Transplantation of coral fragments from ship groundings on electrochemically formed reef structures

H. Schuhmacher1, P. van Treeck1, M. Eisinger1 and M. Paster1

ABSTRACT

Various scleractinians and hydrocorals were investigated with regard to their suitability for transplantation by a novel transplantation technology. Coral fragments produced by ship groundings and other mechanical damages were collected and transplanted onto a steel mesh matrix coated with mineral crusts induced by electrolysis (ERCON technology). Mortality and growth rates were assessed: more than 90% of the fragments survived the first six months. Within this phase all acroporids and Millepora dichotoma developed a strong holdfast at their bases by actively overgrowing the coated grid. Some trials severely suffered from predation by the corallivorous snail Drupella cornus and from a heavy algae bloom in spring 2000. Additionally, different designs of the mesh matrix were tested and bigger reef structures assembled from small modules. Special complex structures could serve as stepping stones thus supporting spontaneous recolonization of degraded areas by stony corals and other benthic biota.

Keywords Transplantation, electrochemical accretion, Artificial reefs, Reef rehabilitation, Recolonization, Coral growth rates, Drupella cornus

Introduction

Coral reefs in the Red Sea are exceptional in not being bordered by deforested land with heavy run off into the sea or by densely populated coastlines; they are – enclosed by deserts – rather unaffected by perturbations such as sedimentation and eutrophication which deteriorate most other reefs in the world. In the last two decades, however, diving tourism, followed by construction activities along the whole Egyptian shoreline has become a major threat to Red Sea reefs. One of the best known diving destinations of the Red Sea are the reefs around the Sinai peninsula including the Ras Mohammed National Park at its southern tip. During high season, up to 400 dive boats invade this area and leave their traces in the reefs. Trampling by reef walkers and snorklers, poorly trained divers, anchoring in coral beds and ship groundings cause mechanical damages resulting in increasing areas of dead rubble (Rieg1 and Velimirov 1991). Additionally, big passenger and cargo ships occasionally hit the reefs in the Straits of Tiran.

Natural recolonization by stony corals of such devastated areas formed by coral gravel is extremely slow most probably due to unstable substrate conditions and high grazing pressure.

We report here about a research project aiming to develop rehabilitation measures for mechanically degraded reef areas with a minimum of environmental harm and interference with living resources. The CONTRAST project (coral gubbin transplantation study) – jointly run with the Egyptian Environmental Affairs Agency (EEAA) and the Ras Mohammed National Park authorities – mainly focuses on the application and further development of an environmentally friendly technology for reef rehabilitation including trials to select suitable coral species for transplantation.

Our approach to rehabilitate leveled unconsolidated dead reef areas includes the provision of artificial colonization substrate for coral larvae. This is most effective when an elevated framed structure is provided. Transplantation of coral nubbins onto these structures will additionally speed up the recolonization process by several years as the uncertainties of larvae arrival and post-settlement risks are overcome. These structures seeded with coral nubbins of different species form small reef entities and could serve as stepping stones for the restoration of degraded areas (Schuhmacher & van Treeck 1998).

Conventional approaches dealing with coral transplantation usually apply methods where broken fragments from donor colonies are fixed in situ by an epoxy glue (Yap et al. 1992) or tied on a transportable base (e.g. ceramic tiles, metal sticks and concrete blocks) before seeding them out in the target area (Heeger and Soto 2000). Risks may stem from sedimentation and from being toppled over by fish especially when the units are small and hardly rising above the surrounding reef profile. Our observations and preliminary experiences in the Northern Gulf of Aqaba showed that erect structures are favorable to “collect” larvae from the water current. Whereas a case study of a coral gravel bed caused by a ship grounding showed that such areas rest unchanged for at least five years, the mast and other superstructures of a ship sunk nearby as tourist attraction were colonized after a few months by dendronephthiid soft corals, synascidians, and other fouling organisms. Principally the same colonization pattern is displayed on the “pyramid”. This is a divers’ attraction off the coast of Eilat, a metal frame construction rising approximately 18 m above the sea bed. Stony corals have not settled in higher abundances on the ship wreck or the “pyramid” and if this occurred, it only did after several years. Thus, material properties of the erect structure have to be considered as well. Structure made of concrete are heavy and difficult to handle and manoeuvre into place (if not just dumped onto the sea bed), and can not be colonized by typical reef endolithes. The same holds true for other artificial reef types such as old tires and other scrap material still

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frequently used as FADs.

We used the ERCON (electrochemical reef construction) technology to form reef structures of various designs and to fix coral fragments thereon (v. Treeck and Schuhmacher 1997). By this method, only a minimum of alien materials is introduced into the marine environment, basically a thin wire matrix serving as a cathode. The mesh structure is strengthened by a cover of calcium carbonate deposited from the sea water by principles of electrolysis. As only low voltage is required to generate the electrical field photo-electric cells are the best choice as regenerative source of power. This method mitigates energy expenses and costs for transport of prefabricated heavy modules and does not add to CO₂ emission as e.g. the production of concrete modules (Hilbertz 1992).

The electrochemically generated crusts successively cement the coral nubbins which are just stuck into the wire mesh thus saving time and material for fixing the nubbins to their substrate. Within this study the coral nubbins were not broken from healthy donor colonies but collected as loose fragments from areas where ship groundings just occurred.

The selection of candidate species for transplantation considered

• vitality, especially hardiness regarding handling,
• regeneration potential, especially at the base of the fragment in order to develop a firm foothold on the wire matrix,
• axial growth potential
• skeleton strength.

Theoretical considerations behind the selection criteria are explained in the discussion (outlook). Practical constraints, of course, were the availability of fragments.

Material and methods

Study site

The experimental site is located at Kashaba beach and at the northern end of the large Bareika Bay north of Ras Mohammed (Fig. 1). The inner end of the bay is exposed to permanent importation of sand and dust, resulting in a comparably low cover of living corals (10-30%). The seabed off Kashaba beach is gently sloping down to about 15 m depth followed by a steeper slope down to a terrace in 40 m dropping further to more than 400 m in the middle of the bay. The shallow seafloor is the continuation of a wadi mouth showing an irregular pattern of sand areas, low coral-/rock-outcrops, and some coral blocks 1-3 m high mainly formed by hydrocorals (*Millepora* sp.) and *Porites* spp.

The site is in the vicinity of the National Park workshop and a set of 40 photo-electric panels was installed nearby. The ERCON installations had to be in reach of 200 m cable length in depths from 5 to 15 m. Apart from logistic reasons the site was chosen as we wanted to test the applicability of the method under realistic conditions for rehabilitation of a stressed coral community.

![Fig. 1 Location of the rehabilitation study site inside the Ras Mohammed National Park (Marsa Bareika).](image1)

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Experimental design

The principle of electrochemical deposition of calcium and – to a lower extent – magnesium minerals on a given template is known (e.g. Hilbertz and et al. 1977, Hilbertz 1981, Schuhmacher and Schillak 1994); the technology to transplant and fix coral nubbins to the new substrate is described by van Treeck and Schuhmacher (1997). We followed these prescribed methods using an steel mesh wire as cathode and a titanium wire net as anode, but the design of the installations was modified: tent- and staircase-like installations of 1.5 m height and 4-5 m length were applied to follow the development of coral transplants. For these experimental trials the roughness of the substrate (mesh with crusts) was enhanced by zigzag folding to reduce the grazing pressure by herbivores (van Treeck et al. 1996). Triangular pyramids (1 m edge length, 1.5 m height) and column-like structures (3 m height) served as modules to be assembled thus forming elevated installations of up to 3 m height. Fabrication of the mesh matrix was done on land; two divers transported the structures onto site. 40 photovoltaic panels were used as power supply to electrify the underwater installations.

![Fig. 2 Sketch of the basic experimental design showing the arrangement of the cathode and anode.](image2)

Fig. 2 Sketch of the basic experimental design showing the arrangement of the cathode and anode.

Coral fragments (hereinafter “nubbins”) used for transplantation derived from sites with recent mechanical breakage by ship groundings or reef tourists (walker, snorkeler, diver). Using scuba diving, we collected the remaining living fragments, transferred them to the study
site and kept them for several days on husbandry trays allowing them to adapt to the new environmental conditions. After the adaptation phase they were, if needed, broken in situ into smaller fragments and transplanted onto the steel matrix by cutting open the grid and inserting them without using additional fixing material. With the exception of the vertical columns all structures were seeded with nubbins. On the staircase-shaped modules we separated the nubbins by species, on other designs such as the tetrahedrons we selected a mix on the basis of the community composition in the proximity of the selected site.

Experiments commenced at the end of August 1999; in May 2000 the second series of structures were submerged. Thus winter and summer characteristics of solar energy supply could be compared. Some modules were – after accretion had been completed – cut off from the electric current.

Results and discussion
Design of the applied installations

The first modules built with the ERCON technology were experimental trials primarily designed to test nubbins for their suitability for transplantation. Due to a massive infestation of the transplants with the corallivorous snail *Drupella cornus* the initial tent-like design (Fig. 3) was modified by mounting the whole structure on rods, thereby significantly reducing predation (Fig. 4).

All transplanted nubbins were regularly checked and measured with a caliper in order to assess mortality and axial growth rates.

After the successful application of these structures in the first phase various new designs were tested. They were developed for several purposes considering local environmental conditions (e.g. higher structures to reach out into the water column, catch larvae and to mitigate sedimentation stress). Some could serve as stepping stones for the reinvasion of benthic fauna into degraded areas (Fig. 6).

Additionally, all these structures are intended to function as components for bigger units. Fig. 5 shows a vertical column-like structure with a puzzled-out mesh.
design, Fig. 6 shows one pyramidal module. After four months of electrochemical accretion four units of the latter design were mounted to a single, three meter high pyramid that was also equipped with crane-like extensions and repeatedly electrified. The new structure now offers a lot of openings and crevices for reef biota. The shape resembles features of coral blocks as recognizable in Fig. 7.

Apart from a significant upscaling the new approach offers an effective method for building bigger units out of smaller, prefabricated units. Structures can be made at a “manufacturing site” and the ready modules transported and assembled at the final location. The small units are much easier to handle and the facilities for their construction and electrochemical coating can be reused several times.

**List of coral tested for transplantation**

In total 15 scleractinian coral species, mainly branching acroporids and 2 hydrocorals were tested for transplantation, (Tab. 1). For further data analyses only the marked species were used as the availability of probes of other species was too low. Furthermore, we compared only data from nubbins which were simultaneously transplanted and grew under the same environmental conditions.

**Status of the coral transplants**

**Environmental conditions and disturbance**

The first phase of our study was characterized by harsh environmental conditions for the transplanted nubbins as water temperatures dropped down below 20°C in winter and corals had to face an extraordinary heavy algae bloom in spring 2000. The bloom of benthic macroalgae (blue-green and filamentous green algae) affected the upper water layers down to approximately 10 m depths partially forming dense mats and covering the reef communities. The weather conditions during this time period were adverse as well: nearly no mixing of the water column occurred as a consequence of very calm winds. Furthermore, a dense population of planktonic algae seemed to cause additional stress by limiting PAR; visibility temporarily dropped below 5 m. Fig. 8 shows a *Millepora dichotoma* nubbin covered with a mix of filamentous green algae and sediment. To prevent further stress on the transplants we moved the experiments from 5m into deeper waters (to 8-10 m, respectively) where the algae bloom was less prominent.

**Table 1 List of coral species used for transplantation**

<table>
<thead>
<tr>
<th>Species</th>
<th>Number of nubbins</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Acropora hemprichi</em></td>
<td>104*</td>
</tr>
<tr>
<td><em>Acropora squarrosa</em></td>
<td>160*</td>
</tr>
<tr>
<td><em>Acropora granulosa</em></td>
<td>99*</td>
</tr>
<tr>
<td><em>Acropora hyacinthus</em></td>
<td>57</td>
</tr>
<tr>
<td><em>Acropora clathrata</em></td>
<td>72*</td>
</tr>
<tr>
<td><em>Acropora digitifera</em></td>
<td>138*</td>
</tr>
<tr>
<td><em>Acropora eurystoma</em></td>
<td>118*</td>
</tr>
<tr>
<td><em>Acropora valida</em></td>
<td>27</td>
</tr>
<tr>
<td><em>Acropora cytherea</em></td>
<td>12</td>
</tr>
<tr>
<td><em>Stylophora pistillata</em></td>
<td>116*</td>
</tr>
<tr>
<td><em>Porites lutea</em></td>
<td>68*</td>
</tr>
<tr>
<td><em>Echinopora gemmacea</em></td>
<td>48</td>
</tr>
<tr>
<td><em>Goniopora sp.</em></td>
<td>8</td>
</tr>
<tr>
<td><em>Pocillopora damicornis</em></td>
<td>27</td>
</tr>
<tr>
<td><em>Hydnophora exaesa</em></td>
<td>7</td>
</tr>
<tr>
<td><em>Millepora dichotoma</em></td>
<td>104*</td>
</tr>
<tr>
<td><em>Millepora exaesa</em></td>
<td>12</td>
</tr>
</tbody>
</table>

Algae blooms in the Northern Red Sea are natural phenomena (Schuhmacher 1973) and known to take place in spring-time when the temperature of upper water layers rise. It seems that the bloom in 2000 has by far exceeded the normal levels and the degree of influence on affected reefs along the whole Sinai coastline (pers. comm. rangers of the Ras Mohammed Park).

Apart from the above-mentioned disturbance some of the transplants severely suffered from infestations with the corallivorous gastropod *Drupella cornus*. Although the installations were regularly checked for infestation, *Drupella* specimens reached the structures and progressively attacked the transplants, especially acroporids. Once infested, the small nubbin is most likely lost within a few hours. Fig. 9 shows an *Acropora*
transplant with several snails. Even if the snails are removed immediately survivorship is unlikely as the transplant is weakened and very susceptible to additional threats such as sedimentation or algae infestation.

![Fig. 9 Acropora digitifera transplant on a husbandry tray highly infested with Drupella cornus (in interstices).](image)

In order to assess population densities of Drupella in the vicinity of the installations we performed a series of line transects. The results will be published later this year (in single Acropora colonies up to 100 specimens were counted). Temporarily high population densities of Drupella cornus in coral reef communities are described by several authors (e.g. Schuhmacher 1992, Al-Moghrabi 1997). Our study site inside Bareika bay however, appears to represent an exceptional position as densities were much higher than those described before and to be observed throughout the year. A big portion of coral mortality in the bay can be explained by the presence of this predator.

Drupella cornus has to be considered as a severe threat for transplantation experiments as individuals seem to be particularly attracted by weakened coral fragments (probably by wounds originating from the fragmentation process itself). Acropora nubbins left on husbandry trays were infested within 3 days and completely eaten after one week whereas neighbouring healthy colonies remained unharmed. Therefore, precaution must be undertaken to limit the accessibility of the installations to the snail. Additionally, all structures with freshly seeded transplants should be very frequently checked for infestation, a task not easily manageable in the field as the snail is mainly nocturnal and is inconspicuous in appearance.

Data presented in the following are exclusively from the second phase of the project (May 2000 - January 2001) where we applied the modified staircase-like design elevated from the sea floor to reduce predation by D. cornus.

Survival and mortality rates

After improving the experimental design the coral nubbins exhibited comparably low mortality rates. Within Millepora dichotoma 97 % of the transplanted nubbins survived the first six months, a high portion of them with a remarkable axial growth (Fig. 10 and Fig. 12). Acropora granulosa and A. hemprichii (Fig. 10) had similar survival rates whereby the higher mortality of the A. hemprichii nubbins can be partially explained by an infestation with Drupella cornus which could not be completely excluded. Most of the dead nubbins had already developed a strong holdfast and suffered later from the predator.

![Status of the Millepora dichotoma nubbins six months after transplantation (n=35)](image)

![Status of the Acropora hemprichii nubbins six months after transplantation (n=33)](image)

![Status of the Acropora granulosa nubbins six months after transplantation (n=42)](image)

![Status of the Porites lutea nubbins six months after transplantation (n=33)](image)

![Fig. 10 Survival and mortality rates of selected species.](image)
Among the Porites lutea nubbins a total of 97 percent were still alive after six months, but only 45% showed an increase in size within this period.

Fig. 11 Acropora hemprichii nubbin with a strong Holdfast development.

All acroporids and Millepora dichotoma showed a very high regeneration potential manifested by the development of a firm proliferating foothold onto the wire matrix by the electrochemical accretion. Hereby, they were not only cemented onto the matrix by the electrochemical accretion. In opposition to it, Stylophora pistillata did not develop such a holdfast at its base; it gets only cemented in the grid by the forming mineral crusts. Mortality rates, however, were comparably low and the nubbins kept on growing. All collected pocilloporid nubbins had died within 3 months after transplantation and were not further used. As already reported by Yap et al. (1992) and confirmed by van Treeck and Schuhmacher (1997) high rates of mortality of Pocillopora transplants might be explained by the fragmentation and transplantation stress.

Axial growth rates

In contrast to other publications on coral growth in the Red Sea Millepora dichotoma exhibited higher growth rates than most of the acroporids within a 6 months trial (average of 11 mm; Fig. 12). Even Millepora exaesa, usually found as encrusting form on reef edges with high turbulence, displayed similar growth rates. We used a fairly uncommon arborescent ecomorph found in deeper water.

Among the acroporids A. hemprichii was the fastest grower with an average increase of 13 mm within 6 months, followed by A. granulosa (8 mm) and A. squarrosa (7 mm). Measurements conducted by Kotb (1996) in the same area showed an annual linear extension of only 9 mm for A. granulosa in 15 m depth. The same pattern holds true for Stylophora pistillata nubbins which exhibited an increase of 7 mm per 6 months in our study compared to the same value per one year in Kotb’s work. The considerable discrepancy to our findings might be explained by his applied staining method for the assessment of growth rates: treatment with Alizarin is suspected of hampering coral growth (pers. comm. G. Lamberts).

Axial growth rates of the Acropora hemprichii nubbins (n=33)

Fig. 12 Average axial growth rates of transplanted coral nubbins.

The massive form Porites lutea grew on average 3 mm within 6 months which is within the range of other data from the Northern Red Sea (e.g. Klein et al. 1993).
The linear extensions within one species (Fig. 13) varied to a great extent. While the average axial growth for *A. hemprichii* was 13 mm in 6 month maximum values of more than 20 mm could be observed.

Natural recruitment

Eight months after setting up the experiments we found the first natural recruits of pocilloporid corals on the staircase-like installations. This is all the more noteworthy as the settlement of these recruits took place while the cathode mesh was still electrified. The development of recruits will be followed further on.

Conclusion

As already shown in previous studies our transplantation method meets some of the major demands for reef rehabilitation: besides the provision of a nature-like substrate with limestone character generated *in situ* the time needed for recolonization is significantly shortened by transplanting scleractinian coral nubbins onto the matrix.

We could identify a spectrum of coral species suitable for transplantation, mainly branched species, but were restricted to material derived from mechanical damages by ship groundings and diving/snorkling activities. Some of the collected nubbins had been covered by sediments up to several days or had rolled down the reef slope which caused a severe stress. Furthermore, the nubbins had to face a severe algae bloom in spring 2000 and grazing pressure by the corallivorous snail *Drupella cornus* so that we could not always clearly identify the primary cause of coral mortality. For future investigations it would be desirable to use unharmed coral fragments and to test additional growth form.

After having put CONTARST into practice it is interesting to check if the theoretical criteria for the selection of nubbins (see introduction) could be sustained and followed under the given conditions:
- Vitality is definitely of paramount importance since stress by transplantation and storage are inevitable if the donor colony is not located close to the transplantation site. *Pocillopora damicornis* turned out to be a poor candidate as its fragments have a drastically reduced life expectancy. All other fragments had successfully overcome the stress from the transport and transplantation process itself and exhibited low mortalities if not affected by *Drupella cornus*. It will be of major importance to follow the hypothesis that stressed and rather moribund corals are especially attractive to this predator.
- Regeneration potential: The function of the fragment’s base is not only to seal the wound left from the breakage and hereby to close an entrance for infections and borers, but is also a prerequisite to develop an enlarged foothold on the wire grid. A living coral foothold may still ensure a stable fixation after continued growth of the colony. *Stylophora pistillata* is a coral surprisingly not developing its own “grip” over the anchoring provided by the electrochemical accretion. Staghorn corals of the *Acropora formosa* or *Acropora nobilis* type (not used here) are other examples of unsuitable candidates from this point of view since their endless terminal growth is accompanied by disintegration of the basal end by tissue decay and bioerosion.
- Fast growth is a factor speeding up the transformation of the artificial setup into a more natural setting with high spacious heterogeneity.
- Skeletal strength varies within wide extremes with branching and foliaceous species ranging at the high and massive species at the bottom end (Hughes 1987). It has to be considered that a hard skeleton will withstand bioerosion much longer than a weak skeleton (e.g. *Goniopora spp.*, *Alveopora spp.*) thus providing hiding place and other ecological functions for a long time span.

Outlook

Up to now methods for large-scale rehabilitation measures are missing. Transplantation of large areas would be costly and therefore impracticable. It might be more promising to investigate methods which significantly support natural recolonization processes. One option could be the creation of stepping stones characterized by stable, spaciously heterogeneous substrates carrying donor colonies transplanted onto these small “protoreefs”. These protoreefs are intended to serve as receiver and provider of coral recruits. In this way, the dispersal of sexual propagules could be enhanced over a large area.

Fig. 14 Formation of a “protoreef” by applying the electrochemical accretion technology

Apart from the application of completely new structures in degraded areas (as demonstrated in this study) single units could be inserted as “reef prostheses” in partially impoverished reefs (Fig. 14.).

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