

Effects of fishing pressure and trophic group on abundance and spillover across boundaries of a no-take zone

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Abstract

We investigated factors influencing fish abundance and emigration across the boundaries of a no-take zone (NTZ), and its adjacent fished zones, within the Nabq Managed Resource Protected Area, South Sinai, Egyptian Red Sea. Underwater visual census of eight families of reef fish was undertaken at three depths across the whole NTZ (1.2 km), and for a similar distance into the adjacent fished zones. Because most fishing occurs in shallow water, the effect of the NTZ changed with depth. On reef flat transects (1 m depth), seven families showed significantly higher abundance in the NTZ, whereas at 10 m depth only two herbivorous families, Acanthuridae (surgeonfishes) and Siganidae (rabbitfishes) showed a significant difference, both being more abundant in the fished zones, an effect most likely due to reduced competition or predation. To look for evidence of emigration (spillover) of fish from the NTZ, data were also tested for evidence of gradients in abundance extending from within the NTZ to within the fished zones. In shallow water six families showed significant declines in abundance moving away from the centre of the NTZ, whereas at 10 m, the only significant gradients were for acanthurids and siganids, both becoming more abundant moving further into the fished zones. Comparisons of estimated fish length between areas also showed significant differences. The results indicate that at Nabq, while fishing reduces the abundance of most families, especially predators, abundance of some families and species, especially herbivores, may increase under light fishing pressure. Thus, spillover may occur to an extent and in a direction depending on trophic group and fishing intensity.

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1. Introduction

There is much current interest in the use of marine protected areas (MPAs), particularly no-fishing areas or no-take zones (NTZs), as tools for managing fishing effort (see recent reviews by National Research Council, 2000; Roberts and Hawkins, 2000; Ward et al., 2001; Russ, 2002). A series of benefits have been envisaged, including protection of spawning sites, enhancement of spawning biomass, and conservation of a proportion of the stock, resulting in maintenance or enhancement of yields in adjacent fished areas (Roberts and Polunin, 1991; Dugan and Davis, 1993; Rowley, 1994; Bohnsack, 1998; Roberts and Hawkins, 2000).

Increases in fish abundance, size and biomass within newly established or enforced NTZs have been clearly established. In reviewing 89 studies of marine reserves, Halpern and Warner (2002) found that in 63% of cases fish density, in 90% of cases fish biomass, and in 80% of cases fish size, were higher inside reserves than outside. Thus Rakitin and Kramer (1996) found increased abundance of large trappable fish within a reserve in Barbados, and Russ and Alcala (1996) recorded increased density of large predators within a few years of reserve protection. Similarly Watson et al. (1996) and Jennings and Kaiser (1998) found increased abundance of grouper (Serranidae), snapper (Lutjanidae) and emperor (Lethrinidae) at sites in Kenya and in the Seychelles.

In a smaller number of studies, increased fisheries landings have been recorded from areas adjacent to NTZs. Increased catches, sometimes coupled with

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increased catch per unit effort (CPUE), were reported adjacent to protected areas in the Philippines and Kenya (McClanahan and Kaunda-Arara, 1996; Russ and Alcala, 1996; Watson et al., 1996; McClanahan and Mangi, 2000). Similarly in St. Lucia, catches in areas adjacent to the NTZs in the Soufriere Marine Management Area increased by up to 90% (Roberts et al., 2001).

Most recently attention has turned to investigating the mechanisms through which fish stocks may be enhanced in areas adjacent to NTZs. Two principal mechanisms proposed are (a) that increased stock biomass within the NTZ leads to increased production and dispersal of larvae (larval export), and (b) that fish which have grown larger within the NTZ show net export into adjacent fishing areas (spillover). Indirect evidence of spillover from increased CPUE in adjacent fished areas has been coupled with evidence of fish movements into non-reserve areas from inside reserves, often along density gradients, in South Africa, at Apo Island in the Philippines, in Barbados and in Kenya (Attwood and Bennett, 1994; Rakitin and Kramer, 1996; Russ and Alcala, 1996; McClanahan and Mangi, 2000; Zeller et al., 2003). However Zeller et al. (2003) and Chapman and Kramer (2000) found little evidence of spillover movements across boundaries.

In the South Sinai portion of the Egyptian Red Sea several MPAs have now been established, including the fully protected Ras Mohammed National Park, and two multiple-use Managed Resource Protected Areas (MRPAs) at Nabq and at Abu Galum, both further north along the Gulf of Aqaba coast. While fishing is prohibited in inshore areas south of the Nabq MRPA (around Sharm El Sheikh and within the Ras Mohammed National Park), it is permitted within the MRPA to local artisanal fishermen using traditional gear. However, since 1995 this fishery has been further regulated to ensure its sustainability. The northernmost 15 km section of coast is a scientific reserve, and following consultation with the Bedouin community, the remaining 20 km of coast was divided, on an experimental basis, into a series of alternating take and NTZs, with the NTZs together covering a total of about 5 km of coast (Fig. 1). The network of NTZs was selected so as to encourage spillover of fish from NTZs into fished areas, so that fished areas would be accessible to fishermen living in different parts of the MPA, and to provide a suitable experimental design for testing the benefits and mechanisms involved (Galal, 1999). Three of the NTZs were established in areas only lightly fished by the Bedouin whereas the NTZs at Ras Tantor and South El Ghargana were moderately fished before being declared as NTZs. It was expected that the strongest reserve effects would be seen at these areas.

Within two years of closure, several commercial species showed increases in size and/or abundance be-

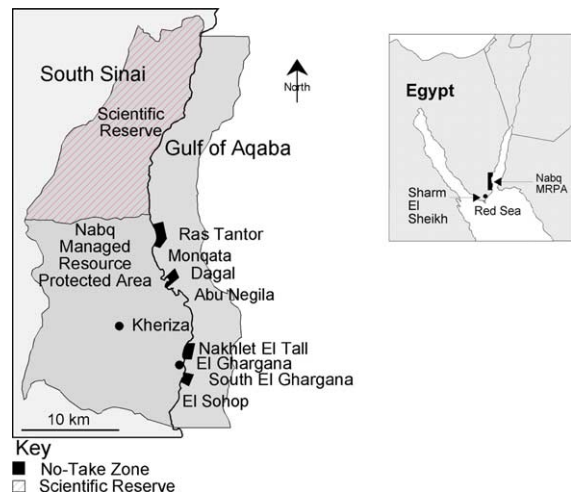


Fig. 1. Map of the Nabq MRPA with the NTZs highlighted and the areas named. Inset picture shows the position of Nabq MRPA in relation to Egypt.

tween open and closed areas, and after a further three years, mean CPUE within fished areas increased by about two-thirds (Galal et al., 2002). Overall increases in fish abundance were statistically significant within the two NTZs (Ras Tantor and South El Ghargana) which had previously been more heavily fished, but not in the three others, which had previously been only lightly fished (Galal, 1999). Here we describe the results of a preliminary study undertaken to check for indications of such spillover. However since only two of the NTZs showed a statistically significant increase in overall fish abundance, and access to one of these (Ras Tantor) was impracticable, research was obliged to concentrate on the other NTZ at the South El Ghargana, and its adjacent fished areas of El Ghargana and El Sohob.

2. Materials and methods

2.1. Study area

Nabq Managed Resource Protected Area is situated on the west side of the Gulf of Aqaba, about 35 km to the north of Sharm El Sheikh (Fig. 1). It extends 47 km along the coast, incorporating a semi-continuous fringing reef, and four large areas of mangrove (*Avicennia marina*), as well as inland coastal plain and mountain.

The fringing reef is typical of the Gulf of Aqaba, being well-developed with a broad shallow reef flat that is from 100 to 800 m (typically about 350 m) across (Head, 1987; Galal, 1999). In places the hard-bottomed reef flat contains small pools or extensive shallow sandy lagoons, within which seagrass patches of several species are common. In some locations gaps in the reef crest connect these lagoons with the reef edge. Beyond the reef edge, the reef slopes steeply to between 3 and 20 m,

where it meets a wide (> 50 m) sandy terrace spotted with coral mounds and pinnacles and further seagrass beds.

Nabq is home to a semi-resident Bedouin population of approximately 250 individuals, mostly living in two permanent villages, but with others occupying temporary fishing shelters along the shoreline (Galal, 1999). This population is permitted to fish within fishing zones in the MRPA, but only using traditional gear, which mainly consists of gill or trammel nets set on the outer reef flat or reef edge, although some hand-lining also takes place off the reef edge when conditions allow. The catch is mainly composed of the following families in descending order of biomass: Scaridae, Siganidae, Acanthuridae, Lethrinidae, Mugilidae, Kyphosidae, Haemulidae, Labridae, and Serranidae (Galal, 1999).

The present research looked in detail at fish populations within, and to either side of, a single NTZ, referred to as South El Ghargana (SEG). This extends along the coast for about 1.2 km, between (to the north) an open (i.e. fished) area opposite the Bedouin village of El Ghargana, referred to below as take zone North – TZ (N), and another open area, El Sohob, that extends southwards to the boundary of the MRPA, referred to below as take zone South – TZ (S). While the South El Ghargana NTZ was identified by Galal (1999) as showing a strong reserve effect, the El Ghargana TZ (N) is one of the most heavily fished areas at Nabq, with relatively high total yields and low catches per unit effort, and El Sohob TZ (S), while less intensively exploited, is still subject to significant fishing activity (Galal, 1999; Galal et al., 2002). Thus the South El Ghargana NTZ seemed the most likely site to be generating spillover of fish into the adjacent fished areas on either side.

2.2. Underwater visual census

During spring 2002 underwater visual census (UVC) was used to estimate the abundance and size of fish across the South El Ghargana NTZ and into the adjacent fished areas. Fish were censused along band transects 100 m long \times 10 m wide. Although this length and width of transect is larger than that used by many researchers (English et al., 1997), transects of this or similar size have been used by some researchers (Rigton et al., 1996; Watson et al., 1996) and in our view, provided visibility is adequate, generate greater precision due to larger sample size. To provide six replicate data sets, six transects, extending from within the NTZ to within fished areas, were arranged running parallel to the reef face within each of three reef zones: mid-lagoon or reef flat (1 m depth), reef edge (the zone at the top of the reef face, just below the reef crest at 3 m depth), and reef slope (10 m depth), and extending out from the NTZ in both directions along the coast. To achieve this,

12 transects were surveyed at each of the three depths (i.e. 36 transects) within the NTZ, and a further 36 in the adjacent parts of each of the two adjacent fished areas, giving a total of 3×36 (= 108) transects (total area = 108,000 m²). Transects were continuous with one another, apart from a 10 m gap at the boundary of the take/no-take zone. The transects covered the whole of the NTZ (1.2 km), and extended for the same distance into each of the adjacent open areas. While this arrangement of transects could be considered a form of pseudo-replication if the results were to be assumed as applying to a series of replicate areas, our purpose, given the circumstances described, was to draw conclusions about the abundance of fishes within and adjacent to a single no-take area.

Sale (1997) notes possible bias in visual census counts arising from laying a tape to measure transect length. To counteract this, no tapes were laid, but transect lengths measured by swimming for 10 min at a constant speed of 10 m min⁻¹, a speed attained through training and measured using an underwater watch. As a check on this procedure the speed of observers on repeated swims over a short course was monitored. With experience, up to 84% of attempts were within $\pm 10\%$ of the required speed. There were no significant differences in accuracy between observers (Mann–Whitney test, $p > 0.05$).

Eight families of fish were surveyed encompassing both commercial and non-commercial species: snappers (Lutjanidae), emperors (Lethrinidae), groupers (Serranidae), butterflyfishes (Chaetodontidae), angelfishes (Pomacanthidae), surgeonfishes (Acanthuridae), rabbitfishes (Siganidae) and parrotfishes (Scaridae). All fish were recorded to species except for Scaridae, which could not always be distinguished. Observations were undertaken by the two authors plus two additional researchers who were trained to the required standard. Families were separated between observers, with each observer concentrating on no more than a few related families that required a particular searching strategy to count efficiently (Watson and Ormond, 1994; Sale, 1997). Up to three observers were involved in counting fish at any one time and transects were re-swum as necessary to count all families. Estimation of substrate and discarded fishing equipment was undertaken on a separate swim. We have found this method considerably more reliable than simultaneous counts of numerous species by a single observer.

Lengths of fish were also recorded, with individuals of less than 30 cm being estimated by eye to the nearest 5 cm, and fish of larger size to the nearest 10 cm. Following Bell et al. (1985) observers were trained at this task by estimating the lengths of pre-cut pieces of wood (from 5 to 100 cm long) suspended underwater on the reef flat. The exercise was repeated at intervals throughout the study period, with observers being required on each occasion to reach, after one or more

attempts, an accuracy of 100%, from distances of both 1 and 3 m. Mean daily scores showed an increase in accuracy over time, with the last two days having a mean score of >90%. Overall there was no significant difference in scores between the observers at either distance (Mann–Whitney test, $p > 0.05$).

Reef substrate and reef base depth were recorded on the transects by estimating cover visually to the nearest 5% over consecutive 10 m² sections of the transect (i.e. every 2 min). However, no important conclusions were generated by this part of the study, hence the results are not included here. Also recorded as indicators of fishing activity were discarded fishing lines, nets, hooks and sacks, most of which had presumably been lost after entanglement in coral. The age of the fishing equipment could not be reliably assessed, and some may have been present on the reef from before the establishment of NTZs, although much in the fished areas was clearly of more recent origin.

2.3. Data analysis

Since abundance data were non-normally distributed and variance was heterogeneous, non-parametric tests of significance were employed. Mean fish abundance was compared between take and NTZs at both family and species levels, both across all depths (Scheirer–Ray–Hare test) (Scheirer et al., 1976) and for each depth separately (Kruskal–Wallis test). Since non-parametric tests were involved, multifactorial analysis (>2 factors) was not possible. The presence of horizontal gradients in abundance extending from within the NTZ to within the adjacent fishing zones was tested for with Spearman's rank correlations between abundance and distance from the centre of the NTZ. Mean lengths of fish in different areas were compared using Kruskal–Wallis tests and estimates of fish length obtained from different observers during training were compared using Mann–Whitney tests.

3. Results

3.1. Family abundances

Fig. 2 displays mean abundance of each fish family at each depth in each of the three areas. With transects in different reef zones initially intended as replicates, data were pooled across depths. Kruskal–Wallis tests showed significant differences across the three areas for Lethrinidae, Serranidae, Chaetodontidae and Pomacanthidae. Using Kruskal–Wallis multiple comparisons tests, TZ (N) showed significantly lower densities of serranids and chaetodontids ($H = 10.29$, $df = 2$, $p = 0.006$ and $H = 13.18$, $df = 2$, $p = 0.001$ respectively), South El Ghargana (the NTZ) a significantly higher density than TZ (S) of lethrinids ($H = 7.43$, $df = 2$, $p = 0.024$), and TZ

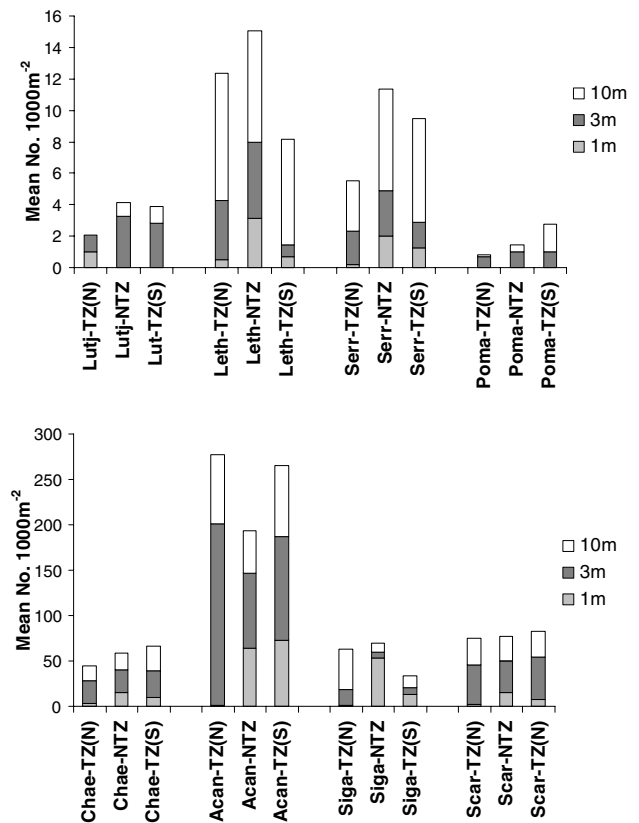


Fig. 2. Mean abundance (1000 m⁻²) of fish families at each area and each depth (N.B. bars are stacked). Family abbreviations are Lutj = Lutjanidae, Leth = Lethrinidae, Serr = Serranidae, Poma = Pomacanthidae, Chae = Chaetodontidae, Acan = Acanthuridae, Siga = Siganidae and Scar = Scaridae. TZ (N) and TZ (S) represent the fished areas (take zones) of El Ghargana and El Sohob respectively and NTZ indicates the no-take zone of South El Ghargana. (Error bars not shown due to limited space.)

(S) a significantly higher density of pomacanthids than both other zones ($H = 9.56$, $df = 2$, $p = 0.008$). Comparisons between the NTZ and both the fished zones taken together revealed that Lethrinidae and Serranidae were significantly more abundant in the NTZ (Kruskal–Wallis test $H = 3.95$, $df = 1$, $p = 0.047$ and $H = 4.09$, $df = 1$, $p = 0.043$ respectively), whereas Acanthuridae were more abundant in the fished zones (Kruskal–Wallis test $H = 4.47$, $df = 1$, $p = 0.034$).

Further analysis to check for differences in abundance with depth as well as area (Scheirer–Ray–Hare test) showed significant differences in all families (Table 1). Depth was a significant factor for all families, and area a significant factor for lethrinids, serranids and chaetodontids; for pomacanthids, acanthurids and siganids there was a significant interaction between area and depth. Comparison of mean abundances at different depths across all areas (Table 2) showed the Siganidae to be the only family that had its greatest abundance on the reef flat. Lutjanids, chaetodontids, pomacanthids, acanthurids and scarids were most abundant at the reef

Table 1

Results of Scheirer–Ray–Hare tests on the differences in abundance of each fish family with area and depth (total $df = 107$, significant p values < 0.05 indicated by asterisks)

Family	Area	Depth	Interaction
Lutjanidae	0.117	$< 0.001^*$	0.094
Lethrinidae	0.021*	$< 0.001^*$	0.196
Serranidae	0.017*	$< 0.001^*$	0.240
Chaetodontidae	0.018*	$< 0.001^*$	0.261
Pomacanthidae	0.052	$< 0.001^*$	0.007*
Acanthuridae	0.076	$< 0.001^*$	0.002*
Siganidae	0.748	0.028*	$< 0.001^*$
Scaridae	0.975	$< 0.001^*$	0.137

Table 2

Mean abundance (1000 m^{-2}) of each fish family at each depth across all areas (95% confidence intervals are shown within the brackets)

Depth	1 m	3 m	10 m
Lutjanidae	0.33 (0.60)	2.39 (0.97)	0.67 (0.54)
Lethrinidae	1.44 (0.77)	3.11 (1.98)	7.31 (1.76)
Serranidae	1.14 (0.46)	2.25 (0.60)	5.39 (1.11)
Chaetodontidae	9.31 (2.88)	26.81 (2.50)	20.53 (3.23)
Pomacanthidae	0.00 (n/a)	0.89 (0.43)	0.78 (0.38)
Acanthuridae	46.14 (18.85)	132.14 (34.61)	66.67 (10.18)
Siganidae	22.25 (12.85)	10.89 (3.09)	22.17 (11.84)
Scaridae	8.44 (3.08)	41.44 (6.51)	22.47 (4.94)

edge (3 m), and lethrinids and serranids most abundant on the reef face (10 m).

Kruskal–Wallis tests on these data revealed that the effects of the NTZ on families varied with depth (see Table 3). On the reef flat (1 m) all families apart from the Lutjanidae showed significantly higher abundances in the NTZ than in the fished zones taken together (Lethrinidae, $H = 10.76$, $df = 1$, $p = 0.001$; Serranidae, $H = 11.52$, $df = 1$, $p = 0.001$; Chaetodontidae, $H = 8.44$, $df = 1$, $p = 0.004$; Acanthuridae, $H = 6.53$, $df = 1$, $p = 0.011$; Siganiidae, $H = 11.61$, $df = 1$, $p = 0.001$ and Scaridae, $H = 10.19$, $df = 1$, $p = 0.001$). At 3 m depth only the Lethrinidae ($H = 4.17$, $df = 1$, $p = 0.041$) maintained this trend, while Acanthuridae and Siganiidae showed the opposite pattern, with higher abundances in the fished areas than in the NTZ ($H = 7.77$, $df = 1$, $p = 0.005$ and $H = 4.29$, $df = 1$, $p = 0.038$ respectively). At 10 m depth only Acanthuridae and Siganiidae showed a significance difference, with higher abundance in the fished areas than in the NTZ ($H = 9.24$, $df = 1$, $p = 0.002$ and $H = 6.35$, $df = 1$, $p = 0.012$ respectively).

Comparing areas individually, lethrinids and serranids were more abundant on the reef flat in the NTZ than at TZ (N) (El Ghargana) or TZ (S) (El Sohob), whereas chaetodontids, acanthurids, siganids and scarids showed significantly lower densities at TZ (N) than in either the NTZ or at TZ (S). At the reef edge acanthurids and siganids were significantly more abundant at

TZ (N) than in the NTZ, whereas lutjanids were significantly more abundant at TZ (S) than at TZ (N). On the reef face lutjanids and serranids were significantly less abundant, and siganids more abundant, at TZ (N) than in the other areas, chaetodontids and pomacanthids more abundant at TZ (S), and acanthurids significantly more abundant at each of the TZs than in the NTZ.

3.2. Species abundances

When mean abundances of individual species were compared (Kruskal–Wallis test) across depth between the take zones and NTZ (Table 3), 19 species (two lethrinids, two lutjanids, four serranids, four chaetodontids, one pomacanthid, three acanthurids, two siganids and one scarid) showed significantly higher abundances in the NTZ at one or more depths. On the reef flat zone all of the species showing significant differences had higher abundances in the NTZ. At the reef edge and reef face, species that were more abundant in the NTZ included lutjanids, lethrinids, serranids and a pomacanthid, whereas species that were more abundant in fished zones than in the NTZ were an acanthurid, two siganids and a chaetodontid. Comparing abundance across all depths between each of the three areas separately, nine species (one lutjanid *Macolor niger*; two serranids *Cephalopholis hemistiktos* and *Variola louti*; two chaetodontids, *Chaetodon austriacus* and *Chaetodon melannotus*; two pomacanthids, *Pomacanthus maculosus* and *Pygoplites diacanthus*; one acanthurid, *Ctenochaetus striatus*; and one siganid *Siganus stellatus*) were found to be significantly more abundant at TZ (S), the less intensively fished of the two fished areas, than at TZ (N). Only one species, the lethrinid *Lethrinus nebulosus*, was significantly more abundant at TZ (N) than TZ (S), and only *Acanthurus nigrofuscus* was significantly more abundant at TZ (N) than in the NTZ at South El Ghargana.

3.3. Density gradients

To check for evidence of spillover from the NTZ into the fished areas, transect data were analysed for the presence of horizontal abundance gradients extending from within the NTZ to within the fished zones. Plots for families showing significant trends with Spearman's rank correlation analysis are shown in Figs. 3 and 4. At 1 m depth six families, Lethrinidae, Serranidae, Chaetodontidae, Acanthuridae, Siganiidae and Scaridae showed significant trends of decreasing abundance moving from the centre of the NTZ into the northern take zone of El Ghargana ($R_s = -0.565$, $p < 0.001$; $R_s = -0.727$, $p = 0.001$; $R_s = -0.818$, $p < 0.001$; $R_s = -0.775$, $p < 0.001$; $R_s = -0.555$, $p = 0.017$ and $R_s = -0.745$, $p < 0.001$ respectively). At this depth Lethrinidae were

Table 3
Mean abundances (1000 m⁻²) of species and families at each depth in the TZs and the NTZs

Species	1 m		3 m		10 m	
	NTZ	TZ	NTZ	TZ	NTZ	TZ
<i>Lutjanus bohar</i>	0.00	0.00	0.83	0.58	0.42	0.38
<i>Lutjanus ehrenbergi</i>	0.00	0.50	1.00*	0.46*	0.00	0.00
<i>Lutjanus monostigma</i>	0.00	0.00	0.50	0.42	0.17*	0.00*
<i>Macolor niger</i>	0.00	0.00	0.83	0.50	0.33	0.17
<i>Lutjanid</i> sp.	0.00	0.00	0.08	0.00	0.00	0.00
Lutjanidae	0.00	0.50	3.25	1.96	0.92	0.54
<i>Lethrinus borbonicus</i>	0.08	0.00	0.00	0.04	0.00	0.00
<i>Lethrinus harak</i>	0.00	0.08	0.00	0.00	0.00	0.00
<i>Lethrinus mahsena</i>	1.47*	0.25*	3.00*	0.38*	3.33	5.33
<i>Lethrinus nebulosus</i>	0.00	0.00	0.00	1.63	0.08	0.58
<i>Lethrinus obsoletus</i>	0.25	0.04	0.00	0.00	1.42	0.25
<i>Monotaxis grandoculis</i>	0.17*	0.00*	1.75*	0.21*	2.25	1.25
<i>Lethrinid</i> sp.	0.08	0.08	0.08	0.00	0.00	0.00
Lethrinidae	3.17*	0.58*	4.83*	2.25*	7.08	7.42
<i>Cephalopholis argus</i>	0.08	0.04	0.92	0.83	0.50*	0.13*
<i>Cephalopholis hemistiktos</i>	0.00	0.00	0.00	0.00	0.25	0.38
<i>Cephalopholis miniata</i>	0.00	0.00	0.25	0.25	1.50	1.08
<i>Epinephelus fasciatus</i>	1.67*	0.67*	0.75*	0.29*	3.17	2.13
<i>Epinephelus malabaricus</i>	0.00	0.0	0.00	0.08	0.00	0.00
<i>Epinephelus tauvina</i>	0.25*	0.00*	0.33	0.21	0.17	0.21
<i>Plectropomus marisrubri</i>	0.00	0.00	0.17	0.21	0.00	0.13
<i>Variola louti</i>	0.00	0.00	0.42*	0.04*	0.83	0.83
<i>Serranid</i> sp.	0.00	0.00	0.08	0.00	0.00	0.00
Serranidae	2.00*	0.71*	2.92	1.92	6.42	4.88
<i>Chaetodon auriga</i>	4.92*	2.54*	2.75	2.79	1.50	1.96
<i>Chaetodon austriacus</i>	3.67*	0.83*	9.67	8.63	5.17	7.33
<i>Chaetodon fasciatus</i>	1.83	1.00	3.25	3.88	0.67	0.67
<i>Chaetodon lineolatus</i>	0.00	0.00	0.42	0.13	0.00	0.04
<i>Chaetodon melannotus</i>	0.92	1.17	0.42*	1.54*	0.58	1.21
<i>Chaetodon paucifasciatus</i>	2.58*	0.83*	3.17	3.92	7.33	6.75
<i>Chaetodon trifascialis</i>	0.42	0.08	3.08	4.33	1.17	1.17
<i>Chaetodon semilarvatus</i>	0.00	0.00	0.67	0.42	0.00	0.00
<i>Heniochus intermedius</i>	4.00*	0.42*	2.42	1.67	1.42	2.75
Chaetodontidae	14.92*	6.50*	25.83	27.29	17.83	21.88
<i>Pomacanthus imperator</i>	0.00	0.00	0.25*	0.00*	0.08	0.04
<i>Pomacanthus maculosus</i>	0.00	0.00	0.00	0.08	0.00	0.25
<i>Pygoplites diacanthus</i>	0.00	0.000	0.75	0.75	0.33	0.67
Pomacanthidae	0.00	0.00	1.00	0.83	0.42	0.96
<i>Acanthurus nigrofuscus</i>	50.67*	32.80*	38.67*	109.00*	32.08*	58.25*
<i>Acanthurus sohal</i>	0.25	0.17	10.75	6.63	0.08	0.21
<i>Ctenochaetus striatus</i>	10.00*	3.08*	22.33	29.46	13.42	15.17
<i>Zebbrasoma desjardini</i>	3.33*	0.83*	5.17	3.38	0.75	1.71
<i>Zebbrasoma xanthurum</i>	0.00	0.04	4.83	4.00	0.42	1.13
<i>Naso literatus</i>	0.00	0.17	0.50	0.80	0.00	0.00
<i>Naso unicornis</i>	0.00	0.00	0.08	1.71	0.00	0.17
Acanthuridae	64.30*	37.10*	82.33*	157.00*	46.75*	76.63*
<i>Siganus argenteus</i>	49.30*	5.83*	0.00	3.46	2.42*	19.63*
<i>Siganus luridus</i>	4.00*	0.75*	6.50	8.83	6.75*	8.75*
<i>Siganus stellatus</i>	0.17	0.08	0.17	0.71	0.08	0.25
Siganidae	53.40*	6.67*	6.67*	13.00*	9.25*	28.63*
<i>Hipposcarus harid</i>	4.00*	0.42*	3.67	6.92	5.17	4.38
Scaridae	14.92*	5.21*	34.75	44.79	27.92	28.75

Species and families showing significance (<0.05), following Kruskal–Wallis tests, at the various depths are indicated with asterisk for the pair of means.

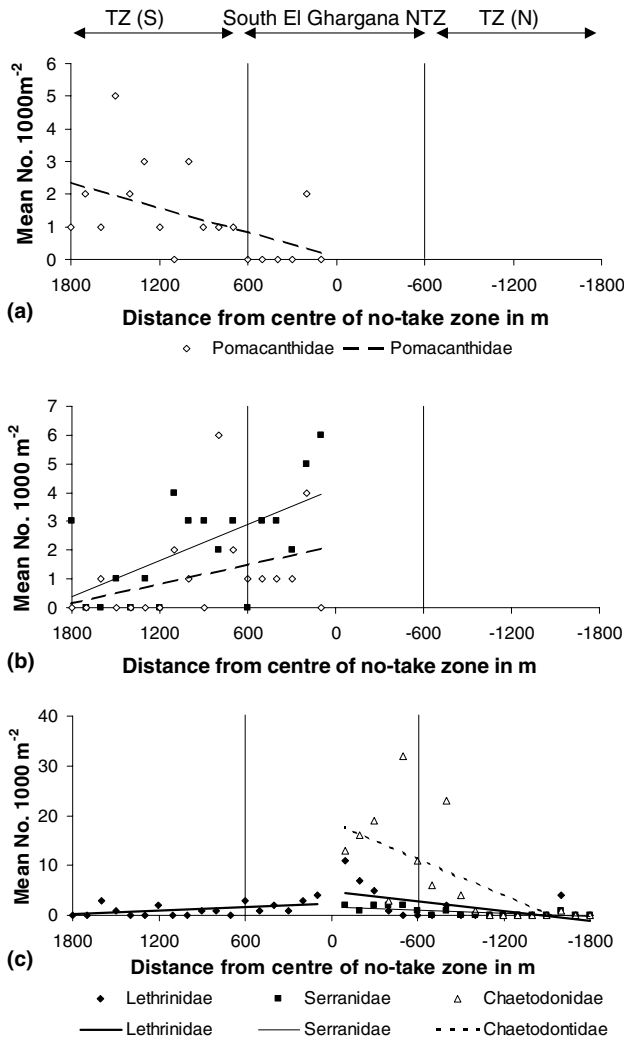


Fig. 3. Trends in abundance for various fish families showing significant change with distance away from the centre of the no-take zone (Spearman's rank correlation, $p < 0.05$). (a) 10 m depth, (b) 3 m depth, and (c) 1 m depth. The vertical lines at 600 and -600 m indicates the location of the boundaries of the NTZ.

the only family to show a significant trend of decreasing abundance into the southern take zone of El Sohob ($R_s = -0.531$, $p = 0.023$). At 3 m, Siganidae showed a trend of increasing abundance into TZ (N) ($R_s = 0.618$, $p = 0.006$), while Serranidae and Pomacanthidae showed significant trends of decreasing abundance and Acanthuridae and Scaridae increasing abundance into the fished area of TZ (S) ($R_s = -0.561$, $p = 0.016$; $R_s = -0.476$, $p = 0.046$; $R_s = 0.657$, $p = 0.003$ and $R_s = 0.496$, $p = 0.036$ respectively). At 10 m, Siganidae showed a significant trend of increasing abundance into TZ (N) while Acanthuridae and Pomacanthidae showed significant trends of increasing abundance into TZ (S) ($R_s = 0.771$, $p < 0.001$; $R_s = 0.552$, $p = 0.017$ and $R_s = 0.543$, $p = 0.020$ respectively). The pattern shown by the Siganidae and Acanthuridae is especially notable since

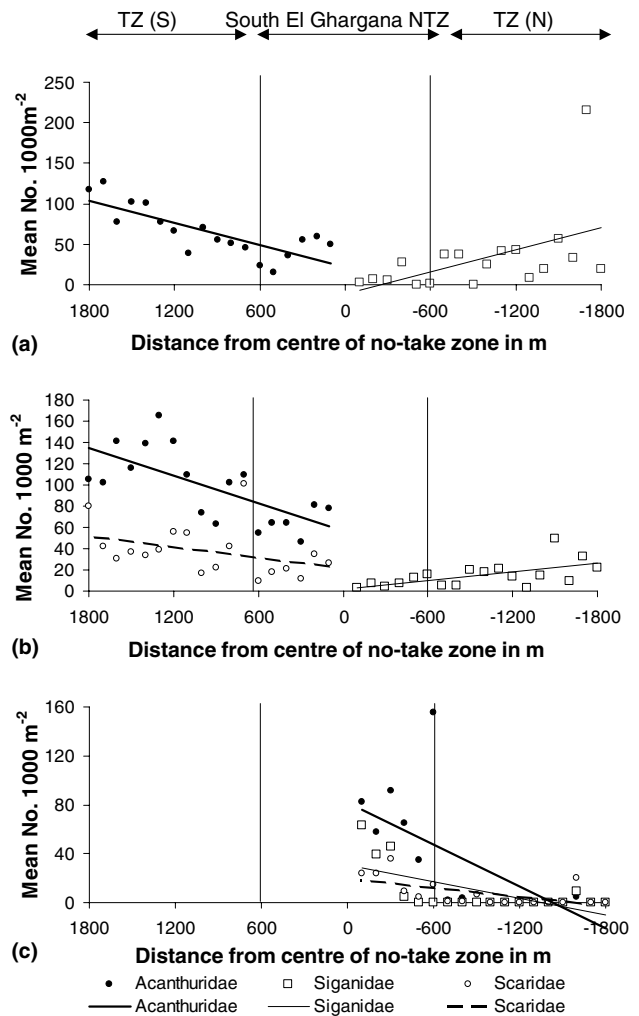


Fig. 4. Trends in abundance for herbivorous fish families showing significant change with distance away from the centre of the no-take zone (Spearman's rank correlation, $p < 0.05$). (a) 10 m depth, (b) 3 m depth, and (c) 1 m depth. The vertical lines at 600 and -600 m indicates the location of the boundaries of the NTZ.

while they show a significant trend at each depth, the direction of the gradient changes from a decrease in abundance moving out of the NTZ at 1 m, to an increase in abundance at both 3 and 10 m.

3.4. Fish length

Comparisons of mean estimated fish length at the family level across all depths and areas revealed that Lutjanidae were significantly larger in the fished areas, whereas Acanthuridae were larger in the NTZ (Table 4). On comparison between individual areas, Serranidae were found to be significantly larger at TZ (S) than at TZ (N) ($H = 6.54$, $df = 2$, $p = 0.038$), Acanthuridae significantly smaller at TZ (N) than in the other areas ($H = 1275$, $df = 2$, $p = 0.002$), and Siganidae significantly larger at TZ (S) than in the other areas

Table 4
Comparison of mean fish length within fish families between the NTZ and the combined fishing areas (TZ)

Family	Depth (m)	Mean length (TZ)	Mean length (NTZ)	<i>H</i>
Chaetodontidae	1	8.46	10.90	4.98
Lutjanidae	3	49.95	35.63	4.91
Acanthuridae	3	14.29	15.79	5.06
Lutjanidae	10	59.33	46.17	4.06
Acanthuridae	10	12.09	12.94	3.92
Lutjanidae	Combined	49.14	39.39	3.94
Acanthuridae	Combined	12.63	13.67	6.00

Only families showing significant differences are listed with the level of the test statistic *H* also shown (Kruskal–Wallis test, $p < 0.05$).

($H = 11.09$, $df = 2$, $p = 0.004$). Analysis of data for individual depths confirmed the trends for Lutjanidae and Acanthuridae at 3 and 10 m, with lutjanids significantly larger at fished areas, and acanthurids larger at unfished areas. Chaetodontidae were the only family to show a significant difference in size at 1 m depth, being larger in the NTZ. Following Chiappone et al. (2000) serranids were split into two size classes (≤ 30 cm and >30 cm) to assess whether larger and smaller fish might respond

differentially to fishing pressure, but only minor differences were found (Table 5).

Differences in mean fish length were also analysed at the species level. On comparison of fished areas with the NTZ, only one species (*Chaetodon auriga*) showed greater length in the NTZ at 1 m ($H = 6.42$, $df = 1$, $p = 0.011$). At 3 m depth the lutjanid *Macolor niger* had a greater mean length in the NTZ, whereas the chaetodontid *Chaetodon trifascialis* was larger in the unfished areas ($H = 4.61$, $df = 1$, $p = 0.032$ and $H = 5.25$, $df = 1$, $p = 0.022$ respectively). Two species, the serranid *Cephalopholis argus* and the acanthurid *Acanthurus nigrofuscus*, showed increased mean length in the unfished areas at the 10 m depth ($H = 3.99$, $df = 2$, $p < 0.05$; $H = 4.06$, $df = 2$, $p < 0.05$ respectively). Further species were found to have significantly smaller or larger mean lengths at TZ (N) than at one or both other areas, either at individual depths or across all depths combined (see Table 6).

3.5. Fishing activity

Total numbers of fishing items (nets, lines, hooks etc), recorded on each transect, were significantly higher in the fished areas than in the NTZ at 1 m (back reef) and 3

Table 5
Comparison of differences in abundances between areas for large (>30 cm) and small (≤ 30 cm) serranids

	Depth (m)	<i>H</i>	Area	<i>p</i>
Serranids ≤ 30 cm	1	16.39	NTZ > TZ (N), NTZ > TZ (S)	<0.001
	3	1.66	–	Ns
	10	4.61	–	Ns
	Combined	7.84	NTZ > TZ (N), NTZ > TZ (S)	0.020
Serranids >30 cm	1	1.03	–	Ns
	3	1.89	–	Ns
	10	9.73	NTZ > TZ (N), TZ (S) > TZ (N)	0.008
	Combined	6.88	NTZ > TZ (N), TZ (S) > TZ (N)	0.032

Pairs of areas significantly different from each other are shown (Kruskal–Wallis Multiple Comparisons test). NTZ indicates the no-take zone of South El Ghargana, TZ (N) the fished area of El Ghargana and TZ (S) the fished area of El Sohoh. $Df = 2$.

Table 6
Comparison of mean fish length for individual species between areas and for each depth

Species	Depth (m)	TZ (N)	NTZ	TZ (S)	<i>H</i>
<i>Chaetodon auriga</i>	1	5.92 ^a	13.05 ^a	10.18	9.09
<i>Chaetodon melannotus</i>	1	5.00 ^a	10.80	14.08 ^a	9.01
<i>Macolor niger</i>	3	N/A	52.00 ^a	58.33 ^a	4.61
<i>Lethrinus mahsena</i>	10	14.75 ^{a,b}	28.35 ^a	37.13 ^b	14.23
<i>Cephalopholis miniata</i>	10	19.38 ^{a,b}	28.35 ^a	27.22 ^{a,b}	6.78
<i>Epinephelus fasciatus</i>	10	23.42 ^a	23.72 ^b	27.22 ^{a,b}	6.36
<i>Chaetodon paucifasciatus</i>	10	8.91 ^a	9.02 ^b	7.49 ^{a,b}	6.95
<i>Siganus luridus</i>	10	16.97 ^{a,b}	19.43 ^a	20.29 ^b	7.14
<i>Lethrinus mahsena</i>	Combined	16.06 ^{a,b}	29.37 ^a	36.70 ^b	14.91
<i>Cephalopholis miniata</i>	Combined	21.43 ^a	28.29 ^b	27.58	6.43
<i>Chaetodon austriacus</i>	Combined	9.77 ^{a,b}	8.80 ^a	9.15 ^b	9.42
<i>Chaetodon auriga</i>	Combined	13.52 ^a	11.74 ^a	12.44	6.02

Mean length in cm for each area is given. Pairs of areas significantly different from each other are indicated by superscripts (Kruskal–Wallis Multiple Comparisons test).

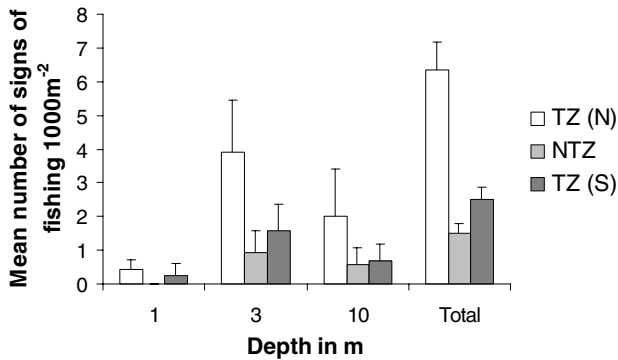


Fig. 5. Variation in abundance of discarded fishing gear across the two fished areas (TZs) and the no-take zone (NTZ) and across depths. Error bars represent 95% confidence intervals.

m (reef edge), and across all depths combined (Kruskal–Wallis test: $H = 4.20$, $df = 1$, $p = 0.040$; $H = 6.52$, $df = 1$, $p = 0.011$ and $H = 9.47$, $df = 1$, $p = 0.002$ respectively) (Fig. 5). In addition more items were recorded at TZ (N) than at TZ (S) (Kruskal–Wallis multiple comparisons test over combined depths $H = 10.64$, $df = 2$, $p = 0.005$, significant pairwise differences between TZ (N) and SEG NTZ and TZ (N) and TZ (S)).

4. Discussion

4.1. Fish abundance

Initially, in planning this study, we had hoped to be able to study gradients in fish abundance across four or five sets of take and NTZs, established for this purpose in 1995. This would have enabled us to draw generalisations likely to be true for NTZs, at least in the study region. In practice we were obliged to restrict the study to part of the area, and thus chose to undertake a detailed survey of a single NTZ and its adjacent fished areas, using sufficient replicates within these areas that we could with confidence determine whether or not there were differences in abundance across the boundaries of this one NTZ. In focusing on a single site our study resembles almost all others that have looked for effects of NTZs on fish abundance, save that we have recorded more replicate abundance estimates in a way that has enabled us to detect less obvious trends.

This comparison between the NTZ (South El Ghargana) and the adjacent fishing zones (El Ghargana and El Sohob) did reveal differences in abundance, but not always of the size and in the direction anticipated. Across all transects only two predatory fish families, Lethrinidae and Serranidae, and also the coral-feeding Chaetodontidae, were significantly more abundant in the NTZ than in either or both fished areas. The differences in mean abundance were not large, even though serranids and lethrinids are regarded locally as prime

target species, and showed an increase in abundance across all sites five years after NTZ establishment (Galal et al., 2002). In other studies also these have often been the first families to be depleted by increasing fishing pressure (Russ, 1985; Roberts and Polunin, 1991). By comparison the difference in abundance of chaetodontids was unexpected, since they are not targeted by the fishermen; however they are frequently landed after becoming entangled in set nets, after which they are discarded (Galal, 1999). By contrast with the patterns for these families, the herbivorous Acanthuridae were more abundant in the open areas than in the NTZ.

A fuller appreciation of the processes involved emerges if differences in abundance between the NTZ and fished zones are examined for each depth separately. Results will be influenced by the species-specific differences in abundance between reef zones reflected in Table 2, which showed the Siganidae to be the only family that was more abundant at 1 m (on the reef flat) than at other depths, and the Lethrinidae and Serranidae to be the only families that were most abundant at 10 m (on the reef face). Such zonation within reef fish communities is well established, including in the Gulf of Aqaba (Williams, 1991; Galal, 1999). Nevertheless, if abundances are compared at a single depth between the NTZ and the fished areas, then it is found that, at 1 m, with the single exception of the Lutjanidae, all families are more abundant in the NTZ than on one or both fished zones. For herbivorous families (Scaridae, Acanthuridae and Siganidae) this difference is only statistically significant when the NTZ is compared with El Ghargana (TZN). By contrast, at 3 m, only Lethrinidae are more abundant in the NTZ than in the fished areas, while Acanthuridae and Siganidae are more abundant in the fished areas, (although again the difference between individual areas is only significant if the NTZ and TZ (N) are compared). Finally, at 10 m, Acanthuridae and Siganidae remain more abundant in the fished areas, and no families are significantly more abundant in the NTZ than in the fished zones taken together, although Lutjanidae are more abundant in the NTZ than at TZ (N).

These patterns appears related to the fact that, at Nabq, fishing pressure is greatest on the reef flat, less at the reef edge, and least on the reef slope (Galal, 1999). In the reef flat zone, where fishing pressure is greatest, the abundance of all surveyed families is reduced in the fished areas (except the Pomacanthidae, which are non-commercial species naturally less abundant than the other families). Where fishing pressure is a little less, at 3 m, only Lethrinidae show reduced numbers in the fished areas, while the herbivorous Acanthuridae and Siganidae show an increase. And at 10 m, where fishing pressure is least, it is only the greater numbers of Acanthuridae and Siganidae in the fished areas that are statistically significant. Thus with heavier fishing pressure the abundance of most families is decreased,

whereas under lighter fishing pressure, there are fewer signs of a decrease in abundance of exploited species, and the abundance of some fish may actually increase.

It was also evident that, comparing the two fished areas, fishing pressure is greater at TZ (N) than at TZ (S), as well as being greater at both fished areas than in the NTZ. These differences in fishing pressure, as well as being noted by National Park Rangers and the fishermen, were evident during survey work, and are confirmed by the data (Fig. 5) for the abundance of fishing gear abandoned on the reef. This would explain why in addition to differences already mentioned, at 3 m Lutjanidae, and at 10 m Lethrinidae, Serranidae and Lutjanidae, are significantly more abundant at TZ (S) than at TZ (N).

The greater abundance of the Acanthuridae in the fished area than in the NTZ across all depths, and of both the Acanthuridae and Siganidae (both herbivorous families) at both 3 and 10 m (i.e. under lighter fishing pressure) is of particular interest. Although in most comparable studies herbivores have been found to be more abundant (or at least as abundant) within NTZs as in adjacent fished areas (Halpern, 2003), a greater abundance in fished areas than in neighbouring unfished ones has been observed in some studies, including others in South Sinai (Roberts and Polunin, 1992). It seems most likely that such a greater abundance of herbivores in fished areas (especially the small acanthurid *Acanthurus nigrofuscus*) is the result of decreased predation by large individuals of species such as serranids (Russ, 1985). Another possibility is that the removal of scarids, which are predominantly grazing herbivores, and significant competitors of acanthurids, which are mostly browsers, may favour larger numbers of the latter. In addition, it should be noted that an increase in abundance (as opposed to biomass) of a stock can occur as a direct result of exploitation, if the removal of larger individuals leads to the increased survival or growth of smaller ones (Roberts and Polunin, 1991, 1992; King, 1995). The significantly larger size of Acanthuridae in the NTZ suggests the latter effect may be operative.

Other families or species besides herbivores may also show some increase in actual numbers under light (as opposed to heavy) fishing pressure. Thus, several species were more abundant in the lightly fished El Sohob area than in the NTZ, including the small serranid *Cephalopholis hemistiktos*, for which greater abundance in fished areas was also recorded in South Sinai (Randall, 1983; Roberts and Polunin, 1992). This species may benefit from reduced competition and predation from larger serranids, when the latter are removed by fishing. Similarly Watson and Ormond (1994), observed higher populations of small serranids *Cephalopholis* spp. in fished areas than in a NTZ in southern Kenya.

4.2. Fish size

Another common effect of reserve establishment is that fish attain greater lengths in an NTZ (Roberts and Polunin, 1992; Chapman and Kramer, 1999; Galal et al., 2002; Halpern, 2003). Such an effect is evident in the present study for some families and species at some depths and locations, including Acanthuridae across all depths, Chaetodontidae at 1 m, and Serranidae and Siganidae across all depths on comparing TZ (S) with TZ (N). However other families and species showed greater mean fish length in fished areas, including Lutjanidae across all areas and depths, and four species of chaetodontid. Three possible explanations are suggested for the occurrence in some cases of larger mean size under greater fishing pressure. First, larger individuals may avoid capture in set nets if the mesh size is small. Second, perhaps linked to such an effect, forms of fishing may favour some larger species at the expense of smaller ones; thus higher proportions of the larger species *Lutjanus bohar* and *Macolor niger* were seen in the fished area. Third, larger individuals of prey species may experience a greater reduction in predation if larger individuals among its predators are removed disproportionately.

4.3. Indicators of spillover

Increased CPUE at fished sites within Nabq MRPA was seen two years after establishment of NTZs and was statistically significant after five years (Galal, 1999), suggesting the NTZs may be benefiting the fishery through spillover. Movement of individuals, especially larger species of lethrinid and lutjanid, across the boundaries of the NTZ was frequently observed, but could not easily be used to determine net migration. A number of studies have attempted to observe spillover by intensive tagging campaigns across the boundaries of an NTZ. Chapman and Kramer (2000) for example tagged fish of 35 species in the Barbados Marine Reserve and adjacent non-reserve, monitoring their movement both by recapture and by underwater visual observations. Mean recovery distance varied between species, but did not, show direct evidence of emigration from the reserve into the adjacent fished area. This could however be because the reef was not continuous across the boundary, which may have prevented movement (Kramer and Chapman, 1999). In Nabq, the continuous nature of the fringing reef will make spillover movements more likely.

Other studies used the presence of horizontal gradients in fish abundance moving away from NTZs to infer spillover of adult fish (Rakitin and Kramer, 1996; Chapman and Kramer, 1999; McClanahan and Mangi, 2000). The present study provides directly comparable data, with six families at 1 m and two families at 3 m

showing significant density gradients away from the centre of the NTZ into either one or both of the fished areas. However, at 3 and 10 m, Siganidae and Acanthuridae, showed a reverse gradient, with density increasing on moving away from the central NTZ. Several individual species within these families also showed comparable abundance gradients. The contrasting directions of gradients match those that would be anticipated from the overall differences in abundance discussed above. They suggest that where, adjacent to an NTZ, fishing intensity is most intense, as at 1 m at TZ (N), fish of most families will be moving into the fished area. By contrast, where fishing intensity is reduced, as at Nabq on the reef slope, some species, particularly herbivorous acanthurids and siganids, appear to be moving into the NTZ from adjacent fished areas where their populations are higher. The point has been made that since spillover is likely to be a density-dependent process, it can be expected that movement will be greater at higher levels of fishing intensity (Chapman and Kramer, 1999; Nowlis and Roberts, 1999; Roberts and Hawkins, 2000). The present data suggest not only that the extent of spillover will depend on fishing intensity, but that the actual direction of spillover may depend both on relative fishing intensity and the trophic group of the species concerned. To confirm the extent and direction of spillover further work is required which could follow the experimental design proposed by Russ (2002).

4.4. Fishing intensity

Russ (2002) states that it is an implicit assumption that fishing intensity is lower within reserves than outside, with however very few studies giving an indication of the difference in fishing intensity inside and outside reserves. At Nabq the frequencies of discarded items of fishing equipment on transects confirm that the NTZ experiences little fishing by comparison with the two fished areas. They also confirm that the fished area in front of El Ghargana village (TZ N) is subject to higher fishing intensity than is El Sohob (TZ S). It was notable however that some discarded fishing lines and other gear were encountered within the NTZ, an observation which, together with that of three observed instances of illegal fishing within the NTZ, confirm that the NTZ is not totally unfished. The amounts of discarded fishing items within the NTZ increased towards the boundary with the fished zones. Roberts and Hawkins (2000) discuss the phenomenon of 'fishing the line' where fishers target the boundaries, believing they will obtain higher catches there due to spillover from reserves. Fishers in Nabq appear to be encroaching on the boundaries, probably for similar reasons, although the effect is probably exacerbated by the fact that the boundaries of the NTZs in Nabq are poorly marked, being indicated only by signposts set some way back

from the beach. This encroachment may contribute to the gradients in fish abundance recorded here.

Normally, illegal fishing within an NTZ might be expected to hinder the effectiveness of the NTZ. However, it should be emphasised that even within the fished zones at Nabq the fishing intensity is assessed to be only moderate, and, over Nabq as a whole, the fishery is thought to operate at close to or below its maximum sustainable yield (Galal, 1999). Thus the intensity of fishing observed at El Ghargana (TZ N) is not so severe as that which has led to chronically over-exploited reefs in parts of the Caribbean or Southeast Asia, as may be judged from the numbers of fish still present on the reef. This situation is the result of other restrictions imposed on the fishery, including the numbers of fishermen and the types of gear, the size of mesh and number of hooks. It is probably because fishing pressure at Nabq is relatively low that, as anticipated from modelling studies (Holland and Brazee, 1996; Nowlis and Roberts, 1999), differences in fish abundance between fished and unfished areas are not very large.

5. Conclusions

In conclusion a picture emerges under which, as fishing pressure becomes more intense, first the main predators, Lethrinidae, Serranidae and Lutjanidae, then the Chaetodontidae and Scaridae, and finally the dominant herbivores, Acanthuridae and Siganidae, begin to show a reduction in numbers within fished areas, as compared to the NTZ. But as, with increasing depth, fishing becomes increasingly light, so the herbivorous Acanthuridae and Siganidae actually show an increase in numbers in the fished zones, as may some other families or species to a lesser extent. Thus the effects of fishing on fish abundance depend both on fishing intensity and trophic group. If spillover takes place from areas of greater abundance to areas of lower abundance, since relative abundance varies with fishing pressure and trophic group, so to will the extent and direction of spillover. The present study provides evidence for these effects across the boundaries of a single NTZ; further work will be necessary before the findings can be generalised to other NTZs, at Nabq or elsewhere.

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