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Transplantation of juvenile corals: a new approach for enhancing colonization of artificial reefs

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Abstract Coral reefs in the northern Gulf of Eilat are exposed to continuous man-made disturbances, resulting in decreased coral coverage and reduced recruitment at the Nature Reserve of Eilat. The construction of artificial reefs on sandy bottoms is a possible option to decrease diving pressure on natural reefs. In the present study we tested this hypothesis by submerging an experimental artificial reef anchored to the bottom at 18 m depth and floated vertically 3 m below water surface. The reef was composed of PVC plates, attached both vertically and horizontally along a wire. Propagules of two coral species, the stony coral *Stylophora pistillata* and the soft coral *Dendronephthya hemprichi,* were transplanted to this artificial reef. Planulae of *S. pistillata* were obtained during the breeding season, seeded in petri dishes in the laboratory and after 2 wk the dishes were transferred to the experimental artificial reef. Automized fragments of *D. hemprichi* which had previously settled on 10 × 10 cm PVC plates were transplanted onto the experimental artificial reef. The survivorship of the transplanted *D. hemprichi* colonies was significantly higher on the lower sides of shallower plates. Survivorship of *S. pistillata* colonies increased with depth when located on the vertical plates, or on the upper sides of the horizontal plates. The highest survivorship of this coral was on the vertical plates and on the upper sides of the horizontal plates, while very low survivorship was recorded on the lower sides. The results indicate that vertical artificial surfaces offer the optimal biotic and abiotic conditions for the survival of the two examined corals. The vertical plates are characterized by low sedimentation rates, low coverage of turf-algae, minimal grazing by sea urchins and absence of the competitor tunicate *Didemnum* sp. In addition, the vertical orientation of the experimental plates reduces shading and offers the required light intensity for zooxanthellate corals such as *S. pistillata*. Only a few studies to date have tried to implement artificial reefs in a coral reef environment. The results of the present study indicate the potential of enhancing recruitment of corals by transplantation of juvenile recruits onto appropriate artificial structures. Maximal survivorship of these recruits is dependent upon the structural features of the artificial reef, which should offer optimal conditions.

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Introduction

The coral Nature Reserve at Eilat (Red Sea) was established in 1960 along a 1.5 km strip of shoreline. The Nature Reserve is situated only 1 km south of the local harbor, which includes a phosphate loading terminal and two oil jetties. The harbor activities, along with the massive crude oil transportation in the northern Gulf of Eilat, have resulted in many years of damage to the adjacent reefs (Fishelson 1973). The continuous phosphate and chronic oil pollution at Eilat constitute the major man-made disturbances, severely interfering with coral colonization on the Nature Reserve reef. A detailed study of changes in the coral community structure on this reef, due to oil spills, was carried out by Loya and Rinkevich (1980). In recent years, oil pollution at Eilat has become rare while concern for the well-being of the reefs has increased. However, damage is caused by divers who stir up the sandy bottom, cause breakage, and consequently prevent corals from developing normally (Kay and Liddle 1984; Kinsey 1988).

Artificial reefs have been used for over 200 years to enhance fishing catches (Lewis and MaKee 1989), yet their use to rehabilitate degraded coral reefs has received scant attention (Clark and Edwards 1994). Little information exists on recruitment of benthic organisms, including corals, on artificial reefs in a tropical reef environment (Birkeland 1977; Schuhmacher 1977; Fitzhardinge and Bailey-Brock 1989; Wendt et al. 1989).

Settled corals can cement the artificial reef structure, thus making it more stable and perhaps longer lasting. In addition, they improve the aesthetic appearance of the artificial reef, making it appear more natural (Fitzhardinge and Bailey-Brock 1989). Corals are inconspicuous on newly immersed substrata compared to algae and other colonial organisms such as ascidians and bryozoans (Schumacher 1977; Bailey-Brock 1989; Wendt et al. 1989). Various studies have suggested that a conditioning period of 4 to 12 mo is required prior to coral recruitment on newly deployed substrata (Sammarco 1982; Bailey-Brock 1989; Wendt et al. 1989). In the Red Sea submerged artificial surfaces similarly require adequate conditioning periods before coral settlement takes place (Benayahu and Loya 1987). A potential means to accelerate rehabilitation of denuded reefs is to transplant adult corals onto artificial reefs or natural ones (Maragos 1974; Alcala and Gomez 1979; Birkeland et al. 1979; Harriot and Fisk 1987). However, the high costs involved in such transplantation and the need to remove colonies from other sites are negative factors (Clark and Edwards 1994).

This study examines for the first time the potential of transplanting juvenile coral stages to accelerate colonization of an experimental artificial reef. In Eilat (Red Sea) we tested the application of this method using transplants of the stony coral *Stylophora pistillata* and the soft coral *Dendronephthya hemprichi.* Their survivorship was examined in relation to major abiotic factors such as depth, spatial orientation of the substratum, light intensity and sedimentation. In addition, we examined in the laboratory the effect of grazing pressure on the survivorship of primary polyps of the soft coral *Heteroxenia fuscescens.* This, in turn, enabled evaluation of the relative success of the transplanted species and assessment of the feasibility of this method for enhancing coral colonization on artificial reefs.

Materials and methods

Experimental artificial reef

In late August 1991 a modular experimental artificial reef was deployed at the reef in front of the Marine Biology Laboratory (MBL) at Eilat. This artificial reef was constructed of a steel wire anchored to the bottom at a depth of 18 m, and vertically floated by a buoy 2 to 3 m below the water surface. Settling substrata made of PVC plates, 50 × 50 cm, and 3 mm in width, were attached in vertical and horizontal positions along the wire (Fig. 1). The appearance of algae on the plates was monitored from August 1991 to October 1992 (Oren 1993).

Transplantation of corals and their survivorship

Planulae were obtained from *Stylophora pistillata* (Rinkevich and Loya 1979) and autotomized fragments from *Dendronephthya hemprichi* (Dahan and Benayahu 1997). These propagules were attached to the experimental substrata and later transplanted to the horizontal and vertical plates of the experimental artificial reef. Survivorship time (ST) of the transplants was monitored biweekly, and the accumulated data were recorded as time in days until their numbers had decreased by 25, 50 or 75% (i.e., ST-25, ST-50 and ST-75, respectively). Survivorship of the transplants on the horizontal plates was statistically verified by a backward stepwise multiple regression analysis. Survivorship of *S. pistillata* on the vertical plates was statistically verified by *t*-test, since their survivorship was recorded only at two different depths.

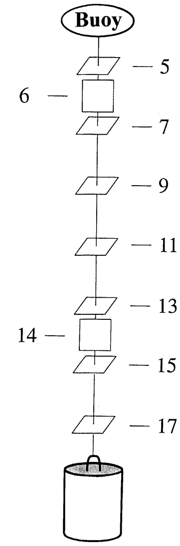

Fig. 1 The experimental artificial reef; *numbers* indicate depth in meters of the 50 × 50 cm PVC plates

Stylophora pistillata

This is the most common scleractinian species on the shallow reefs of Eilat, reproducing by planulae release from December to July each year (Rinkevich and Loya 1979). Planulae of *S. pistillata* were collected from large colonies by plankton netting. In the laboratory, groups of 30 planulae were placed in perforated petri dishes, maintained in 20-liter aquaria, supplied with running seawater and aeration. After 2 wk, the time required for most of the planulae to settle, the petri dishes were carefully opened, and the settled polyps were counted. Dishes settled with more than 15 primary polyps were transplanted to the experimental artificial reef: groups of three such petri dishes were attached on each side of the horizontal plates at 7, 11 and 15 m, and on the vertical plates at 6 and 14 m. From May to August 1992 polyp survivorship was monitored biweekly, and the ST-25 and ST-50 values were calculated and analyzed.

Dendronephthya hemprichi

High densities of this soft coral are found on the underwater surfaces of the oil jetties of Eilat. *D. hemprichi* reproduces vigorously by autotomy of small-sized fragments, each composed of a few polyps. These propagules tend to attach to the upper sides of vacant horizontal surfaces (Dahan and Benayahu 1997). Settled fragments were obtained by placing PVC plates (10 × 10 cm, 2 mm in width) adjacent to large colonies of the species at the oil jetties. After 3 mo these plates were removed, brought to the MBL, and the *D. hemprichi* recruits were counted. On the following day, groups of four plates were attached on both sides of the 7, 11, 15 and 17 m horizontal 50 × 50 cm plates of the experimental artificial reef. From April to August 1992 the survivorship of *D. hemprichi* recruits was monitored biweekly; the ST-50 and ST-75 values were calculated and statistically analyzed.

Light intensity and sedimentation

Light intensity along the experimental artificial reef was measured in May and June 1992 using a data logger (Li-Cor 1000). Light intensity was recorded on both sides of the horizontal plates at 5, 10, 15 and 17 m and additionally on the sea surface. The ratio was calculated between the values obtained at each depth and on the surface.

Sedimentation rates were measured along the experimental artificial reef in September and December 1991, and January and August 1992. We used cylindrical sediment traps, 30 cm long with an opening of 6.5 cm in diameter (Gardner 1980). On each of the four dates the traps were placed on the upper sides of the horizontal plates for a period of 1 mo (one trap at each depth). The traps were then sealed underwater and transferred to the MBL, where their contents were paper filtered, dried for 24 h at 80 °C and weighed.

Grazing activity of sea urchins

Sea urchins found on the experimental artificial reef were counted monthly in relation to the position of the plates. In addition, their potential effect on the survivorship of the juvenile corals was experimentally examined in the laboratory. For this purpose, planulae of the soft coral *Heteroxenia fuscescens* were obtained from colonies kept in the MBL (Benayahu 1991) and transferred to 20-liter aquaria, with 10 × 10 cm PVC plates. After settlement of most planulae, the resulting primary polyps were counted on each plate, and the eight most populated plates, with at least 15 recruits, were individually placed in separate aquaria. *Tripneustes gratilla* were collected from the natural reef of the MBL, and two individuals were introduced into each of the four aquaria, while the other four with no sea urchins were used as controls. After 2 wk, the percentage survivorship of the primary polyps of *H. fuscescens* in all eight aquaria was recorded. The survivorship of the juvenile recruits under grazing was tested only with primary polyps of *H. fuscescens* since its planulae are available in high numbers throughout most of the year (Benayahu 1991). In addition, they initiate metamorphosis within 24 to 48 h under laboratory conditions and develop successfully into primary polyps.

Results

Transplantation of corals and their survivorship

Stylophora pistillata

The time in days, in which the survivorship of *S. pistillata* transplants decreased by 25% (ST-25) and later by 50% (ST-50) on the horizontal plates and on the vertical ones at the various depths is presented in Tables 1 and 2, respectively. Regression curves presenting the relationship between the survivorship of the transplants and depth on the horizontal plates are presented in Fig. 2a,b. These regression curves at ST-25 and ST-50 indicate that on the upper sides of the horizontal plates the survivorship of *S. pistillata* was positively related to depth (backward stepwise multiple regression analysis: $p < 0.01$, $R^2 = 0.86$ and $R^2 = 0.83$, respectively). However, on the lower sides of the plates the survivorship of the transplants was low and constant for the two ST periods at all studied depths (Fig. 2a,b). An examination of the two average ST periods of *S. pistillata*, on the vertical plates at 6 m (13.3 ± 2.9 and 25 ± 5 d, respectively) and at 14 m (85 ± 8.7 and 133.3 ± 15.3 d, re-

Table 1 *Stylophora pistillata.* Survivorship rates of primary polyps on the upper and lower sides of the horizontal plates at 7, 11 and 15 m on the experimental artificial reef (*ST*-25, *ST*-50 time in days survivorship decreased by 25 or 50%, respectively)

Depth (m)	Upper side		Lower side	
	ST-25	ST-50	ST-25	ST-50
7	15	30	25	35
	15	35	20	25
	15	30	20	30
11	25	55	25	45
	30	50	20	35
	40	60	30	75
15	45	75	15	20
	50	75	15	20
	45	65	20	25

Table 2 *Stylophora pistillata.* Survivorship rates of primary polyps on the vertical plates at 6 and 14 m on the experimental artificial reef (*ST-25*, *ST-50* time in days survivorship decreased by 25 or 50%, respectively)

Depth (m)	ST-25	ST-50
6	15	25
	15	30
	10	20
14	75	150
	90	130
	90	120

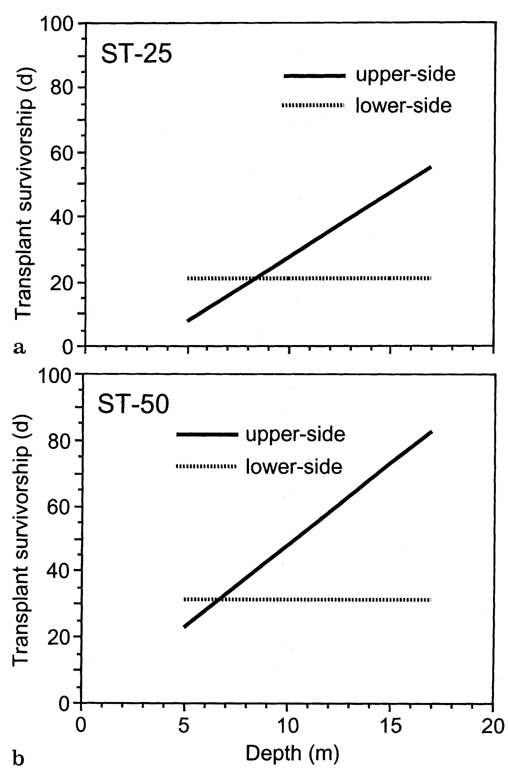

Fig. 2 *Stylophora pistillata.* Survivorship regression curves of transplants on both sides of the horizontal plates along the experimental artificial reef at (**a**) ST-25 and (**b**) ST-50

spectively), reveals a significantly higher survivorship on the deeper plate during both periods (t-test, $p < 0.001$).

Dendronephthya hemprichi

Table 3 presents the time in days, in which the survivorship of the transplants of *D. hemprichi* on the horizontal plates decreased by 50% (ST-50) and later by 75% (ST-75) at the four studied depths. The relationship between the survivorship of the transplants and depth is presented in Fig. 3a,b. These regression curves show that the survivorship of *D. hemprichi* on the lower sides of the horizontal plates was negatively related to depth for both ST-50 and ST-75 periods (backward stepwise multiple regression analysis: $p < 0.001$, $R^2 = 0.44$ and $R^2 = 0.45$, respectively). The transplants on the upper sides of the plates had lower and constant survivorship at all depths.

Light intensity and sedimentation

We calculated the ratio between light intensity on the sea surface and at the different depths as recorded on both upper and lower sides of the horizontal plates of the experimental artificial reef on two dates (Fig. 4). The light intensity on both sides of the plates decreased with depth. The light intensity on the upper sides of the plates was five times higher than on their respective lower sides along the entire depths of the experimental artificial reef.

Sedimentation rates along the experimental artificial reef on the four measuring dates are presented in Fig. 5.

Table 3 *Dendronephthya hemprichi.* Survivorship rates of transplants on the upper and lower sides of the horizontal plates at 7, 11, 15 and 17 m on the experimental artificial reef *(ST-50, ST-75* time in days survivorship decreased by 50 or 75%, respectively)

Depth (m)	Upper side		Lower side	
	ST-50	ST-75	ST-50	ST-75
7	15	45	75	100
	10	30	80	110
	15	45	40	80
	8	25	50	95
11	30	45	25	30
	25	40	20	25
	25	40	15	20
	15	35	20	40
15	8	15	15	45
	8	15	20	50
	8	12	25	55
	6	10	12	45
17	35	40	30	55
	30	35	20	50
	35	40	25	45
	35	40	25	55

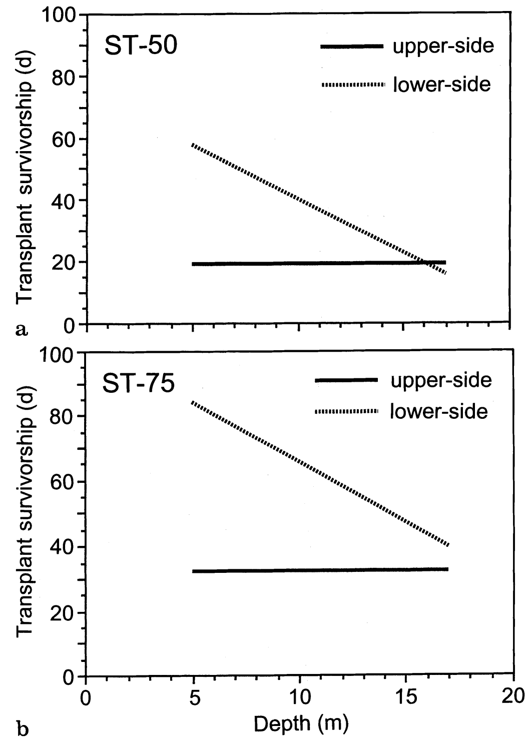

Fig. 3 *Dendronephthya hemprichi.* Survivorship regression curves of transplants on both sides of the horizontal plates along the experimental artificial reef at **(a)** ST-50 and **(b)** ST-75

The lowest values, of approximately 0.5 mg cm^{-2} d^{-1}, were obtained in September 1991 and January 1992 at all depths. During December 1991 and August 1992 higher

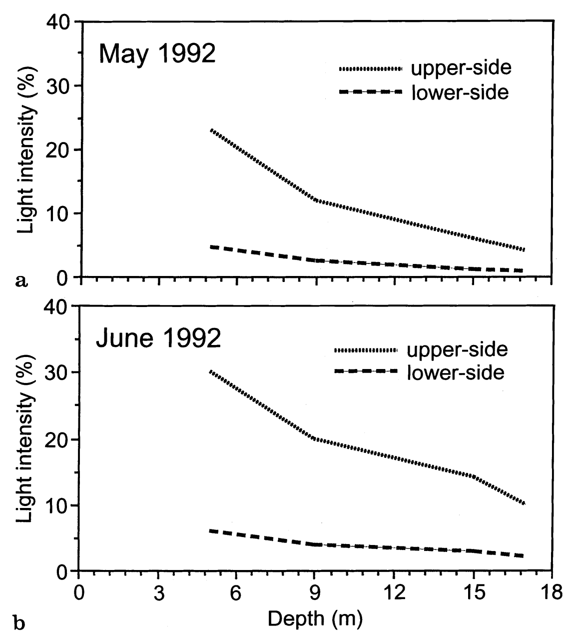

Fig. 4 Ratio between light intensity at various depths and at the sea surface on both sides of the horizontal plates along the experimental artificial reef on two measuring dates

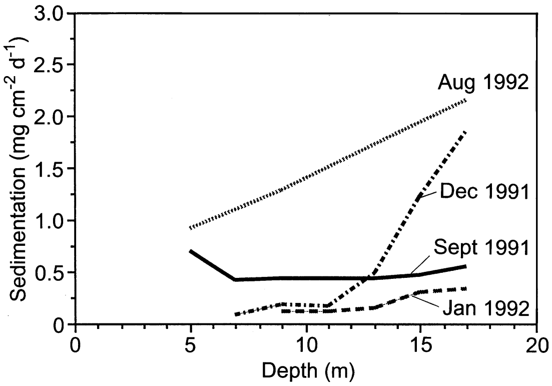

Fig. 5 Sedimentation rates in mg cm^{-2} d^{-1} along the experimental artificial reef on different dates

sedimentation rates were recorded, and they increased with depth to approximately 2 mg cm^{-2} d^{-1} (Fig. 5).

Grazing activity of sea urchins

The accumulative number of *Tripneustes gratilla* and *Diadema setusum* individuals found on the upper sides of the horizontal plates throughout the study is shown in Fig. 6. Sea urchins were never observed on the lower sides of the plates. *T. gratilla*, the more common species of the two, was mostly found on the shallower portion of the experimental artificial reef. In the laboratory, 2 wk of *T. gratilla* activity decreased the survivorship of primary polyps of *Heteroxenia fuscescens* to 58 ± 15% ($n = 4$), which was significantly lower than the control (92 ± 2%, $n = 4$) (Mann–Whitney test, $p < 0.05$).

Discussion

The use of artificial substrata for rehabilitation of reef communities has received little attention to date. A novel application in this respect is the use of coral transplantation to help replenish damaged reef areas (Harriot and Fisk 1987; Yap et al. 1992). Clark and Edwards (1994) suggested that transplantation of mature coral colonies may help to restore degraded reefs. However, such procedures cause damage to other reef areas and are labor intensive. Knowledge obtained on the reproductive patterns and settling preferences of the Red Sea corals (Shlesinger and Loya 1985; Benayahu et al. 1990) urged us to assess for the first time the potential use of their propagules for transplantation to an artificial reef. In addition, the unique autotomy process in *Dendronephthya hemprichi* (Dahan and Benayahu 1997) facilitated the use of its fragments for this purpose. The survivorship rates of both transplanted species, *Stylophora pistillata* and *D. hemprichi,* were found to be related to the structural features of the modular experimental artificial reef.

Space in the light is one of the most important limiting factors for a coral reef ecosystem, resulting in competitive interactions among coexisting species (Benayahu and Loya 1981; Schuhmacher 1988). The stony coral *Stylophora pistillata* is a hermatypic, light-dependent species (Rinkevich and Loya 1979), which may explain its relatively high survivorship on the upper sides of the horizontal plates (Fig. 2). Light intensity at the lower side of the 5 m horizontal plate was approximately 5% of the light at the water surface and it decreased to about 2% at 17 m (Fig. 4). The low survivorship rate of *S. pistillata* transplants on the lower sides of the horizontal plates might indicate that the prevailing light conditions are below its requirements. In contrast, its high survivorship on the upper side of the deepest plate at 17 m indicates that an illumination value around10% is still adequate for successful recruitment. Nevertheless, we assume that the positive relationship between the survivorship of *S. pistillata* and depth on the upper sides of the horizontal plates (Fig. 2) is probably due to high competition with algae on the shallow and light-exposed surfaces (Schuhmacher 1988).

High sedimentation rates may affect coral settlement and survivorship (Rogers 1990; Wittenberg and Hunte 1992). Similarly, coral community structure is strongly influenced by grazing activity of sea urchins (Sammarco 1982; Keats et al. 1990), particularly the juveniles, which are susceptible to such activity (Carpenter 1981). The high survivorship of *Stylophora pistillata* on the upper surfaces at 17 m near the bottom, where sedimentation rates were approximately 2 mg cm^{-2} d^{-1}, emphasizes that such rates were tolerable for the recruits. This conclusion is further supported by Rogers (1990) who found that only sedimentation rates above 10 mg cm^{-2} d^{-1} are destructive for most coral species. Settlement of algae on the plates was qualitatively monitored throughout the study (Oren 1993), and a clear algal cover decrease with depth was found. No algae were ever observed on the lower sides of the horizontal plates or on the vertical plates, probably due to inadequate light intensity. The appearance of *Tripneustes gratilla*, the most common sea urchin on the experimental artificial reef, coincided with the occurrence of the turf algae (Oren 1993). Its grazing activity diminished the survivorship rates of the primary polyps of *Heteroxenia fuscescens* (see "Results"). We

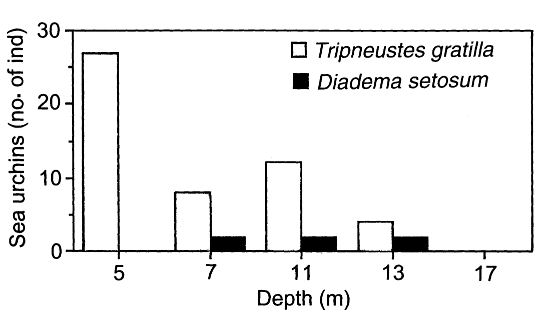

Fig. 6 *Tripneustes gratilla and Diadema setusum.* Distribution of sea urchins on the upper sides of the horizontal plates along the experimental artificial reef

assume, therefore, that grazing has similar consequences upon the juvenile stages of *S. pistillata*. On the upper surfaces, their survivorship gradually increased with depth and coincided with low grazing activity of *T. gratilla*.

The high survivorship of *Stylophora pistillata* recorded on the 14 m vertical plate compared to the 6 m plate (Table 2) is probably an outcome of appropriate light intensity and lack of grazing activity. Spatial competition between *S. pistillata* transplants and naturally recruited compound ascidian *Didemnum* sp. colonies played a major role in determining the survivorship of the transplants, especially on the 6 m vertical plate. This encrusting species settled and grew rapidly over most of the plate area at this depth (Oren and Benayahu in preparation) and subsequently overgrew the transplants. We conclude that increased survivorship of the transplants of *S. pistillata* can be achieved in the future by placing vertical and horizontal surfaces on artificial reefs at a depth range of 12 to 20 m.

Dendronephthya hemprichi is an azooxanthellate soft coral (Dahan and Benayahu 1997), which might explain its relatively high survivorship on the lower sides of the horizontal plates (Fig. 3). Its low survivorship on the upper sides of these plates is probably derived from its failure to compete with light-dependent organisms. At Eilat *D. hemprichi* is a frequent colonizer of artificial substrata, and commonly its colonies grow upside down (Goren 1992). It is suggested that such a position assists the expansion of its inflated colonies and, therefore, improves their feeding ability (Fabricius et al. 1995). The ascidian *Didemnum granulatum* recruited on the lower sides of the horizontal plates was first found at 17 m, and then gradually appeared on the shallower plates (Oren and Benayahu in preparation). The fast growing ascidian colonies overgrew the *D. hemprichi* transplants and excluded them with time from the lower sides of the horizontal plates at 17, 15 and 13 m.

Recently, planning and construction of artificial underwater habitats has been directed towards more specific objectives (Bortone and Kimmel 1991). Accordingly, a need has arisen for more specialized methods to assess and monitor such habitats quantitatively. Transplantation of corals along controlled substrata attached to an artificial structure enables a detailed examination of their optimal niches through their survivorship. The use of juvenile coral stages for transplantation is recommended in light of the following: (1) the presence of mature colonies is an outcome of their juvenile survivorship and (2) juvenile stages of most coral species can be obtained in large quantities and monitored without causing any damage to the natural coral reef environment. Through examination of the adjustment of other common coral species, using such an approach, it will be possible to construct successful artificial reefs. Such reefs can be constructed with the adequate niches required for highest survivorship of the transplants and should then achieve natural recruitment by a variety of other coral species within a comparatively short time.

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