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# A direct test of the effects of protective management on abundance and yield of tropical marine resources

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Despite a vast body of traditional knowledge on management of marine resources in the tropics there are few direct tests, utilizing manipulative or natural experiments, of the effect of protective management on the abundance of marine resources and, more importantly, their yield. This paper reports on a natural experiment which makes such a direct test. Approximately 25% of the sub-tidal coral reef of Sumilon Island (total reef area to 40 m isobath = $0.5\ km^2$) in the central Philippines was protected from all forms of exploitation from 1974 until May 1984. Cessation of protective management led to fishing of the entire coral reef. This resulted in a significant reduction in abundance within the previously protected area of the fishes which constituted the majority of the yield from the reef. Catch per unit effort (c.p.u.e.) measured over a one-year period eighteen months after protective management ceased (1985/1986, $\bar{x} = 0.99\ kg\ man^{-1}\ trip^{-1}$, 95% CL = 0.42) was significantly less than that measured over a one-year period before protective management ceased (1983/1984, $\bar{x} = 1.98\ kg\ man^{-1}\ trip^{-1}$, 95% CL = 0.31). There was a decline of 54% in the total yield of reef fishes from Sumilon Island reef between 1983/1984 and 1985/1986 (from 36.9 to 19.87 metric $t/km^2$) despite the fact that only 75% of the reef was fished in 1983/1984. The yield from traps and gill nets (approximately 64% of the total yield) from the whole reef in 1985/1986 was significantly less than the average yield of the non-reserve (75% of the reef) measured during three of the years of protection. Similarly, the yield from traps (approximately 45% of the total yield) in 1985/1986 was significantly less than the average yield of the non-reserve (75% of the reef) measured during six of the years of protection. Protective management maintained high abundances of fishes in the reserve and significantly higher yields to fishermen from areas adjacent to the reserve. Migration of adult fish from the reserve to the non-reserve area during protection is the simplest explanation of these results.

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## Introduction

Traditional methods of protective management of marine resources in the tropics often have involved the temporary or permanent closure to fishing of portions of coral reef or even whole coral reefs (Johannes, 1978, 1981a, b; Ruddle and Johannes, 1985). The aim of such practices is to prevent resources, particularly fishes, from becoming depleted and thus to maintain or even enhance yields from areas adjacent to them. The mechanisms by which enhancement may occur are by migration of adult fish from the protected to the fished area and by larval dispersal over much larger areas (Russ, 1985). In developed countries marine reserves are sometimes established to maintain marine systems for aesthetic appreciation, particularly of tourists (Woodley, 1985; but see also Kenchington, 1988).

Given such expectations of protective management within developing countries it is surprising that there are so few direct tests, utilizing manipulative or natural experiments, of the effect of protective management on the abundance and yield of tropical marine resources. The lack of direct tests is even more surprising in the light of arguments made a decade ago that "fisheries science will not advance much further unless management becomes experimental" (Larkin, 1978). Such sentiments were expressed in a more explicit manner by the same author recently when summarizing the discussions of a group of experts addressing the question of strategies for multi-species management: "The group agreed with the other groups in strongly recommending experimental procedures designed to give empirical information about the consequences of various management regimes and the seizing of opportunities that may be provided by 'Natural experiments'" (Larkin, 1984). This paper reports on a unique natural experiment in the central Philippines which provides a direct test of the effectiveness of a management strategy.

Smith (1978) estimated the fisheries potential of coral reefs world-wide at 6 million metric tonnes per year. This represents close to 7% of the current world catch. Approximately 10 to 15% of the total yield of fishes in the Philippines is taken from coral reefs (Carpenter, 1977; Murdy and Ferraris, 1980). Over 50% of this yield is taken by subsistence and artisanal fishermen (Carpenter, 1977; Smith *et al.*, 1980). There is strong evidence that serious degradation of Philippine coral reefs has occurred (Gomez *et al.*, 1981) and that a majority of reefs may be overfished (Carpenter, 1977; Carpenter and Alcala, 1977; Smith *et al.*, 1980). There is some agreement that control of fishing effort is likely to be more effective than control of catch as a management strategy (May, 1984) and indeed, control of fishing effort by closed areas or seasons appears to be one of the few viable options available to managers of marine municipal fisheries in the Philippines. There are 18 marine reserves in the Philippines. Experimental evidence of the effectiveness of this form of management in terms of yield is required.

## Materials

The Sumilon Island reserve in the central Philippines (Fig. 1) was established in 1974 (Alcala, 1981, 1988). Sumilon Island is fringed by 50 hectares of coral reef down to the 40 m isobath. Approximately 25% of this sub-tidal reef on the western side of Sumilon Island was protected from all forms of exploitation from 1974 until May 1984. The non-reserve area has been fished regularly by approximately 100 municipal (i.e. artisanal and subsistence) fishermen using traditional gear – hook and line, gill nets, bamboo traps, and spears (Alcala, 1981, 1988).

## Methods

Yields of fishes taken from the non-reserve area of Sumilon Island reef were estimated in six separate years during the period of protection (1974 to 1984) and again between December 1985 and December 1986. Sumilon Island had only one permanent resident between 1976 and 1984 – a caretaker-assistant who was a fisherman working for Silliman University. It was estimated that 96 to 106 fishermen fished Sumilon Island regularly over the period 1976 to 1980 (Alcala, 1981). All of these fishermen were from the mainland (Cebu Island), approximately 2 km away, and all used hand-paddled canoes. This estimate of the total number of fishermen fishing the island at any one time was almost identical to that made for the period 1983–1986 (Alcala, 1988).

The caretaker-assistant residing on Sumilon Island recorded the types of fish caught, their estimated weights, the gear used to catch them and (for 1983/

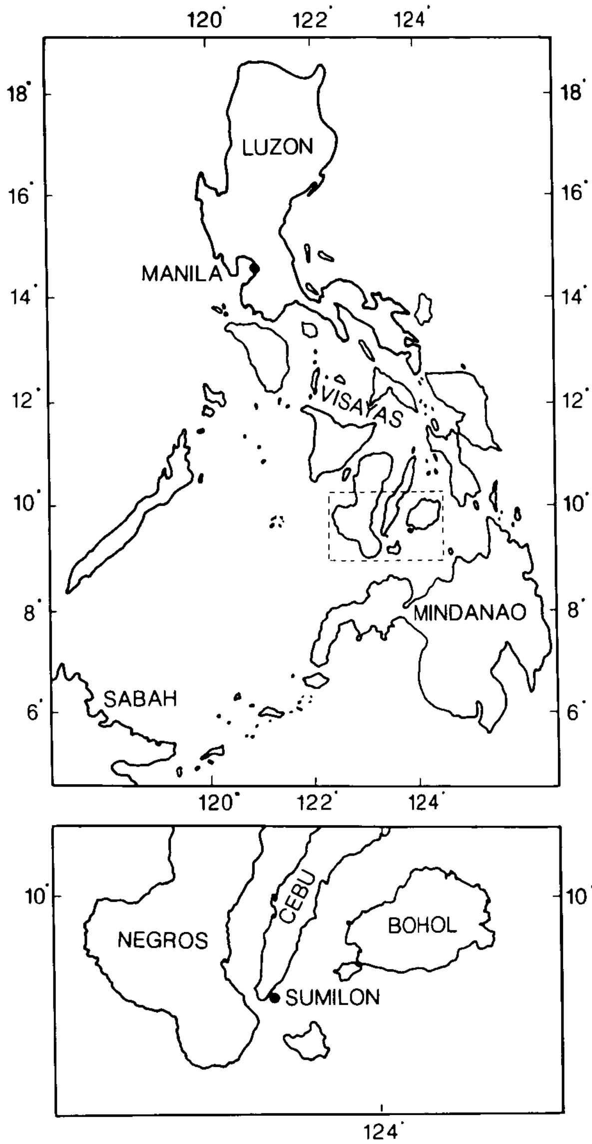


Figure 1. Map of the Philippines showing location of Sumilon Island.

1984 and 1985/1986 only) the number of hours spent fishing by all fishermen. Weights of fish were estimated by eye by the assistant. Error in estimates was measured to be ±10% per kg. From 1976 to 1984 the fish catch was sampled approximately six to seven days per month. These days included the one day each week when all traps were lifted plus days selected haphazardly for observations and interviews. Yields and c.p.u.e. were not estimated during the period August 1984 to December 1985. From December 1985 to December 1986, yields and c.p.u.e. were estimated in the manner described above. A new assistant, an experienced fisherman trained in the estimation of weights of catch, had to be used and this assistant was not resident on the island. The fish catch was sampled four to five days per month (days chosen haphazardly but including at least two days when trap fishermen landed their catch).

In addition to estimates of yield and c.p.u.e., quantitative estimates of abundance of coral reef fishes were made inside and outside the reserve at Sumilon Island and at two other control sites using a technique of visual census. Study sites for the visual censuses were Sumilon Island reserve, Sumilon Island non-reserve, Apo-Island reserve and Apo Island non-reserve. Apo Island is located at 9°4′N, 123°16′E. Eighty species of coral reef fishes in 15 families were censused visually and simultaneously. The abundances of species deemed to be numerically dominant and visually obvious (56 species) within a census area were estimated cumulatively on a log 4 abundance scale from 0 to 8 (Russ, 1985). The abundances of species of large reef fishes deemed to be favoured targets of fishermen (24 species) were determined by counting each individual in a replicate census area. A replicate census covered an area of approximately 875 $m^2$ of reef slope (50 m along the reef crest by 17.5 m down the reef slope, to a depth of 14 m). Six replicate, non-overlapping censuses were made at each of the four sites in December 1983 and again in December 1985, 18 months after fishing began within the Sumilon Island reserve.

In May 1984 protective management broke down, resulting in intensive fishing inside the reserve by approximately 100 municipal fishermen. There was no increase in the number of fishermen fishing the reef, but in addition to traditional methods of fishing two other methods were used occasionally – muro-ami (drive net) and dynamite fishing. Muro-ami fishing involves a cordon of swimmers, each holding a vertical scareline, driving fish toward a large bag net. Scare-lines have short strips of plastic or coconut leaves tied to them and have a 2–4 kg stone weight attached at their base to offset their buoyancy. These weights are continually lifted up and dropped back on to the coral substratum to scare fish toward the net. Both methods are very effective and particularly destructive to the benthic habitat (Carpenter and Alcala, 1977; Gomez *et al.*, 1981).

## Results

The cessation of protective management for an 18-month period resulted in a significant change in community structure of the assemblage of coral reef fishes inside the reserve but not at the three control sites. The complex details of change in community structure in response to the rapid increase in fishing pressure have been presented elsewhere (Russ and Alcala, 1989). The most important aspects of change in community structure relevant to yield were the massive declines in abundance of those species which constituted the majority of the yield from the reef (Table 1). The caesionids, which constituted 65% of the yield in 1983/

Table 1. Percentage contribution of families to total yield from Sumilon Island reef in 1983/1984, the direction and percentage change in density of the family inside the reserve between December 1983 and December 1985 (estimated visually), and the significance level of the change (Mann-Whitney U-test).

| Family | Composition of catch in 1983/1984 % | | Magnitude and direction of change in density % | | Significance level of change |
|---|---|---|---|---|---|
| Caesionidae | 65 | | 64 | – | * |
| Acanthuridae | 13.5 | | 10 | – | ns |
| Carangidae | 8.36 | 10.12 | 64 | – | ns |
| Scombridae | 1.76 | | | | |
| Labridae (large spp.) | 3.0 | | 68 | – | ** |
| Scaridae | 2.25 | | 280 | + | ** |
| Serranidae | 0.36 | | 46 | – | ns |
| Lutjanidae | 0.1 | 0.24 | 93 | – | ** |
| Lethrinidae | 0.14 | | | | |
| Mullidae | 0.05 | | 3 | – | ns |
| Belonidae | 4.85 | | not censused | | – |

ns = non-significant, + = increase in density, – = decrease in density, * $p < 0.05$, ** $p < 0.01$.

1984, declined significantly in density (by 64%) in the reserve. The carangids and scombrids, which accounted for 10% of the total yield, also decreased in density by 64% in the reserve. These decreases in density of fishes, which constituted 75% of the total yield from the island, were most likely a direct consequence of the intense fishing inside the reserve between May 1984 and December 1985. Although the large predators (lutjanids, lethrinids, larger labrids, serranids) constituted only a small amount of the total yield, they exhibited very large percentage decreases in density and were thus very good indicators of fishing pressure (Russ and Alcala, 1989). The significant increase in abundance of scarids (Table 1) was likely to be due to fishing techniques such as drive nets forcing these herbivorous fishes from their normal habitat (the shallow reef flat – see Russ, 1989) to the reef slope where the visual censuses were made. Such substantial changes in abundance and distribution of coral reef fishes in response to intense fishing pressure are consistent with those discussed and predicted by Munro *et al.* (1987).

The results of the visual censuses were supported strongly by independent estimates of c.p.u.e. and yield. Mean c.p.u.e. measured over a one-year period in 1985/1986 (18 months after protective management ceased) was 0.99 kg $man^{-1}$ $trip^{-1}$ (95% CL = 0.42) (Fig. 2). This was significantly less ($t_{23} = 3.67$, $p < 0.01$) than the mean c.p.u.e. measured over a one-year period in 1983/1984 before protective management ceased: 1.98 kg $man^{-1}$ $trip^{-1}$ (95% CL = 0.31, Fig. 2). Mean c.p.u.e. for the eight-month period immediately following breakdown of protection (May to December 1984) showed some evidence of a rapid increase followed by a decline, but the mean c.p.u.e. for this period ($\bar{x}$ = 1.85 kg $man^{-1}$ $trip^{-1}$, 95% CL = 0.39) did not differ significantly from that measured during the 12 months before protection broke down.

The significant decline in c.p.u.e. after protection broke down (Fig. 2) was a result of significant decreases in c.p.u.e. for all three major fishing gears (hook and line, gill net, and trap). Catch per unit effort declined between 1983/1984 and 1985/1986 by 57%, 58%, and 33% for hook and line, gill net, and traps, respectively (Fig. 3). All of these decreases were significant (paired *t*-tests, all $p < 0.05$).

The total yield of reef fishes taken from Sumilon Island in the last 12 months of protection (May 1983 to April 1984) was 36.90 metric t/$km^2$ (Alcala, 1988). The total yield of reef fishes taken from the island during December 1985 to December 1986 (18 months after protection broke down) was 19.87 metric t/$km^2$. Thus, total yield declined by 54% after protection of the reserve ceased. This decline occurred despite the larger area of reef fished in 1985/1986 (i.e. the reserve

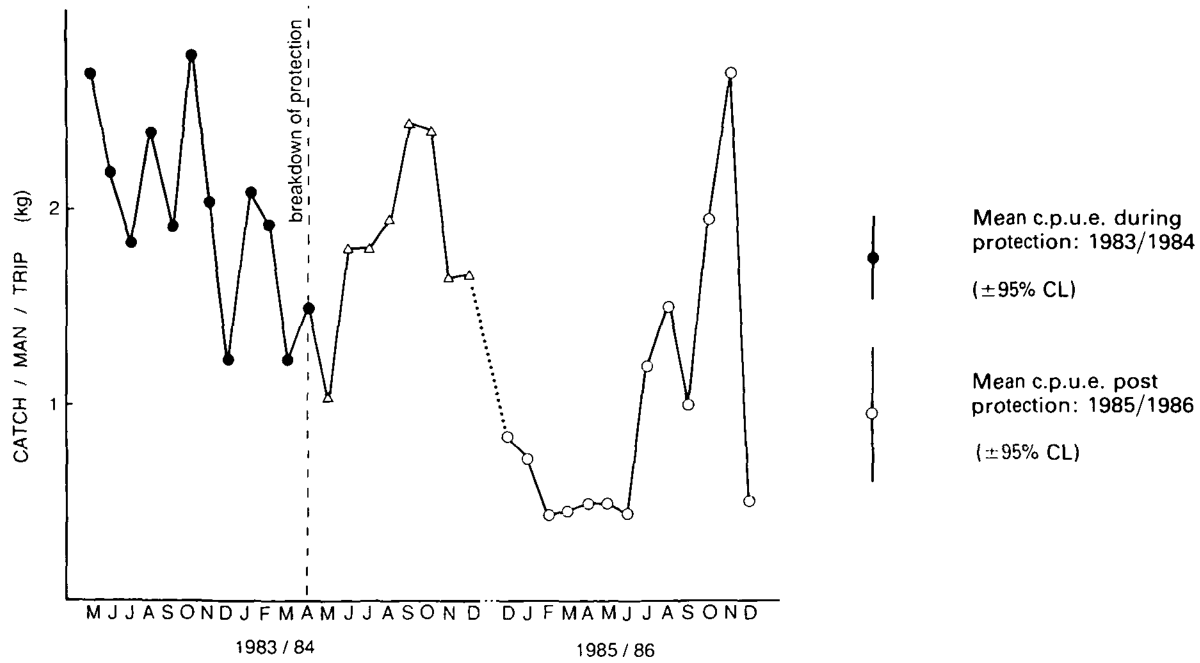


Figure 2. Monthly catch per unit effort (c.p.u.e.) at Sumilon Island. Closed circles are c.p.u.e. for the final 12 months of protection of the reserve (May 1983 to April 1984). Open triangles are c.p.u.e. for 8 months immediately following breakdown of the reserve (May 1984 to December 1984). Open circles are c.p.u.e. for the 12-month period beginning 18 months after breakdown of the reserve. Mean c.p.u.e. was significantly higher during protection (closed circles) than well after breakdown of protection (open circles). Data shown by triangles were not used in calculation of either mean.

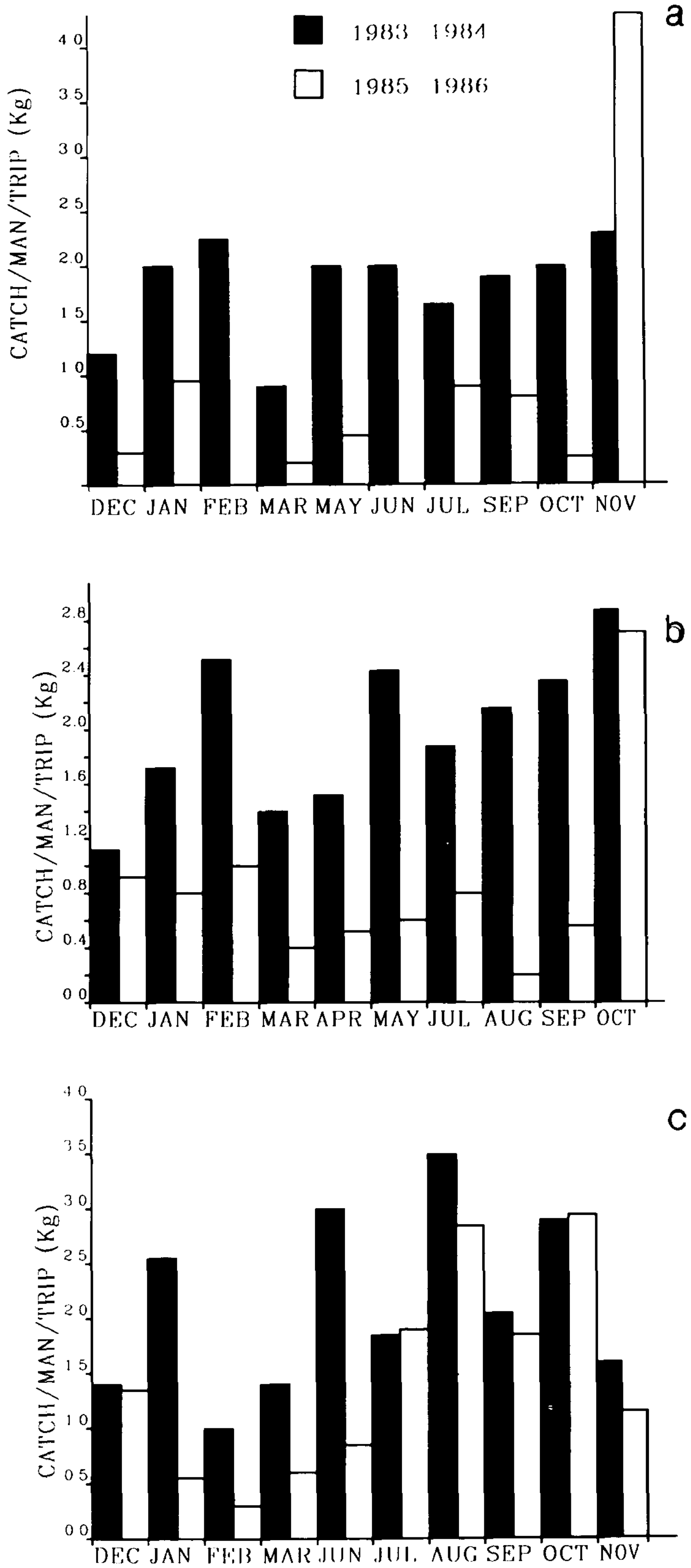


Figure 3. Catch per unit effort (c.p.u.e.) at Sumilon Island reef before (dark bars) and after (white bars) protective management broke down for (a) hook and line; (b) gill nets; and (c) traps. White bars represent c.p.u.e. 18 months after protection broke down (December 1985 to November 1986). Dark bars represent c.p.u.e. data for the final 12 months of protection (May 1983 to April 1984). The monthly data collected during protection are matched with the corresponding months after protection broke down. C.p.u.e. declined significantly by 57%, 58%, and 33% for hook and line, gill net, and traps respectively. These three gears accounted for approximately 98.5% of the total yield in 1983/1984 and 1985/1986.

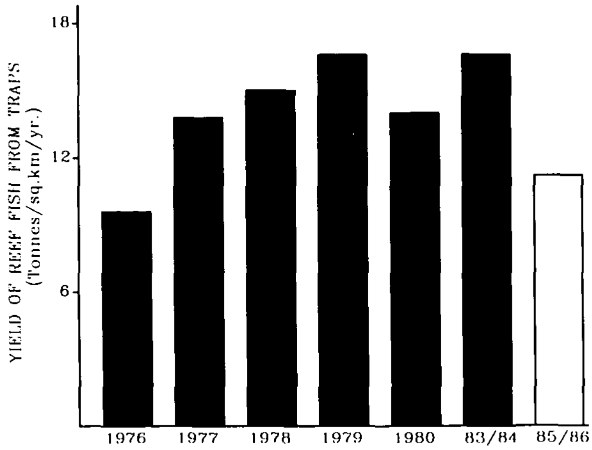


Figure 4. Yield of reef fishes (metric tonnes/$km^2$/year) taken in traps from Sumilon Island in six separate years during the period of protection (1974 to 1984) and yield from traps measured 18 months after protective management broke down (1985/1986). The yield from traps (approximately 45% of the total yield) from the whole island in 1985/1986 was significantly less than the average yield from the non-reserve area (75% of the reef) measured over six separate years during the period of protection (one sample *t*-test, $t_5 = 3.05$, $p < 0.05$).

and non-reserve areas). Furthermore, there was no evidence of a change in the number of fishermen fishing the island before and after protection broke down and caesionids and acanthurids made up the bulk of the catch in each period.

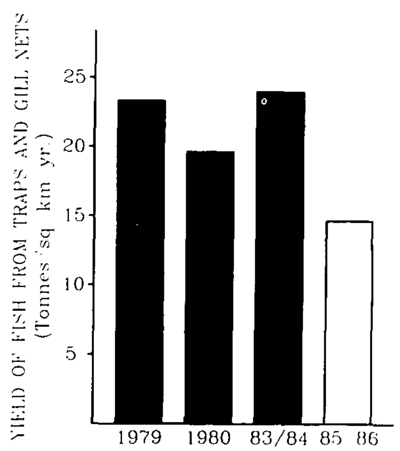


Figure 5. Yield of reef fishes (metric tonnes/$km^2$/year) taken in traps and gill nets from Sumilon Island in three separate years during the period of protection (1974–1984) and yield from traps and gill nets measured 18 months after protective management broke down (1985/1986). The yield from traps and gill nets (approximately 64% of the total yield) from the whole island in 1985/1986 was significantly less than the average yield from the non-reserve area (75% of the reef) measured over three separate years during the period of protection (one sample *t*-test, $t_2 = 6.18$, $p < 0.01$).

Most importantly, the yield of fishes from traps (approximately 45% of the total yield) from the whole island in 1985/1986 was significantly less than the average yield from the non-reserve area (75% of the reef) measured over six separate years during the period of protection (Fig. 4 and one sample *t*-test, $t_5 = 3.05$, $p < 0.05$). The yield from both traps and gill nets (approximately 64% of the total yield) from the whole island in 1985/1986 was significantly less than the average yield from the non-reserve area measured over three separate years during the period of protection (Fig. 5 and one sample *t*-test, $t_2 = 6.18$, $p < 0.01$).

## Discussion

The results indicate clearly that protective management maintained high abundances of fishes in the Sumilon Island reserve and significantly higher yields to fishermen from areas adjacent to the reserve. This is the first unequivocal demonstration that closing areas to fishing enhanced yield to fishermen significantly in this manner in the tropics. Johannes (1978) and Ruddle and Johannes (1985) review a good deal of descriptive information which suggests that such a phenomenon is possible.

The only study similar to that described here appears to be that of Davis (1977) in Florida. In an experimental investigation of the role of a marine reserve on fishery harvests, Davis established complete protection from harvest for spiny lobsters (*Panulirus argus*) in a portion of a marine reserve (95 $km^2$) for 29 months. When part of this protected area was re-opened to recreational fishermen, Davis demonstrated that the abundance of spiny lobsters in this part of the reserve declined by nearly 60% and that catch rates of experimental traps there were 22% below pre-harvest levels 12 months after complete protection was re-imposed. Davis was unable to demonstrate that another section of the marine reserve (19 $km^2$) which was permanently protected from harvesting enhanced yields of lobsters in adjacent areas, despite establishing that spiny lobsters were capable of dispersing up to 10 km.

Permanent closures of areas to trawling in the tropics have been made in Indonesia (Sardjono, 1980) and Thailand (Pramokchutima and Vadhanakul, 1987) with the aim of reducing conflict between trawl fisheries and small scale, traditional fisheries close to the coast. In Thailand, areas were made unsuitable for trawling by construction of artificial reefs. There is some evidence that small-scale fishermen using hook and line and traps have increased their yields by fishing the artificial reefs, but no information is available on the effect of these permanent refuges on the yield from the trawl fishery (Pramokchutima and Vadhanakul, 1987).

In the present study the most likely mechanism of maintenance of high yields from areas adjacent to the reserve is emigration of adult fishes from the reserve to the non-reserve area during the period of protection. It is suggested that increases in density of fishes within the reserve during prolonged protection may lead to expansion of the local population into the non-reserve area in response to a shortage of a resource such as space or food. Such an expansion of the local population certainly appears to be possible for the caesionids, which constituted 65% of the total yield in 1983/1984 (Table 1). Caesionids are highly mobile, schooling planktivores which appear capable of swimming around the entire island within hours (Russ, personal observation). Expansion of the local population of caesionids into the non-reserve area could occur in response to absolute or relative shortages of planktonic food but it is more likely that the resource in short supply may be space in the form of sleeping sites for the massive schools of planktivores within the reserve. The trap fishery on the island relies almost exclusively upon entry of schools of caesionids into unbaited traps as the schools descend to the substratum at dusk to sleep (Russ, unpublished data). There appear to be no *a priori* reasons why lack of a resource such as space or food may not lead to expansion of the spatial range of a local population of reef fishes which have more benthic habits than the caesionids, particularly those that are territorial.

Despite the suggestion here that adult emigration of reef fishes may occur in response to local increase in density, there is surprisingly little evidence demonstrating such a phenomenon in coral reef fishes. In a recent review of the replenishment of coral reef fish populations, Doherty and Williams (1988) conclude that "there is little evidence of resource-saturation at natural densities". Even in the absence of strong evidence of resource limitation there is good evidence that adult reef fishes can move between habitat patches on reefs. This subject was reviewed recently by Robertson (1988), who concluded that movements resulting in redistribution of adult fishes within reefs were important in the organization of communities of coral reef fishes.

Evidence for expansion and contraction of the spatial range of fish populations in response to changes in abundance does exist at geographic scales. Beverton (1984) discusses a number of examples. Murphy (1977) provides examples of such phenomena for the schooling, planktivorous clupeids. This body of evidence at geographic scales and the evidence of substantial potential for relocation of adult fishes within reefs (Robertson, 1988) supports the contention that a density-dependent mechanism leading to expansion of the spatial range of fishes from the reserve to the non-reserve during the period of protection is possible.

It should be noted that it is not necessary to postulate that overcrowding increases the tendency of adult fish to move out of the protected area. Beverton and Holt (1957), assuming random dispersion between fished and unfished areas, showed theoretically that for high levels of fishing mortality, yield per recruit can be enhanced by fishing only part of the area occupied by the stock (see their Fig. 18.23). In other words, at high levels of fishing mortality, closing certain areas to fishing as a regulative measure can enhance yield per recruit. Such a mechanism could explain the significantly higher c.p.u.e. during protection of 25% of the island than that recorded after protection broke down (Fig. 2).

There are important implications of this study to management of municipal marine fisheries in the Philippines. The control of fishing effort in spatial refuges has been demonstrated to enhance yields of marine resources. Such a management strategy may well be one of the few viable options for management of declining resources of reef fishes exploited by subsistence and artisanal fishermen.

In addition, the results argue in favour of long-term closure of portions of coral reefs rather than closure of whole reefs. Ensuring that areas directly adjacent to reserves are left open to fishing permits the hypothesized mechanism of adult emigration to operate. Permanent closure of a few whole reefs is unlikely to have much local effect on yield of reef fishes because larvae from the protected populations may disperse over tens or hundreds of kilometres (Doherty and Williams, 1988). Temporary closures of whole reefs or parts of reefs, followed by a re-opening of them to fishermen may not be as effective as permanent or long-term closure to fishing of spatial refuges unless there is very strict control of fishing intensity following re-opening.

The consequences of the results are cogent and timely for countries of the developing world whose marine resources are coming under increasing rates of exploitation. Protective management may have an important role to play not only in maintaining the abundance of marine resources, but, more importantly, in maintaining or even enhancing the yield of those resources to man.

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