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Coral recruitment to the reefs of Eilat, Red Sea: temporal and spatial variation, and possible effects of anthropogenic disturbances

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Abstract

The accelerating deterioration of the coral reefs of Eilat has raised debate over the exact causes and how they affect the reefs. The hypothesis of the present study was that a low recruitment rate of reef-building coral species may play an important role in the decline of the Eilat reefs. Our goal was to assess spatial and temporal recruitment patterns in Eilat, focusing on examining the possible impact of human activities. The results of coral recruitment to 10 series of ceramic tiles on metal racks, revealed very low overall recruitment relative to other geographical regions. In addition, we found that recruitment rates and recruit survival were lowest at sites closest to the major eutrophication sources in Eilat. The low recruitment rates may be chronically too low to compensate for the elevated coral mortality rates of recent years. The significant differences between the present study and a similar study carried out during the same period using a different method, emphasize the crucial need for a standardized method for recruitment assessment in coral reefs worldwide.

Keywords: Coral reefs; Recruitment; Larvae; Pollution; Red Sea; Eilat

1. Introduction

The coral reefs of Eilat have deteriorated extensively during the last decade (e.g. Fishelson, 1995; Loya, 2004; Loya et al., 2004). Studies dealing with the Eilat reefs have suggested anthropogenic disturbances (e.g. sewage and fish-cage farms) as the main cause for the reefs' regression (Mancy, 1993; Fishelson, 1995; Abelson et al., 1999; Loya, 2004; Loya et al., 2004). At present, however, the exact causes are a source of ongiong debate.

The hypothesis that led to the present study was that low recruitment rates of reef-building corals may play an important role in accelerating the deterioration of the coral reefs of Eilat. Over the last two decades there has been a growing recognition that the rate of recruitment of larvae back to adult habitats can determine patterns of community structure (e.g. Connell, 1985; Gaines and Roughgarden, 1985; Lewin, 1986). Consequently, the pattern and magnitude of recruitment have been suggested as strongly influencing choices of conservation and management (e.g. Brock and Kam, 1994; Dunstan and Johnson, 1998).

Recruitment involves a fragile life stage that can be affected by diverse environmental factors, including human-mediated factors, such as pollution (e.g. Tomascik, 1991; Hughes and Connell, 1999). Despite the

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potential adverse impact of human activities on coral recruitment, until recently there was no attempt to examine coral recruitment patterns in Eilat or the possible effects of anthropogenic disturbances (but see Glassom et al., 2004; Ben Zvi et al., 2004).

Recruitment has three components: the rate of arrival of competent larvae to the site; the probability that larvae will settle on the reef once they arrive; and the probability that new settlers will survive after settling long enough to be censused (Keough and Downes, 1982; Connell, 1985). Low values for any of these components would lead to low recruitment. The aim of the present study was to study coral recruitment to the Eilat reefs: first, by measuring the overall recruitment rates of reef corals to the Eilat coral reefs and comparing them with other reefs; second, by studying variability in recruitment over time (between years) and space (between sites and depths); and finally, by examining possible effects of human-mediated disturbances, by comparing the recruitment pattern in the most disturbed site (i.e. the North Beach; Bresler et al., 1999, 2003; Ben Zvi et al., 2004; Loya et al., 2004) with reference sites at different distances from the North Beach.

2. Materials and methods

Coral recruitment was studied by deploying moored racks of settlement plates at five sites, two depths (10 and 30 m) per site, along the 12 km coast of Eilat, from the 'North Beach' to the southernmost reef knolls across Taba (Fig. 1). The settlement substrata were ceramic tiles, which have been found to be the most suitable settlement surface in a comparative study that examined various plate types for experiments on the recruitment of stony corals (Harriott and Fisk, 1987). The plates were mounted on moored racks made of galvanized metal mesh, in a similar setup to that described by Sammarco and Andrews (1988). The racks were designed so that 12 sets of two tiles were attached to both sides of the mesh and suspended vertically, from one to three meters above bottom. The plates were collected by divers and placed in protective carrying cases to prevent movement and minimize abrasive damage to the young settlers. They were then taken to the lab and immersed in deep trays for examination under a dissecting microscope. All coral settlers at any developmental stage were counted, recorded and their condition documented. Subsequent to the microscopic examination, plates were returned carefully back to their exact spots on the racks to enable long-term monitoring of recruitment and survival rates.

Plate censuses occurred after two short-term (5 months each) and three long-term (one year each) sampling intervals. The short-term censuses were carried out in Sept. 1998 and Feb. 1999, following deployment of plates in May 1998. The long-term censuses were carried out in 1998, 1999 and 2000, following a one year sampling interval.

Recruitment to natural substrates in the field was quantified from 112 10×20 cm quadrats, which were placed haphazardly on the reef at four sites (Fig. 1). The four sites were chosen to extend the spatially extent of the sampling further down the coast of Sinai, where moored sampling was not feasible. Each of the quadrats was censused for new recruits, using 1×1 cm grids and a 2× magnifying lens. All visible spat up to 2 mm in diameter were counted.

Statistical analyses were conducted using *Statistica 6*. A non-parametric Kruskal–Wallis Rank test was used to

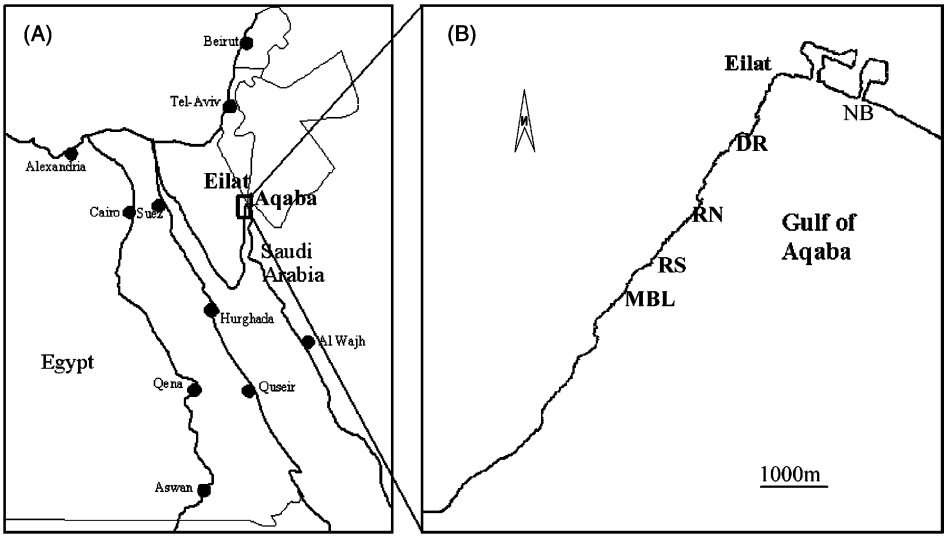

Fig. 1. (A) Regional map of the northern Red Sea and Gulf of Aqaba, and (B) a local map of the study sites along Eilat coast (Gulf of Aqaba, Red Sea). (NB) North Beach, (DR) Dolphin Reef, (RN) Nature Reserve-North, (RS) Nature Reserve-South, (MBL) Marine Biology Lab.

measure spatial variation in the recruitment of coral recruitment among the different sites. A posterior examination of the data was conducted by Post-hocs for Kruskal–Wallis Rank test.

3. Results

We detected an average of only 0.8 recruits per tile-pair over the three years of this study. The vast majority of recruits (>75%) were Pocilloporid corals. Within this exceedingly low average recruitment, stony coral recruitment onto settlement plates in the Eilat reefs varied both spatially (between sites and depths) and temporally (between years; Figs. 2, 3, 5 and 6). However, due to the low numbers of recruits, only a few of the observed trends were statistically significant.

3.1. Short-term sampling rounds

Spatial patterns of recruitment at 10 m depth differed between the two short term sampling intervals (Fig. 2). During the first study, recruitment at the NB was significantly higher than at the other sites ($p < 0.01$; Fig. 2). However, during the second study there was an increase in recruitment to the southern sites and a dramatic decline in the NB recruitment to zero recruits. Ten months after deployment the southern sites had accumulated some recruits, while the NB possessed no new recruits (Fig. 2).

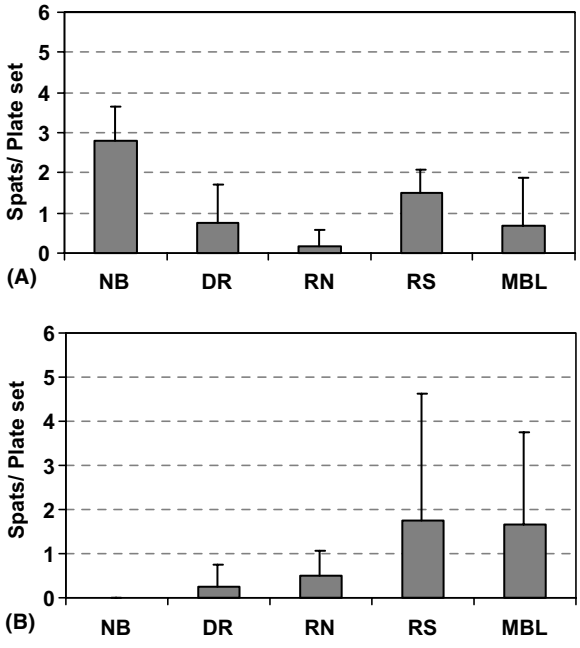

Fig. 2. Mean density (±SD) of coral recruits (number of spats per pair of ceramic tiles) accumulated during the two short-term sampling rounds, from May to September 1998 (A), and from October 1998 to February 1999 (B) in five sites, 10 m depth, along the Eilat coasts. Abbreviations to sites are as in Fig. 1.

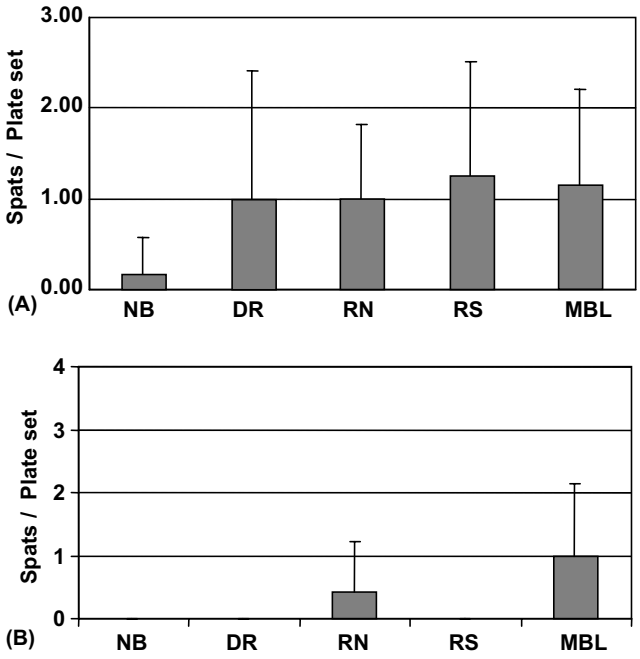

Fig. 3. Mean density (±SD) of coral recruits (number of spats per pair of ceramic tiles) accumulated during the two short-term sampling rounds, from May to September 1998 (A), and from October 1998 to February 1999 (B) in five sites, 30 m depth, along the Eilat coasts. Abbreviations to sites are as in Fig. 1.

At 30 m depth, overall recruitment rates were too low to detect significant differences among sites. Recruitment at NB, however, was consistently low, or zero (Fig. 3).

The survival rates of recruits after 5–10 months show a consistent trend for both 10 m and 30 m depth stations. Survival rates increase substantially from the northern to the southern sites, with zero survival rates at the NB station (Fig. 4).

3.2. Long-term sampling rounds

The long-term surveys during 1998–2000 revealed patterns of coral recruitment similar to the final pattern of the short-term samplings, namely low recruitment

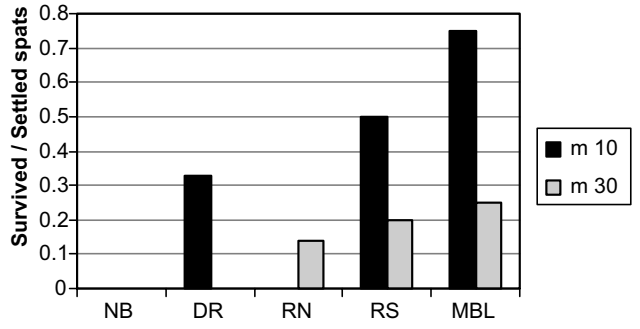

Fig. 4. Survival rates of coral recruits between the first and second short-term sampling rounds, at 10 and 30 m depths. Abbreviations to sites are as in Fig. 1.

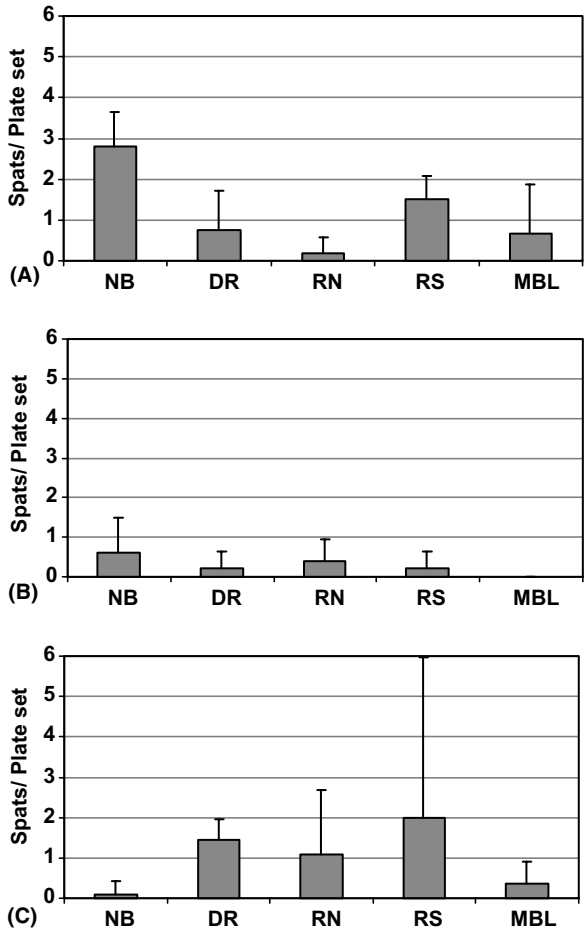

Fig. 5. Mean density (±SD) of coral recruits (number of spats per pair of ceramic tiles) accumulated during the three long-term sampling rounds; A: September 1998, B: September 1999, C: September 2000, in the five studied sites at 10 m depth. Abbreviations to sites are as in Fig. 1.

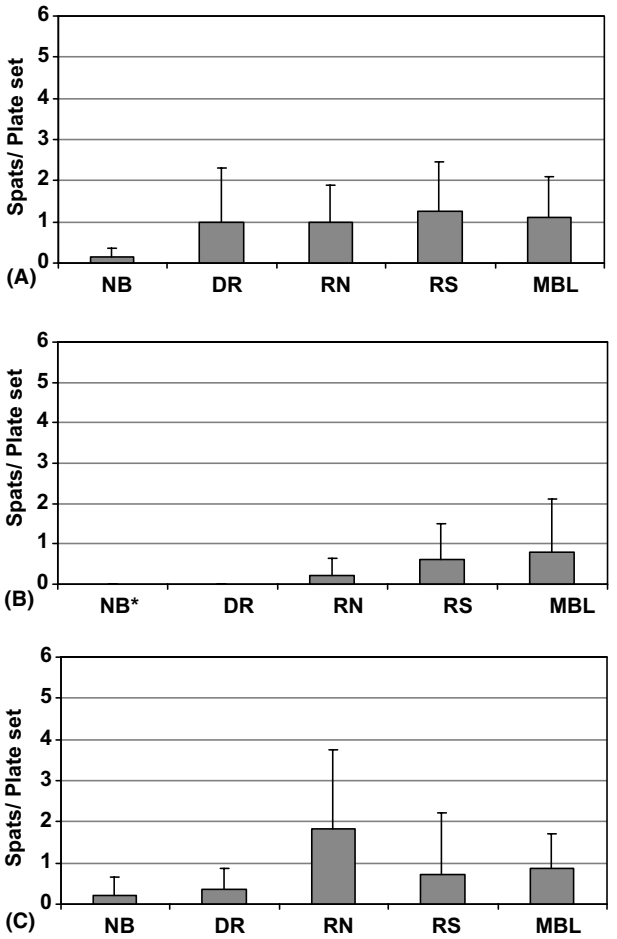

Fig. 6. Mean density (±SD) of coral recruits (number of spats per pair of ceramic tiles) accumulated during the three long-term sampling rounds; A: September 1998, B: September 1999, C: September 2000, in the five studied sites at 30 m depth. Asterisk in NB indicates no data for 30 m depth in North Beach due to collapse of its settlement-plate rack. Abbreviations to sites are as in Fig. 1.

rates at all sites and lowest rates in the NB site relative to the southern sites (Figs. 5 and 6). The lowest rates in the NB site were accompanied by the lowest survival rates (Fig. 4) and the highest live cover (typically 100%) of biofouling species (notably turf cyanobacteria, sponges, tunicates and bryozoans).

Recruitment to natural substrate. The natural substrate censuses revealed a strong north-south gradient, where the lowest recruitment was in RS and the highest in the southernmost site, NUE, with significant differences between sites ($p < 0.001$; Fig. 7). This patterns suggests that gradients in recruitment continue as one progresses further south in the Gulf of Eilat. The recruitment rates to the natural substrates in the Eilat reefs were similar to those onto the settlement tiles.

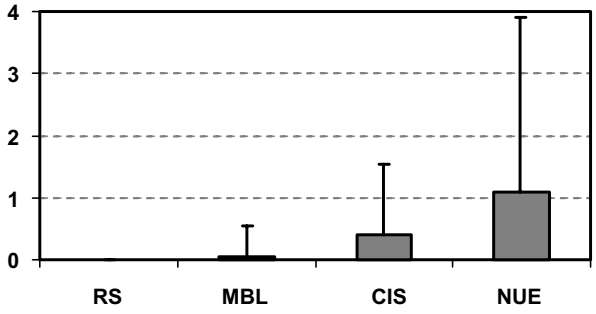

Fig. 7. Stony-coral recruitment onto natural substrates along the Gulf of Aqaba (Eilat and northern Sinai), Red Sea. Mean density (±SD) of coral spats per quadrate; 200 cm^2 at 10 m depth. (RS) Nature Reserve South, (ML) Marine Lab, (CIS) Coral Island, 10 km south to Eilat, (NUE) South Nueba, 70 km south to Eilat.

4. Discussion

The recruitment process plays a pivotal role in molding the structure and dynamics of many benthic marine communities. Understanding recruitment patterns and their governing factors is therefore crucial for sound

Table 1
Stony coral recruitment rates onto ceramic tiles in different geographic regions

Region	Plate area (cm^2)	Period (months)	Mean # recruits	Source
Eilat	225	5–12	0.8	Our data
SE Australia	225	2	2.8	Banks and Harriott (1996)
SE Australia	225	6	4	Harriott (1999)
Barbados	225	12	15	Tomascik (1991)
FP	225	4	6.4	Gleason (1996)
S GBR	400	5	18	Dunstan and Johnson (1998)
Mid GBR	225	6	95	Fisk and Harriott (1990)
Mid GBR	122	2	193	Hughes and Connell (1999)

Abundances of recruits were averaged across sites and time in each location (number of recruits per 450 cm^2 per year). FP: French Polynesia, SE AU: South-East Australia, GBR: Great Barrier Reef, Australia.

policy-making of Coastal Zone Management (CZM) and nature conservation. The results of our three-year study suggest chronically low overall recruitment of corals to the coral reefs of Eilat relative to other geographical regions, including high-latitude regions. This assertion is based on a comparison with a short list of studies that have used ceramic tiles as settlement plates (Table 1; further comparison is given in Smith (1992) and Glassom et al. (2004)). Our findings, however, are not in accord with the results of Glassom et al. (2004), who concluded that the overall recruitment in Eilat is similar to other high-latitude coral reefs. Their conclusion, which may have critical consequences in decision-making of the Eilat region environmental management, was based on a comparison with diverse studies that had applied highly different experimental protocols and designs. Several factors can impart significant variation among studies, and consequently may lead to erroneous conclusions. These include duration of plate deployment, substrate type, rack orientation, depth and height above the seabed.

The problem of a comparison between studies that lack standardized methodologies can be demonstrated by a comparison between the results of Glassom et al. (2004) and the present study. Both studies were conducted in the same locale and during the same period, but nonetheless revealed substantial differences in their recruitment patterns. In addition to the above noted factors that might have contributed to the dissimilar results, there are two other causes that are assumed to be dominant in determining the differences between the two studies. First, the tiles in Glassom et al. (2004) were significantly smaller (10×10 cm) than the tiles used in our study (15×15 cm). The edge effect of smaller tiles is much greater and may enhance settlement densities. The edge effect can enhance settlement through the creation of a separation bubble and resultant substrateward flow (Mullineaux and Butman, 1991; Abelson and Denny, 1997). Second, Glassom et al. (2004) did not examine recruitment in the North Beach, which is the most human affected region in Eilat, and whose final recruitment and survival rates were found to be the lowest in Eilat (Figs. 2–6). The first issue may have resulted in methodologically driven variation; whereas, the latter omission may misrepresent the broader geographic pattern of recruitment in the Eilat region.

The dramatic change in recruitment to the NB racks, from the highest rates among all sites (in 10 m depth, Fig. 2) during the initial stages of deployment to extremely low recruitment during later stages, may be explained by the high cover (in most cases 100%) of fouling species (e.g. turf cyanobacteria, hydrozoans, bryozoans and sponges). Biofouling cover is known to inhibit settlement and reduce the survival of newly settled recruits (e.g. Walker and Ormond, 1982; Tomascik, 1991). An alternative explanation may be that the NB decline is due to a drop in larval supply rates. However, the relatively high recruitment rates at the first short-term round in the 10 m NB and the lack of survivors among these recruits, support the former hypothesis. Moreover, the long-term study provided the same trend of high recruitment soon after deployment followed by decline in number of recruits during later stages. The repeated pattern of 'high to low' recruitment rates that coincides with the "new" and "old" highly covered settlement plates, respectively, supports the inhibitory role of biofouling, which appears to be directly tied to the effects of eutrophication driven by nearby fish-cage farms (e.g. Loya, 2004; Loya et al., 2004). A similar pattern of reduced recruitment and low survival anomalies related to high biofouling cover has been reported by Shemla (2001), who found a relatively high recruitment accompanied by very low survival rates of coral recruits onto artificial-reef modules in the NB.

Another aspect that emphasizes the role of recruitment in the deteriorating process of the Eilat reefs is that of the high fraction of Pocilloporid recruits, mainly of the brooding coral Stylophora sp., as observed in the present study as well as in Glassom et al. (2004). Smith (1992) has suggested that the relatively low recruitment of longer-lived massive species, both in the Atlantic and the Pacific, is compensated by their low rate of post-settlement mortality. If such were the case in the Eilat reefs, one would expect that the very low fraction of low-recruited species (16.1%; Glassom et al., 2004), would increase with time. However, the long-term study (15 months) of Glassom et al. (2004) shows the opposite trend, in which the fraction of these species was reduced to less than 10%. This trend suggests that in Eilat, as opposed to other regions, the low-recruit species also display lower survival rates.

Based on the above-noted patterns, it appears that the exceedingly low recruitment rates may contribute to the deteriorating state of the Eilat reefs. The low recruitment rates, regardless of their governing factors (natural or anthropogenic), seem to be too low to compensate for the elevation in mortality rates in recent years (Ben Zvi et al., 2004). The general pattern of North-South gradient in both the natural substrates and the settlement plates, as well as the observed low survival and high biofouling cover in the North Beach, suggest a human-mediated geographical impact superimposed on the region-wide natural low recruitment rates.

The results of the present study add to those of other studies that indicate anomalies in vital symptoms and ecological processes in the North Beach site (e.g. Bresler et al., 1999, 2003; Ben Zvi et al., 2004; Loya et al., 2004; Loya, 2004). In the only other study that investigated coral recruitment in Eilat (Glassom et al., 2004), such findings, as mentioned above, do not appear, since none of the 20 designated sites were in the North Beach. However, the closest site to the NB (site no. 20 in their paper) indicates very low rates of Pocilloporids and zero recruitment of all the massive and encrusting species.

Finally, the substantial differences in recruitment patterns between two parallel studies in the same area and during the same period, stress the crucial importance of a standardized methodology of recruitment assessment in coral reefs. Clearly, methodological differences can alter the findings in such a way that comparisons across studies are compromised. The findings for the Eilat reefs consequently call for a serious discussion that will lead to a clear protocol for standardized assessment of recruitment of coral reef organisms.

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