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Influence of social, management and enforcement factors on the long-term ecological effects of marine sanctuaries

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SUMMARY

Marine sanctuaries are increasingly being promoted as tools for conservation and fisheries management. This study investigates the effects of protection over 19 years on substrate composition and fish communities in four marine sanctuaries and corresponding non-sanctuary areas in the Philippines and examines the importance of community support, management measures and enforcement of regulations on these ecological effects. Between 1981 and 2000, substrate cover variables were measured using line transects with scuba and snorkel surveys, and fish censuses (identification to family level) were conducted using scuba within a 500 m^2 area. Semi-structured interviews collected data on community support for the sanctuaries, and observations and interviews established management and enforcement aspects of the sanctuaries. Over time, all sanctuaries showed improvements, or maintenance of, ecological variables compared with pre-enforcement times, with maintenance of hard coral cover and average increases of 8.3% in fish species richness and 54.9% in fish abundance. In comparison, non-sanctuary areas showed maintenance of the status quo or declines in ecological variables. However hard coral cover, fish abundances and fish species richness showed significant declines as well as increases in sanctuary areas. Community, management and enforcement factors were significantly related to positive ecological trends in sanctuary areas; management and enforcement were related to a wider variety of ecological factors than community score. Community support was significantly related to an increase in hard coral cover in deep areas. Enforcement of regulations was significantly related to an increase in abundance of fishery target fish species in sanctuary areas, and simple management measures were significantly related to an increase in abundance of large predators. Supportive communities that voluntarily implemented sanctuary regulations, improved enforcement, and small discrete cohesive communities may have facilitated the process of building this community support. Well-enforced sanctuaries that showed an increase in abundance of target species may have contributed to the maintenance of fish yields in adjacent non-sanctuary areas. The effects of sanctuary implementation varied on a case-by-case basis, influenced by environmental, biological, physical and human factors. However, a combination of community support, management measures and enforcement of regulations contributed towards positive ecological trends in sanctuary areas.

Keywords: marine sanctuaries, marine reserves, fish communities, coral reefs, community-based management, Philippines

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INTRODUCTION

Marine sanctuaries (also referred to as marine reserves, marine protected areas and no-take zones) are being promoted increasingly as tools for conservation and fisheries management in tropical regions (Kelleher & Kenchington 1992; Roberts & Polunin 1993; Dugan & Davis 1993; Ballantine 1994; Munro 1996; Bohnsack 1998; Hall 1998; Lauck *et al.* 1998; Fogarty 1999). The term 'marine sanctuary' is used throughout this text to refer to a marine area where extractive and destructive uses are banned by law. In the tropics, coral reefs occur primarily in developing countries and are socio-economically important (Cesar *et al.* 1997), providing livelihood options and improving food security for coastal communities (McAllister 1988). However, threats to coral reefs are increasing worldwide (Wilkinson 1998), many marine fisheries are heavily exploited (Polunin *et al.* 1996) and in many countries in the tropics, inshore catches of fish and shellfish are in decline (King & Faasili 1998). Reasons for the decline include over-exploitation (often as a result of increasing human population), use of destructive fishing methods (Alcala & Gomez 1987; Gomez *et al.* 1987), and environmental disturbances.

The fisheries associated with coral reefs are typically multispecies and difficult to regulate (Roberts & Polunin 1993). They suffer from conventional management problems experienced in temperate developed countries' fisheries, such as lack of theory, data, personnel, infrastructure and enforcement, as well as additional 'unconventional' constraints such as exceptionally long coastlines with very large numbers of artisanal fishers distributed along them, making data collection and enforcement of regulations very difficult (Marr 1982; Williams 1998).

Marine sanctuaries potentially provide a tool to tackle these causes of resource degradation and fishery management problems. For fisheries, they have been suggested to, *inter alia*, protect critical spawning stock biomass, provide recruits to fishing grounds, replenish fish stocks in adjacent areas through emigration of adults, provide a buffer against uncertainty or against management miscalculations, decrease user conflicts and provide for ease of enforcement (Dugan & Davis 1993; Roberts & Polunin 1993; Bohnsack 1996, 1998; Allison *et al.* 1998; Hall 1998; Lauck *et al.* 1998; Fogarty 1999). The implementation of management measures in established sanctuary areas and the enforcement of sanctuary regulations are expected to have a positive impact towards the sanctuaries' resource and fisheries management goals. However, direct evidence of the effects of marine sanctuaries on target species and community ecology is generally restricted to short-term studies of local populations where harvest has been prohibited or restricted. Few studies have considered the ecological effects of protection over long timescales (19 years).

The 1300 reported marine sanctuaries worldwide reflect the popularity of the sanctuary concept (Kelleher *et al.* 1995). However, most of these are not enforced; 71% are of 'unknown management' status (Williams 1998; McClanahan 1999). Similarly, in the Philippines, of the 439 marine sanctuaries reported in Pajaro *et al.* (1999), many exist merely as 'paper parks' (Alcala 2001) and only a small proportion (approximately 44) are being well maintained (White *et al.* 2002).

There is an increasing awareness of the role local communities and fishers can and should play in management of marine resources (Pomeroy 1994; Ruddle & Pomeroy 1994; White *et al.* 1994). In the majority of developing countries, successful protective management depends on the cooperation of the resource users who will be affected most by sanctuary establishment (Polunin & Roberts 1996; Pomeroy *et al.* 1997). A community-based approach to marine sanctuary management involving key stakeholders is one way of achieving this and is considered by many to be the only way management and enforcement will be successful in the long term (Roberts & Polunin 1993; Courtney & White 1996; Kelleher & Rechhia 1998; King & Faasili 1998; Lam 1998; Tsing *et al.* 1999). Where users understand and support the purpose of marine sanctuaries, compliance is high and regulations are largely self-enforcing (Ballantine 1994). As a result of fewer violations by the local community, the sanctuaries may be expected to be better enforced and hence more successful towards their ecological goals.

The potentially crucial role of community involvement and support for the effectiveness of marine reserves is frequently discussed, but most studies of marine sanctuaries have concentrated only on their ecological effects, or have provided only descriptive information about traditional or community-based management regimes (White *et al.* 1994; Pomeroy *et al.* 1997; Russ & Alcala 1999; Tsing *et al.* 1999; King & Lambeth 2000; Pollnac *et al.* 2001).

Ecological variables (substrate cover and fish communities) were monitored in four marine sanctuaries and corresponding non-sanctuary areas in the Philippines between pre-establishment times and 2000. This study links trends in ecological variables of sanctuaries and non-sanctuary areas to community perceptions and support, management and enforcement of the sanctuaries, attempting to identify the importance of the respective social, management and enforcement factors on the ecological effects of marine sanctuaries.

The objectives of this study were to determine whether (1) significant changes have occurred over time in the benthic substrates and fish communities in sanctuary and non-sanctuary areas, (2) the extent of community support for a marine sanctuary has influenced its success in ecological terms (coral cover and fish communities), and (3) management measures and enforcement of the regulations of the sanctuaries have an influence on their success in ecological terms.

MATERIALS AND METHODS

Study sites

Legally established, small sanctuaries (extending 300–750 m along the shore) were studied at each of four islands in the central Visayas region of the Philippines, namely Apo Island (Negros), Balicasag Island (Bohol), Pamilacan Island (Bohol) and Sumilon Island (Cebu) (Fig. 1). Details of the islands and their sanctuaries are given in Table 1.

The sanctuaries in this study were set up as fisheries management tools in coral reef areas, to allow regeneration of coral and fish communities, to provide an undisturbed breeding area for the fish and to enhance fishery stocks (White & Vogt 2000) through 'spill-over' into adjacent areas (Russ & Alcala 1996*a*). Their aim therefore, was to maintain or improve ecosystem health and maintain or increase fish abundance and diversity of target and non-target fish species. Hard coral cover was used as an indicator of reef health in this study because it reflects (inversely) the amount of breakage through destructive actions and has direct effects on the fish communities and other components of the ecosystem (Alcala & Gomez 1987).

For both substrate and fish surveys, the sanctuary areas were treated as single sampling areas since they were small and the substrates within were fairly uniform. Sampling within the sanctuary and non-sanctuary areas was random and transects within an area were placed so as not to overlap with each other. Non-sanctuary sites were selected from habitat similar to that inside the sanctuary, in non-sanctuary areas where some level of management was in place but fishing was allowed. Generally, the non-sanctuary sites were at least 200 m from the sanctuary areas, ensuring a clear distinction between the fishing and non-fishing areas.

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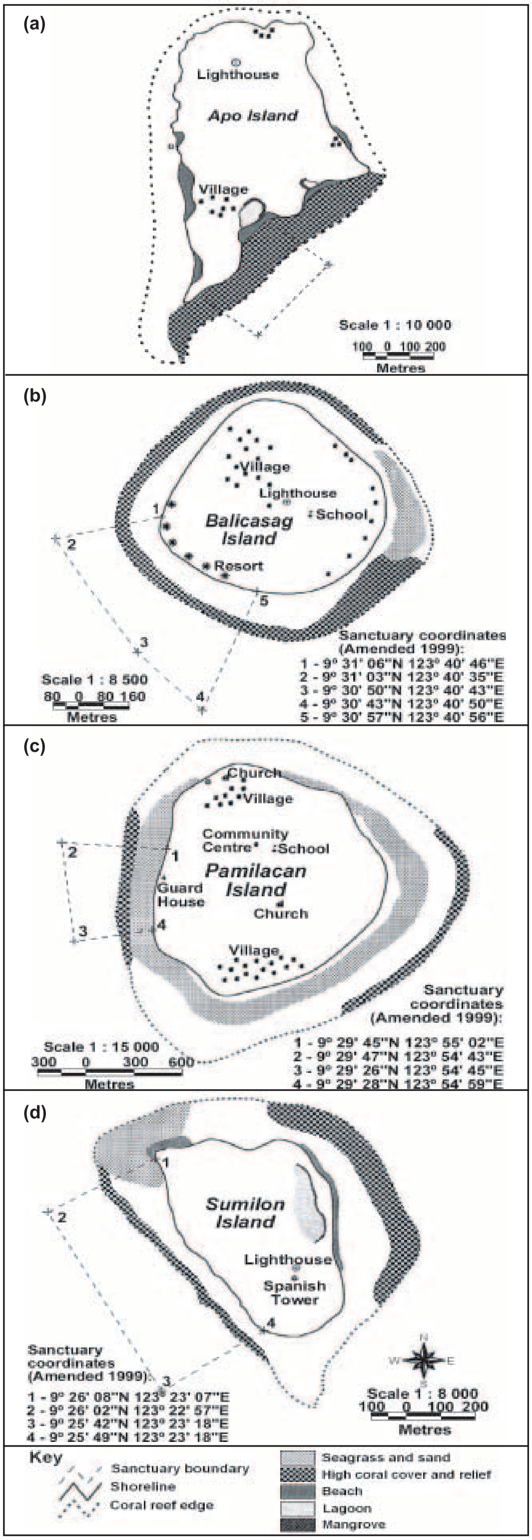

Figure 1 The study sites, showing the locations of marine sanctuaries. (*a*) Apo Island, Negros; (*b*) Balicasag Island, Bohol; (*c*) Pamilacan Island, Bohol; (*d*) Sumilon Island, Cebu. (Maps (*b*), (*c*) and (*d*) are from the 1: 50 000 Topographic Map Series (NAMRIA), prepared by the Geoplan Cebu Foundation Inc., with support from the Coastal Resource Management Project, June 1999.)

Data collection

Substrate cover

A.T. White and volunteers collected data on substrate cover in sanctuary and non-sanctuary sites between 1981 and 1999 (White & Calumpong 1992; White *et al.* 1999). Snorkel and scuba surveys were used to collect data in shallow areas (1–5 m) and at depth (5–14 m, average 6–7 m), respectively. Snorkelling surveys covering 1–1.5 km of reef crest or reef flat parallel to the beach and the drop-off were conducted at sanctuary and non-sanctuary sites. Bottom cover variables were estimated for 1 m^2 of bottom area at 50 m intervals. Scuba surveys were conducted using the line-intercept method (English *et al.* 1997) using 50 m transect lines laid parallel to the reef drop-off in depths ranging from 5–14 m. The living and dead substrate immediately under the transect line was recorded by category per cent cover (sand and silt; coral rubble; rock and block; white dead standing coral; dead coral with algae; branching, massive, flat/encrusting and foliose/cup hard coral; and soft coral) under each 25 cm segment of the line. The number of replicates at each site for each year is given in Table 2. Transects were placed randomly within sanctuary and non-sanctuary areas. Replicates in early years were few, but they were largely representative of the areas, being consistent with results of other monitoring data in the same years (Russ 1985; White 1988*a*) and warrant inclusion in this study as part of a relatively long time-series. The results of the scuba and snorkel methods are comparable (A.T. White, unpublished data 2000). Earlier surveys (1981–1986) used transects laid perpendicular to the reef drop-off and thus ranged in depth from 1–14 m. The results of these surveys were split into shallow areas (1–5 m) and deep areas (5–14 m) so that variability in habitat as a result of depth was removed, consistent with the recent surveys. Reefcheck substrate data (L. Raymondo, unpublished data 2000) were used to update the Apo Island sanctuary data.

Fish

A total of 126 species in 19 families were censused simultaneously in a 500 m^2 area using two techniques: we determined (1) abundances of large numbers of numerically dominant and visually obvious species (chaetodontids, labrids, anthiids, balistids, pomacentrids, pomacanthids and zanclids) by placing species into abundance categories based on a $\log_4$ abundance scale from 0–8 (category 1 = 1 fish, 2 = 2–4 fishes, 3 = 5–16 fishes, 4 = 17–64 fishes, 5 = 65–256 fishes, 6 = 257–1024 fishes, 7 = 1025–4096 fishes, 8 = 4097–16384 fishes; Russ 1985); and (2) abundances of fishery 'target' species (acanthurids, siganids, serranids, lutjanids, haemulids, lethrinids, carangids, caesionids, nemipterids, mullids, scarids and kyphosids) by counting each individual (except for those with large numbers, i.e. caesionids and acanthurids, which were recorded as in [1]).

A.T. White undertook the surveys for all years, with assistance from P. Christie and J. Apurado from 1997

Table 1 The four islands and their marine sanctuaries. Sources [1] White and Savina (1987), [2] White (1988*a*), [3] Savina and White (1986), [4] White (1989), [5] Manne Conservation and Development Programme (1986), [6] White (1988*b*), and [7] Russ and Alcala (1999).

Island	*Apo Island*	*Balicasag Island*	*Pamilacan Island*	*Sumilon Island*
Location	9°4'N, 123°16'E; 5 km SE of Negros Island	9°31'N, 123°41'E; SW of Bohol Island	9°29'N, 123°55'E; S of Bohol Island	9°21'N, 123°23'E; 2 km SE of Cebu Island
Size	76 ha	22 ha	135 ha	23 ha
Reef area	106 ha to 60 m isobath[1]	31 ha to 20 m isobath[2]	180 ha to 20 m isobath[3]	50 ha to 40 m depth[4]
Number of households	88 in 1984; 129 in 2000	59 in 1984; 110 in 1997	>200 in 1997	0 in 2000
Population	460 in 1984; >600 in 2000	680 in 1997	1119 in 1997	0 in 2000
General information	Each household has one fisher; main gear is hook and line, nets and traps also used	Tourism and fishing are main sources of income	Whale shark and manta ray fishery was the main source of income until 1999 when it was banned by national law. Hook and line, traps and nets are used	Fished by approx. 100 fishers from Oslob and Santander on Cebu Island, using hook and line, nets and traps[4]
Marine sanctuary				
Established	1985	1986	1985	1975
Size	500 m stretch on SE side of island	400 m along the SW shore	600 m along west shore, 500 m offshore	750 m reserve area along west shore
Management history	1982: community began non-formal management and protection of a sanctuary area; 1985: declared a municipal marine sanctuary, effective management began; 1994: included under National Integrated Protected Areas law as a Protected Seascape and Landscape	1984 : workers from the Marine Conservation Development Programme, Silliman University, began education and awareness campaigns; 1986: declared a municipal marine sanctuary; 1992: establishment of government-owned resort, since which the Philippine Tourism Authority (PTA) has played an increasing role in the management of the sanctuary	Since 1985: marine sanctuary has been strictly enforced by the community	1974: sanctuary established, managed by Silliman University in cooperation with Oslob municipality, Cebu; 1980: designated a National Fish Sanctuary by BFAR due to management problems after a new mayor elected; 1980s: fished regularly, and with destructive drive-net technique; 1984: sanctuary caretaker was removed for his own safety[6]; 1984–1987: fished regularly; 1988–1992: protected; 1992: fished down[7]; 2000: protected by two caretakers who allow local fishers to fish with hook and line

Table 2 Number of replicates for substrate surveys for each site in each year (x / y = number of replicates in shallow areas / number of replicates in deep areas). * Reefcheck data (L. Raymundo, unpublished data 2000).

Year	*Apo Island*		*Balicasag Island*		*Pamilacan Island*		*Sumilon Island*	
	Sanctuary	*Non-sanctuary*	*Sanctuary*	*Non-sanctuary*	*Sanctuary*	*Non-sanctuary*	*Sanctuary*	*Non-sanctuary*
2000	4/4*	–/–	–/–	–/–	–/–	–/–	–/–	–/–
1999	–/–	–/–	27/11	26/25	11/18	14/6	13/12	12/12
1992	11/5	12/7	9/6	4/3	11/5	11/3	6/5	1/1
1985	–/–	2/3	–/–	–/–	–/–	4/4	1/1	–/2
1984	–/–	–/–	–/–	–/–	2/4	–/–	1/1	–/–
1983	1/–	4/4	2/2	3/2	–/–	–/–	3/2	3/2
1982	1/1	–/1	–/–	–/–	–/–	–/–	2/1	3/3
1981	1/–	–/–	–/–	–/–	–/–	–/–	2/–	2/2

onwards. A census area was defined by using a 50 m transect line laid out at 7 m depth parallel to the reef crest. An observer began 5 m from the end of the line and swam (using scuba) perpendicular to the transect down the reef slope, counting or estimating the abundances of all species within 5 m either side of and above the observer. At a distance of 10 m from the transect line, the observer turned 90° and swam parallel to the line at this depth for 10 m, then swam up the slope again recording the abundances of fish. This procedure was repeated along the entire length of the tape, thus covering a total area of 50 m by 10 m, and was repeated back to the starting end to check that all fish had been counted (trained fish observers know when they are seeing the same fish; the repeat swim was needed to look in all the different habitat areas, since some fish swim in the water column but many hide under corals or in crevices and need to be searched for). The number of replicates at each site for each year is given in Table 3.

Fish data were grouped into ‘all species’, fishery ‘target species’ (acanthurids, siganids, serranids, lutjanids, haemulids, lethrinids, carangids, caesionids, nemipterids, mullids, scarids and kyphosids) and ‘large predators’ (serranids, lutjanids, lethrinids and carangids) categories (Russ & Alcala 1996*b*), referred to henceforth as ‘fish indicators’. ‘Fish abundance’, as used throughout this paper, refers to the number of fish in a 500 m^2 unit area.

Community support

S.F. Walmsley conducted semi-structured interviews with community members from the four locations in May and June of 2000. Interviews followed the outline of Cadiz (1997), who conducted earlier interviews at three of the sites (in 1986, 1992 and 1999 at Balicasag and Pamilacan islands; and in 1986 and 1992 at Apo Island), so that the 2000 results could be compared to these earlier investigations to assess changes in community attitudes over time. Between 15 and 21 individuals were selected arbitrarily from a cross-section of ages, genders and professions, and interviewed during a stay of several days at each location. Interviews were conducted in the local language (Visayan) with the help of a translator, or in English where appropriate. Interviews explored individuals’ knowledge about the marine sanctuary, attitudes towards it, perceptions of its influence on their fish catch, benefits gained from it for the community and occurrences of violations of the regulations.

There was no resident community on Sumilon Island, so questionnaires were conducted with visiting fishers at the island and with members of the communities of Oslob and Santander, the closest towns on the main island of Cebu, and the home ports of most of the fishers who fish at Sumilon (White 1988*b*).

Scores from 0–3 were allocated for four aspects of community involvement based on the percentage of respondents (0 = 0–33%, 1 = 34–66%, 2 = 67–90%, 3 = 91–100%) from each island who (1) knew about the sanctuary, (2) were in favour of it, (3) believed the whole community was involved in the sanctuary’s management and (4) believed the whole community benefited from the sanctuary. The interval 91–100% was chosen for the score of 3 in order to distinguish locations that had excellent (almost 100% support), from those that had good but not comprehensive support. The community involvement score

Table 3 Number of replicates for fish transects at each site for each year.

Year	*Apo Island*		*Balicasag Island*		*Pamilacan Island*		*Sumilon Island*	
	Sanctuary	*Non-sanctuary*	*Sanctuary*	*Non-sanctuary*	*Sanctuary*	*Non-sanctuary*	*Sanctuary*	*Non-sanctuary*
1999	–	–	5	5	3	1	2	2
1992	5	–	3	–	5	–	2	–
1986	6	4	7	–	7	–	–	–
1985	4	6	3	7	3	11	–	–

(henceforth 'community score') had a potential range of 0–12.

Management measures and enforcement status
We observed the sanctuaries' management measures and the enforcement of sanctuary regulations by noting the marking of the sanctuary areas (by signs), delimitation of their boundaries and presence of mooring buoys, and by watching the activities in and around the sanctuaries. Interviews also provided information regarding enforcement and violations of the sanctuary regulations. It was possible to distinguish between sanctuaries that were fully enforced and those that suffered small-scale violations by the local community through the interviews conducted and by watching the sanctuary area. The *barangay* captains (village captains) and *Bantay Dagats* ('Sea Watch' Committees) were key informants for determining the enforcement and management status of the sanctuaries, because they were knowledgeable about the sanctuaries and the communities and were usually open with their comments.

Four management and four enforcement measures were each scored on an ordinal scale from 0–3 (Table 4), giving a potential range of 0–12 for both 'management score' and 'enforcement score' for each island. The 'total score' for each

Table 4 Scores given for management and enforcement measures.

Score	*Description*
	Management 1: marking of sanctuary
0	Sanctuary boundaries not defined or marked and are not known by anyone, sanctuary not sign-posted
1	Sanctuary boundaries are defined but not clearly marked, sanctuary not sign-posted
2	Sanctuary boundaries are defined and marked in some way, but sanctuary is not clearly sign-posted
3	Sanctuary boundaries defined and marked, and sanctuary clearly sign-posted
	Management 2: education and information
0	No information available
1	Sign specifying 'sanctuary'
2	Information visible concerning the regulations of the sanctuary
3	Educational materials concerning the aims, regulations, set-up and management of the sanctuary
	Management 3: mooring buoys
0	Buoys not present, but are needed (boats observed anchoring in the sanctuary)
1	Buoys present and used, but anchoring also occurring
2	Buoys not present, but are not needed
3	Buoys are present and used, no anchoring occurring
	Management 4: guards
0	No guards
1	Guards occasionally present
2	Guards present for a limited period per day
3	Guards present 24 hours a day
	Enforcement 1: anchoring
0	Unrestricted anchoring in the sanctuary, damage to the reef observed
1	Some anchoring seen and anchor damage apparent
2	No anchoring seen but some anchor damage apparent
3	No anchoring, and no anchor damage apparent
	Enforcement 2: integrity of sanctuary / fishing violations
0	None of the regulations of the sanctuary are enforced
1	Sanctuary is frequently violated (daily–weekly)
2	Sanctuary is occasionally violated (monthly–annually)
3	Sanctuary is never violated (or there is no evidence of violations in the past 5 years)
	Enforcement 3: severity of violations
0	High: destructive fishing methods
1	Medium: non-destructive fishing methods or frequent gleaning (daily–weekly)
2	Low: occasional fishing/gleaning by the local community
3	No violations
	Enforcement 4: enforcement of punishments
0	Regulations not enforced, no backup when violations occur
1	Some violators caught and punished
2	Jurisdiction, authority and ability to arrest are present and usually adequate. Most violators caught
3	All violators caught and punished. Jurisdiction, authority and ability to arrest and fine are present

island (total score = community score + management score + enforcement score) therefore had a potential range of 0–36.

Statistical analysis

Substrate

Per cent hard coral cover data were converted to proportions ($p = x/100$) where x is the per cent hard coral cover and p is the observed proportion (range 0–1.0), and transformed using $p' = \arcsin\sqrt{p}$ as recommended by Zar (1994) for percentages or proportions data. One-way ANOVA tests were performed on transformed data in sanctuary and non-sanctuary areas of each island for all years to determine whether any changes in hard coral cover over time were significant ($\alpha = 0.05$). Data were tested for normality using the Ryan-Joiner normality test ($\alpha = 0.1$) and homogeneity of variances were checked with plots of residuals against fitted values. Data for Apo Island sanctuary shallow area, Apo Island non-sanctuary deep area, and Balicasag Island sanctuary shallow areas were further transformed using the Box-Cox transformation (lambda = 1.124, 0.899 and −0.377, respectively) to normalize the data. Years in which only one replicate was available were excluded from the analysis. A non-parametric Kruskal-Wallis test was performed on Balicasag Island sanctuary deep data, as they were not able to be normalized.

Reefcheck data (L. Raymundo, unpublished data 2000) for Apo Island in 2000 were included in analyses in order to update the Apo Island sanctuary data. Although methods of data collection were slightly different from A.T. White's, the results are broadly comparable and provide an indication of the state of the sanctuary.

Changes in composition of the substrate over time in the sanctuary and non-sanctuary areas of each island were analysed. A double square-root transformation was performed on per cent cover data following the recommendations of Clarke and Warwick (1994). Substrate per cent cover data from all years surveyed were subjected to cluster analysis in Primer (Version 4.0). Multi-dimensional scaling (MDS) was performed with 50 random starts. Two-way crossed ANOSIM procedures (protection crossed with year), with 5000 permutations and the test statistic R, were used to determine the significance of changes in substrate per cent cover in sanctuary and non-sanctuary areas of each island over time ($\alpha = 0.05$), for those years when both sanctuary and non-sanctuary areas of each island were surveyed.

Fish species richness

One-way ANOVA tests were performed on species richness of fish (all species, target species and large predators) over time in sanctuary and non-sanctuary areas to determine whether any changes were significant ($\alpha = 0.05$). Data were tested for normality using the Ryan-Joiner normality test ($\alpha = 0.1$) and homogeneity of variances were checked with plots of residuals against fitted values. Non-parametric Kruskal-Wallis tests were performed on Apo Island non-sanctuary 'all species' data which could not be normalized, and on Pamilacan Island non-sanctuary and Sumilon Island sanctuary data because of low replication.

Fish abundance

Fish abundances (of all species, target species and large predators) over time in sanctuary and non-sanctuary areas were analysed using one-way ANOVA tests ($\alpha = 0.05$). Fish abundance data were transformed by $x' = \sqrt{x + 0.5}$ (Bartlett 1936), as recommended for data involving counts (Zar 1994). Data were tested for normality using the Ryan-Joiner normality test ($\alpha = 0.1$). Additional transformations of $x' = \ln(x)$ for target species and $x' = \ln(x + 1)$ for large predators in Pamilacan Island sanctuary, $x' = \sqrt{x}$ for target species in Apo Island sanctuary and for large predators in Apo Island non-sanctuary, were performed to normalize the data. Non-parametric Kruskal-Wallis tests were performed on data that were not able to be normalized (abundance of large predators in Apo Island sanctuary, abundance of target species in Balicasag Island sanctuary) and for data in Pamilacan Island non-sanctuary and Sumilon Island sanctuary because of low replication. Homogeneity of variances were checked with plots of residuals against fitted values.

Changes in fish community structure over time in the sanctuary and non-sanctuary areas of each island were analysed using ANOSIM. Fish abundances, grouped according to family, were subjected to cluster analysis in Primer. MDS and two-way crossed ANOSIM procedures were performed, as described above for substrate, to determine the significance of changes in fish community structure in sanctuary and non-sanctuary areas of each island over time.

Influence of social, management and enforcement factors

Stepwise regressions were performed to determine which of the human factors (community, management, enforcement and total scores) were most important in explaining the change in each ecological indicator from pre-enforcement times to the most recent surveys in the sanctuary areas. These four human factors were entered in stepwise regression models as predictors ($F = 4.0$ to enter and to remove) against twelve response variables, specifically, the change in mean per cent cover of hard coral, soft coral and total coral in shallow and in deep sanctuary areas, and mean species richness and abundance of all fish species, target species and large predators between pre-sanctuary times and the most recent surveys in the sanctuary areas (i.e. effectively 48 regressions). Change in per cent coral cover data were converted to proportions as described above and transformed using $x' = \arcsin\sqrt{x + 0.5}$ as recommended for proportions data (Zar 1994, adapted to take into account the negative changes). Changes in fish abundances were transformed by $x' = \sqrt{x + 0.5}$ for all species, $x' = \sqrt{x + 1391}$ for target species and $x' = \sqrt{x + 4}$ for large predators as recommended by Zar (1994; adapted from Bartlett 1936, as changes were negative in the latter two cases). Regressions for fish variables excluded Sumilon Island because the fish data from that island were not available for pre-sanctuary times, thus confounding possible relationships between trends from pre-sanctuary times and the human factors involved. Non-normal data were first transformed to normality ($x' = 1/x$ for change in species richness of all species in deep sanctuary areas). Regressions were then performed on those models indicated by the stepwise regressions to test their significance ($\alpha = 0.05$). Homogeneity of variances were checked with plots of residuals against fitted values and hard coral data in deep sanctuary areas against community score were transformed by $x'' = \sqrt{x'}$ to homogenize the variances.

RESULTS

Substrate

Overall mean substrate composition varied between sanctuary and non-sanctuary areas and between shallow and deep areas of some islands (Fig. 2). Hard coral cover was generally stable in sanctuary and non-sanctuary areas over time, although some sanctuary areas showed significant increases or declines in mean per cent cover. However, all shallow and deep sanctuary areas showed hard coral cover to have been maintained at least at pre-sanctuary levels.

In Apo Island sanctuary and non-sanctuary areas, hard coral cover remained stable (sanctuary deep ≈ 43.0%, non-sanctuary deep ≈ 32.8%) with no significant changes. From pre-sanctuary times to 2000, there were small overall, but not significant, increases in mean hard coral cover in shallow and deep sanctuary and non-sanctuary areas (Fig. 3*a*).

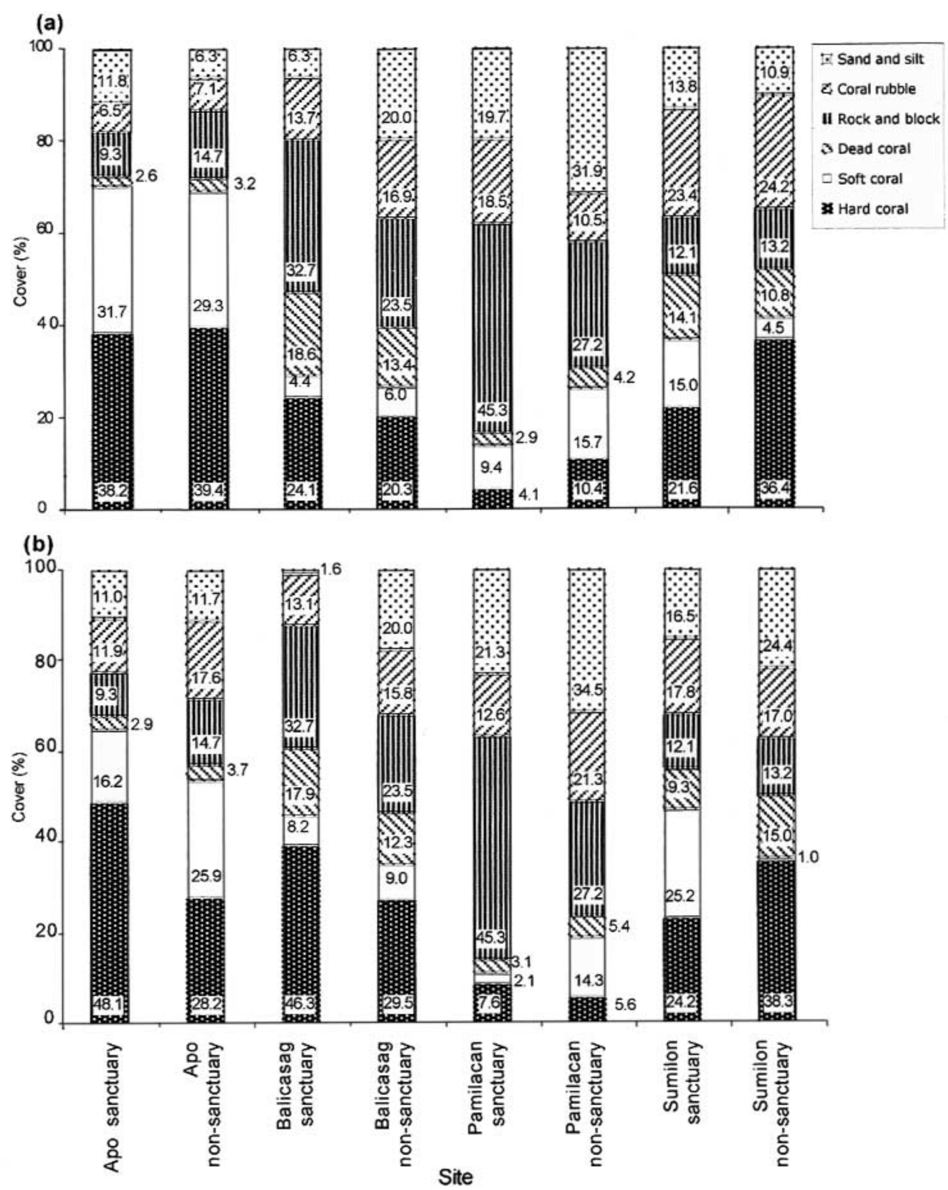

Figure 2 Mean substrate composition of sanctuary and non-sanctuary areas in 1999 (1992 for Apo) by per cent cover by type in (*a*) shallow areas; (*b*) deep areas.

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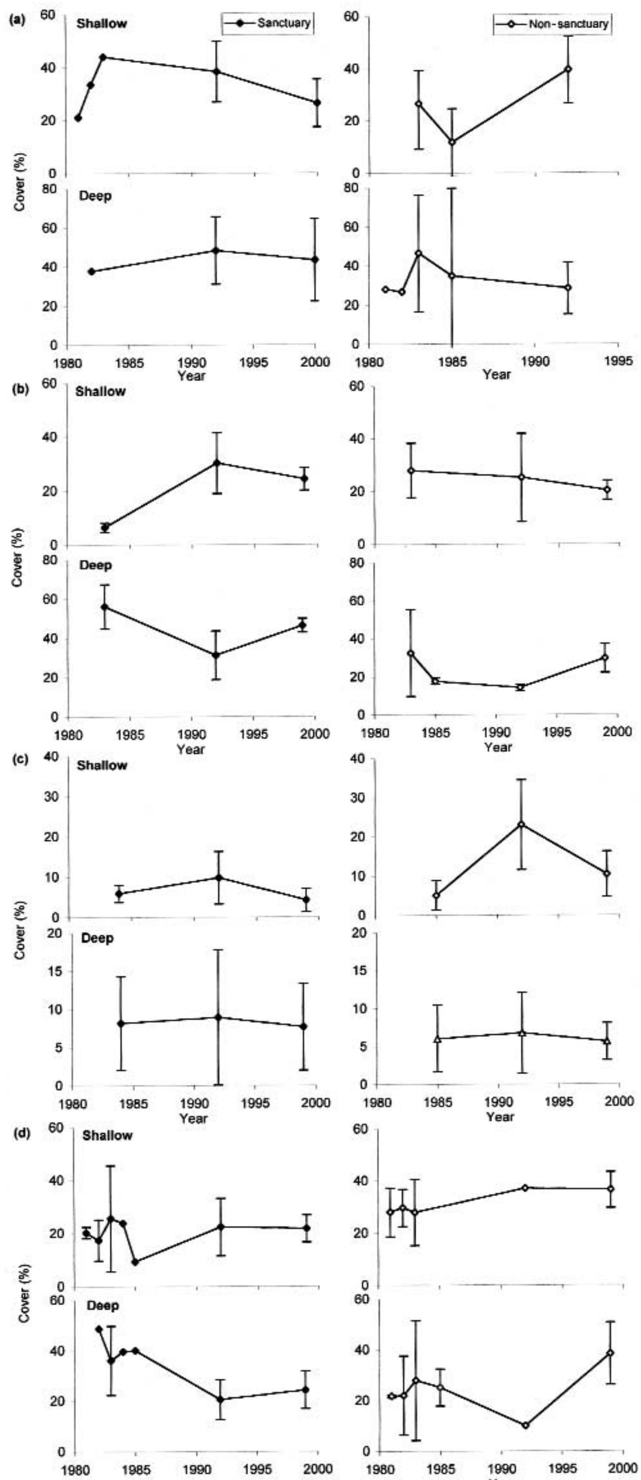

Figure 3 Hard coral mean per cent cover over time in shallow and deep sanctuary and non-sanctuary areas with 95% confidence intervals. (*a*) Apo Island; (*b*) Balicasag Island; (*c*) Pamilacan Island; (*d*) Sumilon Island (95% confidence intervals indicated where replications were sufficient to permit their calculation).

There was a significant increase in hard coral cover from pre-sanctuary levels (1983 = 6.4 ± 1.7 [95%CI] %) to after 13 years of sanctuary protection (1999 = 24.1 ± 4.2 [95%CI] %) in Balicasag Island sanctuary shallow areas (F = 7.42, df = 37, $p < 0.01$; Fig. 3*b*). In the deep sanctuary area, hard coral cover showed no overall change (1983 = 56.0 ± 11.3 [95%CI] %; 1999 = 46.3 ± 3.6 [95%CI] %), but declined between 1983 and 1992, and increased by 15.2% between 1992 and 1999 (H = 6.39, df = 2, $p < 0.05$). There were concomitant overall decreases in hard coral cover in both shallow and deep non-sanctuary areas, which were not significant. Hard coral cover increased between 1992 and 1999 in the deep non-sanctuary areas although the replication in 1992 was insufficient to detect a significant response (Fig. 3*b*).

Per cent cover of hard coral in Pamilacan Island sanctuary was fairly stable over 14 years of protection, remaining relatively low (≈6%). This was also evident in the non-sanctuary deep area (1984 = 6.0 ± 4.4 [95%CI] %; 1999 = 5.6 ± 2.4 [95%CI] %), but in the non-sanctuary shallow area, hard coral increased significantly between 1985 (5.0 ± 3.8 [95%CI] %) and 1992 (23.0 ± 11.5 [95%CI] %) and subsequently declined to 10.4 ± 5.7 (95%CI) % in 1999 (F = 3.70, df = 28, $p < 0.05$; Fig. 3*c*).

Per cent cover of hard coral in Sumilon Island sanctuary remained roughly stable since the early 1980s in the shallow area and tended to decline in the deep area (Fig. 3*d*), though this was not significant. Over the same period in the non-sanctuary, hard coral cover remained stable in shallow areas (1981 = 28.0 ± 9.4 [95%CI] %; 1999 = 36.4 ± 7.0 [95%CI] %) and showed an overall increase (non-significant) in deep areas (1981 = 21.6 ± 0.6 [95%CI] %; 1999 = 38.3 ± 12.3 [95%CI] %; Fig. 3*d*).

ANOSIM analysis showed that there were significant differences in substrate composition between Balicasag Island sanctuary and non-sanctuary areas (R = 0.143, $p < 0.05$) and over time in both areas (R = 0.586, $p < 0.001$). Substrate composition did not differ significantly between Pamilacan Island sanctuary and non-sanctuary areas but changes in each area over time were significant (R = 0.222, $p < 0.05$). Differences over time at Apo Island and Sumilon Island were not significant.

Fish

Fish species richness and abundance in the sanctuary areas showed average increases of 8.3% and 54.9%, respectively, over the period studied. Increases were most marked in the first year following sanctuary establishment, showing a 20.6% increase in fish species richness and a 72.4% increase in abundance (average calculated for Apo Island, Balicasag Island and Pamilacan Island sanctuaries, for which pre-establishment data were available). In various cases these increases were followed by further increases, no change, or subsequent declines. Fish abundance was more likely to increase significantly or remain stable in sanctuary areas than

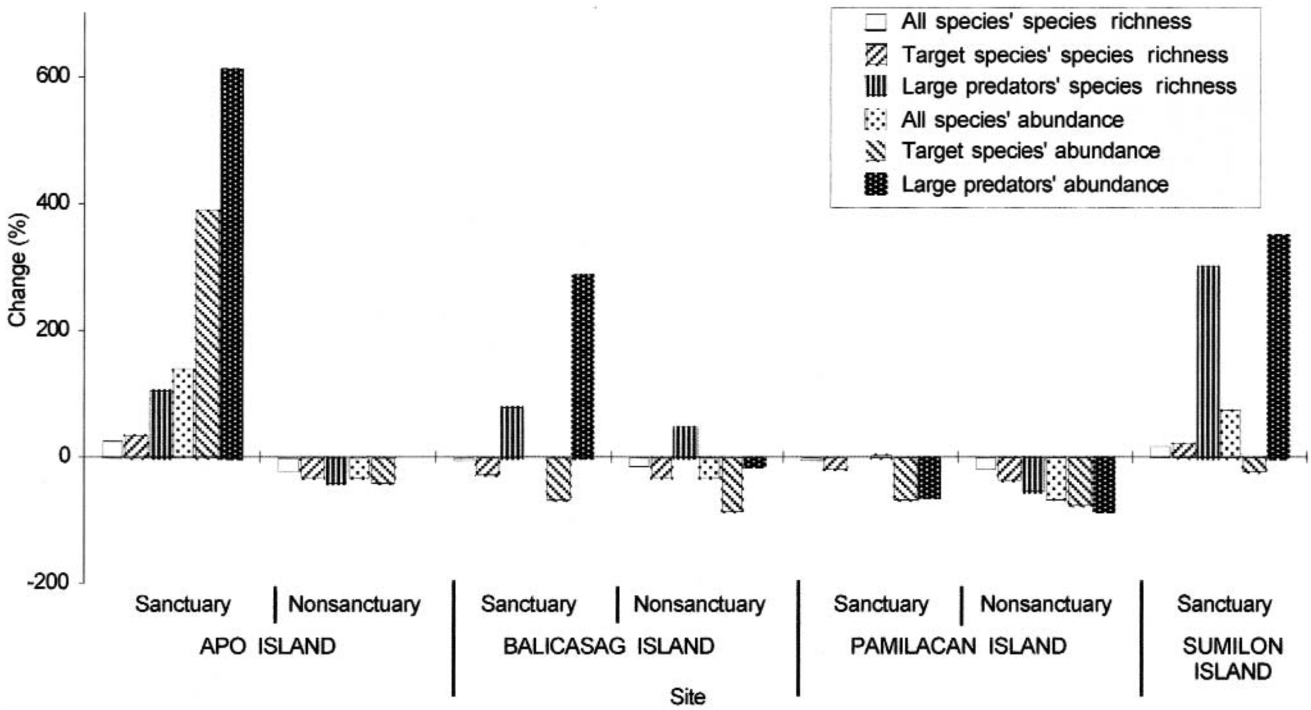

Figure 4 Per cent change in mean fish indicators between the earliest and most recent surveys in sanctuary and non-sanctuary areas of each island.

in non-sanctuary areas. Despite the increases and decreases in fish indicators at some sites, most indicators showed an overall improvement on pre-enforcement times in the sanctuary areas. In contrast, the same variables in the non-sanctuary areas almost universally showed declines or remained unchanged over the same period (Fig. 4) and no fish indicators showed significant increases at any non-sanctuary site. Overall, protection had a significant effect on the structure of the fish community over time in three of the four islands studied.

Species richness

The number of fish species increased significantly in Apo Island sanctuary from 44.0 ± 5.8 (95%CI) species in 1985 to 56.0 ± 5.8 (95%CI) species in 1992 ($F = 8.80$, df = 14, $p < 0.01$), an increase of 27.3%, and decreased significantly in the non-sanctuary from 58.7 ± 3.7 (95%CI) species in 1985 to 44.5 ± 18.1 (95%CI) species in 1986 ($H = 6.59$, df = 1, $p < 0.01$). Species richness of target species and large predators remained stable in the sanctuary and non-sanctuary areas (Fig. 5*a*).

Changes in species richness of all fish indicators in Balicasag Island sanctuary were significant, showing initial increases, subsequent declines and further increases (all species $F = 7.91$, df = 17, $p < 0.01$; target species $F = 9.06$, df = 17, $p < 0.001$; large predators $F = 4.85$, df = 17, $p < 0.05$), reaching 53.6 ±4.5 (95%CI) species in 1999. In the non-sanctuary area, species richness of all species and target species declined significantly (all species $F = 6.06$, df = 11, $p < 0.05$; target species $F = 7.63$, df = 11, $p < 0.05$) from 54.1 ± 4.2 (95%CI) species (of which 18.4 ± 3.2 [95%CI] were target species) in 1985, to 46.2 ± 4.6 (95%CI) species (of which 12.4 ± 2.4 [95%CI] were target species) in 1999. Species richness of large predators remained stable (Fig. 5*a*).

Fish species richness in Pamilacan Island sanctuary increased initially from 47.3 ± 12.0 (95%CI) species to 59.3 ± 5.1 (95%CI) species (of which 22.9 ± 3.2 [95%CI] were target species) in 1986 and subsequently declined to 44 ± 8.2 (95%CI) species (of which 13.7 ± 3.5 [95%CI] species were target species) in 1999 (all species $F = 3.82$, df = 17, $p < 0.05$; target species $F = 4.64$, df = 17, $p < 0.05$; Fig. 5*a*). The species richness of large predators in Pamilacan sanctuary and of all fish indicators in the non-sanctuary remained stable (Fig. 5*a*). Species richness of all fish indicators remained stable in Sumilon Island sanctuary, at 55.0 ± 5.9 (95%CI) species in 1999 (Fig. 5*a*).

Analysis of changes in fish community structure using two-way ANOSIMs showed that there were significant differences in fish community structure between sanctuary and non-sanctuary areas at Apo Island ($R = 0.474$, $p < 0.01$), and significant changes over time in fish community structure at Apo ($R = 0.403$, $p < 0.01$) and Balicasag Islands ($R = 0.565$, $p < 0.001$) in both sanctuary and non-sanctuary areas. Data for Pamilacan were influenced by a lack of replication for the non-sanctuary site in 1999, but a one-way ANOSIM showed that changes in fish community structure over time in the sanctuary were significant ($R = 0.371$, $p < 0.01$).

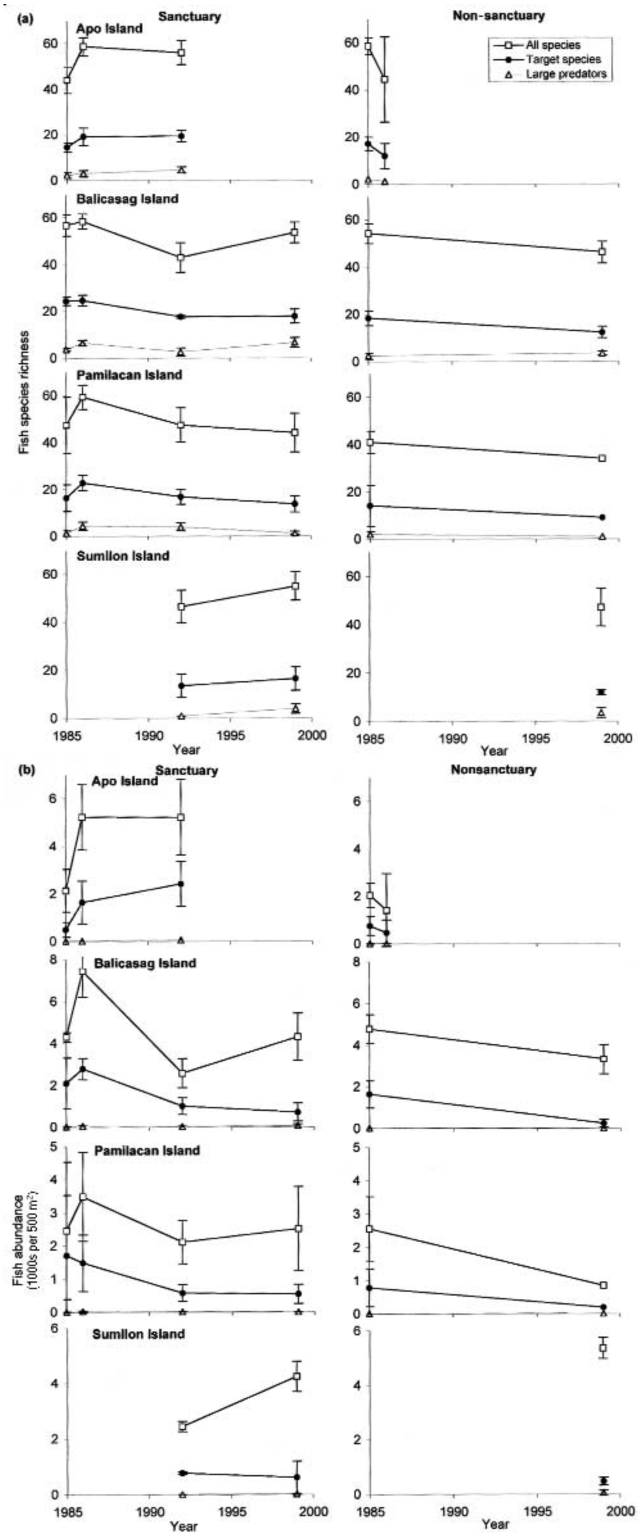

Figure 5 (*a*) Mean fish species richness and (*b*) mean fish abundance per 500 m^2, of all species, target species and large predators over time in sanctuary and non-sanctuary areas of Apo Island, Balicasag Island, Pamilacan Island and Sumilon Island (95% confidence intervals indicated where replications were sufficient to permit their calculation).

Abundance

Fish abundance in Apo Island sanctuary showed a 143% increase between 1985 (sanctuary establishment) and 1992 and all fish abundance indicators (all species, target species and large predators) showed significant increases during this period (all species: 1985 = 2142 ± 898 [95%CI], 1992 = 5214 ± 1580 [95%CI], $F = 7.04$, df = 14, $p < 0.01$; target species: 1985 = 495 ± 316 [95%CI], 1992 = 2417 ± 949 [95%CI], $F = 7.58$, df = 14, $p < 0.01$; large predators: 1985 = 7.8 ± 4.8 [95%CI], 1992 = 55.0 ± 64.4 [95%CI], $H = 6.81$, df = 2, $p < 0.05$; Fig. 5*b*). This increase was especially marked between 1985 and 1986, directly following sanctuary establishment. In contrast, abundances of the fish indicators did not change significantly in the non-sanctuary area.

In Balicasag Island sanctuary all fish indicators increased between 1985 and 1986, although most declined subsequently. Abundance of all species in Balicasag Island sanctuary area changed significantly between 1985 and 1999, both increasing and declining ($F = 12.76$, df = 17, $p < 0.001$), and in 1999 it was at roughly the same level as in 1985 (≈ 4295). In the sanctuary, abundance of target species declined significantly ($H = 11.06$, df = 3, $p < 0.05$), while abundance of large predators increased, but not significantly. In Balicasag Island non-sanctuary abundance of all species and of target species declined significantly between 1985 and 1999 (all species: 1985 = 4778 ± 678 [95%CI], 1999 = 3314 ± 700 [95%CI], $F = 8.38$, df = 11, $p < 0.05$; target species: 1985 = 1642 ± 678 [95%CI], 1999 = 230 ± 188 [95%CI], $F = 22.32$, df = 11, $p < 0.001$; Fig. 5*b*).

In Pamilacan Island sanctuary there were increases in all fish indicators during the initial period of sanctuary enforcement (1985–1986), except for abundance of target species, followed by subsequent declines. Abundance of all species and target species in the sanctuary area remained stable during 14 years of sanctuary enforcement. The abundance of large predators changed significantly, both increasing and declining ($F = 4.88$, df = 17, $p < 0.05$). Abundances in the non-sanctuary area remained stable (Fig. 5*b*).

In Sumilon Island sanctuary, abundances of all species and of large predators tended to increase between 1992 and 1999, although this was not significant. Abundance of target species remained stable. Trends in the non-sanctuary cannot be analysed because of a lack of time series data for this area, although the abundance of target species was less than in the sanctuary area (Fig. 5*b*).

Community attitudes and support for marine sanctuaries

Awareness of the existence of the marine sanctuary was always high at Apo Island (100% of respondents), and has increased at Balicasag Island and Pamilacan Island over the past 14 years, such that in 2000, 100% of respondents at both locations were aware of the existence of the sanctuary at their island (Fig. 6). At Sumilon Island, in contrast to the other locations, not everybody was aware that a sanctuary existed,

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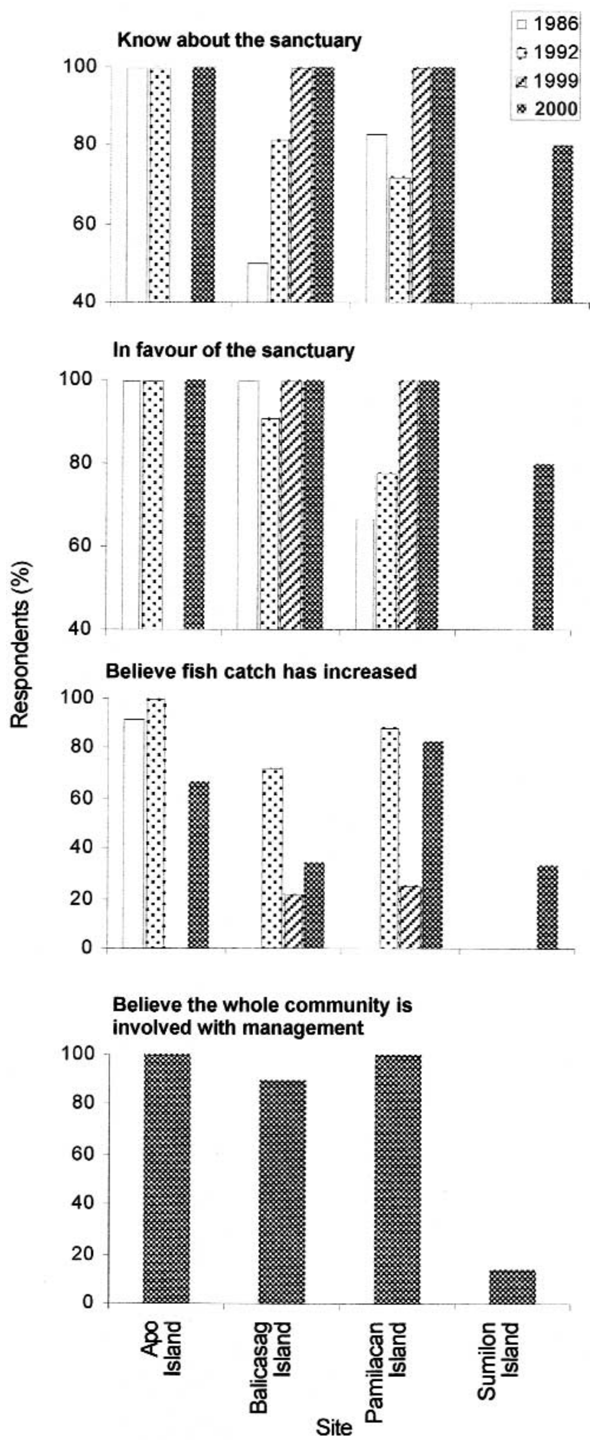

Figure 6 Summary of community attitudes towards, and knowledge of, local sanctuaries over time. Numbers of respondents: Apo Island, 12 in 1986, 21 in 1992, and 21 in 2000; Balicasag Island, 6 in 1986, 11 in 1992, 14 in 1999, and 20 in 2000; Pamilacan Island, 12 in 1986, 18 in 1992, 12 in 1999, and 18 in 2000; and Sumilon Island, 15 in 2000.

despite it being the first sanctuary that was established (Table 1).

Apo Island respondents were unanimously in favour of their sanctuary. Balicasag islanders were also very supportive of their sanctuary and support for the sanctuary at Pamilacan Island increased steadily from 67% in 1986 to 100% in 2000 (Fig. 6). Compared to the other islands, the sanctuary at Sumilon Island still had relatively poor support from the fishers and the community in 2000 (80%). This figure included support for a sanctuary area in theory from some respondents who believed that a sanctuary currently did not exist at Sumilon Island.

Most respondents at Apo (100%), Balicasag (90%) and Pamilacan (100%) Islands felt that the whole community was involved in the management of the sanctuary, which reflects the sense of ownership and management by the communities at these islands. This is in contrast to only 13% at Sumilon Island, where the respondents felt they had no power or control over the regulations that were in place at the sanctuary and felt no sense of ownership (Fig. 6).

Community score was significantly positively related to the change in mean per cent hard coral cover (between the earliest and most recent surveys) in deep sanctuary areas; the sanctuaries of islands that had less supportive communities showed greater decreases in hard coral cover (Fig. 7*a*; Table 5).

The influence of management and enforcement on the sanctuaries

Management and enforcement scores were both related to positive ecological effects in sanctuary areas and were incorporated in the stepwise regression models (as the first or second predictor variable fitted) for seven and four different ecological variables, respectively (Table 5). Management score was significantly related to an increase in abundance of large predators in the sanctuary areas between pre-enforcement times and the most recent surveys, and to the change in soft coral cover in deep sanctuary areas (Fig. 7b). Management score also explained a lot of the variation in the change in species richness of large predators in sanctuary areas although it was not significant (Table 5).

Enforcement score was significantly positively related to the change in abundance of target species in sanctuary areas from pre-sanctuary times to the most recent surveys (Fig. 7*c*). It explained a lot of the variation in the change in species richness of target species and abundance of all species, although not significantly (Table 5). Enforcement score was also significantly related to a decrease in soft coral cover in shallow areas and related to a trend of increasing hard coral cover in deep areas, although not significantly (Fig. 7*d*). Total score was significantly positively related to an increase in total coral cover in deep sanctuary areas (Table 5, Fig. 7*e*).

Abundance of all fish species and of target fish species tended to decline in all non-sanctuary areas, albeit non-significantly, however the magnitude of their decline was less

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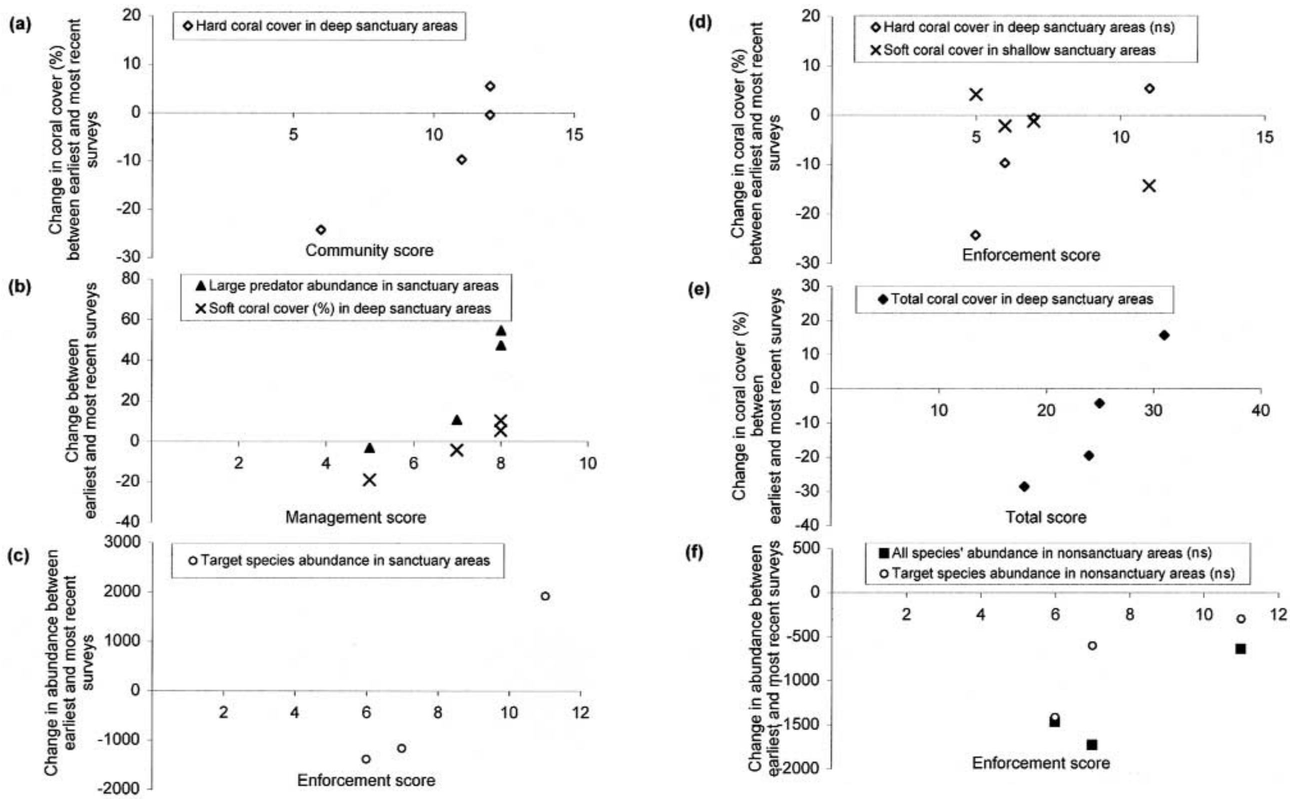

Figure 7 Plots of ecological variables (change in mean per cent coral cover and change in mean fish variables between the earliest and most recent surveys) against community, management, enforcement or total scores. (*a*) Change in hard coral cover in deep sanctuary areas against community score; (*b*) change in abundance of large predators and change in soft coral cover in deep sanctuary areas against management score; (*c*) change in abundance of target species against enforcement score; (*d*) change in hard coral cover in deep sanctuary areas and change in soft coral cover in shallow sanctuary areas against enforcement score; (*e*) change in total coral cover in deep sanctuary areas against total score; and (*f*) change in abundance of all fish species and target fish species in non-sanctuary areas against enforcement score. (ns = not significant).

severe in those non-sanctuary areas adjacent to a sanctuary with a high enforcement or total score (Fig. 7*f*).

DISCUSSION

The potentially crucial role of human factors in sanctuary effectiveness is frequently discussed (McClanahan 1999; Russ & Alcala 1999), but so far has not been the subject of analysis. Very few studies have considered timescales of the duration here or the influence of human factors on sanctuary ecological success in a replicated way.

Sanctuary areas were able to improve or maintain the ecological conditions more effectively than non-sanctuary areas. Sanctuaries generally showed overall improvements, or maintenance of the status quo, of ecological factors (hard coral cover, fish species richness and abundance), although temporal trends were not always unidirectional. In contrast, the non-sanctuary areas generally showed maintenance of the status quo or declines in ecological factors.

Community support, management measures and enforcement of regulations were all contributing factors towards positive ecological effects in the Philippine sanctuaries studied. Management and enforcement were most important, although a supportive community is likely to contribute to effective enforcement. Negative trends (such as declining abundance of target species) were less pronounced in non-sanctuary areas of islands that had sanctuary areas with a high enforcement score, suggesting that sanctuaries can contribute to the maintenance of ecological conditions in the immediate surrounding area. Many factors are involved in determining the ecological conditions within marine sanctuaries, including, for example, larval supply, currents, local conditions and climatic events (Allison *et al.* 1998). However, a combination of community support, management measures and effective enforcement of regulations can contribute towards positive ecological trends in sanctuary areas.

Ecological effects of marine sanctuaries

Effect of protection on substrate

All shallow and deep sanctuary areas show per cent hard coral cover to have been maintained at pre-sanctuary levels or

Table 5 Transformations and regression results for changes in mean ecological factors between pre-sanctuary and most recent surveys in sanctuary areas, against community, management, enforcement and total scores (Sumilon Island excluded for regressions involving fish variables). * = $p < 0.05$. (COM = community score; MAN = management score; ENF = enforcement score; TOT = total score; A = all species; T = target species; L = large predators; SR = species richness; AB = abundance; HC = hard coral cover; SC = soft coral cover; TC = total coral cover; s = shallow; and d = deep.)

Response variable	*Transformation*	*Stepwise regressions results*				*Regression results*					
		1st predictor fitted	R^2	*2nd predictor fitted*	R^2	*Predictor*	*Transformation (homogeneity of variances)*	*Regression equation*	*F*	R^2_{adj}	*p*
ASR	$x' = 1/x$	ENF	98.2%			ENF		ASR = – 0.868 + 0.0859 ENF	55.7	96.5%	–
TSR		ENF	97.8%			ENF		TSR = – 18.8 + 2.17 ENF	44.5	95.6%	–
LSR		MAN	96.5%			MAN		LSR = – 4.40 + 0.881 MAN	27.3	92.9%	–
AAB	$x' = \sqrt{x + 0.5}$	ENF	98.9%	COM	100.0%	ENF		AAB = – 65.4 + 10.9 ENF	92.6	97.9%	–
						COM		AAB = – 315 + 28.9 COM	0.49	0.0%	–
TAB	$x' = \sqrt{x + 1391}$	ENF	99.6%			ENF		TAB = – 65.5 + 11.2 ENF	278.9	99.3%	*
LAB	$x' = \sqrt{x + 4}$	MAN	99.6%			MAN		LAB = – 10.2+2.20 MAN	235.3	99.2%	*
HC (d)	$x' = \arcsin\sqrt{\frac{x}{100}} + 0.5$	COM	88.9%	ENF	98.5%	COM	$x'' = \sqrt{x'}$	HC(d) = 0.561 + 0.0272 COM	19.8	86.2%	*
						ENF		HC(d) = 0.395 + 0.0434 ENF	5.1	58.0%	–
SC (d)	$x' = \arcsin\sqrt{\frac{x}{100}} + 0.5$	MAN	96.3%	ENF	100.0%	MAN		SC(d) = 0.127 + 0.0911 MAN	51.6	94.4%	*
						ENF		SC(d) = 0.602 + 0.0225 ENF	0.51	0.0%	–
TC (d)	$x' = \arcsin\sqrt{\frac{x}{100}} + 0.5$	TOT	91.9%	MAN	99.9%	TOT		TC(d) = – 0.204 + 0.0364 TOT	22.7	87.9%	*
						MAN		TC(d) = 0.082 + 0.0865 MAN	1.2	4.9%	–
HC (s)	$x' = \arcsin\sqrt{\frac{x}{100}} + 0.5$	None	–								
SC (s)	$x' = \arcsin\sqrt{\frac{x}{100}} + 0.5$	ENF	95.2%			ENF		SC(s) = 0.964 – 0.0294 ENF	39.9	92.8%	*
TC (s)	$x' = \arcsin\sqrt{\frac{x}{100}} + 0.5$	None	–								

increased over time, in contrast to the non-sanctuaries (Fig. 3). This supports the suggestion that marine sanctuaries can help maintain coral cover and possibly increase it, through the prevention of fishing, which may alter the substrate (Russ 1991) and of other destructive activities in the area. Few other studies have considered trends in coral cover in protected areas over long time-frames, but a study by McClanahan *et al.* (1999) documented decreases in coral cover in unprotected areas after 22 years. The present study, in contrast, has shown that some non-sanctuary areas also show increases in hard coral cover over time (Apo Island shallow, Pamilacan Island shallow and Balicasag Island deep non-sanctuary areas between 1992 and 1999). This may have been due to voluntary compliance with regulations and more rational resource use in non-sanctuary areas, influenced by the increased awareness and understanding of environmental issues by the communities (White *et al.* 1994) because of the education campaigns conducted during sanctuary establishment. Alternatively, these increases may be because of changes in coral cover as a result of natural growth and recruitment.

The sanctuaries in this study generally showed higher per cent hard coral cover than non-sanctuary areas, which may have been a reason for their location rather than a result of protection. Previous studies have shown higher coral cover in sanctuary compared to non-sanctuary areas using static comparisons at one point in time: Epstein *et al.* (1999) documented higher coral cover in a 'no-use zone' compared to open areas in the Northern Red Sea; McClanahan *et al.* (1999) found coral cover in northern Tanzania was 20% lower in unprotected sites than in protected sites and was of different generic composition.

Environmental, biological and physical factors play a fundamental role in determining reef structure at any particular site. Pamilacan Island sanctuary has had low per cent hard coral cover ($\approx$7%) since surveys began in 1985 (White *et al.* 1999). Despite 15 years of protection and restriction of fishing activities in the area, hard coral cover has not increased markedly, demonstrating that implementation of a marine sanctuary will not necessarily result in a coral reef with high per cent coral cover if the conditions at the site are not naturally favourable for it.

Stochastic natural events can have a detrimental effect on a sanctuary (Allison *et al.* 1998), regardless of the human factors (social, management and enforcement) involved. The only sanctuary area to show a decline in hard coral cover was Sumilon Island deep area. This was probably due to a typhoon that hit the sanctuary side of the island in 1988 (Russ & Alcala 1999), from which the reef had not fully recovered. The sanctuary was also heavily fished with the destructive *muro-ami* (drive-net) technique (Gomez *et al.* 1987) in the late 1980s.

Effect of protection on fish

Fish indicators in the sanctuaries generally showed improvements over, or were at least as good as, pre-enforcement times in almost all cases, and were more likely than non-sanctuary areas to show increases in fish abundance or species richness (Fig. 4). Sanctuaries showed an average 8.3% increase in fish species richness, and an average 54.9% increase in fish abundance between the earliest and latest surveys, in comparison with the non-sanctuary areas which showed an average 18.7% decline in fish species richness and an average 45.0% decline in fish abundance. Sanctuary areas over time showed both increases and declines in fish abundance and species richness, but no consistent trends were evident as increases were sometimes confounded by subsequent declines (Fig. 5). However, the non-sanctuary areas almost consistently showed declines or no changes in fish species richness and abundance. This suggests that protection was effective in at least maintaining the status quo, or in improving conditions in the sanctuary areas against a background of declining fish abundance and species richness in unprotected areas. Sanctuary areas showed increases in fish species richness and abundance within a year of sanctuary implementation (Fig. 5; White 1988*a*). This complements the finding of Roberts (1995) that small no-fishing areas can rapidly build up fish biomass, by showing that they can also rapidly build up fish abundance. Evidence exists of increases in biomass, density, abundance, mean body size, species richness and reproductive output of fishes and invertebrates following the implementation of no-take zones in many coral reef systems, for example, the Philippines (Russ 1985; Alcala & Russ 1990; Russ & Alcala 1996*b*), the Caribbean (Roberts 1995; Rakitin & Kramer 1996; Roberts & Hawkins 1997), the Bahamas (Sluka *et al.* 1997), the Seychelles (Jennings *et al.* 1996; Jennings 1998), Tanzania (McClanahan *et al.* 1999), New Caledonia (Wantiez *et al.* 1997) and Tasmania (Edgar & Barrett 1999).

Protection from fishing pressure can significantly increase the abundance of fishery target species, as shown by the significant increase in abundance of target species in Apo Island sanctuary. This supports the finding of Mosquera *et al.* (2000), in a review of existing studies, that protection increased the abundance of fish species targeted by fishers independently from the effects of protection on substrate.

Generally, sanctuary areas had higher fish species richness and abundance, especially of target species, than non-sanctuary areas. This is probably due to a reduction in fishing pressure, which is the primary determinant of fish populations in the locations studied in the Philippines, where marine ecosystems are already at their limit of exploitation (White *et al.* 2002). Several other studies have demonstrated higher abundances, densities, species richness and biomass of fish in protected compared to unprotected areas (Alcala 1988; Polunin & Roberts 1993; Rakitin & Kramer 1996; Edgar & Barrett 1997, 1999; Roberts & Hawkins 1997; Sluka *et al.* 1997; Wantiez *et al.* 1997; Watson *et al.* 1997; Jennings 1998; McClanahan *et al.* 1999).

For increased abundance of fish in a sanctuary area to benefit local fishers, there must either be a movement of fish from sanctuary to fished areas ('spill-over effect'), or a net export of larvae from the sanctuary to fished reefs. In a study of fish yields in an area adjacent to a sanctuary, Alcala (1988) attributed the maintenance of high fish yields to the high abundance of fish in the sanctuary area following ten years of protection. Circumstantial evidence for this effect has been provided for Sumilon Island (Alcala & Russ 1990) and for Apo Island (Russ & Alcala 1996*a*). Using tagging techniques, Chapman & Kramer (2000) showed that many fish species move over a wide enough area, on a continuous reef, to take them out of small reserves to fished areas. Maintenance of fish populations by export of fish from the sanctuary areas may occur in some cases from the species that school around a small island. These effects are site-specific and the extent to which they occur will depend on the size of the sanctuary, the nature of the local fishery, the mobility of the species and the topography and composition of the substrate.

Most fishers maintained (at Apo, Balicasag and Pamilacan Islands) that their fish catch was stable or had increased in recent years (Fig. 6). The number of fishers on the islands has remained relatively stable, their fishing patterns are very predictable and stable over several years, and usually they can see small changes in their catch, including in type of catch and fish size; fishers who noted an increase in catch were not usually spending more time fishing but were catching more fish for a given effort (A.T.White, personal observation 1992). Indeed, catch per unit effort of the hook and line fishery at Apo Island increased ten-fold, from 0.13–0.17 kg per person per hour in 1980–1981, to 1–2 kg per person per hour in 1997–2001 (Maypa *et al*. 2002). However, the occurrence of spill-over cannot be concluded from the data presented here.

Influence of social, management and enforcement factors on sanctuary success

The management and enforcement aspects considered in this study were related to positive ecological effects in the sanctuaries, as would be expected in accordance with their conservation and resource management objectives. Management measures provided a good indication of sanctuary effectiveness with respect to improvements in coral cover and fish abundance, even though these management measures in themselves did not guarantee enforcement of the sanctuary regulations. Simple management measures, such as the signs, mooring buoys and delimitation of sanctuary boundaries used in some of the sanctuaries studied, can have significant positive effects on the regeneration of soft corals and the abundance of large predators in deep sanctuary areas (Fig. 7*b*).

Enforcement score provided the best indicator of sanctuary effectiveness with respect to fish populations' species richness and abundance, explaining over 95% of the variation in changes over time for four of the six fish variables. Most significantly, the results showed that with effective enforcement, small sanctuary areas can build up abundance of fishery target species over time. Enforcement score was also related to a trend of increasing hard coral cover in deep sanctuary areas (Fig. 7*d*). This may be as a result of the prevention of fishing and other destructive activities that may alter the substrate (Russ 1991). In general, non-sanctuary areas adjacent to well-enforced sanctuary areas showed less severe declines in abundance of target species than those next to less well-enforced sanctuaries (Fig. 7*f*). The sanctuary with the highest enforcement score (Apo Island) was the only sanctuary to show an overall increase in abundance of target species (Fig. 4), rather than a decline, and this may have been a factor that has helped to maintain stocks in adjacent non-sanctuary areas.

Community support was significantly related to increased hard coral cover in deep sanctuary areas. However, communities were often supportive of their marine sanctuary and positive about its role, even if it had not shown major ecological improvements. Such support is important in maintaining the integrity of a sanctuary, contributing to enforcement of regulations, and support can increase as the community becomes convinced of the sanctuary's benefits through experience, such as on Pamilacan Island, where support increased steadily from 67% in 1986 to 100% in 2000.

The social factors studied in relation to the sanctuaries, such as community support, awareness and involvement, are related to the goals of marine sanctuary projects and their achievement should form an integral part of the process of sanctuary establishment (White *et al.* 2002). These factors are important for sanctuary ecological success by contributing to enforcement through voluntary compliance with the regulations by the community or resource users, but the ultimate requirement for sanctuary effectiveness is management and enforcement of the regulations.

A community that is small (population size allows frequent face-to-face interactions among community members), cohesive (community members are able to cooperate) and discrete (geographic limits of the 'community' are easily defined with respect to use-rights of the sanctuary area), and their early and continued involvement in the sanctuary establishment process, have been noted as important factors for project success in other studies of community-based or local resource management initiatives (Pomeroy *et al.* 1997; Tsing *et al.* 1999; King & Lambeth 2000; White & Vogt 2000; Pollnac *et al.* 2001; White *et al.* 2002). Sumilon Island stands out as the one location where not all interview respondents were aware of the existence of the sanctuary or were in favour of it and very few felt that the community were involved in its management. One reason for this is that the establishment process failed to adequately to involve the community (White 1988*c*; Russ & Alcala 1999), because the fishers who fished the island did not belong to a discrete community that could easily be targeted and mobilized towards resource management (White 1996). Additionally, the election of a new mayor in 1980, who was not supportive of the sanctuary, led to violations of the sanctuary regulations, demonstrating that the implementation of marine sanctuaries can depend heavily on local politics or influential individuals in the communities, and probably contributed to some people's belief that no sanctuary existed at the time.

A major benefit derived from sanctuary establishment is that the communities have been given the power and jurisdiction to prevent illegal fishing around their islands. The communities of Apo and Balicasag Islands also benefit from revenues generated by tourism, which is related to the presence of the marine sanctuaries. Fees collected from tourists coming to Apo Island averaged US$ 2500 per month, 75% of which went to the Municipality and the community, and 25% of which went to the National Integrated Protected Area fund (Protected Area Management Board, personal communication 2000) and have been used to improve infrastructures for the community (Barangay Captain, personal communication 2000). Many of the residents of Apo, Balicasag and Pamilacan Islands spoke with authority about marine resources and the importance of the sanctuary as a place where the fish were undisturbed from fishing. This is attributable to the extensive educational work that was carried out with the islanders by the Marine Conservation and Development Programme of Silliman University through community workers who lived in the communities from 1984 to 1986 prior to and during sanctuary establishment (Manne Conservation and Development Programme 1986; Flores & Silvestre 1987; Alcala 1988). At Apo Island, the Head of the Bantay Dagat said that since the establishment of the sanctuary, islanders were more aware of the importance of marine resources, destructive fishing practices were no longer used by islanders, and such actions by outsiders were not tolerated. However, for communities to gain this understanding and support for a sanctuary, the establishment process is time-consuming and must be carefully implemented.

Social, management and enforcement factors act together towards positive ecological effects in sanctuary areas. However, they are not the only determinants of sanctuary success and outside factors (natural and human) also play a role. Marine sanctuaries are one possible tool for management, to be implemented when and where appropriate, and must be complemented by conservation and management efforts outside sanctuary areas. Whilst they can be effective management and conservation tools at a local scale, there are many threats to marine ecosystems that they cannot be effective in controlling. Because they do not have functional boundaries, they cannot protect against biological or chemical pollution (Boersma & Parrish 1999), their effectiveness is limited by the interconnectivity of marine ecosystems (Roberts 1998), and fundamental processes, such as population replenishment, often occur on scales far greater than the area a sanctuary can encompass (Allison *et al.* 1998). The potential influence of natural events, including coral bleaching, should not be ignored when promoting the concept of a marine sanctuary to local stakeholders. The community-based management approach seeks to gain support for protective management from the community from the very start, thus improving compliance with the regulations and decreasing the need for outside enforcement measures. It has been shown to be effective, community support for the sanctuaries in most cases is high and regulations have been implemented in the long term in three of the four sites studied here.

CONCLUSIONS

- This study shows that social, management and enforcement factors all contributed towards sanctuary success, although management and enforcement were most important. For enforcement to be effective, community support for the sanctuary, resulting in voluntary compliance by the community with sanctuary regulations, is a necessary prerequisite.
- Protection and enforcement of regulations contribute to maintaining and increasing fish abundance and species richness within the sanctuary areas. Even without clear scientific evidence of increases in fish yields, or of evidence of spill-over of fish from the sanctuaries, almost all the communities attested to increases in fish catch in areas adjacent to enforced sanctuary areas.
- The time series data show higher levels of fish abundance and species richness than pre-sanctuary times, although the increases were not always continuous.
- Simple management measures (signs, boundary markers, mooring buoys) and enforcement of regulations can significantly improve coral cover and fish abundance in sanctuary areas.
- Communities can be supportive and positive about the role of a marine sanctuary even if it does not show major ecological improvements.
- Effective education and awareness programmes can increase the awareness of the communities about environmental issues and they can become much more pro-active about their natural resource management.
- The effects of sanctuary implementation will vary on a case-by-case basis, depending on the environmental, biological and physical factors involved. Natural variability in recruitment and settlement, and natural climatic events, will influence the ecological effects of protection.
- Although the Philippine context does not allow for many large marine sanctuaries to be implemented because of the dependence of people on the immediate livelihood benefits of coral reefs, the opportunity for many more small but effective sanctuaries is substantial.

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References

Alcala, A.C. (1988) Effects of marine reserves on coral fish abundances and yields of Philippine coral reefs. *Ambio* **17**: 194–199.

Alcala, A.C. (2001) *Marine Reserves in the Philippines: Historical Development, Effects and Influence on Marine Conservation Policy*. Manila, Philippines: Bookmark Inc.

Alcala, A.C. & Gomez, E.D. (1987) Dynamiting coral reefs for fish: a resource-destructive fishing method. In: *Human Impacts on Coral Reefs: Facts and Recommendations,* ed. B. Salvat, pp. 51–60. French Polynesia: Antenne de Tahiti Museum EPHE.

Alcala, A.C. & Russ, G.R. (1990) A direct test of the effects of protective management on abundance and yield of tropical marine resources. *Journal du Conseil International pour l'Exploration de la Mer* **46**: 40–47.

Allison, G.W., Lubchenco, J. & Carr, M.H. (1998) Marine reserves are necessary but not sufficient for marine conservation. *Ecological Applications* **8**(1): S79–S92.

Ballantine, W.J. (1994) Networks of 'no-take' marine reserves are practical and necessary. In: *Marine Protected Areas and Sustainable Fisheries,* eds. N.L. Shackell & J.H.M. Willison, pp. 13–20. Wolfville, Nova Scotia, Canada: Science and Management of Protected Areas Association.

Bartlett, M.S. (1936) The square root transformation in analysis of variance. *Journal of the Royal Statistical Society* Supplement **3**: 68–78.

Boersma, P.D. & Parrish, J.K. (1999) Limiting abuse: marine protected areas, a limited solution. *Ecological Economics* **31**(2): 287–304.

Bohnsack, J.A. (1996) Marine reserves, zoning, and the future of fishery management. *Fisheries* **21**(9): 14–16.

Bohnsack, J.A. (1998) Application of marine reserves to reef fisheries management. *Australian Journal of Ecology* **23**(3): 298–304.

Cadiz, P.L. (1997) Marine reserve management systems in four small islands of Central Visayas, Unpublished report, The Coastal Resource Management Project, Cebu City, Philippines.

Cesar, H., Lundin, C.G., Bettencourt, S. & Dixon, J. (1997) Indonesian coral reefs – an economic analysis of a precious but threatened resource. *Ambio* **26**(6): 345–350.

Chapman, M.R. & Kramer, D.L. (2000) Movements of fishes within and among fringing coral reefs in Barbados. *Environmental Biology of Fishes* **57**(1): 11–24.

Clarke, K.R. & Warwick, R.M. (1994) Change in marine communities: an approach to statistical analysis and interpretation, Unpublished document, Natural Environment Research Council, Plymouth Marine Laboratory, UK.

Courtney, C.A. & White, A.T. (1996) Onwards to more aggressive leadership in Philippine Coastal Resource Management. *Tambuli* **1**: 1–5.

Dugan, J.E. & Davis, G.E. (1993) Applications of marine refugia to coastal fisheries management. *Canadian Journal of Fisheries and Aquatic Science* **50**: 2029–2042.

Edgar, G.J. & Barrett, N.S. (1997) Short term monitoring of biotic change in Tasmanian marine reserves. *Journal of Experimental Marine Biology and Ecology* **213**(2): 261–279.

Edgar, G.J. & Barrett, N.S. (1999) Effects of the declaration of marine reserves on Tasmanian reef fishes, invertebrates and plants. *Journal of Experimental Marine Biology and Ecology* **242**(6): 107–144.

English, S., Wilkinson, C. & Baker, V., eds. (1997) *Survey Manual for Tropical Marine Resources,* Second Edition. Townsville, Australia: Australian Institute of Marine Science, Townsville.

Epstein, N., Bak, R.P.M. & Rinkevich, B. (1999) Implementation of a small-scale 'no-use zone' policy in a reef ecosystem: Eilat's reef lagoon six years later. *Coral Reefs* **18**(4): 327–332.

Flores, E. & Silvestre, G. (1987) Community-based coral reef fishery resource management in the Philippines: the Balicasag Island experience. In: *Proceedings of the Symposium on the Exploitation and Management of Marine Fishery Resource in Southeast Asia, 16–26 February 1987*, pp. 300–329. Darwin, Australia: FAO Regional Office for Asia and the Pacific and the Indo-Pacific Fisheries Commission RAPA/REPORT 1987/10.

Fogarty, M.J. (1999) Essential habitat, marine reserves and fishery management. *Trends in Ecology and Evolution* **14**(4): 133–134.

Gomez, E.D., Alcala, A.C. & Yap, H.T. (1987) Other fishing methods destructive to coral. In: *Human Impacts on Coral Reefs: Facts and Recommendations,* ed. B. Salvat, pp. 67–75. French Polynesia: Antenne de Tahiti Museum EPHE.

Hall, S.J. (1998) Closed areas for fisheries management – the case consolidates. *Trends in Ecology and Evolution* **13**(8): 297–298.

Jennings, S. (1998) Cousin Island, Seychelles: a small, effective and internationally managed marine reserve. *Coral Reefs* **17**(2): 190.

Jennings, S., Marshall, S.S. & Polunin, N.V.C. (1996) Seychelles' marine protected areas: comparative structure and status of reef fish communities. *Biological Conservation* **75**: 201–209.

Kelleher, G., Bleakey, C. & Wells, S. (1995) *A Global Representative System of Marine Protected Areas*. Washington, DC, USA: The World Bank.

Kelleher, G. & Kenchington, R. (1992) *Guidelines for Establishing Marine Protected Areas*. Gland, Switzerland: IUCN.

Kelleher, G. & Rechhia, C. (1998) Editorial – lessons from marine protected areas around the world. *Parks* **8**(2): 1–4.

King, M. & Faasili, U. (1998) A network of small, community-owned village fish reserves in Samoa. *Parks* **8**(2): 11–16.

King, M. & Lambeth, L. (2000) *Fisheries Management by Communities: a Manual on Promoting the Management of Subsistence Fisheries by Pacific Island Communities*. Noumea, New Caledonia: Secretariat of the Pacific Community, Multipress.

Lam, M. (1998) Consideration of customary tenure system in the establishment of marine protected areas in the South Pacific. *Ocean and Coastal Management* **39**(1–2): 97–104.

Lauck, T., Clark, C.W., Mangel, M. & Munro, G.R. (1998) Implementing the precautionary principle in fisheries management through marine reserves. *Ecological Applications* **8**(1): S72–S78.

Marine Conservation and Development Programme (1986) Final report and evaluation for the Marine Conservation and Development Program of Silliman University. Unpublished report, The Asia Foundation and PVO-USAID, Manila, the Philippines.

Marr, J.C. (1982) The realities of fishery management in the Southeast Asian region. In: *Theory and Management of Tropical Fisheries ICLARM Conference Proceedings 9*, ed. D. Pauly & G.I. Murphy, pp. 299–307. Manila, the Philippines: ICLARM.

Maypa, A.P., Russ, G.R., Alcala, A.C. & Calumpong, H.P. (2002) Long-term trends in yield and catch rates of the coral reef fishery at Apo Island, Central Philippines. *Marine and Freshwater Research* **53**: 207–213.

McAllister, D.E. (1988) Environmental, economic and social costs of coral reef destruction in the Philippines. *Galaxea* **7**:161–178.

McClanahan, T.R. (1999) Is there a future for coral reef parks in poor tropical countries? *Coral Reefs* **18**: 321–325.

McClanahan, T.R., Muthiga, N.A., Kamukuru, A.T., Machano, H. & Kiambo, R.W. (1999) The effects of marine parks and fishing on coral reefs of northern Tanzania. *Biological Conservation* **89**(2): 161–182.

Mosquera, I., Côté, I.M., Jennings, S. & Reynolds, J.D. (2000) Conservation benefits of marine reserves for fish populations. *Animal Conservation* **3**: 321–332.

Munro, J. (1996) The scope of tropical reef fisheries and their management. In: *Reef Fisheries,* ed. N.V.C. Polunin & C.M. Roberts, pp. 1–14. London, UK: Chapman & Hall.

Pajaro, M., Olano, F. & San Juan, B. (1999) Documentation and review of marine protected areas in the Philippines: a preliminary report. Manila, the Philippines: Haribon Foundation.

Pollnac, R.B., Crawford, B.R. & Gorospe, M.L.G. (2001) Discovering factors that influence the success of community-based marine protected areas in the Visayas, Philippines. *Ocean and Coastal Management* **44**: 683–710.

Polunin, N.V.C. & Roberts, C.M. (1993) Greater biomass and value of target coral-reef fishes in two small Caribbean marine reserves. *Marine Ecology Progress Series* **100**(1–2): 167–176.

Polunin, N.V.C. & Roberts, C.M., eds. (1996) *Reef Fisheries*. London, UK: Chapman & Hall.

Polunin, N.V.C., Roberts, C.M. & Pauly, D. (1996) Developments in tropical reef fisheries science and management. In: *Reef Fisheries,* eds. N.V.C. Polunin & C.M. Roberts, pp. 361–377. London, UK: Chapman & Hall.

Pomeroy, R.S., editor. (1994) *Community Management and Common Property of Coastal Fisheries in Asia and the Pacific: Concepts, Methods and Experiences*. Manila, Philippines: International Centre for Living Aquatic Resources Management.

Pomeroy, R.S., Pollnac, R.B., Katon, B.M. & Predo, C.D. (1997) Evaluating factors contributing to the success of community-based coastal resources management: the Central Visayas Regional Project-1, Philippines. *Ocean and Coastal Management* **36**(1–3): 97–120.

Rakitin, A. & Kramer, D.L. (1996) Effect of a marine reserve on the distribution of coral reef fishes in Barbados. *Marine Ecology Progress Series* **131**(1–3): 97–113.

Roberts, C.M. (1995) Rapid buildup of fish biomass in a Caribbean marine reserve. *Conservation Biology* **9**(4): 815–826.

Roberts, C.M. (1998) Sources, sinks, and the design of marine reserve networks. *Fisheries* **23**: 16–19.

Roberts, C.M. & Hawkins, J.P. (1997) How small can a marine reserve be and still be effective? *Coral Reefs* **16**(3): 150–150.

Roberts, C.M. & Polunin, N.V.C. (1993) Marine reserves: simple solutions to managing complex fisheries? *Ambio* **22**(6): 363–368.

Ruddle, K. & Pomeroy, R.S. (1994) Changing the focus of coastal fisheries management. *Community Management and Common Property of Coastal Fisheries in Asia and the Pacific: Concepts, Methods and Experiences* **45**: 63–86. Manila, the Philippines: International Centre for Living Aquatic Resources Management.

Russ, G. (1985) Effects of protective management on coral reef fishes in the central Philippines. *Proceedings of the 5th International Coral Reef Congress Tahiti Volume 4*, ed. M. Harmelin-Vivien, B. Salvat, C. La-Croix, C. Gabrie & J.L. Toffart, pp. 219–224. Moorea, French Polynesia: Autenne Museum EPHE.

Russ, G.R. (1991) Coral reef fisheries: effects and yields. In: *The Ecology of Fishes on Coral Reefs,* ed. P.F. Sale, pp. 601–635. San Diego, USA: Academic Press, San Diego.

Russ, G.R. & Alcala, A.C. (1996*a*) Do marine reserves export adult fish biomass? Evidence from Apo Island, central Philippines. *Marine Ecology Progress Series* **132**(1–3): 1–9.

Russ, G.R. & Alcala, A.C. (1996*b*) Marine reserves: rates and patterns of recovery and decline of large predatory fish. *Ecological Applications* **6**(3): 947–961.

Russ, G.R. & Alcala, A.C. (1999) Management histories of Sumilon and Apo Marine Reserves, Philippines, and their influence on national marine resource policy. *Coral Reefs* **18**(4): 307–319.

Savina, G.C. & White, A.T. (1986) Reef fish yields and nonreef catch of Pamilacan Island, Bohol, Philippines. In: *Proceedings of The First Asian Fisheries Forum,* ed. L.B. Maclean, L.B. Dizon & L.V. Hosillos, pp. 497–500. Manila, the Philippines: Asian Fisheries Society.

Sluka, R., Chiappone, M., Sullivan, K.M. & Wright, R. (1997) The benefits of a marine fishery reserve for Nassau Grouper *Epinephelus striatus* in the Central Bahamas. *Proceedings of the Eighth International Coral Reef Symposium Volume 2*, ed. H.A. Lessius & I.G. Macintyre, pp. 1961–1964. Panama: Smithsonian Tropical Research Institute.

Tsing, A.L., Brosios, J.P. & Zerner, C. (1999) Assessing community-based natural resource management. *Ambio* **28**(2): 197–198.

Wantiez, L., Thollot, P. & Kulbicki, M. (1997) Effects of marine reserves on coral reef fish communities from five islands in New Caledonia. *Coral Reefs* **16**(4): 215–224.

Watson, M., Ormond, R.F.G. & Holliday, L. (1997) The role of Kenya's marine protected areas in artisanal fisheries management. *Proceedings of the Eighth International Coral Reef Symposium Volume 2*, ed. H.A. Lessius & I.G. Macintyre, pp. 1955–1960. Panama: Smithsonian Tropical Research Institute.

White, A.T. (1988*a*) The effect of community-managed marine reserves in the Philippines on their associated coral-reef fish populations. *Asian Fisheries Science* **2**: 27–41.

White, A.T. (1988*b*) Philippine marine park pilot site: benefits and management conflicts. *Environmental Conservation* **13**(4): 355–359.

White, A.T. (1988*c*) Marine parks and reserves: management for coastal environments in Southeast Asia. ICLARM Education Series 2. Manila, the Philippines: International Center for Living Aquatic Resources Management: 36 pp.

White, A.T. (1989) Two community-based marine reserves: lessons for coastal management. Coastal area management in Southeast Asia: policies, management strategies and case studies. *ICLARM Conference Proceedings* **19**: 85–96.

White, A.T. (1996) Philippines: community management of marine resources. In: *Coastal Zone Management Handbook,* ed. J.R. Clarke, pp. 561–567. Boca Raton, Florida, USA: CRC/Lewis Publishers.

White, A.T. & Calumpong, H. (1992) Summary field report: saving Tubbataha Reef and monitoring marine reserves in the Central Visayas, Earthwatch Expedition to the Philippines, April–May 1992. Unpublished report, Silliman University, the Philippines.

White, A.T. & Savina, G.C. (1987) Reef fish yield and nonreef catch of Apo Island, Negros, Philippines. *Asian Marine Biology* **4**: 67–76.

White, A.T. & Vogt, H.P. (2000) Philippine coral reefs under threat: lessons learned after 25 years of community-based reef conservation. *Marine Pollution Bulletin* **40**(6): 537–550.

White, A.T., Christie, P., & Divinagracia, M.Fe. (1999) Summary field report 'Saving Philippine Reefs', Earthwatch Expedition to the Philippines, May 1–May 22, 1999, coral reef surveys for conservation in Southwest Bohol. Unpublished report, The Coastal Resource Management Project and the Sulu Fund for Marine Conservation Foundation, Inc., Cebu, the Philippines.

White, A.T., Courtney, C.A. & Salamanca, A. (2002) Experience with marine protected area planning and management in the Philippines. *Coastal Management* **30**: 1–26.

White, A.T., Hale, L.Z., Renard, Y. & Cortes, L., editors. (1994) *Collaborative and Community-Based Management of Coral Reefs: Lessons from Experience*. West Hartford, Connecticut: Kumarian Press.

Wilkinson, C. (1998) *Status of Coral Reefs of the World: 1998*. Townsville, Australia: Australian Institute of Marine Science.

Williams, M.J. (1998) Do fisheries and marine protected areas need each other? *Parks* **8**(2): 47–53.

Zar, J.H. (1994) *Biostatistical Analysis*, Third Edition. Upper Saddle River, USA: Prentice-Hall Inc.