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A mid-water coral nursery

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Abstract The nursery component in an active reef restoration program is used as a tool that provides coral source material for the rehabilitation of denuded reef areas. Here, we present the first mid-water floating coral nursery, an improved prototype of earlier attached-to-substrate coral nurseries. A total of 7119 fragments sampled from 11 branching species and 21 intact colonies of *Favia favus* were maricultured at six meter depth, 14 m above sea bottom in close vicinity to fish farm facilities and 8 km away from the coral nature reserve, at Eilat, Red Sea. Total mortality of fragments during 10 nursery months was very low (less the 10%) while growth rates were high (up to 6 fold in height). The massive coral *F. favus* showed zero mortality and an average growth rate of 159% during 270 nursery days. We conclude that floating nurseries, installed away from major reef structures, improve coral culturing as compared to attached-to-substrate nurseries by providing better water and nutrient fluxes, promoting the elimination of sediment, improving cleaning by whole nursery movements, and providing optimal PAR to maricultured coral colonies through depth adjustment. In addition, detrimental impacts caused by recreational activities and corallivorous organisms are eliminated.

Key words: coral, Eilat, mid-water nursery, Red Sea, restoration

Introduction

The continued decline of coral reefs worldwide (Bellwood et al. 2004) has led to an urgent need for the development of improved conservation techniques. In many reef areas, especially in small size reefs that are excessively exploited by human activities (Rinkevich 1995; Risk 1999; Epstein et al. 2001, 2003), conservation measures alone are not enough in rescuing the reefs from decline. As a result, active restoration practices should be implemented (Epstein et al. 2001). The active reef rehabilitation methodologies currently used include the construction of artificial reefs (Pickering et al. 1998; van Treeck and Schuhmacher 1999), the application of coral transplantation measures (e.g. Harriot and Fisk 1988; Smith and Hughes 1999), and the use of underwater nurseries (Rinkevich 1995; Epstein et al. 2001, 2003; Shafir et al. submitted).

Direct transplantation of coral colonies/coral fragments from one locality (donor reef) to a new site is the most common methodology used for expediting the recovery of denuded reef areas. However, while techniques for the removal, transportation, and re-attachment of corals are straightforward, varying degrees of success at new sites have been reported. This limited success is often attributed to transplantation stress, insufficient number of colonies at the donor site, and the use of various fragment sizes (Edwards and Clark 1998; Becker and Mueller 2001). Moreover, in many cases the transplantation act itself has inflicted additional stress to the donor coral populations (Edwards and Clark 1998; Rinkevich 2000). To minimize failure or circumvent the obstacles originating from some transplantation approaches, Rinkevich (1995) has suggested the strategy of 'gardening coral reefs', a two-step protocol whose central concept is the mariculture of coral recruits (spats, nubbins, coral fragments, and small coral colonies) in nurseries. The *in situ* nurseries are installed in sheltered zones, where the different types of coral recruits are maricultured to an adequate size. Initially, large numbers of farmed corals and spats are established in the nurseries, followed by transportation of the nursery-grown coral colonies to degraded reef sites. This strategy is similar to the one used in terrestrial forest plantation (Epstein et al. 2001, 2003; Shafir et al. submitted). This *in situ* nursery approach sustains the mariculture of large number of colonies developed from nubbins, coral fragments and small colonies on a year-round basis. The protected nursery phase provides the transplanted material with an acclimation (gardening) period, essential for increasing survival rates and allows growth to sizes best suitable for transplantation.

Up to date, most *in situ* coral nurseries were developed in reef areas at or near sea bottom in shallow water (Epstein et al. 2001; Soong and Chen 2003). Bongiorni et al. (2003) employed a similar approach by using small size floating nurseries for experimental purposes. Here, we present a novel approach for *in situ* coral nursery, which is based on the establishment of large mid-water nursery in a protected site, away from major natural reef areas. This floating nursery, situated away from impacts inflicted on the reefs by tourist activities and by corallivorous organisms, proved to be superior to all

former approaches. In this study, results are presented on the construction of a prototype mid-water nursery and growth and survival of nursed corals during the first year of operation.

Materials and Methods

A mid-water floating nursery was established at a depth of 6 m (14 m above the sea bottom). The nursery was situated at the Ardag fish farm facility, located at the northern shore of the Gulf of Eilat, Red Sea (29º32.45'N, 34º58.40'E). Ambient nutrient concentrations at the site were previously reported by Bongiorni et al. (2003). The nursery consisted of a flexible rope net (10X10 meter size, 100 cm^2 hole size, Fig. 1a) tied to cables, anchoring a large fish cage (containing gilthead seabream, *Sparus aurata*).

Ramets from coral branching forms were pruned to small size fragments (0.5-2 cm high) and nubbins by the use of an electrician's wire cutter. Old and recently developed parts of each colony as well as tip and mid-branch zones were used as source material for fragment preparation. Ten coral colonies from 5 branching species were completely fragmented into small ramets. The corals included: three *Stylophora pistillata* colonies (10-20 cm diameter each), four *Pocillopora damicornis* colonies (15 cm diameter) and one colony from each of the three *Acropora* species, *A. pharaonis* (15 cm diameter), *A. eurystoma* (termed also *A. tenuis*, 20 cm diameter) and *A. valida* (15 cm diameter). Ramets of colonies from six additional branching species were used: one *Acropora humilis*, one *A. variabilis*, one *A. squarrosa*, one *A. lamarcki*, one *Seriatopora hystrix* and three from the hydrozoan *Millepora dichotoma*. In addition, 21 small colonies (< 5 cm diameter) of the massive coral *Favia favus* were transplanted to the nursery. All colonies and colony fragments were collected from artificial substrates at the northern part of the Gulf of Eilat and transported, submerged in seawater, to the nursery site. *Favia* colonies were glued, one colony per plastic pin, without any experimental manipulation. Most of the branching species ramets were glued in upright position, except from *Acropora squarrosa* and *A. lamarcki* ramets that were glued randomly at three positions: upright, with the terminal polyp at the top; sideways, with the terminal polyp to the side; and upside down, when middle parts of the branches, cut from both sides were used.

In an attempt to minimize stress conditions (Shafir et al. 2001), the isolated fragments were instantaneously immersed upon separation in a tank of fresh seawater. Then, the exposed skeletal surface area of each individual fragment was dried with a paper towel and the ramet was glued with a drop of cyanoacrylate glue (Super Glue 3, Loctite, Ireland) to the flat surface of a plastic pin (9 cm long, 0.3-0.6 cm wide leg with a 2 cm diameter "head"; Red Sea Corals LTD., Israel). After less then 1 min exposure to air the glued fragment was immersed in fresh seawater. Whole *Favia* colonies were glued directly to the pins without fragmentation. The plastic pins carrying the glued coral ramets and colonies were positioned within plastic nets (0.25 cm^2 mesh size) that were stretched over PVC frames (each 50X30 cm). Frames with the pins were tied at 6 m depth to the rope net. Each plastic frame carried 21-125 pins with coral ramets or colonies. Detailed observations on the status of each ramet (missing, dead, alive) were conducted monthly. *Favia* colonies were photographed by a digital camera (Nikon coolpix 995) with a ruler just before immersing and at day 270. Photographs were taken from above. *Favia* photographs were analyzed with the image-analysis software TINA 2.07 to obtain the area from top projection of each colony.

Results

The mid-water nursery was constructed in July 2003 with the help of several untrained volunteers within three days. A total of 3844 fragments were prepared from four branching coral species (*Acropora pharaonis*, *A. eurystoma*, *Pocillopora damicornis* and *Stylophora pistillata*, Table 1).

Source Colony	date	Fragments #	Frames #	Fragments per frame
A. pharaonis	7/03	527	5	105
A. eurystoma-L	7/03	311	3	104
Pocillopora 1	7/03	577	5	115
Pocillopora 2	7/03	927	9	103
Stylophora 1	7/03	1047	10	105
Stylophora 2	7/03	212	2	106
Stylophora 3	7/03	243	2	122
Total		**3844**	**36**	**107**
A.eurystoma-S	8/03	376	3	125
A.valida	8/03	1054	10	105
Pocillopora-3	8/03	825	9	92
Pocillopora-4	8/03	714	10	71
Total		**2969**	**32**	**93**
Favia favus	9/03	21	1	21
Millepora 1	10/03	48	1	48
Millepora 2	10/03	48	1	48
Millepora 3	10/03	60	1	60
Seriatopora	10/03	48	1	48
A. humilis	10/03	18		*
A. variabilis	10/03	36	1	54*
A. squarrosa	10/03	18		*
A. lamarcki	10/03	30	1	48*
Total		**327**	**7**	**47**
Grant total		**7140**	**75**	**95**

Table 1: Source material for the mid-water coral nursery prototype. *A. eurystoma* fragments were divided into two group sizes (L-large, >2 cm; S-small <1 cm). Asterisks denote cases where a single frame contained fragments from two different species.

One month later, 2969 additional fragments were prepared during three days (376 from the same *A. eurystoma* used for preparation on July and the rest from *A. valida* and *P. damicornis*). All preparations (n= 6813) were monitored and measured for growth until day 200 (Shafir et al. submitted). The crowded plastic frames (containing 103-125 coral fragments, each; Table 1) were partly overgrown by macro algae and dense populations of a sea anemone (*Boloceroides memurrichi*). After 144

nursery days, the frames were thinned to 48-60 cultured corals per frame and the excess cultured corals were transferred to new plastic frames. This procedure resulted in a significant reduction of algae and *B. memurrichi* within 30 days. Cleaning was performed by fish and by sea urchins that resided in the nursery area.

Two months after the construction of the nursery, 21 colonies of the massive coral *Favia favus* were added (Fig. 1a). The *Favia* colonies throve (Fig. 1 b,c) without any signs of stress for more than 11 months. This was in contrast to what was proposed for this species in nutrient enriched areas (Loya and Kramarsky-Winter 2003).

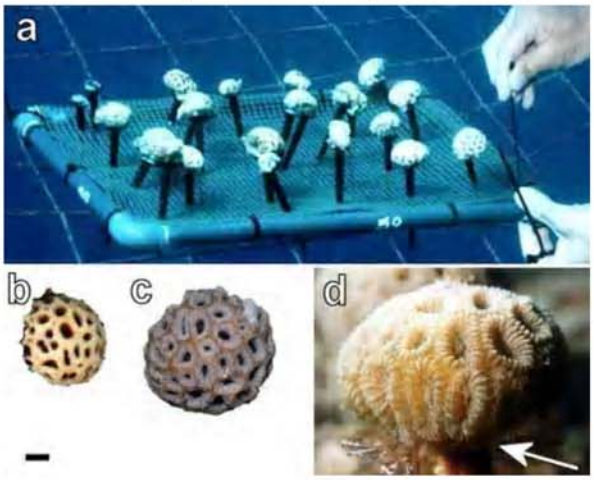

Fig. 1. Mariculture of *Favia favus* colonies. (a) at day of installment 21 colonies on a single plastic frame; (b) colony no. 8, aerial view at day 0 (57.0 mm^2); (c) colony no. 8 aerial view after 270 nursery days (102.6 mm^2, Table 3); (d) colony no. 11, after 270 nursery days, arrow points to polyps growth covering the pin's head, bar = 2 cm, (photo d by D. Gada).

During this period, three colonies detached from the pins (at days 35, 238 and 270, Table 3). Two were detached by divers during observation dives and one was detached for unknown reasons. In three *Favia* colonies, polyps grew downward, covering the plastic pin head (Fig. 1d).

	Aerial surface area (mm^2)		
No.	day 0	day 270	% growth
1	48.8	70.2	144%
2	47.3	80.9	171%
3	47.7	70.4	147%
4	17.2	22.3	130%
5	51.1	70.2	137%
6	19.9	40.2	202%
7	34.6	49.9	144%
8	57.0	102.6	180%
9	28.3	47.5	168%
10	61.4	92.7	151%
11	58.2	101.8	175%
Average	**42.8**	**68.1**	**159%**
S.D.	15.47	25.96	22%

Table 2. Aerial surface area of maricultured *Favia favus* colonies after 270 mid-water nursery days.
Colony size was measured for 11 *Favia* colonies at day 0 and after 270 nursery days, (top projection) revealing fast growth rates of 159±22% in aerial surface area (range: 130%-202%; Table 2, Fig. 1 b,c).

Three months after the construction of the nursery we added fragments prepared with six new species (*Acropora squarrosa*, *A. lamarcki*, *A. humilis*, *A. variabilis*, *Seriatopora hystrix* and *Millepora dichotoma*). Survival after 292 nursery days was very high: 77.8% for *Acropora squarrosa*, 97.2% for *A. variabilis*, 94.4% for *A. humilis* and 73.3% for *A. lamarcki* (Table 3). The loss in the *Acropora* species was mainly caused by detachment of the fragments (2.8%-23.3%) while the loss due to mortality was very low (2.8%-5.6%, Table 3). It was observed that the initial orientation of *Acropora squarrosa* and *A. lamarcki* ramets did not have any impact on their growth pattern. In all *Acropora* ramets, development started from the secretion of calcareous and tissue basal layer over the plastic pin head. Fragments that were glued to the side grew in upward direction, growing branches from the former branch side (Fig. 2b,c). Those that were glued upside down developed simultaneously also a terminal polyp at the former broken base of the ramet (Fig. 2d).

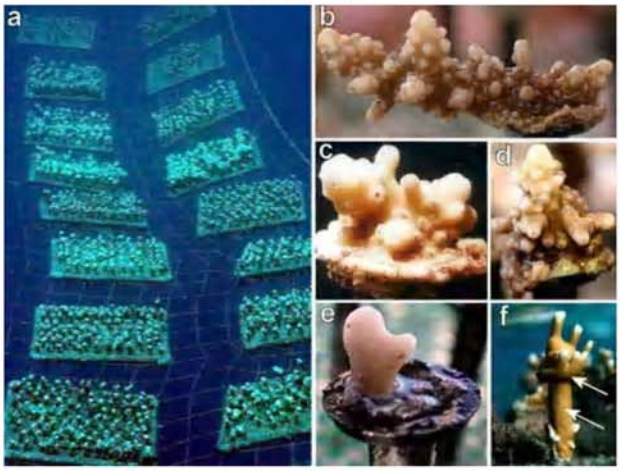

Fig. 2. Ramets from branching species at the mid-water nursery. (a) a general view of part of the mid-water nursery, three months after construction, the nursery held 75 frames similar to the 14 depicted in the picture; (b, c) *Acropora lamarcki* and *A. squarrosa*, respectively, glued on the side, after 292 nursery days, in both cases new upward branches developed after lateral growth; (d) development of a new terminal polyp on a upside down glued *A. lamarcki* ramet; (e) a small fragment (1.5 cm high) of *Millepora dichotoma* immediately after preparation; (f) a *M. dichotoma* ramet at day 292, the whole pin (head and base, arrows) is covered with tissue and skeleton, (photos b, d, f, by M. Cooper, c by D. Gada).

After 292 nursery days, 32.7% of the *Millepora dichotoma* colonies had detached from the plastic pins and 4.5% died (Table 3). All remaining fragments (62.8%) survived.

Species/Colony	Fragment Status	Number (percentage) of fragments, at day								
		0	13		44		87		292	
Millepora 1	Lived	48	44	91.7%	40	83.3%	40	83.3%	32	66.7%
	Detached		4	8.3%	8	16.7%	8	16.7%	12	25.0%
	Died		0		0		0		4	8.3%
Millepora 2	Lived	48	41	85.4%	37	77.1%	37	77.1%	32	66.7%
	Detached		7	14.6%	11	22.9%	11	22.9%	15	31.3%
	Died		0		0		0		1	2.1%
Millepora 3	Lived	60	53	88.3%	45	75.0%	44	73.3%	34	56.7%
	Detached		7	11.7%	15	25.0%	16	26.7%	24	40.0%
	Died		0		0		0		2	3.3%
Seriatopora	Lived	48	37	77.1%	20	41.7%	11	22.9%	9	18.8%
	Detached		11	22.9%	28	58.3%	37	77.1%	39	81.3%
	Died		0		0		0		0	
A. humilis	Lived	18	17	94.4%	17	94.4%	17	94.4%	17	94.4%
	Detached		1	5.6%	1	5.6%	1	5.6%	1	5.6%
	Died		0		0		0		0	
A. variabilis	Lived	36	35	97.2%	35	97.2%	35	97.2%	35	97.2%
	Detached		1	2.8%	1	2.8%	1	2.8%	1	2.8%
	Died		0		0		0		0	
A. squarrosa	Lived	18	16	88.9%	14	77.8%	14	77.8%	14	77.8%
	Detached		2	11.1%	3	16.7%	3	16.7%	3	16.7%
	Died		0		1	5.6%	1	5.6%	1	5.6%
A. lamarcki	Lived	30	26	86.7%	24	80.0%	22	73.3%	22	73.3%
	Detached		4	13.3%	5	16.7%	7	23.3%	7	23.3%
	Died		0		1	3.3%	1	3.3%	1	3.3%
Total Fragments	**Lived**	**306**	**269**	**87.9%**	**232**	**75.8%**	**220**	**71.9%**	**195**	**63.7%**
	Detached		**37**	**12.1%**	**72**	**23.5%**	**84**	**27.5%**	**102**	**33.3%**
	Died		**0**		**2**	**0.7%**	**2**	**0.7%**	**9**	**2.9%**
	Days	0	35		79		238		270	
Favia favus	Lived	21	20	95.2%	20	95.2%	19	90.5%	18	85.7%
	Detached		1	4.8%	1	4.8%	2	9.5%	3	14.3%
	Died		0		0		0		0	

Table 3. The status of farmed branching coral ramets and whole *Favia* colonies in the mid-water nursery during the first 10 months of growth.

Growth of small ramets of *M. dichotoma* (Fig. 2e) was characterized by the secretion of a large disk of tissue and skeleton over the plastic pin head and in several cases over the whole plastic pin (Fig. 2f). The upward growth was surprisingly small. On average, after 292 nursery days, *M. dichotoma* fragments tripled in height, which was slow compared to *Acropora valida*, for example, which showed a six-fold height increase after 309 nursery days (Shafir et al. submitted). *M. dichotoma* colonies in the Red Sea inhabit the upper shallow water layers between 1-3 m depth (Loya 1972) and are exposed to intensive light and wave energies. At a depth of six meters adjacent to the fish cage, light, currents and wave energy are significantly reduced. These environmental condition probably affected growth rates and patterns of development in *Millepora* ramets.

Seriatopora ramets developed vertical branches quickly and formed small branching colonies within a period of four months. On the other hand, neither one of the 48 colonies developed lateral growth on the plastic pin head as did all other branching species tested (*Stylophora pistillata*, *Pocillopora damicornis*, *Acropora variabilis*, *A. valida*, *A. eurystoma*, *A. squarrosa*, *A. humilis*, *A. pharaonis*, *A. lamarcki* and *Millepora dichotoma*). Therefore, their holdfast to the pins was restricted to only the glued area. This led to the highest detached rate recorded (81.3% within 292 days, Table 2). Even the movement of passing fish was shown to cause detachment.

In the nursery, 7140 coral fragments and colonies, positioned on 75 plastic frames, were maricultured (Table 1). Many fragments grew very fast, forming large colonies to the size of 8-10 cm in diameter (Fig. 3). Recently we started to use the maturing colonies as a source material for the development of additional fragments.

Fig. 3. *Acropora eurystoma* growth during 400 nursery days (bar = 2 cm). (photos by D. Gada and M. Cooper).

Specimens of various invertebrate species, originating from the plankton, settled on the new coral colonies and on the plastic frames. *Acropora valida* and *A. lamarcki* were the most "favorable" coral species for *Spirobranchus giganteus* settlement. On several fragments we found up to three *S. giganteus* specimens. The corallivorous snail *Drupella cornus* and *Coralliophila erosa* were found mainly on *Stylophora*

pistillata fragments. The sea urchin *Diadema setosum* appeared in October and *Tripneustes gratilla* appeared in June – July of the following year.

Discussion

The prototype mid-water, floating coral nursery reported in this study provides improved environmental conditions for colonies when compared to more common sea floor nurseries (Epstein et al. 2001; Soong and Chen 2003). Almost no mortality in the 306 coral fragments (2.9%; 292 days) and zero mortality for *Favia* colonies were found while growth rates were fast (up to 202% within 11 months). These results differ from those of Loya and Kramarsky-Winter (2003) who found that *Favia* colonies died within seven months when placed at <50 cm above the seafloor sediment. It may, therefore, be concluded that the use of floating nurseries provide a significant advantage over nurseries constructed close to the sea bottom. In addition, grazing by settling herbivorous organisms helped in keeping spaced coral colonies clean from attachment by algae and invertebrates. A number of characteristics can be identified when comparing floating nurseries with bottom nurseries: 1. *Water flow*: supplies the mid-water nursery system with large quantities of plankton particles, probably enhances the dissolved oxygen flow around the coral tissue and helps in removing mucus secreted by the coral tissue in a more efficient way; 2. *Movement of the nursery*: in sea bottom nurseries attached to the reef floor (Oren and Benayahu 1997; Epstein 2001; Soong and Chen 2003), water movement around the corals results strictly from currents or wave action. In a mid-water floating nursery, the complete nursery moves in the sea water column to all directions. This flexibility enables the nursery to further increase water exchange around the coral tissue and promotes a better elimination of debris, sedimentation particles and other settling material that might accumulate on developing coral colonies; 3. *Sedimentation*: one of the obstacles of raising coral colonies in attached to the substrate nurseries is the detrimental effects of sedimentation of the corals that may negatively influenced the health and growth of corals (Rinkevich et al. 2003). In the current mid-water nursery, the sea floor was 14 m down so that sedimentation was significantly reduced; 4. *PAR*: mid-water nurseries can be depth adjusted according to the needs of each specific coral species. For example, frames with *Millepora* colonies that thrive in shallow depths (more light, more water movement) can be placed in the floating nursery at shallower depths (1-3 m) while other species may thrive at deeper depths. The flexibility of the mid-water nursery enables a gradual adjustment to irradiation conditions similar to those at the final transplantation site; 5. *Reduction in coral predators and other stressors*: shallow water sea bottom nurseries are usually situated near natural reefs. This exposes them to corallivorous fish and invertebrates as well as to divers' impacts in tourist areas. Installing the nursery at a distance from the reef may reduce harmful impacts of predators and recreational activities. However it will not protect from corallivorous invertebrates in the plankton, such as the snail *Drupella cornus*.

In summary, mid-water coral nursery is an improved nursery type for the mariculturing of coral colonies. As in the development of silviculture methodologies (Berg 1995), active restoration of denuded coral reefs requires the development of specific techniques and protocols. This study describes the first simple prototype of floating, mid-water coral nursery and the feasibility of culturing thousands of new coral colonies amenable for transplantation back into the reef. Although there are still many unknowns (e.g., multi-layer nursery, optimal nursery time and seasonality, optimal fragments size, number of ramets per genet, active maintenance), it is evident that the ability to produce and develop numerous coral colonies by means of this method may change the way end-users manage denuded reef areas.

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