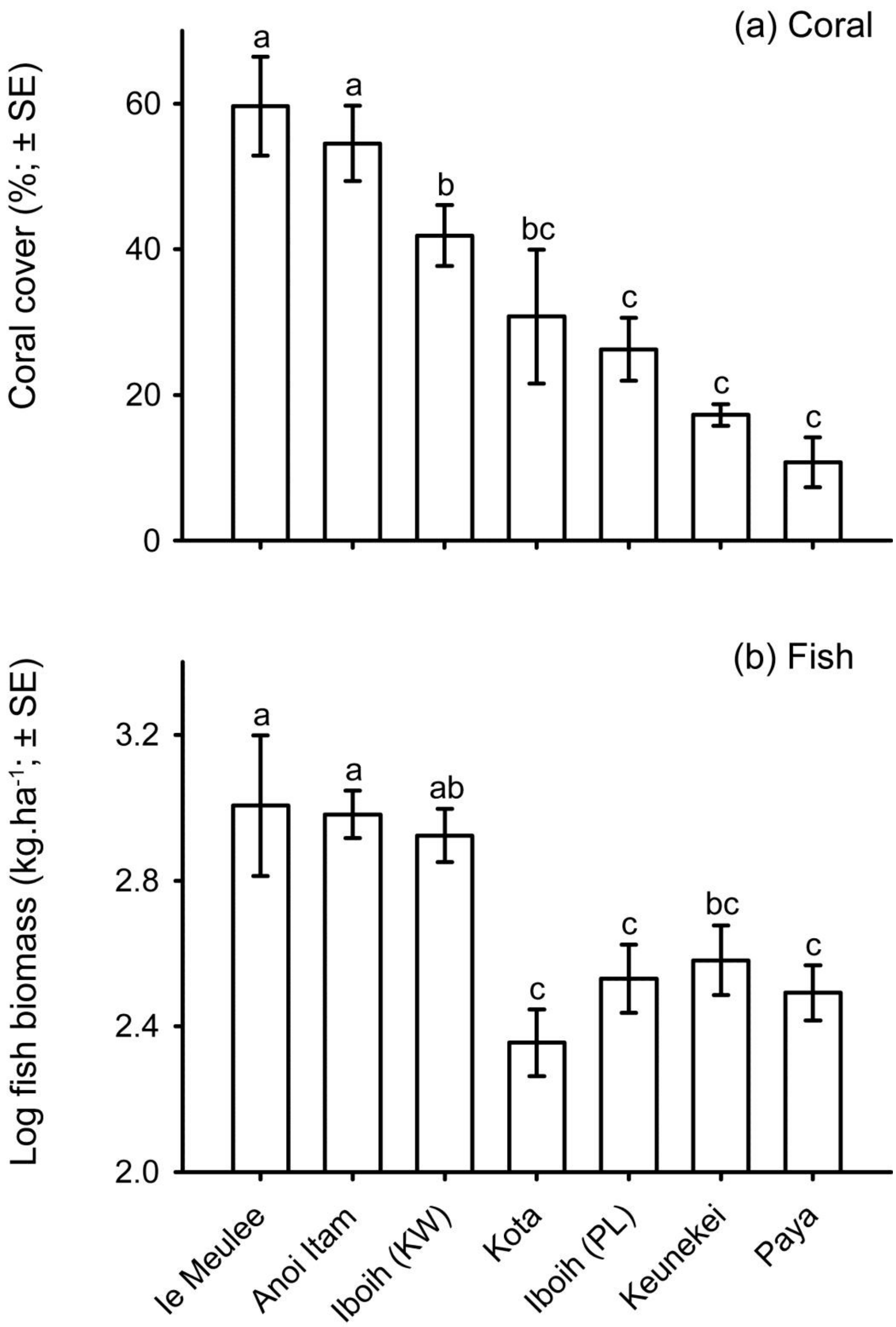
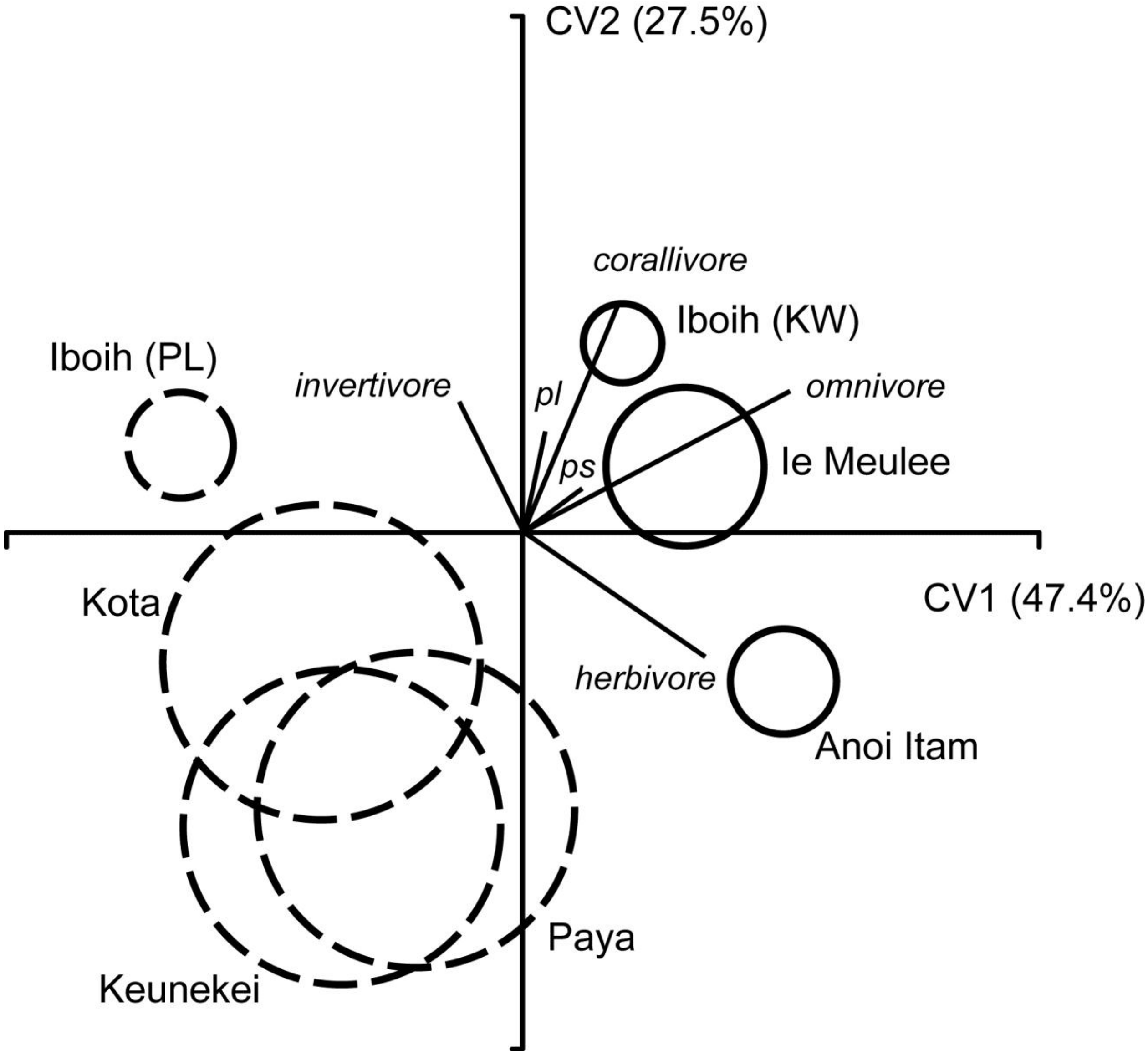

(a) Coral
Coral cover (%; ± SE)
60
40
20
0
a
a
b
bc
c
c
c
(b) Fish
Log fish biomass (kg.ha-1; ± SE)
3.2
2.8
2.4
2.0
a
a
ab
c
c
bc
c
Ie Meulee
Anoi Itam
Iboih (KW)
Kota
Iboih (PL)
Keunekei
Paya

FIG. 2

FIG. 3


CV2 (27.5%)
CV1 (47.4%)
corallivore
Iboih (KW)
Iboih (PL)
invertivore
pl
omnivore
ps
Ie Meulee
Kota
herbivore
Anoi Itam
Paya
Keunekei