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Effect of a network of no-take reserves in increasing catch per unit effort and stocks of exploited reef fish at Nabq, South Sinai, Egypt

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Abstract. In 1995, in collaboration with local Bedouin fishermen, five no-take fisheries reserves were established within the Nabq Natural Resource Protected Area, South Sinai, Egyptian Red Sea. The abundance, size structure and catch of commercially targeted groupers (Serranidae), emperors (Lethrinidae) and snappers (Lutjanidae) were investigated before the establishment of these reserves, then in 1997 and again in 2000. By 1997, these fish had shown a significant increase in mean abundance within two of the no-take reserves. By 2000 each family and three individual species (*Lethrinus obsoletus*, *Cephalopholis argus* and *Variola louti*) had increased in abundance in the reserves. There were significant increases in mean individual length of the serranids *Epinephelus fasciatus* and *C. argus* and of the lethrinids *L. nebulosus* and *Monotaxis grandoculis*. Meanwhile, mean recorded catch per unit effort (CPUE) within the adjacent fished areas increased by about two-thirds ($P < 0.05$) during the 5 years. The establishment of the no-take reserves appears to have played a key role in maintaining the sustainability of the fishery. The involvement of local Bedouin and fishermen in the co-management of fisheries resources was critical to the success of this initiative.

Introduction

The past decade has seen increasing adoption of 'no-take' or no-fishing zones or reserves as a means of regulating fishing effort, in order to prevent overfishing or to restore fish stocks (see reviews by Roberts and Polunin 1991, 1993; Dugan and Davies 1993; Rowley 1994; National Research Council 2000; Roberts and Hawkins 2000). No-take reserves were first promoted in tropical, mainly coral reef, areas, in response to the difficulties of applying classical quota-based management techniques to high-biodiversity, multi-species fisheries in regions where catches could only with difficulty be monitored, much less regulations enforced (Munro and Williams 1985; Bohnsack 1993). Results have been sufficiently encouraging that they are currently being proposed as a means of combating stock depletion in Western Europe and North America.

A series of studies have now confirmed that protection of previously exploited reef areas as no-take zones or fisheries reserves, within which fishing is prohibited, typically results in a recovery or build-up in numbers, and an increase in individual fish size, among previously exploited fish species (Halpern in NRC 2000). This was first demonstrated with respect to a no-fishing reserve established on Sumilon I., Philippines (Russ 1985). Subsequently, other clear demonstrations of the same effect have been described from the southern Great Barrier Reef Marine Park in Australia (Ayling and Ayling 1986), the Tsitsikama Coast National Park in South Africa (Buxton and Smale 1989), within Malindi and Kisite Marine National Parks in Kenya (McClanahan and Muthiga 1988; Watson and Ormond 1994), and in two reserves in St Lucia, in the Caribbean (Polunin and Roberts 1993).

An increasing number of cases have also been described where no-take reserves have increased fish abundance or increased fish catch in adjacent fished areas (Russ and Alcala 1994, 1996; Sluka *et al.* 1997; Watson *et al.* 1997). This is thought possible through two mechanisms (Russ and Alcala 1994). Increased stock biomass may occur as a result of the export of pelagic larvae that settle in areas outside the reserve, thus replenishing these fishing grounds. This has been presumed to occur over considerable distances (Jennings *et al.* 1996; Roberts 1996, 1997), but may also be important to adjacent areas given increasing evidence for some local retention of larvae (Jones *et al.* 1999; Swearer *et al.* 1999). In addition there is evidence that, as stocks build up, emigration ('spillover') of adults will occur from areas of high population density to areas where stocks are being reduced by fishing mortality (Funicelli *et al* 1989; Attwood and Bennett 1994, 1995; Gaudian *et al.* 1995).

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An opportunity to investigate further the effectiveness and mechanisms of no-take zones as tools in fisheries management arose at Nabq, on the south-east Sinai coast of the Egyptian Red Sea (Fig. 1), where a small-scale, artisanal, reef fishery is conducted by Bedouin. Here, in 1992, a multiple-use Marine Protected Area was established, within which traditional fishing by local Bedouin would be permitted, so long as this was at a sustainable level. Given that fishing intensity at Nabq was believed to have increased markedly in the previous few years, as a result of growing demand from hotels and restaurants in the rapidly increasing international tourism sector (Pearson 1998), research was initiated to assess the status of the artisanal fishery, and to test options for its sustainable management. Consequently, it was decided by EEAA to establish within the protected area a number of no-take or non-fishing zones, of different sizes, and to investigate their effectiveness in sustaining the populations of exploited fish species and enhancing the catch in intervening fished areas.

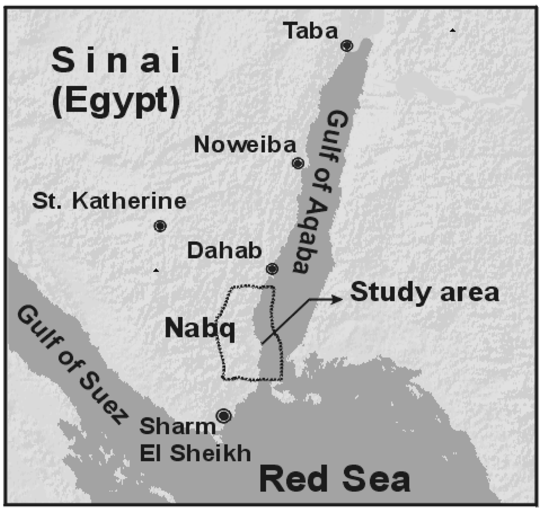

Fig. 1. Location of the study area, the Nabq Managed Resource Protected Area, on the south-east coast of South Sinai, south-western Gulf of Aqaba, within the Red Sea.

Methods

Study area

The Nabq Managed Resource Protected Area stretches along 47 km of the eastern coast of the South Sinai Peninsula, occupying most of the southern-western portion of the Gulf of Aqaba. It was established as an adjunct to the Ras Mohammed National Park, which is separated from it by the tourist resort of Sharm El Sheikh. The Nabq protected area incorporates both coast and inshore marine areas and also extends inland to give a total terrestrial area of 465 km^2. It is managed by the Egyptian Environmental Affairs Agency (EEAA) as part of the South Sinai Protectorates. Although it is protected from development, sustainable use by local Bedouin populations using traditional methods is permitted. This includes both grazing of camels and other livestock, and fishing by access from the shore or using non-mechanized vessels.

Along most of the coastline, a moderately well developed fringing reef runs parallel to the coast, with the reef edge lying between 100 m and 1 km from the shore. The reef, however, is discontinuous at some locations, where water from inland rain occasionally reaches the sea down otherwise dry wadis. At four of these localities there are extensive monospecific (*Avicennia marina*) mangrove stands, which are the most northerly in the Indian Ocean region. In these localities, and at others where the reef edge lies furthest from the shore, occur sandy-bottomed lagoonal areas up to 500 m across and 16 m in depth. These are often covered by dense sea-grass meadows dominated by *Halophila stipulacea*, *Thalassia hemprichi* and *Thalassodendron ciliatum*. Elsewhere, a shallow predominantly hard-bottomed irregular reef flat, mostly exposed during low tides, extends between shore and reef crest. The reef face, which supports a diverse coral assemblage notable for its dense stands of *Acropora* spp., large *Acropora* tables and large colonies of *Porites* spp., drops away to ~10 m, and then in a series of steps to greater depth.

The fishery

Local Bedouin, of whom some are semi-resident at two small encampments within the protected area, and others live around the more northerly towns of Dahab and Nuweiba, conduct a multi-gear, multi-species fishery. The gear used are trammel nets, gill-nets and hand-lines, types widely found in tropical artisanal fisheries (Munro and Williams 1985). Hand-lining is conducted from the reef edge or small boats. Trammel and gill-nets are, however, the principal gear used, and these are most frequently set at points where gaps in the outer reef give

Table 1. Regulations concerning artisanal fishing activities applying to fished and non-fished (no-take) areas within the Nabq Managed Resource Protected Area as enacted by the Egyptian Environment Affairs Agency, April 1995

Gear type /method	Fished areas	No-take zones	Additional specifications
Gill nets	Permitted	Forbidden	Minimum mesh size (>5cm)
Trammel nets	Permitted	Forbidden	Minimum mesh size (>5 cm)
Deep (long) nets	Permitted	Forbidden	Minimum mesh size (>10 cm). Permitted only in sandy-bottom areas
Hook and line	Permitted	Forbidden	One hook per line per fisherman
Spears & spear-guns	Forbidden	Forbidden	
Dynamite fishing	Forbidden	Forbidden	
Trawling	Forbidden	Forbidden	
Reef-top molluscs	Permitted	Forbidden	
Spiny lobsters	Permitted seasonally	Forbidden	Only during September–January. Minimum individual size 25 cm or 450 g. No berried females (bearing eggs) to be taken

access to the reef-top lagoons, so creating small embayments (*sharm*) across which the nets can be strung.

Fishery management

On the establishment of Nabq as a protected area, discussions were held with local fishermen and community leaders that led to their being supportive of new fisheries regulations, including a ban on the use of destructive or highly selective fishing techniques (Table 1). Support for the objectives of the protected area was further encouraged by employing a proportion of local Bedouin as 'Community Rangers', integrating them into the day-to-day management work of protected-area staff. When the establishment of a series of no-take reserves was under consideration, local fishermen were further involved in the fisheries management process, by being included in the decision-making procedures that determined the number, size and location of the no-take reserves. A series of community gatherings were held at which marine ecological principles and conservation and management issues were introduced and discussed, and interpretative material distributed. The fishermen showed a preference for establishing no-take zones in certain areas, which were either more difficult to access or were customarily treated as fall-back fishing localities. Agreement was significantly eased by the local Bedouin's respect for a variety of traditional resource conservation measures, such as a tribal ban on cutting of living timber for fuel or construction purposes or selective release of by-catch in the sea before fish catches are landed. Following a decision to establish five no-take zones (Fig. 2), no-fishing signs and border marker posts were installed to mark the boundaries of each area.

Underwater visual census

Estimates of in-water reef-fish abundance were made by underwater visual census (UVC) during August–September 1995, 1997 and 2000 at 10 permanent stations, two inside each no-take reserve. The UVC protocol followed that established by the Reefwatch Project (TMRU, University of York). At each site fish were counted along four band transects (200 × 10 m) running parallel to the reef face, one in each of the following reef zones: mid lagoon or reef flat (0–2 m depth), the reef edge (3 m depth), reef face (10 m depth) and reef slope or terrace (17 m depth). The lengths of these transects were measured by tape along the reef top, and the start and end points permanently marked. Fish within each band transect were counted by observers swimming along the appropriate depth contour at a standard speed of 10 m min^{-1}, searching carefully for and recording relevant species. Band transect width was judged from experience following training. Also following training (see Bell *et al.* 1985), the lengths of individual fish were estimated by eye (where possible by reference to marked underwater slates or to stationary objects) to the nearest 5 or 10 cm depending on size of species. The data reported here relates to three commercially important families of largely or partly piscivorous predators, groupers (Serranidae), emperors (Lethrinidae) and snappers (Lutjanidae) (Table 2). To enhance the accuracy of the counts, each observer counted fish within only a single or two closely related families with which they were familiar; such focusing on fish of a particular general form and behaviour has been found to increase the ease and reliability of the count (see also Watson and Ormond 1994). Further, the accuracy or 'catchability coefficient' (CC) of the counts made by each diver was determined by comparison with one or more abundance estimates made simultaneously by the senior authors, where

$$[CC] = \Sigma_{(1-n)} O_1 / \Sigma_{(1-n)} O_2$$

and n is the number of transects, O_1 is Observer 1 counts and O_2 is Observer 2 counts.

Subsequently, counts made independently by other observers were adjusted by reference to their determined catchability coefficient.

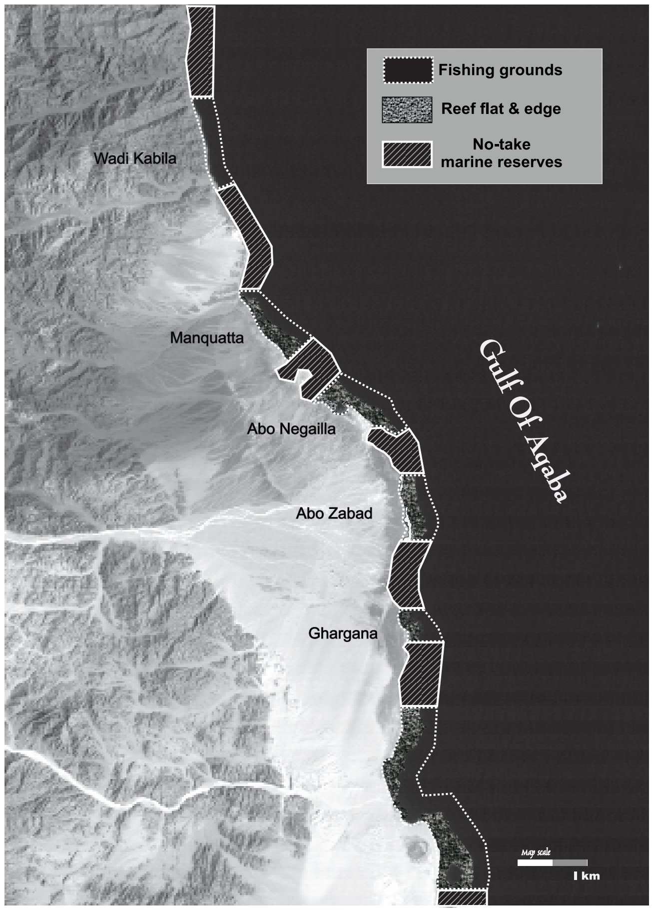

Fig. 2. Locations and extent of the no-take zones (fisheries reserves) within the Nabq Managed Resource Protected Area. Also shown are the major fishing and landing sites used by the fishermen

Catch and effort

The principal fishing and landing sites in the Nabq fishery were identified during a preliminary survey in 1994 (Fig. 2). Landings were sampled on a multiple stratified-random design, such that, at each of these sites, the total number of catches (normally 80–100) intercepted and sampled were distributed evenly across the four fishing seasons of each of the years 1995,1997 and 2000. For each intercepted catch, total weight of catch and, where possible, the total weight of each species were recorded. Also recorded were fishing method and, through interviewing the fishermen, fishing effort (usually the number of nets,

Table 2. Fishes observed by underwater visual census during the present study

Serranidae	Lethrinidae	Lutjanidae
Cephalopholis miniata	*Lethrinus mahsena*	*Lutjanus monostigma*
Cephalopholis hemistiktos	*Lethrinus nebulosus*	*Lutjanus ehrenbergi*
Cephalopholis argus	*Lethrinus obsoletus*	*Lutjanus bohar*
Epinephelus fasciatus	*Monotaxis grandoculis*	*Macolor niger*
Epinephelus tauvina		
Variola louti		

size of each net, and active soak time). Fishing effort was calculated as number of gear units × soak time. Catch per unit effort (CPUE) was calculated as follows:

$$[\text{CPUE}] = W / TN$$

where W is total catch wet weight, N is the number of gear units (i.e. equivalent number of nets of standard length), and T is the active soak time (i.e. the number of hours that the fishing gear was actually active, excluding the setting and collection times).

Data analysis

For fish abundance, total abundances for different fish species and families at each station (2 stations in each of 5 reserves) were compared among years by Wilcoxon signed-rank test. For mean fish length, population length–frequencies for each species were compared among the years 1995, 1997 and 2000 by the Kruskal–Wallis H-test. For CPUE, mean CPUEs for the whole years 1995, 1997 and 2000 were compared both for individual sites and also across all sites by Mann–Whitney U-Test.

Results

Fish abundance

When data were pooled across all five no-take reserves (Table 3), they showed a significant increase in abundance of the serranids *Variola louti* and C*ephalopholis argus* and the lethrinid *L. obsoletus*. When data for each no-take reserve were examined separately (Table 4), it was found that two of them, Ras Atantour and South Ghargana, showed a statistically significant increase in the overall abundance of the three test families, Serranidae, Lethrinidae and Lutjanidae, combined.

Mean fish length

There was a significant increase (Kruskal–Wallis test) in mean length of four of the commonest species (Fig. 3), the serranids *E. fasciatus* (P <0.01) and *C. argus* (P <0.001), and the lethrinids *L. nebulosus* (P <0.01) and *M. grandoculis* (P <0.01). There was, however, a decrease in the mean population length of the lutjanid *L. bohar*.

Table 3. Mean abundance of each species across all five no-take marine reserves in 1995, 1997 and 2000

Values represent the mean ± s.d. across 10 stations, two within each reserve, each station consisting of four band transects 200 × 10 m (combined area 8000 m^2 for each station). Significance, P: comparison between 1995 and 2000 (Wilcoxon signed-ranks test); n/s, not signficant

Species / Family	1995	1997	2000	P
Lethrinidae	30.9 ± 10.2	40.1 ± 19.3	42.0 ± 25.8	<0.05
L. mahsena	11.3 ± 2.6	18.6 ± 5.5	17.0 ± 6.6	n/s
L. nebulosus	5.8 ± 1.1	3.8 ± 1.1	4.7 ± 2.2	n/s
L. obsoletus	10.5 ± 2.2	13.6 ± 2.2	17.4 ± 6.3	<0.005
M. grandoculis	3.2 ± 3.3	4.1 ± 4.3	2.9 ± 4.1	n/s
Lutjanidae	9.6 ± 3.3	11.6 ± 3.3	14.1 ± 5.2	<0.05
L. bohar	6.2 ± 2.1	6.9 ± 2.1	8.8 ± 3.3	n/s
Other lutjanids	3.4 ± 1.2	4.7 ± 1.5	5.3 ± 1.9	n/s
Serranidae	50.0 ± 14.8	49.5 ± 14.7	58.6 ± 21.7	<0.05
C. argus	4.1 ± 1.9	7.3 ± 1.9	7.5 ± 5.0	<0.05
C. hemistiktos	4.9 ± 3.0	3.2 ± 3.0	5.1 ± 2.1	n/s
C. miniata	21.9 ± 4.7	18.6 ± 4.8	20.7 ± 7.1	n/s
E. fasciatus	15.3 ± 3.6	14.6 ± 3.6	17.1 ± 5.4	n/s
E. tauvina	1.4 ± 0.6	1.6 ± 0.7	1.5 ± 0.9	n/s
V. louti	2.5 ± 1.0	4.2 ± 1.0	6.7 ± 1.2	<0.005

Table 4. Total abundances of fished groupers (Serranidae), emperors (Lethrinidae) and snappers (Lutjanidae) in each of the five no-take marine reserves in 1995, 1997 and 2000

Values represent the mean at each of two replicate stations within each reserve (four 2000 m^2 band transects for each station). Significance, P: comparison between 1995 and 2000, matched pairs data for the same transects (n = 8) (Wilcoxon signed-ranks test); n/s, not signficant

Reserve	1995	1997	2000	P
Ras Nasrani	78	57.5	62.5	n/s
South Ghargana	97.5	112	142.5	<0.05
Nakhlet El Tal	102.5	99	107.5	n/s
El-dakal	87.5	95	97.5	n/s
Ras Atantour	87	142.5	150	<0.05

CPUE

By 1997 mean CPUE across all sites showed a slight but not statistically significant increase from 0.79 ± 0.19 (s.e.) kg net^{-1} h^{-1} to 0.86 ± 0.24 kg net^{-1} h^{-1} (Table 5). CPUE had increased at 5 of the 9 sites, but had decreased at a few of the more heavily fished sites. By 2000 CPUE was greater than in 1995 at 7 out of 9 sites, and mean CPUE had shown a further increase to 1.31 kg net^{-1} h^{-1}, a level now significantly greater (Mann–Whitney U-Test, P <0.05) than that recorded in 1995.

Discussion

In recent years it has come to be accepted that elimination of fishing mortality within marine fishing reserves can lead to an increase in both abundance and mean individual size of fishes, especially of the larger predatory species generally targeted by fishing (Halpern, in NRC 2000). In the present study such an increase in abundance was observed at family level for each of the three families, groupers, emperors and snappers, as well as individually for two species of grouper (*Variola louti* and *Cephalpholis argus*) and one species of emperor (*L. obsoletus*), across the five no-take reserves combined. Ras Atantour and South Ghargana, where there was a significant increase in overall abundance across the three families of piscivores combined, were the two reserve areas that had been more heavily fished than the others prior to reserve establishment. These findings support the view that no-take zones may be used to conserve fish stocks, at least of those more vulnerable K-selected predators that tend to be most readily overfished even in the presence of fisheries management.

The statistically significant increase in mean length of *E. fasciatus*, *C. argus*, *L. nebulosus* and *M. grandoculis* is similar to results obtained elsewhere (Bell 1983; Russ 1985;

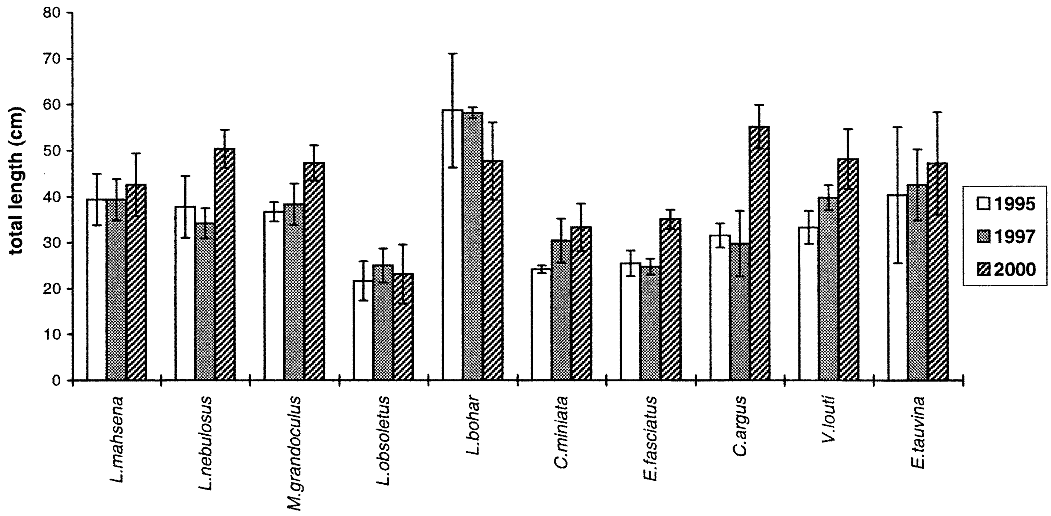

Fig. 3. Mean lengths of the commonest species of exploited piscivore within the five no-take reserves in 1995, 1997 and 2000. Lengths were estimated, following training, by eye during UVC at two permanent stations (8000 m^2) within each reserve. Error bars: s.e.m.

Ayling and Ayling 1986; Alcala 1988; Koslow *et al.* 1988; McClanahan and Muthiga 1988; Polunin and Roberts 1993; Watson and Ormond 1994). Inspection of the data suggests that this effect may be most evident within those no-take zones that were previously heavily exploited by hook-and-line (as opposed to by set-nets), a fishing method that tends to be highly selective for these larger predatory species; because of their dominant aggressive behaviour, the larger individuals tend to be caught first, and it is also these that the fishermen target, because of their greater market value.

Some increase in fish numbers was apparent relatively soon after closure of the no-take reserves. This observation is consistent with the suggestion of Polunin and Roberts (1993) that 2–3 years of protection is usually sufficient for changes in the abundance and biomass of commercially targeted stocks to begin to be evident. For example, White (1988) and Russ and Alcala (1994) detected increases in fish abundance within coral reef reserves in the Philippines within a few years of their establishment.

That there could be an increase in catches in fishing grounds adjacent to new no-take reserves was suggested by White (1986), Roberts and Polunin (1991) and Rowley (1994). Several studies (Russ and Alcala 1989; Alcala and Russ 1990; Rakitin and Kramer 1996; Watson *et al.* 1997) have now provided evidence of such an effect. The rise in mean CPUE at fished sites at Nabq, following establishment of no-take reserves, is in keeping with such evidence, and is one of only a few cases to date (Bennett and Attwood 1993; McClanahan and Mangi 2000; Roberts *et al.* 2000) in which such an increase in CPUE has been clearly documented. Given that the same numbers of fishermen were fishing the area as previously, the rise in CPUE strongly suggests an increase in total catch, despite the reduction in fishing grounds.

Two mechanisms have been proposed to account for an increased catch in fishing grounds adjacent to no-take areas. Emigration (or 'spillover') of adults from the no-take zones may occur as stocks build up within them (Russ and Alcala 1994). In support of such an effect Alcala and Russ (1990) found a correlation between distance from reserve boundaries and the density of commercially targeted fish species. Alternatively, enhanced recruitment may occur as a result of improved reproductive success of the increase spawning stock within the no-take zones. The present study can not distinguish between these alternative mechanisms, although the former seems more likely to be evident within a short time frame.

In the present study two other factors may have influenced stock response to the introduction of no-take zones. The establishment of the Nabq region as a Marine Protected (Managed Resource) Area had previously involved the introduction of more standard fisheries regulations, such as

Table 5. Overall catch per unit effort (CPUE; kg net^{-1} h^{-1}) at each of the major fishing sites within the fished zones as recorded in 1995, 1997 and 2000, and mean CPUE across all sites for each year

Fishing site	1995	1997	2000
North Nabq	0.65	0.78	0.91
Ghargana village	0.45	0.34	0.75
Marsa Abo Zabad	0.11	0.46	1.56
Lighthouse	0.19	0.79	1.34
Maria Schroeder	0.75	0.65	1.30
Abo Negailla	0.44	1.12	0.92
Al-dakkal	1.22	0.67	0.73
Shora El Manquatta	0.49	1.01	1.66
Wadi Ghorabi	2.79	1.89	2.63
Mean CPUE (kg net^{-1} h^{-1})	0.79	0.86	1.31

restrictions on mesh size and the prohibition of destructive fishing practices. Also, prior to the introduction of the no-take zones, some 20% of the area was only lightly fished, partly because of difficulties of access to more exposed reef sections. Thus taken as a whole the Nabq area was not noticeably overfished prior to the introduction of no-take zones, and this may be the reason that the recorded increases in fish abundance and mean individual length have not been great. Nevertheless, the introduction of no-take reserves there is seen as invaluable in preventing overfishing in response to accelerating demand from the tourism sector.

The introductory period of the present project, extending over a year or more, included interviews and informal discussion with local fishermen and community leaders, and attendance at formal and informal social gatherings. These activities were extremely time-consuming but essential to gaining community support for the establishment of the no-take reserves, as well as individual conformity with these and other fisheries restrictions. Frequent meetings with the community rangers were also required, but these played an invaluable role in patrolling the coast and assisting in the collection of catch and effort data.

The arrangement of no-take reserves at Nabq was agreed with two sets of considerations in mind. First, as discussed above, the siting of reserves had to be acceptable to the fishermen themselves. Social factors affecting the preferred locations and size of the no-take reserves included accessibility to different groups of fishermen living or fishing in different parts of the Protected Area.

Second, it was considered preferable to establish several small no-take areas, rather than one large one, in order to encourage spillover of exploited species to adjacent fished areas. As suggested by Rowley (1994), movement of adult fish from no-take reserves to exploited areas is likely to be greater where the perimeter-to-area ratio of the no-take zones is larger. At the same time, evidence from other regions (such as the Philippines and Belize) indicated that, as concluded by Roberts and Hawkins (1997), no-take reserves of 1–3 km in length are usually large enough to enhance the stocks of a wide range of coral-reef fish species. A further reason why a network of small reserves might be more effective in enhancing fish stocks (Holland *et al.* 1993) is that in a multi-species fishery, such as the present one, it is likely that different locations and habitats will be preferred as spawning grounds by different species. Besides this, marine reserves also have the purpose of protecting habitats and other species (Dayton *et al.* 1995), and a network of reserves is more likely to provide protection for a full range of representative coral reef habitats (Holland *et al* 1993; McClanahan 1994).

Acknowledgments

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