Coral Reefs (1999) 18:327–332

REPORT

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Implementation of a small-scale "no-use zone" policy in a reef ecosystem: Eilat's reef-lagoon six years later

Accepted: 11 August 1999

Abstract A small-scale, "no-use zone policy" has been implemented since 1992 at Eilat's Coral Nature Reserve (Northern Red Sea). Six years later, the status of this closed-to-the-public reef area was compared to two nearby open-to-the-public sites, by evaluating populations of the scleractinian coral *Stylophora pistillata* in the strolling zone (0.5–1.5 m depth). Results from the open sites show that: (1) Live coral cover was three times lower than at the closed site; (2) numbers of small colonies (recruits) were significantly higher than in the closed site, while numbers of medium and large size colonies (geometric mean radius, $\bar{r} > 4.1$ cm) per m^2 were significantly lower; (3) maximum $\bar{r}$ was almost half than that in the closed site (9.6 cm versus 16.7 cm); (4) average number of broken colonies was three times higher than in the closed site; (5) significantly fewer colonies were partially dead. The latter result may reflect senescence processes in the large colonies of the closed site. Although colony breakage is reduced, it appears that the "no-use zone" policy is not sufficient for protecting small reef areas. The intense exploitation of Eilat's coral reef by the tourist industry requires' in addition to the conventional protective measures, the initiation of novel management solutions such as reef restoration by sexual and asexual recruits.

Key words Coral Breakage · Conservation · Marine Protected Area · Partial Mortality · Reef Management · *Stylophora pistillata*

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Introduction

The coral reef of Eilat (Red Sea), once one of the more diverse coral reefs worldwide (Loya 1972), is situated at the northern tip of the Gulf of Eilat (Aqaba). This internationally known recreational destination, stretches along only 3.5 km of fringing reef from Nahal Shlomo to the Israeli-Egyptian border, and is under immense pressure from tourist activities (Meshi and Ortal 1995; Chadwick-Furman 1997). In the last three decades, a significant decline in coral communities has been documented in Eilat's reef, the result of chronic anthropogenic pressures (Fishelson 1973, 1975, 1977, 1980, 1995; Loya 1975, 1976a, 1986; Loya and Rinkevich 1979, 1980; Rinkevich and Loya 1977, 1979, 1983). Today, however, when domestic and industrial sewage, emission of phosphate dust and oil spill disasters are reduced to a minimum due to the enforcement of prevention measures, the major human impact on Eilat's reef is tourism. Reef-based tourism is considered the most important emerging agent of coral reef destruction worldwide (reviewed in Rinkevich 1995). In the last decade, more than one million people visited Eilat each year (Fishelson 1995). Ten SCUBA diving clubs operate in the area and between 200 000 to 300 000 dives are registered annually in Eilat's reef (Meshi and Ortal 1995), a figure which equals most popular nearby dive sites in the Sinai Peninsula (Egypt). SCUBA divers raise sediment and abrade or break coral colonies upon contact (Neil 1990; Riegel and Velimirov 1991). Swimmers, reef walkers and snorkellers stroll the lagoon area (0.5–2.0 m depth) and the back reef (1–2 m depth), adding significantly to mechanical breakage of corals in shallow water populations (Woodland and Hooper 1977; Liddle and Kay 1987; Kay and Liddle 1989; Hawkins and Roberts 1993).

Pollution and recreational activities produce a gradual decline of reef corals. One example is the 19 year follow-up study at Eilat's coral reef that documented a reduction of almost two orders of magnitude in the number of colonies of the branching species *Stylophora pistillata* (Fishelson 1995). In frequently visited Red Sea reef sites, another study (Riegel and Velimirov 1991) has documented an increase of coral breakage and tissue abrasions in shallow water coral populations as compared to less visited locations. These studies did not, however, directly demonstrate the causal mechanisms of the measured changes in biota.

Of the 3.5 km length of Eilat's Coral Reef Nature Reserve, a 120 m long section of coast line is fenced between the Southern Marina and the Underwater Observatory. This is the Coral Beach Reserve. Following the continuous degradation of the coral reef at Eilat, in 1992 the Israeli Nature and National Parks Protection Authority closed the shallow water lagoon in the Coral Beach Reserve to the general public (except for limited research activities), implementing a policy of "no-use" within the small zone (Fishelson 1980; Kelleher and Kenchington 1982; Tilmant 1987). During the first half of the 1990s, several initiatives were undertaken within this small "no-use zone" to monitor population growth (Vago 1994) and damage by diving and boating activities (Meshi and Ortal 1995). Unfortunately, no documentation of the status of the coral populations was available at the time the "no-use zone" policy was implemented. Six years after the closure of the area to the public, the effects of the closure were still unknown. Moreover, because of the limited extent of the coral reef along the Israeli coast and its structural variation, it is difficult to find similar, open-to-the-public sites to serve as controls (same lagoon and reef flat structure, currents, propagule availability, etc.). However, a long-term monitoring study of Eilat's reef (comparison of the closed with open-to-the-public sites) is vital, not only to document the current state of the reef, but also to evaluate the changes with time for the purpose of future management plans and restoration programs in the Red Sea and elsewhere.

The present study shows significant differences in the population structures of a common coral species when comparing populations in the closed site to two open-to-the-public reef sites of Eilat. In addition it sets up the baseline data for a long-term monitoring program in Eilat's shallow reef area. We concentrated on populations of the branching coral *Stylophora pistillata*, one of the most abundant coral species in the Gulf (Loya 1972). We report here on population densities, size-frequency distributions, quantitative and qualitative measures of colony breakage and tissue death (partial mortality). Results are discussed with an eye to the implementation of restoration protocols (Rinkevich 1995).

Materials and methods

Study sites

Three shallow water reef sites at Eilat were studied. Two 'open-to-the-public' sites are the reef in front of the Princes Hotel (site HP), located just across the Taba border crossing, and the reef in front of the H. Steinitz Marine Laboratory (site MBL), located 1 km north of HP. Although both are open to public, human activities in these sites differ in nature: at the MBL most dives and snorkeling are for research and educational purposes (undergraduate and graduate students, research scientists) while at the HP all activities are recreational in nature. The third site, the Coral Beach Reserve, or Nature Reserve (NR) is located 0.5 km north to MBL and includes the no-use zone of the lagoon (approximately 400 m long and 40 m wide) and other zones with restricted activities. Diving and swimming are allowed only beyond the reef wall, and the entrance to the deep reef through the lagoon is strictly limited to two walkways and one pathway. Otherwise, access to the total area of the shallow lagoon is admissible only for specified research activities by snorkeling during high tide.

Methods of field census

This study was conducted during April and May 1998. At each site, a total area of approximately 400 m^2 of the rear reef was studied by the use of repetitive 1 m^2 quadrats (48 at HP, 51 at MBL and 69 at NR). Quadrats (Goldberg 1973) were randomly selected by tossing a 1 m^2 plastic square-bar to all directions while standing in shallow water. We investigated the shallowest zone (0.5–1.5 m depth) along 40 m of coastline in each location.

Several coral genera are abundant at the three sites, of which two branching genera are common in HP and MBL: *Stylophora pistillata* and *Acropora* spp. (4 species, Loya 1972). At the NR site *Acropora* colonies are not common. Within each quadrat, the height, length and perpendicular width of all coral colonies were measured by a caliper to the nearest 1 mm. The geometric mean radius ($\bar{r}$) of the branching corals was calculated (Loya 1976b). The colonies were also observed for the magnitude of branch breakage and partial tissue death. Breakage was estimated by evaluating the size of the missing part(s) by eye as percentage lost branches out of the whole colony. Tissue death was estimated as percentage of missing tissue from the whole colony.

Statistical analysis on log transformed breakage and partial death data (Duncan, ANOVA) were performed using the SAS/STAT software, Version 6. Geometrical mean radius (Loya 1976b) data were analyzed on original sizes. Tests of significance between proportions were carried out by computation of an equality between two percentages test (Sokal and Rohlf 1980).

Results

A total of 175, 214 and 242 *S. pistillata* colonies and 81, 35 and 6 *Acropora* colonies were measured in the 48, 51 and 69 quadrats sampled at the HP, MBL and NR sites, respectively. When considering colonies of both branching genera as "branching forms", abundances in the open-to-the-public sites (5.3 $\pm$ 2.7 colonies. quadrat^{-1} in HP and 4.9 $\pm$ 3.9 in MBL) were significantly higher than the "no-use zone" (3.5 $\pm$ 2.6; $P < 0.05$, ANOVA). This difference resulted from the fact that *Acropora* colonies were scarce in the studied NR site. Subsequent analysis considered *Stylophora* populations only.

Population analysis

The mean density of *S. pistillata* colonies per 1 m^2 (4.1 ± 2.4 colonies in HP; 4.2 ± 3.5 in MBL and 3.5 ± 2.6 in NR) was similar at all three sites ($P > 0.05$, ANOVA). The average colony size ($\bar{r}$) did not differ significantly between the two open-to-the-public sites, (HP 2.15 ± 1.95 cm, MBL 1.80 ± 1.77 cm, $P > 0.05$, ANOVA). We therefore pooled these sites ($\bar{r} = 1.96 \pm 1.90$ cm, $n = 389$) for comparison with the NR colonies ($\bar{r} = 3.95 \pm 3.43$ cm, $n = 242$), documenting a significantly greater average colony size in the no-use zone ($P < 0.05$, ANOVA).

S. pistillata populations may further be analyzed with respect to five different size groups (< 1.1, 1.1–2.0, 2.1–4.0, 4.1–10.0, > 10.1 cm; Fig. 1). The size frequency distribution of *S. pistillata* colonies differed between the no-use and open sites (Fig. 1). While 5.4% of the NR shallow water population was larger than $\bar{r} = 10.1$ cm in size, none of the colonies in MBL and HP reached this size. In total, significantly less (14.1%) of the colonies in the open-to-the-public sites (16.0% and 12.6% at HP and MBL, respectively) were > 4.1 cm in size, as compared to 41.4% of the NR population ($P < 0.05$, test for equality between two percentages). In contrast, significantly more *S. pistillata* colonies (66.0% of the population) in the two open-to-the-public sites combined were in the small group sizes ($\bar{r} < 2.1$ cm, corresponding to less than 2 years of age, Loya 1976b), as compared to 41.3% in the NR population ($P < 0.05$, test for equality between two percentages). This difference is also revealed from a comparison of last year's recruits ($\bar{r} < 1.1$ cm): 41.9% of the colonies in the open sites (39.4% and 45.8% in HP and MBL, resp.) versus 25.6% in NR.

The average live coverage of *S. pistillata* populations, calculated by multiplying the average number of colonies per square meter in each site by colony average size, was almost three times higher at the NR. Calculated as the total, vertically projected area of all live colonies, it was 1.7% in the protected NR, 0.60% in HP and 0.42% in MBL.

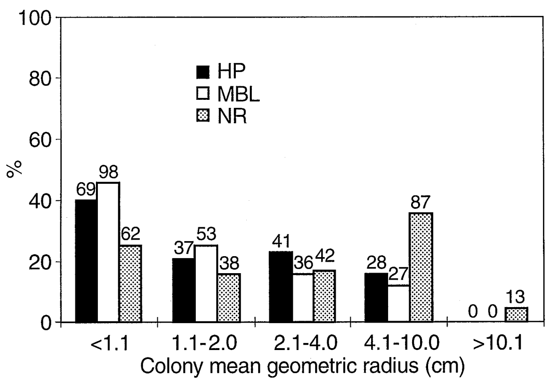

Fig. 1 Colony size distributions of *S. pistillata* at the three study sites along Eilat's Coral Reef Nature Reserve. Columns depict the size group proportions. Numbers of colonies are shown in above columns. Sites: HP (Hotel Princess) and MBL (Marine Biology Lab) are located in public use zones, NR (Nature Reserve) is located in a "no-use" zone

Colony breakage

Significantly more *S. pistillata* colonies (119 colonies, 30.6%) in the open-to-the-public sites had broken branches than in the NR (22 colonies, 9.0%, $P < 0.05$, test for equality between two percentages). Figure 2a depicts a clear tendency for the proportion of broken colonies to increase with size, in all locations. Breakage of colonies in the smallest size group ($\bar{r} < 1.1$ cm) was uncommon (maximum 4.0%, Fig. 2a), but the proportion of broken colonies increased dramatically in the larger size groups. Of these, 79.0% of all living colonies of $\bar{r} = 4.1$–10.1 cm in the open-to-the-public sites were broken (78.6% in HP and 74.0% in MBL) as compared to 17.0% in NR (14.9% in 4.1–10.0 cm and 30.8% in $\bar{r} \geq 10.1$ cm, Fig. 2a). In general, breakage was almost an order of magnitude lower within the protected NR area.

The average extent of individual colony breakage was significantly higher in the open-to-the-public sites combined (40.5%) than in NR (20%, $P < 0.05$, ANOVA; Fig. 2b). Within the open sites the mean proportion of breakage per colony was significantly higher in the smaller size classes (< 2.1 cm) than in the larger classes (> 4.1 cm, $P < 0.05$, ANOVA), while no such difference was found in site NR ($P > 0.05$, ANOVA). The remarkable increase in the number of broken colonies and the magnitude of damage found in intermediate group sizes at the open-to-the-public locations as compared to the protected site (Fig. 2a, b) represents a substantial loss of coral biomass at sites open to visitor activities.

Partial colony mortality

In contrast to colony breakage, the proportion of colonies that displayed partial mortality (tissue loss) was significantly higher in the closed site (28.9%) compared to the open-to-the-public sites (HP = 6.8% and MBL = 2.3%; $P < 0.05$, test for equality between two percentages). Partial death was common in the larger group sizes in all locations (Fig. 3a). In HP, 23% of $\bar{r} > 4.1$ cm colonies displayed partial mortality, compared to 1.9% in the $\bar{r} < 2.1$ cm size groups. In MBL none of the $\bar{r} < 2.1$ cm colonies and 10.7% of the $\bar{r} > 4.1$ cm were partially dead. A similar trend was recorded in NR where 51.0% of the $\bar{r} > 4.1$ cm and only 5.0% in the $\bar{r} < 2.1$ cm colonies were partially dead.

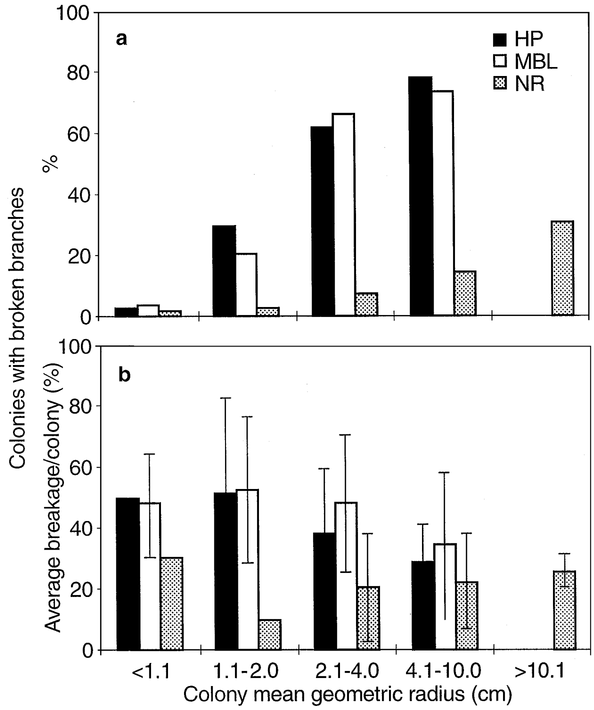

Fig. 2 a,b Colony breakage of *S. pistillata* in the three study sites. **a** Percentage of broken colonies within each size group and **b** the average proportions of breakage/colony ± SD

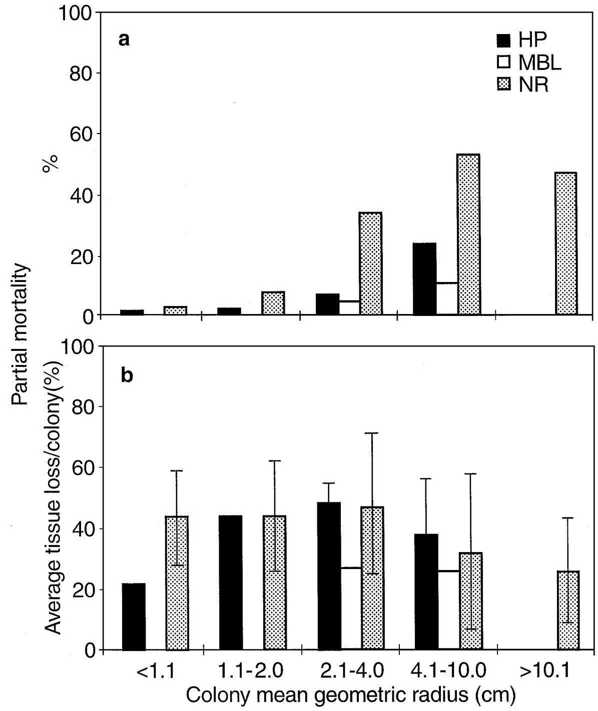

Fig. 3 a,b Partial tissue loss from *S. pistillata* colonies in the three study sites. **a** Percentages of partially dead colonies and **b** the average proportion of tissue loss/colony ± SD

The average magnitude of tissue loss per affected colony (Fig. 3b) however, did not differ significantly among the three locations (HP: 36.0 ± 13.8%, MBL: 24.0 ± 15.2% and NR: 32.0 ± 22.6%; ANOVA), nor between the combined two smallest group sizes ($\bar{r} < 2.1$ cm: 30.0 ± 14.1% in HP, 40.0 ± 14.1% in NR) and the larger group sizes ($\bar{r} > 4.1$ cm: 34.3 ± 16.2% in HP, 23.3 ± 15.3% in MBL and 28.8 ± 22.9% in NR) within each site ($P > 0.05$, ANOVA).

Discussion

Six outcomes emerged from our analysis of *S. pistillata* populations in the three areas studied:

1. Live *S. pistillata* colonies occupied very little of the substratum in the strolling zone in all sites, but cover was three times higher in the NR.
2. While the total number of *S. pistillata* colonies was similar in the three locations, we recorded significant differences in population structures between the closed and the open-to-the-public sites.
3. *S. pistillata* colonies in the open-to-the-public sites reached a maximum geometric mean radius ($\bar{r}$) of 9.4 cm while in the NR the largest colony recorded was 16.7 cm.
4. The frequency of colony breakage was 2–10 times higher (depending on size group) in the open sites than in the closed one.
5. Colony breakage increased with colony size. This is probably a common feature in coral populations (Meesters et al. 1996).
6. The proportion of colonies suffering partial mortality in the protected (NR) site was significantly greater than in the open-to-the-public sites. Although the extent of tissue loss per affected colony was similar in the three localities, the number of affected colonies increased with colony size.

The results reflect the direct physical impact of human activities in the open sites combined with natural processes (storms, predatory fish, etc.). We speculate that one effect was the elimination of the largest colonies (> 10.1 cm) from the open sites and much higher rates of breakage of smaller colonies compared to the closed site. In the closed site, extensive tissue death possibly resulted from senescence of large colonies (Rinkevich and Loya 1986), while the absence of visitor impact was manifested in fewer broken colonies and less breakage of damaged colonies. We interpret the low breakage levels recorded in the NR as evidence of the effectiveness of protective measures such as limiting entrance to the water through marked paths or walkways.

The data show that recruitment to the smallest group size is higher in the two open-to-the-public sites than in the NR. The high number of *Stylophora* recruits compensates for the loss of adults, but implies a reduction in the average colony longevity of these populations

(Johnson et al. 1995; Bak and Meesters 1998). Higher number of small recruits in HP and MBL is unlikely to be the result of reattaching of fragments of broken colonies since loose fragments appear to have low survival in Eilat reefs (Rinkevich, personal communication). It is probably a result of local waves and current regimes, relative to the location of these reefs south of the NR, which may be a major source of larvae. Although the density of *Stylophora* colonies is similar in all localities, the average aerial coverage of corals in the open sites was about one third of that in the NR.

Coral breakage at popular reef sites has been investigated by several workers. Riegel and Velimirov (1991) recorded coral breakage at reef sites in Eilat before closure to the public, and in other localities along the northern Red Sea coast. They documented a general trend of 5.2% broken coral colonies in Eilat's reef (from shallow to deep), half of which were located in the upper 2 m depth. In contrast, at other popular reef locations such as Hurgada (Northern Red Sea, Egypt), breakage in shallow depth was about one fourth of all breakage recorded, which implies that shallow water strolling in Eilat's reef comprises a more serious threat to the reef than in sites elsewhere. Reef walking has been found to exert significant destructive impact on coral reefs worldwide. For example, the impact of four adults traversing a reef area of 12.5 m^2 18 times during several minutes was the destruction of about 607 kg of coral biomass, equivalent to a reduction of 80.0% in living coverage (Woodland and Hooper 1977). The impact of snorkeling on a 2.0 km long reef section in the Maldive Islands during a one month period resulted in a 17.0% reduction of susceptible coral coverage (Allison 1996). In Sharm-el-Sheikh (Sinai) and Kisite Marine Park (Kenya), significantly more broken corals were found in frequently visited reef sites (Hawkins and Roberts 1992, 1993; Muthiga and McClanahan 1997). Similarly, reef trampling at Heron Island (GBR) significantly changed coral community structure by eliminating arborescent species (Kay and Liddle 1989).

Different reef areas worldwide display various coral breakage levels. The Caribbean island of Saba receives up to 1700 $\text{dives}\cdot\text{site}^{-1}\cdot\text{y}^{-1}$, in Bonaire, highest levels of use reach 6000 $\text{dives}\cdot\text{site}^{-1}\cdot\text{y}^{-1}$ while Egyptian reefs receive up to 50 000 $\text{dives}\cdot\text{site}^{-1}\cdot\text{y}^{-1}$ (Hawkins and Roberts 1997). The numbers for Eilat and Egyptian reefs far exceed the maximum sustainable diving levels calculated for coral reefs, i.e. 4000–6000 $\text{dives}\cdot\text{y}^{-1}$ along a reef coast line of 500 m (Dixon et al. 1993; Hawkins and Roberts 1997) or 500 $\text{dives}\cdot\text{y}^{-1}$ at specific sites in the Virgin Islands (Chadwick-Furman 1997).

Over-exploitation of reef resources may be ameliorated by a variety of measures such as a complete closure, active habitat/species management and limitations on usage intensity (Gubbay 1995). The significant degradation of shallow water coral populations in the shallow lagoon (this study) and in the fauna of the Coral Reserve at Eilat as whole (Fishelson 1975, 1995; Loya 1975, 1986) indicates the failure of conventional protection and conservation measures (Fishelson 1995). In the case of *S. pistillata* populations, the 6 year closure of NR lagoon, while probably increasing the average colony size, did not result in increased population density compared to the open-to-the-public sites. Moreover, significantly more colonies in the closed area suffered from partial colony death. Thus, while sharply reducing coral breakage, the implementation of a no-use-zone policy for such a small reef area can not serve as the sole solution for reef rehabilitation as has been suggested for larger reef areas (Hopley 1989; Kelleher and Kenchington 1992; Price and Humphrey 1993; Laffoley 1995). Eilat's situation (a small reef area supporting intense recreational activity), demands in addition to "no-use" conservative measures the initiation of active management solutions, such as reef restoration by sexual and asexual recruits (Rinkevich 1995).

Coral reefs may need thousands of years to fully recover from changes brought about by human activities during the twentieth century (Sebens 1994). As for Eilat, it is for the public, the scientific community, and all other interest groups to be involved in exploitation of the reef, but also to ensure the viability and longevity of Eilat's most precious natural resource.

Acknowledgements We thank the staff of the H. Steinitz Marine Biology Laboratory in Eilat. This study was carried out at the Minerva Center for Marine Invertebrate Immunology and Developmental Biology, and was supported by INCO, H Red Sea Marine Peace Park, and partly by AID-CDR.

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