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A NEW INNOVATED AND CHEEP MODEL IN BUILDING ARTIFICIAL REEFS

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ABSTRACT

A novel and cheep approach for building artificial reefs was designed in such a way that sediments in an area of high sedimentation rate will be utilized in building the artificial substrate with no further sediment accumulation afterwards. The model consists of several steel cylinders which are soldered together in such a way to form a reef flat, a gentle slope and a steep slope, with two layers of narrow opening meshes (a lower plastic and an upper metallic one). Within a short periode (3 months), a substrate layer of a total of ~ 1 cm was formed between the two meshes, this layer increased to ~2 cm after 9 months. Transplants of the three species *Stylophora pistillata*, *Echinopora gemmacea* and *Montipora spongiosa* grow better when the attaching surface is oriented with a narrower angle than 90^{o} with the vertical axis, while *Acropora granulosa* grows better on the reef flat and steep slope (narrower angle than that of the gentle slope).

INTRODUCTION

Habitat degradation has been estimated to affect coral populations through alteration of recruitment, growth, and colony (partial) mortality processes (Bak and Meesters, 1999). Research and development concerning marine artificial reefs and challenges in the field are reviewed by William-Seaman (2002). Planning, licensing, and stakeholder consultation in an artificial reef development were done by Sayer and Wilding (2002). Enhancement can play a major role by preventing habitat loss and endangered habitat. An initiative of establishment of artificial reefs may be seen as “rehabilitation” which implies that some of the ecological features of the pre-disturbed reef eco-system are replaced (Pratt, 1994). Recently, there is a development of concepts and techniques for reef rehabilitation, including the submersion of artificial reef structures (Pickering *et al.,* 1998 and Schillak *et al.,* 2001), coral transplantation (Smith and Hughes, 1999) and establishment of low-profile underwater nurseries (Rinkevich and Shafir, 2000). Ammar *et al.* (2000) used a rational strategy for restoration of coral reefs by application of molecular biological tools to select sites for rehabilitation by asexual recruits. Rinkevich and Shafir (2000) has proposed a two step restoration strategy termed gardening of denuded coral reefs, whose central concept is the mariculture of coral recruits in nurseries. Hobbs and Norton (1996) stated that, restoration ecology has been emergent in recent years as an independent discipline, however, it still lacks a solid theoretical background and general guidelines. With regard to coral reef restoration, the goal of the commonly used coral transplantation techniques is to speed up recovery of degrading reefs. The purpose of the present study is to construct a novel innovated and cheep model of artificial reefs

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in such a way that, sediments in areas of high sedimentation rate will be utilized in building the artificial substrate with no further sediment accumulation afterwards, i.e sediments will be used as an advantage rather than being a disadvantage.

MATERIALS AND METHODS

An artificial reef model was designed, the main body of which consists of several steel cylinders (each is 2m long, 3cm diameter and brownish red in colour), which are soldered together to form a gentle slope, a reef flat and a steep slope (Fig. 3, plates 1a, 1b & 1c respectively). However, the gentle slope has an angle of 45^o with both the bottom and the vertical axis. Each of these artificial reef zones has dimensions of 2m X 2m. All the artificially designed reef zones were covered with a layer of plastic meshes overtopped with another layer of metallic ones with a distance of ~ 1cm between them. The plastic mesh is 2mm thick, 1mm pore width and green in colour, while the metallic one is 1mm thick, 0.5 mm pore width and grey in colour. The two meshes were tied firmly all around onto the steel cylinders bordering the meshes, beside being tied together in such a way to have a 1cm thick layer between them. In addition, the two meshes were fixed together both with galvanized steel wires and plastic stripes to avoid being hit together, stressing the transplanted corals. The metallic mesh is used to attract sediment particles beside it helps healing of corals fastly, the plastic mesh is put as a base for settlement of the base of branches and for long term support in case the metallic meshes erode. Separate small pieces of plastic and steel meshes were tested individually, with a space of water column between them and the bottom, to test the long term tolerance of each of them to the salt water and the validity for building the artificial substrate. The artificial reef model was fixed on the bottom with steel bars in March 2004, between the middle and northern reef in front of Hurghada Marine Research Station (Fig. 1), using a fiber glass boat. The unit was put in such a way that currents coming from the north eastern direction to the southwestern direction will not hit any of the reef zones directly, but most of the current energy will pass through a cavity below the unit (Fig. 3). Coral nubbins were fixed into the artificial reef unit in the second day of fixing the unit, this was done by inserting the base of the nubbin into the pore of the metallic mesh, then inserting it further until protruding from the pore of the plastic mesh, the nubbin is then tied firmly to both meshes with a narrow galvanized steel wire.

Four species, (*Stylophora pistillata*, *Acropora granulosa*, *Echinopora gemmacea* and *Montipora spongiosa*) were selected for transplantation. The reason is that they were dominant and surviving well on the seaward side of the nearby reef; therefore, a good donor site for the nubbins of these four species is guaranteed. Sixteen individuals of each species, distributed in two rows, were transplanted in each zone, thus a total of 48 individuals of each species and a total of 192 individuals of all species were transplanted onto the artificial reef unit. The length of nubbins were measured at the beginning of the experiment and monitored after 3 and 9 months to determine the growth rate. The length of nubbins were estimated by measuring the length of the longest vertically oriented branch, starting from the base. Percent survival and mortality were measured after 3 and 9 months. Building the artificial substrate by the attraction between sediments and the metallic meshes was monitored.

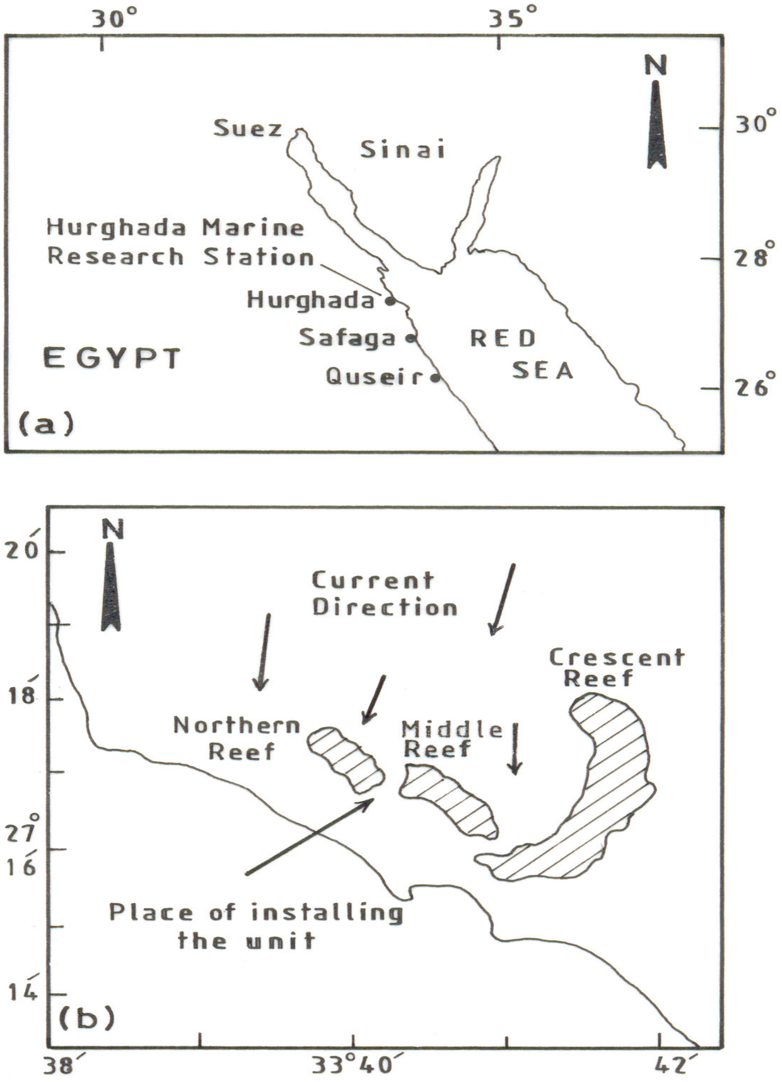

Fig. (1). a) Location map of the studied site on the Red Sea b) Location map for the place of installing the unit.

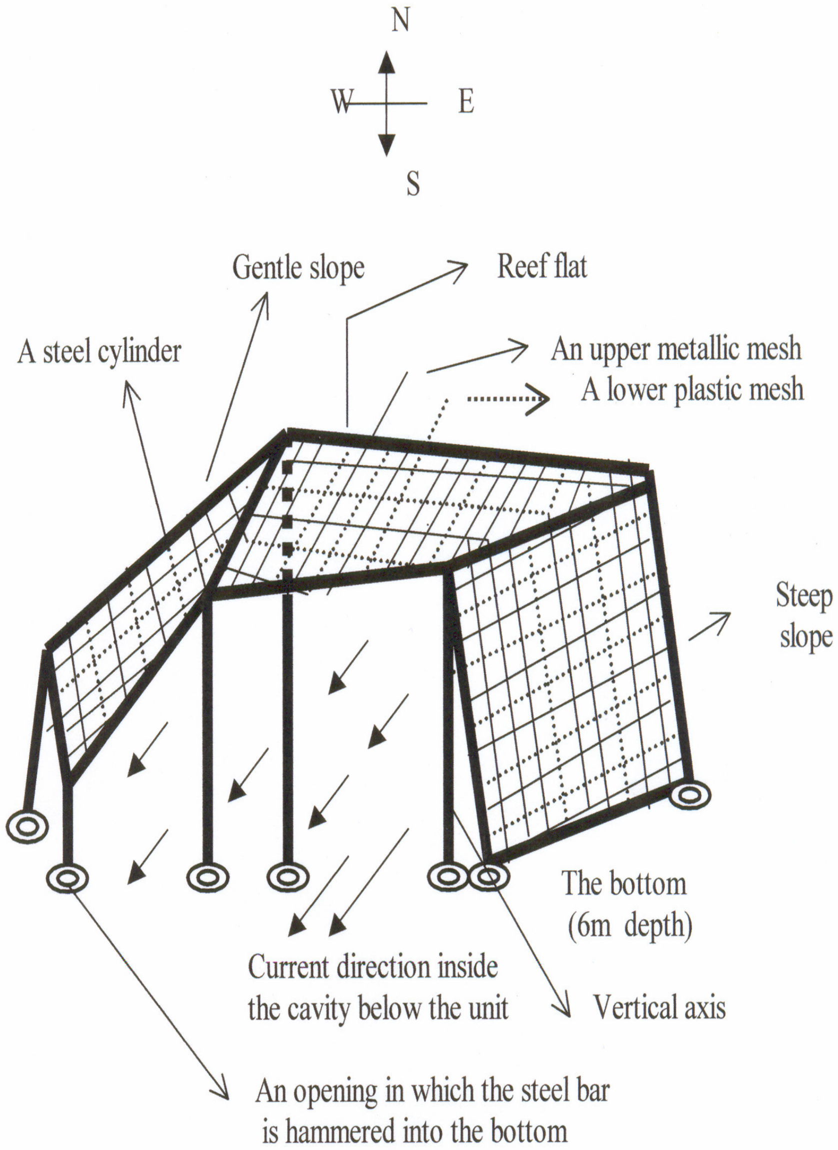

Fig. (3). Diagrammatic representation for the designed artficial Reef model

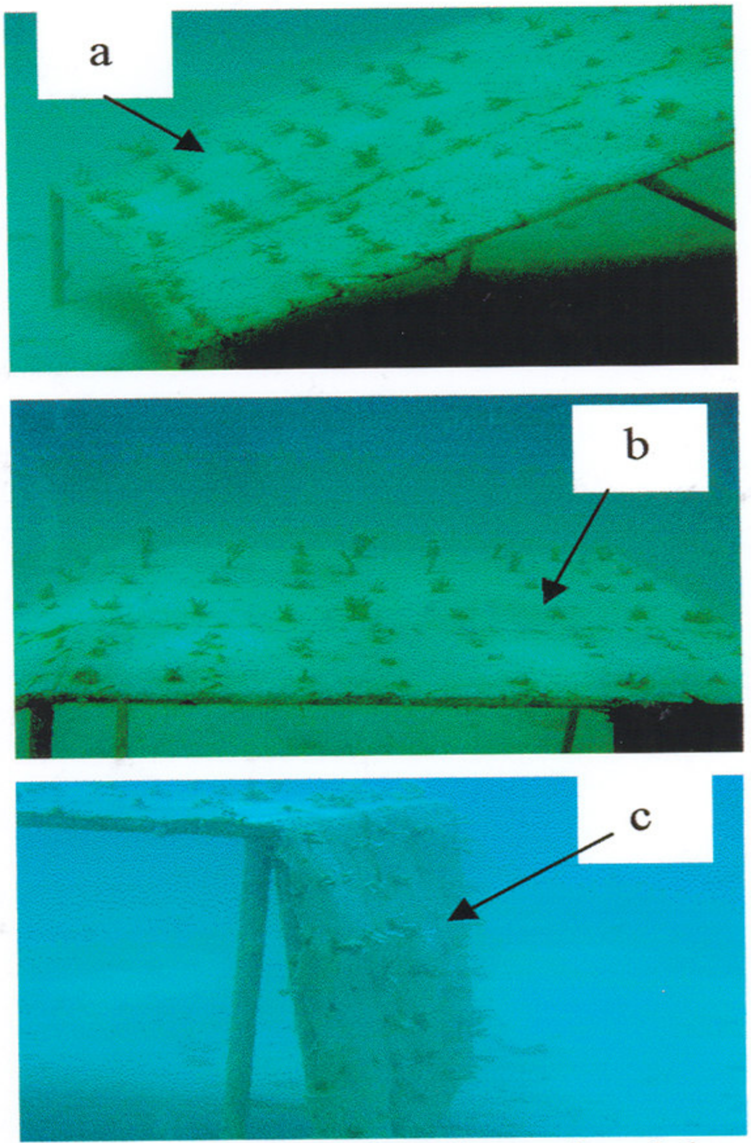

Plate 1. Different orientations of reef slopes, after 6 months of installing the unit a) Gentle slope b) Reef flat c) Steep slope

RESULTS

Building the artificial substrate

Sediments accumulate into the 1 cm thick layer between the two meshes as well as on the surface of the upper metallic mesh. Sediments are better formed on the upper surface of the plastic mesh leading to the formation of the substrate layer "imprisoned" between the two meshes. Trying to wash the sediments from the surfaces of separate test plastic and metallic meshes put on the bottom beside the unit, at regular intervals of 3 weeks, they were washed easily from the plastic meshes but not from the metallic ones. Within a short time (3 months), a substrate layer of a total of ~ 1 cm was formed between the two meshes, this layer increased to ~2 cm after 9 months by being built on both sides of meshes (plates 2 and 3). However, this substrate layer which was similar in thickness in all slope orientations became considerably compact after 9 months, afterwards sediment accumulation considerably decreased and finally stopped. The steel meshes and the galvanized steel wires eroded after 9 months, but the plastic compartments remained tough. No coral juveniles settled on the artificial reef during the first 9 months of building the substrate. However, adult stages of some benthic organisms like bivalves and algae (plate 3) could be able to settle, on the built artificial substrate; besides, adult transplanted coral nubbins expressed high survival rate and considerable budding (plate 3) by the end of the first 9 months of building the substrate.

Growth rates and percent survivals

Growth rates of the transplanted corals after 3 and 9 months are shown in Table (1). On the gentle slope, *Stylophora pistillata* recorded the highest growth rate, both after 3 and 9 months, among the transplanted corals (0.15±0.02 mm/day and 0.11±0.023 mm/day respectively). On the other hand, *Montipora spongiosa* recorded the lowest value after 3 months (0.038±0.007 mm/day) and *Acropora granulosa* recorded the lowest one after 9 months (0.05±0.03 mm/day). Referring to the growth conditions in the other two zones, *Stylophora pistillata* was the most highly growing one on both the reef flat (0.15±0.008, 0.16±0.01 mm/day after 3 and 9 months respectively) and the steep slope after 3 months (0.089±0.01 mm/day). However, *Acropora granulosa* was the most highly growing species on the steep slope after 9 months (0.14±0.06 mm/day), compared to the lowest growing *Montipora spongiosa* after 9 months on the same slope (0.01±0.009 mm/day) (Table 1). Previous field and experimental records of growth rates of the four studied species are shown in Table 2.

Percent survivals of the transplanted corals are shown in Fig. (2). On the gentle slope, each of the two species *Stylophora pistillata* and *Montipora s*pongiosa recorded 100 % survival, both after 3 and 9 months. However, *Acropora granulosa* recorded the lowest survival rate (18.75 %, both after 3 and 9 months respectively). On the reef flat, after 3 months, *Montipora spongiosa* still has 100 % survival, while the lowest survival rate is given by *Acropora granulosa* (43.75%). After 9 months, on the same reef flat, *Stylophora pistillata* has the highest survival rate (93.75%) while *Acropora granulosa* has the lowest one (37.5%). On the steep slope, after 3 months, in a manner similar to that of the reef flat, *Montipora spongiosa* has 100 % survival rate and the other species have considerable survival rates except *Acropora granulosa* (37.5%). After 9 months, *Echinopora gemmacea* recorded the highest survival rate (75.5%) while each of *Acropora granulosa* and *Montipora spongiosa* recorded the lowest values (37.5% each).

Plate 2. Nubbins of *Acropora granulosa* on the steep slope after 9 months of installing the unit, a considerable layer (a) of the substrate is built

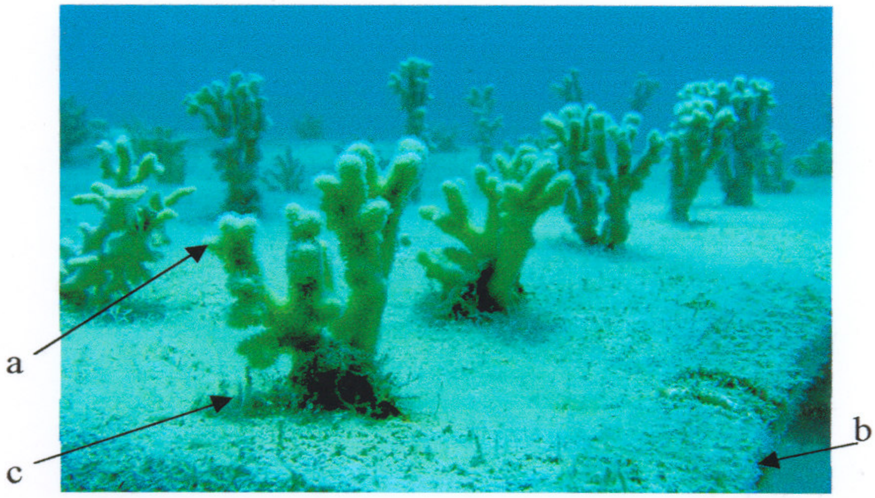

Plate 3. *Stylophora pistillata* on the reef flat after 9 months of installing the unit. (a) New buds at the top of the branches clearly grew. (b) A thick layer of the substrate, built after 9 months of installing the unit. (c) Algae settling on the built substrate

Table 1. Growth rate (mm/day) of the transplanted corals (X`± SE).

Species name	Gentle slope	Reef flat	Steep slope
Stylophora pistillata	* 0.15±0.02	0.15±0.008	0.089±0.01
	# 0.11±0.023	0.16±0.01	0.11±0.01
Acropora granulosa	0.11±0.05	0.05±0.01	0.04±0.019
	0.05±0.03	0.05±0.009	0.14±0.06
Echinopora gemmacea	0.07±0.009	0.029±0.007	0.042±0.0076
	0.09±0.01	0.07±0.02	0.05±0.009
Montipora spongiosa	0.038±0.007	0.052±0.017	0.03±0.005
	0.066±0.009	0.06±0.008	0.01±0.009

* = after 3 months, # = after 9 months

Table 2. Previous field and experimental records of growth rates for the four studied species

Species name	Growth rate	Author	Place of experiment
1- Stylophora pistillata			
fixed without epoxy	0.3 cm/year	Ammar *et al.* (2000)	HMRS, Red Sea
fixed without epoxy	0.5cm/year	Ammar *et al.* (2000)	El-Fanadir, Red Sea
Field observations	6.86mm/year	Mohammed (2003)	HMRS, Red Sea
Field observations	5.9mm/year	Mohammed (2003)	Abu-Galawa, Red Sea
Field observations	5.89mm/year	Mohammed (2003)	El-Fanadir, Red Sea
Field observations	8.95mm/year	Kotb (1996)	South Sinai, Red Sea
Field observations	9.24mm/year	Kotb (2001)	Northern Red Sea
2- Acropora humilis			
fixed without epoxy	0.3 cm/year	Ammar *et al.* (2000)	HMRS, Red Sea
fixed with epoxy	0.7 cm/year	Ammar *et al.* (2000)	HMRS, Red Sea
fixed without epoxy	0.5cm/year	Ammar *et al.* (2000)	El-Fanadir, Red Sea
Field observations	6.86mm/year	Mohammed (2003)	HMRS, Red Sea
Field observations	7.49mm/year	Mohammed (2003)	Abu-Galawa, Red Sea
Field observations	6.87mm/year	Mohammed (2003)	El-Fanadir, Red Sea
Field observations	2-13mm/year	Davies (1989)	Carribbean Sea
3- Montipora spongiosa	X	X	X
4- Echinopora gemmacea	X	X	X

HMRS=Hurghada Marine Research Station, X=not reported in literatures

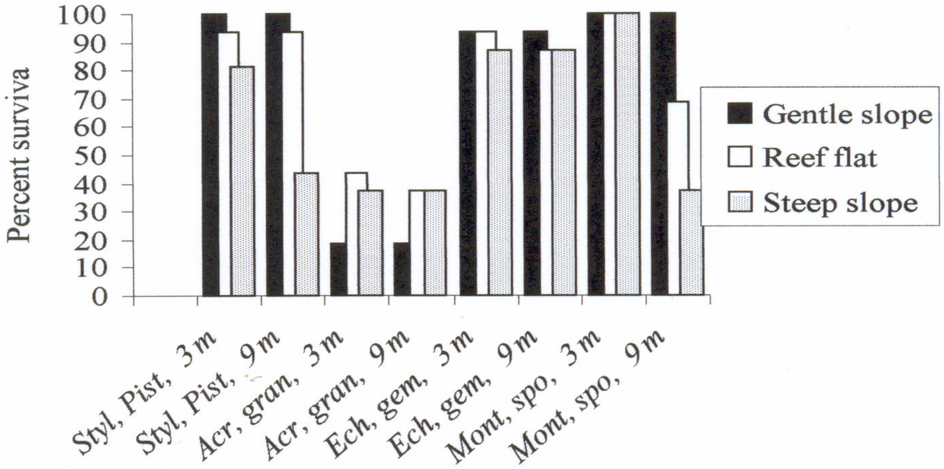

Fig.(2). Percent survival of transplanted coral nubbins. 3m=after 3 months, 9m = after 9 months. *Styl. Pist.* = *Stylophora pistillata*, *Acr. gran.*=*Acropora granulosa*, *Ech. gem.*=*Echinopora gemmacea*, *Mont. spo.* = *Montipora spongiosa*

DISCUSSION

Building the artificial substrate

The artificial reef model was designed and oriented in such a way that, sediments will be utilized as an advantage rather than being a disadvantage. This was accomplished by making a big cavity, instead of the fore reef, below the model, facing the direction of current carrying sediments. Therefore, in contrast to natural reefs, the fore reef will not be facing the current carrying sediments (Aller, 1989). In addition, no back reef (in the direction of current) was designed at the end of the cavity, thus having no foothold for accumulation of the forced sediments upon (Barros *et al.,* 2001). Instead, both reef slopes (the gentle and the steep one) were placed on both sides of the cavity so that the forced current will pass behind them and below the reef flat, therefore coral nubbins on their surfaces will face a little amount of sediments that will not be forced into the cavity. Brander *et al.* (2004) indicated that reef geometry plays a role in the magnitude of wave energy and currents in the reef. Using the two types of meshes, plastic and metallic ones, together was the most successful since testing the plastic meshes alone gave no attraction forces between sediments and mesh surface, while using metallic meshes alone had these meshes being eroded before completion of the substrate, due to the absence of plastic support. The easier removal of sediments from the plastic meshes than from the metallic ones suggest the existance of attraction forces between some charged sediment particles and the steel meshes, indicating the necessity of steel meshes at the beginning to allow accumulation of a compact layer of the substrate. Matgal *et al.* (1998) indicated that, negative charges on the sediment colloides are responsible for cation exchange and the extent to which sediment can act as cation exchanger is expressed as the cation exchange capacity (CEC), helping to attract the sediments to the surface of metals. The similar thickness of the built substrate layers on all forms of slope orientations, disagree with the result of Oren and Benayahu (1997) that, the sedimentation rate is lower on the vertical plates. The reason is the differences in the structural features of both techniques (Perkol-Finkel and Benayahu, 2004). The faster accumulation of sediments in the beginning is due to the attraction forces between some charged sediment particles and the steel meshes beside presence of two mesh layers of narrow openings, that prisoned the sediment particles between them (Matgal *et al.,* 1998). In addition, the solidarity of the formed substrate layer, which has been attained after 9 months, is obtained by two mechanisms. The first one is the mucus secreted by the transplanted corals (Riegl and Branch, 1995) into the accumulated sediments, changing the sediments into a homogenous gelatinous live sediments. The second one is the settlement of benthic organisms (Burgess *et al.,* 2003) that increased the compactness of the substrate layer. The scarce coral larval settlement on the formed artificial substrate during the first 9 months of its building can be explained by the statement of Fabricius *et al.* (2003) that, both sediment composition and short term sediment deposition affect survival of coral juveniles, which has the implications for the capacity of inshore reefs to be recolonised by corals to recover from acute disturbance events. The artificially built substrate may be suitable for coral larval settlement after 9 months of installing the unit due to minimization of further sediment deposition. The possible effect of metallic and plastic meshes on repulsion or attraction of larval stages of corals was not tested in that study as both meshes were completely covered with the substrate.

The erosion of the steel meshes and the galvanized steel wires after 9 months indicates the importance of providing the plastic meshes, below the steel meshes, to provide the long term support for the formed compact substrate. Stopping further accumulation of sediments after 9 months may be due to decreased attraction forces between the superficial sediments and the metallic meshes as the meshes were covered with quite a thick layer of the substrate. Hoitink and Hoekstra (2003) stated that, spatial variation of current amplitudes cause residual sediment transport, largely depending on the availability of erodible sediment, but in case of weak currents, sediment accumulates.

Growth rates and percent survivals

The highest growth rate of the three species *Stylophora pistillata*, *Echinopora gemmacea* and *Montipora spongiosa* on the gentle slope (having a gentle orientation of ~ 45^o) than on the reef flat and the steep slope (having a vertical orientation), indicates that, transplants of these three species grow better when the attaching surface is oriented with a narrower angle than 90^o with the vertical axis. The exception of *Acropora granulosa* (growing better on the reef flat and steep slope) from the previous result lead us to extend the conclusion of Katherine (2003) that, "the spatial recruitment pattern of corals is affected by the orientation of the attaching surface", by adding the phrase "beside being species specific as well". Growth rates of corals of the present study are considered high compared with the previous records of the same species listed in Table (2) after unifying the units of growth rates. This may be due to improving the environment of the current nubbins by transplanting them from a loose sandy substrate into a better and tough one in the artificial reef unit (Ammar, 2001). Growth rate can be also affected by the initial length of the transplanted branch (Oliver *et al.,* 1983), where the longer branches show greater growth. The high survival rate that reached 100% in some coral species, after 9 months, beside the considerably formed substrate and the incredible low cost, recommend the present technique as a good and cheep one for building artificial reefs in comparison with the high costive techniques done by Van Treek and Schuhmacher (1999) and Schillak *et al.* (2001) using electrolysis of seawater to build the substrate. In addition, the result of Sabater and Yap (2002) that, lowest survival rate is found in colonies untreated with electrochemical deposition of

$CaCO_3$ can not be taken as a standard result, as a special artificial reef design, like that of the present study, could provide high survival rate even in areas of high sedimentation rate beside saving the cost of using electrochemical experiments. The highest survivorship of *Stylophora pistillata* nubbins on the gentle slope and the lowest values on the steep (vertical) one of the present shallow artificial reef unit (7m depth), disagree with the result of Oren and Benayahu (1997) that survivorship of *Stylophora pistillata* colonies increased with depth when located on the vertical plates, or on the upper side of the horizontal plates. Perkol-Finkel and Benayahu (2004) stated that, community differences between different artificial reefs are related to the structural stability and age. Mundy (2000), on investigating the effect of differences in depth, settlement plate angle and local topography on the recruitment of corals , found small differences in depth and plate angle among replicate plates. The lowest percent survival of *Acropora granulosa* in all forms of slope orientation, after 3 months, indicates that, this species is highly sensitive to mechanical stress during transplantation. Contrary to that result, fragments of two other species of the same genus (*Acropora muricata* and *A. vaughani*) were not significantly affected by handling during transplantation (Lindhal, 2003). The survival rates of coral transplants of the present experiment (containing steel and plastic meshes on a special model) is higher than those reported by Ammar *et al.* (2000) who attached the nubbins directly on plastic meshes into the dead bottom corals in the same currently used site. This agree with the result of Yap (2004) that, the metal grids as well as live coral tissue apparently provided a favorable substrate for the attached coral fragments than when using the already dead coral colonies as a substrate

CONCLUSIONS

1- A novel and low cost approach of an artificial reef model, having the following main working rules, was designed :

a) Presence of two layers of narrow opening meshes, above each other, help to attract sediments in between until they change into live compact substrate. However, the lower plastic mesh provides the long term support to the erodible metallic one

b) Keeping a considerable space facing the current direction below the transplanting unit, has the advantage of forcing and washing away the non attracted fine particles. In addition, the absence of back reef, facing these washed particles prevents them from finding a suitable foothold to accumulate upon

2- Transplants of the three species *Stylophora pistillata*, *Echinopora gemmacea* and *Montipora spongiosa* grow better when the attaching surface is oriented with less than 90^o with the vertical axis while *Acropora granulosa* grows better on the reef flat and steep slope (narrower angle than that of the gentle slope).

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