universität
wien

DIPLOMARBEIT

Titel der Diplomarbeit

Reef Restoration and Rehabilitation
on a Maldivian high-class tourist resort

angestrebter akademischer Grad

Magistra der Naturwissenschaften (Mag. rer.nat.)

Verfasserin / Verfasser:	Verena Wiesbauer
Matrikel-Nummer:	0304171
Studienrichtung (lt. Studienblatt):	Zoologie A439
Betreuerin / Betreuer:	Prof. Dr. Branko Velimirov

Wien, am 10. September 2008

TABLE OF CONTENTS

1 Abstract

Coral reefs are highly productive ecosystems that provide a variety of valuable goods and services, including recreational opportunities. On the high-end 'Huvafen Fushi' resort in the Maldives, an 'Underwater Spa' building required an artificial reef to enhance the view into the island lagoon for hotel guests. In addition, a coral nursery was set up to rehabilitate the damaged house reef of the island which has suffered from the bleaching mortality event in 1998 and recreational pressure since the hotel's operation.
The present study focuses on several methodological issues that could be important for reef managers, especially on tourist resorts. Survival and growth of coral transplants around the Underwater Spa was compared to undisturbed colonies on the island's house reef. No difference in growth could be recorded for Acroporidae, whereas Pocilloporidae seemed to grow faster at the control side. Within one year, the artificial reef, based on biogenic rock material and concrete, provided habitat for a diversity of fishes and benthic organisms. On the coral nursery, survival was 90,1% after nine months and the highest mortality was recorded within the first two weeks of the project.
Huvafen Fushi decided to employ a resident marine biologist which turned out to be successful in terms of snorkelling revenue (60.000 USD in 2007/08, compared to only 42.000 in 2006/07). Whereas the majority of guests on this island did not know what a coral is before the project started, we can assume that in the following year, over 900 tourists left the island with knowledge about coral reefs and how to behave in them.
Thus, this paper combines marine biology and tourism and tries to offer guidelines for a sustainable management on a Maldivian tourist resort.

Korallenriffe sind hochproduktive Ökosysteme und versorgen uns nicht nur mit wertvollen Gütern, sondern haben auch einen sehr hohen Erholungswert. Ein künstliches Riff wurde um den 'Unterwasser Spa' des Luxusresorts 'Huvafen Fushi' gebaut, um den Hotelgästen eine interessante Sicht in die Insellagune zu bieten. Da das inseleigene Hausriff sehr unter der Korallenmortalität im Jahre 1998 und dem Druck der Touristen gelitten hatte, wurde eine Korallenfarm errichtet, um das zerstörte Riff zu rehabilitieren. Die vorliegende Studie richtet ihren Schwerpunkt auf verschiedene methodische Ansätze, die für Riffmanager, besonders auf Ferienanlagen, interessant sein könnte. Das Überleben und Wachstum der Korallentransplantate wurde mit einer Kontrollgruppe von am Hausriff befindlichen ungestörten Kolonien verglichen. Es wurde kein Unterschied im Wachstum für Acroporidae festgestellt, während Pocilloporidae am Hausriff schneller zu wachsen schienen. Bereits innerhalb eines Jahres diente das künstliche

Riff, welches biogenem Gestein und Beton aufwuchs, einer Diversität von Fischen und benthischen Organismen. In der Korallenfarm betrug das Überleben der Stecklinge nach neun Monaten 90,1% - wobei die höchste Mortalität in den ersten beiden Wochen nach Beginn des Projektes zu verzeichnen war.

Huvafen Fushi entschied sich auch dafür, eine Meeresbiologin auf der Insel anzustellen, was sich in Bezug auf die Einnahmen aus den Schnorcheltouren als Erfolg herausstellte (60.000 USD in 2007/08, verglichen mit nur 42.000 in 2006/07). Während die Mehrheit der Gäste vor Beginn des Projektes nicht wusste, was eine Koralle denn wirklich sei, können wir davon ausgehen, dass nach einem Jahr 900 Touristen die Insel mit einem Wissen über Korallenriffe, und über richtiges Verhalten in diesen, verlassen haben.

Somit vereint diese Arbeit Meeresbiologie mit Tourismus und versucht, Richtlinien für ein nachhaltiges Management auf einer maledivischen Touristeninsel zu geben.

2 Introduction

Coral reefs belong to the most productive ecosystems on this planet (Precht and Robbart 2006), providing habitat for numerous species and serving important ecological functions, including essential coastal sea defence, fisheries and tourism.

The socio-economic benefits of coral reefs are recognized; although it is almost impossible to value something invaluable like coral reefs.

One approach is described in Cesar 2000, who suggests that the value of coral reefs can be estimated by their 'Effect on Production' (mainly applies to tourism and fisheries), by the 'Replacement Costs' (cost of replacing the coral reef with protective constructions), the 'Damage Costs' (the damage to property and infrastructure in the absence of coastal protection), the 'Travel Costs' (travel time or travel costs used as an indicator for a person's willingness to pay for visiting a park) and the 'Contingent Valuation Method', which tries to obtain information on consumers' preferences by posing direct questions about willingness to pay and/or willingness to accept.

Financial gains from coral reef tourism can range from US$ 2 million per year for the tiny 11 km^2 Caribbean Island of Saba (see Fernandes 1995 for valuation techniques), to the US$ 682 million gained in 1991 – 1992 from tourists to the Great Barrier Reef, Australia (see Driml 1994 for valuation techniques). The reefs of southeast Florida, alone, are deemed to have an asset value of $7.6 billion (see Johns 2001 for valuation techniques).

2.1 An ecosystem under siege

Businesses based near reefs create millions of jobs and contribute billions of dollars in tourism-dependent revenue annually to the world's coastal regions. Therefore, sustaining this industry that generates so much money is dependent on maintaining existing reefs and rehabilitating the lost splendour of this fragile ecosystem. Nevertheless, present-day coral reefs are subject to many forces, both natural and human-induced, that severely damage coral communities and lead to rapid degradation (Epstein *et al.* 2001, 2003; Bellwood *et al.* 2004; Wilkinson 2004; Quinn and Kojis 2006). Over-harvesting (e.g. Jackson *et al.* 2001), pollution (Williams *et al.* 2002, McCulloch *et al*. 2003), disease and climate change (Harvell *et al.* 2002) are just some examples of stresses to coral reefs that have exceeded their regenerative capacity, causing dramatic shifts in species composition and resulting in severe economic loss for fisheries and tourism (Bellwood *et al.* 2004). Estimates in Wilkinson (2004) are that 20% of the world's coral reefs have been effectively destroyed and show no immediate prospects of recovery, whereas 24% of the world's reefs are under imminent risk of collapse through human pressures. In the latest assessments of 845 zooxanthellate reef-building corals species using the IUCN Red List criteria, one third of the species that could be assigned conservation status (n=704) are now in categories with elevated risk of extinction (Carpenter *et al.* 2008).

In the Republic of Maldives, almost all shallow reefs in the central and northern atolls have been slowly recovering following the widespread, temperature-induced coral bleaching and mortality event of 1998. However, the typical house reefs which lie adjacent to resort islands remain subject to a number of localised physical impacts from tourism activities, including reef flat walking, swimming, snorkelling, boating and SCUBA diving (LaMer 2008).

Intuitively, damage directly due to recreational use would seem small compared to dredging, coral mining and natural disturbance, but in fact it is chronic and highly concentrated. Technical advances in equipment in addition to a rising interest in nature, conservation and environmental matters have resulted in the increased popularity of coral reef recreation, particularly SCUBA diving (Barker and Roberts 2004). Signs of diver damage such as broken coral fragments and dead, re-attached and abraded corals have been reported at heavily used dive sites throughout the Caribbean, the Red Sea and Australia (Muthiga and McClanahan 1997, Hawkins *et al.* 1999, Tratalos and Austin 2001, Zakai and Chadwick-Furman 2002). Allison (1996) showed that the distribution of broken corals on a Maldivian tourist resort, Kurumba Maldives (Vihamanaafushi Island), was positively correlated with snorkelling activity and no other likely source of damage was observed.

2.2 Reef restoration and rehabilitation

Especially small countries with an economic dependence on coral reefs like the Maldives are suffering under the worldwide decline, which has prompted greater attention to remediation and restoration activities. Efforts to rehabilitate or restore the ecological functions of coral reefs vary from the expensive deployment of artificial structures (e.g. Edwards and Clark 1992, Chua and Chou 1994, Clark and Edwards 1994 and 1995, Oren and Benayahu 1997, Clark and Edwards 1999, Jaap 2000), over the electrochemical deposition of $CaCO_3$ (e.g. Hilbertz 1979, Sabater and Yap 2002) to simple coral culturing activities (e.g. Franklin *et al.* 1998; Lindahl 1998, Yap *et al.* 1998, Shafir *et al.* 2006), depending upon the spatial scale and the logistic potential of the specific countries. In general, coral transplantation serves as a catalyst for recovery by increasing the live coral cover and topographic complexity on a reef. Other activities involve sexual reproduction and larval recruitment to initiate recovery (e.g. Rinkevich 1995, Morse and Morse 1996; Oren and Benayahu 1997).

However, the first question in reef restoration management procedure should always be: Was there a coral reef at the site where restoration efforts should be applied? If there has never been a reef there it is probably best to not create one as the environment (abiotic conditions) may not support a coral reef community. In our case, which is an island lagoon, there had never been a reef before, though larval recruitment in this area was high, which could be observed on artificial structures. The reason for this unusual site selection and the justification for the above question was an underwater recreation building, a Spa (herein after referred to as the Underwater Spa), which was visited by tourists every day. There was a considerable demand for an artificial reef around it to be aesthetically pleasing from the moment it would be first deployed.

Therefore, for this particular location we cannot talk about "restoration" (i.e. returning to pre-disturbance condition, see Pratt 1994) or "rehabilitation" (i.e. the re-establishment of selected ecological attributes, see Pratt 1994) in the sense that we returned a coral reef back to its original condition, rather than "creating" a new topographically complex habitat with fishes and invertebrates for visitors.

Nevertheless, the island's house reef indeed required true rehabilitation techniques after the causative agents of destruction, primarily high sedimentation rates due to renovation works and snorkelling damage, had been removed. The reef condition in terms of live coral cover at the proposed transplant area was poor (5,15% ± 4,0 (mean ± SE)), compared to a control site only a few hundred meters further away (28,9% ± 4,0 (mean ± SE)), confirming the requirement for the reef recovery enhancement effort (La Mer 2008). A coral nursery was considered to be ideal to provide continuous supply of coral nubbins grown under nursery conditions to eventually enhance the existing coral density and growth. Depending on the species (e.g. branching Acroporids) second generation fragments (nubbins) can be prepared from the primary transplant within a few months.

The poor condition of the house reef was largely due to unsuitable reef substratum (e.g. rubble and rocks with algal turfs) which was not appropriate for successful coral larval settlement. A head start of coral juveniles is likely to be more successful in competing with algae and other stressors. In addition, the coral would be embedded to the reef substratum providing a strong holdfast unlike a coral recruit settling on a piece of rubble which is more likely to roll over due to currents and wave action stressing the naturally settled coral larvae.

In contrast to most investigations dealing with one of the above restoration approaches only, we applied different methods of reef rehabilitation in one special location due to its different requirements. We combined them with a compulsory education of tourists because we believe that a large-scale development can only be achieved if the agents of reef degradation have been permanently removed from the impacted area.

Here we report the steps for the construction of an artificial reef - a submarine structure that would resist currents and waves, set up flow fields that are attractive to both juvenile and adult fishes and may enhance coral settlement. This artificial reef was colonized by transplantation of whole coral colonies and loose coral fragments. In addition, to enhance the coral cover of the house reef, a coral nursery was established in the island lagoon of the luxurious Huvafen Fushi Resort in the western North Male' Atoll, Maldives. The evolution of the project was followed for one year to monitor attachment, survival and growth of the corals.

3 Materials and methods

3.1 Study site

The site selected for rehabilitation experiments was Nakatchafushi Island, located in the North Male' atoll approximately 15 km north-west of the capital Male' (4°22'05''N 73°22'14''E, Fig. 1).

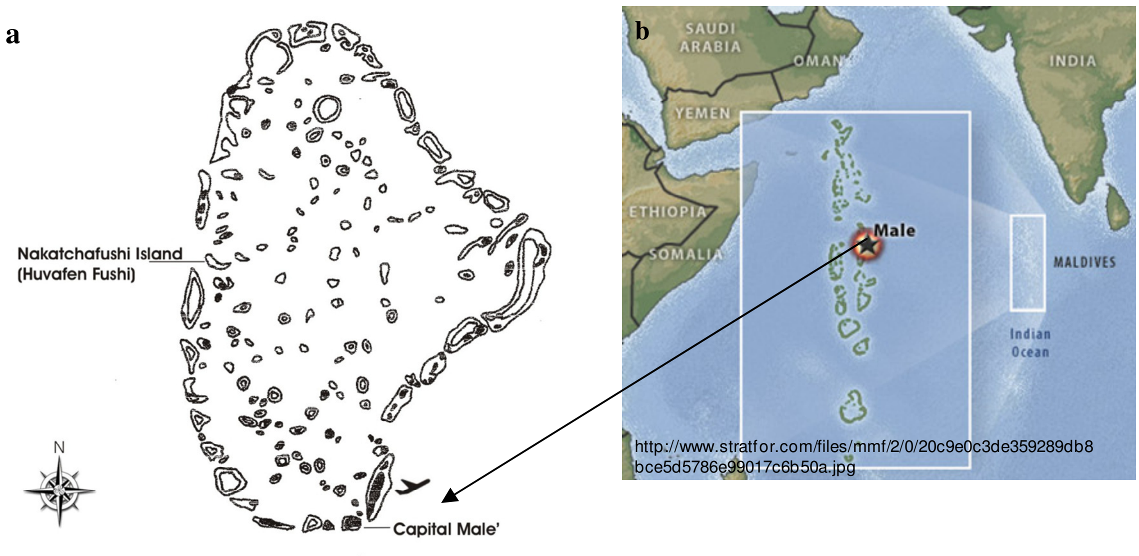


Figure 1. a Map of the island's location in the Indian Ocean. *Arrow* indicates the capital Male' (modified after Clark and Edwards 1999). **b** North Male' Atoll (Kaafu Atoll). Nakatchafushi Island is located 15km north-west of the capital Male'. Source: http://www.stratfor.com

The northern side of the island with its deep lagoon (average 10m, La Mer 2008) was used as a harbour for transfer vessels and diving boats. An aerial view of the island with its associated structures is given in Figure 2.

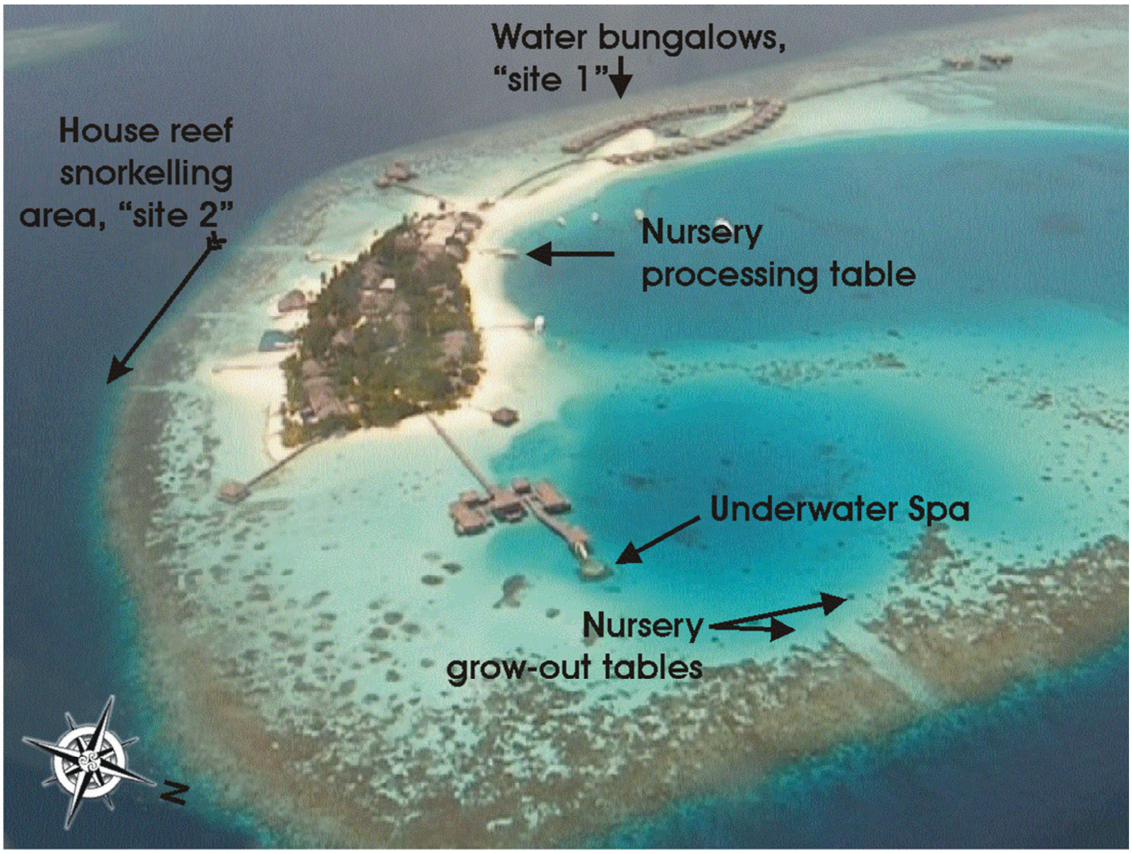


Figure 2. Aerial view of Nakatchafushi island (Huvafen Fushi Resort). Relevant areas for the study are marked with arrows

The island, previously known as "Nakatchafushi Island Resort", re-opened as the luxurious "Huvafen Fushi Maldives" resort in July 2004, managed by PerAquum Pvt. Ltd. This company is a subsidiary of Universal Enterprises Ltd, which is one of the leading resort operators in the Maldives and the Seychelles and has pioneered the tourism industry in the Maldives.

Besides 16 over-water villas and an over-water gymnasium, the renovated island's highlight was the world's first "Underwater Spa" (LIME Spas) – a construction built into the near-shore lagoon in 1,2 (top) - 4m (bottom) depth, offering two double rooms and one separate relaxation area for the guests (Fig. 3). Not only did this unique building serve as a treatment room for massages inside of it, but it also offered larvae of benthic marine biota a substratum to settle on the outside wall, and a marine biologist an ideal place for observations.

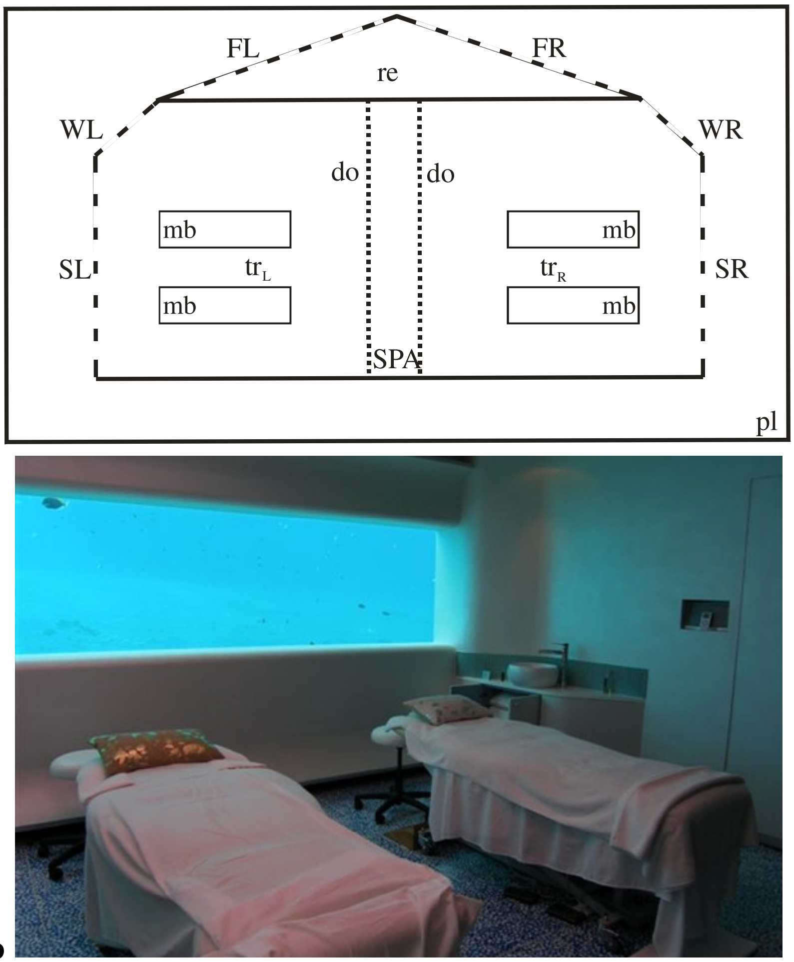


Figure 3. The Underwater Spa. **a** Drawing (top view) of the building with its three rooms and six windows (dashed lines). **b** Right treatment room before the artificial reef was built. do … door (dotted line); FL … left window front; FR … right window front; mb ... massage bed; pl … platform in 4m depth; re … relaxing area; SL … big window left side; SR … big window right side; SPA ... the building; tr_L … Treatment room left; tr_R ... Treatment room right; WL ... small window left side; WR … small window right side

3.2 Requested conditions for the establishment of an artificial reef

It was one aim of the present study to create an aesthetic view of the "ecosystem sea" for the resort guests who came to visit the Underwater Spa, i.e. to build up an artificial coral reef which provided habitat for a number of fishes and invertebrates.

The establishment of topographic complexity and appropriate substratum was a major aspect of restoration, as these factors affect both coral recruitment and fish abundance (Miller *et al.* 1993). Coral larvae require specific substratum and environmental conditions for settlement (see Petersen and Tollrian 2001 for references). Surfaces that have a higher spatial complexity and rugosity are more suitable for recruitment and survival for biota (Spieler *et al.* 2001). Moreover, coral cover is directly related to fish abundance (Bell and Galzin 1984), and topographic complexity shows positive correlation with reef fish diversity and abundance (see Spieler *et al.* 2001 for references). This positive relationship occurs because topographic complexity and epifauna (corals, alcyonarians, sponges, etc.) provide shelter and food resources for reef fish (Bell and Galzin 1984). Lack of herbivorous fish may inhibit the recovery of a reef because coral recruits depend upon herbivory to reduce algal cover (Hughes 1994). The selection of a substratum appropriate for coral recruitment is vital when restoring topographic complexity (Lirman and Miller 2004). Researchers have established that limestone and concrete, the most common materials employed to re-establish three-dimensional relief, are appropriate materials for coral recruitment (Jaap 1998, Miller *et al.* 1993).

3.3 The Artificial Reef

3.3.1 The construction of an artificial reef - the "Spaquarium"

Based on these findings, four three-dimensional concrete structures, designed as massive three-step elements that allowed a continuous water-flow through the steps, were built on the island. Each element comprised of 9 heavy components: 6 vertical supporting stands (70 x 40cm, 100 x 40cm and 130 x 40cm, on each side) that carried 3 horizontal elements (120 x 40 cm) (Fig. 4). These components were assembled on the beach and tied through the lagoon by a diving boat. Each element was carefully lowered and placed along the right window (herein after referred to as 'SR') on the platform (Fig. 3) the Spa was situated on. A distance of about 50 – 70 cm between the window and the lowest level of the concrete structure was kept clear in order to leave space for a diver to remove algae cover from the Spa's windows.

The artificial reef along the remaining length (five windows) of the Underwater Spa was built differently. There it was decided to bring the reef up to the height of the window (approximately 1m above the steel platform) by biogenic material, i.e. loose dead coral colonies instead of the massive concrete structures. In a second step undertaken within two weeks in August 2007, this reef basis was extended to the front side and on the left side, resulting in a more natural appearance. At last, two concrete structures, each comprising two horizontal steps, replaced the bio-rock basis created in February along half the length of the left window.

In front of the Spa's relaxing area (Window 'FR' and Window 'FL', Fig. 3a) another wall (8m x 2m x 1m) and a patch (1m x 2m x 1m) were built up by dead coral rocks. The wall was located in a four meters' distance from the windows in order to create a hopefully busy fish life for the guests to observe when relaxing after their treatments.

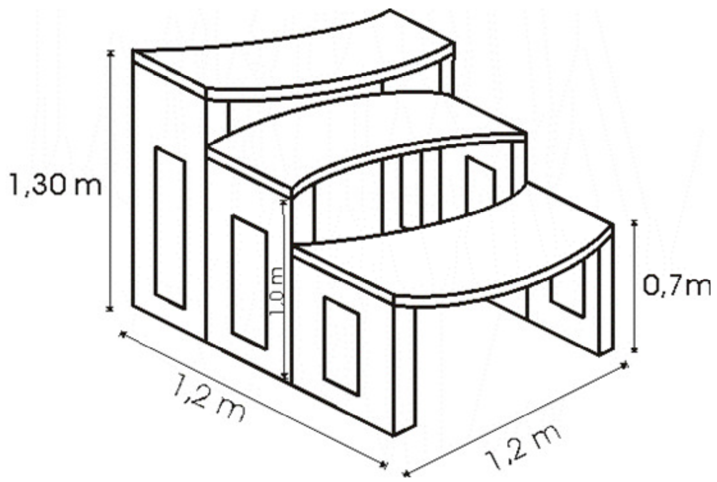


Figure 4. Component of the artificial reef, a massive concrete structure with three horizontal elements

3.3.2 Coral colony transplantation

Corals for the transplantation were brought in from about 30 to max. 100m distance around the Underwater Spa and adjacent coral patches by snorkelling and SCUBA, keeping the animals under water during the whole transportation. The collection and handling of corals were undertaken only by the resident and foreign marine biologists. Keeping damage to reef areas as little as possible, we focused primarily on colonies and fragments partly smothered by sand in the lagoon in close vicinity to the Spa. These corals have been collected during the construction of the building (A. Shareef, personal communication), and we assumed that they would not have survived for many more seasons due to the mobility of the sand in this area. The species composition of these half-buried corals (mainly *Porites sp.* and *Pocillopora pistillata* heads) suited ideally to create a living front line (closest to the Spa windows) to the artificial reef. Due to the weight and shape of these heavy, massive corals there was no need to cement them onto the dead coral rock foundation; their dead limestone bases were just wedged firmly into crevices.

Another source of live corals and fragments was composed of broken-off branching and tabular corals that were found within a maximum swimming distance of 100 meters from the resort's inshore house reef. These corals were damaged mainly due to heavy wave action in combination with their instable substratum (rubble). The selection of corals was determined by the requirements for colourful, fast growing species that would sit on top of the ready-made dead coral rock fundament around the Underwater Spa. High coloration is a guaranteed aesthetic success, and transplanting can quickly infuse a reef with colour. Naturalness, non-repetitive topography and diversity and abundance of species are high on the list of visitor wishes. Familiar species, such as *Acropora spp*. corals, are also key ingredients to the mix of an ecosystem visitors will perceive as healthy and attractive. Some researchers suggest that branching coral species are preferable for the use in transplantation in low-energy areas because they are rapid growers and can quickly increase coral cover and generate conditions that are favourable for recruits (Lindahl 1998 and 1999). Throughout the world, fast-recruiting, fast-growing coral species tend to be the first hermatypic corals to form a canopy over disturbed reef surfaces in shallow waters (less than 20m depth). This list is dominated by branching and foliaceous members of the families Acroporidae, Pocilloporidae and Agariciidae. But branching corals are also highly vulnerable to a suite of transient disturbances, so the community had to be balanced by species with foliaceous, columnar and massive growth forms.

Many of the digitate, arborescent or hispidose corals (Pocilloporids, Acroporids) that created a shelter for other reef organisms were carefully brought in with their harboured fishes, mainly schools of *Chromis viridis* and *Dascyllus aruanus*. A minority of whole coral colonies was removed from reef patches using hammer and chisel.

Finally, our choice was that on the right side of the Spa ('SR'), 60% of the transplanted colonies would consist of various *Acropora sp.* species, whereas 40% would consist of *Pocillopora sp.*, Poritidae and corals of other families. On the left side (herein after referred to as 'SL'), two two-level structures would be filled with 64% Acroporids and to 36% with corals of other families. A list of the coral composition used for the concrete structures on the right and left side is given in Table 1.

Table 1. List of corals used for transplantation to the concrete structures on 'SL' and 'SR'

Structures left ("Side left SL")		
Family	**Species**	**% of all colonies**
Acroporidae	*Acropora sp.*	63,8
Poritidae	*Goniopora sp., Porites sp.*	12,7
Faviidae	*Favia sp., Platygyra sp., Leptoria sp., Diploastrea heliopora*	5,8
Alcyoniidae	*Sarcophyton sp.*	5,4
Mussidae	*Lobophyllia sp., Symphyllia sp.*	4,5
Pocilloporidae	*Pocillopora sp.*	3,1
Tridacnidae	*Tridacna sp.*	1,9
Scleractinia	not identified	1,8
Oculinidae	*Galaxea fascicularis*	1,6
Agariciidae	*Pavona sp., Gardineroseris planulata*	1,4
Dendrophyliidae	*Turbinaria sp.*	1,4

Structures right ("Side right SR")		
Family	**Species**	**% of all colonies**
Acroporidae	*Acropora sp.*	60,7
Pocilloporidae	*Pocillopora sp.*	8,7
Poritidae	*Goniopora sp., Porites sp.*	8,7
Faviidae	*Favia sp., Goniastrea sp., Platygyra sp., Favites sp., Leptoria sp.*	7,1
Scleractinia	not identified	5,9
Fungiidae	*Fungia sp.* or *Cycloseris sp.*	2,9
Stichodactylidae	*Heteractis magnifica*	2,1
Tridacnidae	*Tridacna sp.*	2,1
Alcyoniidae	*Sinularia sp. ?, Sarcophyton sp.*	2,1
Mussidae	*Lobophyllia sp.*	1,9
Helioporidae	*Heliopora coerulea*	1,0

At first, whole coral colonies were directly transplanted onto the concrete shelves. However, this result did not please the management of the island because the concrete structures could still be seen, so we renovated the shelves by equipping them with biogenic rock first, which served as a fundament for the artificial reef, filled gaps and covered edges. As on the right (southern) side there was a greater possibility for corals to get dislocated due to a slightly greater wave action and their exposition on the concrete shelves, some of the light, branching instable colonies were cemented with their bases to the substratum, using the quick-setting hydraulic MAXPLUG® cement (Drizoro Construction Products). This step was undertaken by the marine biologist with the help of qualified and specially trained SCUBA divers among the resort's local staff and expatriates in April 2007.

3.3.3 Monitoring the artificial reef

For the monitoring of the artificial reef, 10 Pocilloporids and 10 Acroporids were chosen from among the transplanted corals both at 'Window left' and 'Window right' (herein after referred to as 'WL' and 'WR', Fig. 3a) in 3,5m depth, and marked with a number fixed with a cable tie. Every 7 weeks, their perimeters were recorded using a flexible measuring tape, and every 3 weeks their survival was monitored using an Olympus C-7070 Widezoom digital camera (7 million pixels). In addition, 10 recruits (*Pocillopora sp.*) which were growing on the Spa steel structure or on the pillars behind the Spa, respectively, were monitored in the same way. The remaining artificial reef around the Spa was monitored by qualitative photo documentation.
As a control side for growth monitoring we had chosen the island's house reef on its southern side along part of a snorkel trail (Fig. 2, "site 2"); a distance of 25m between 2,8m - 4,5m depth. 10 Pocilloporids, 10 Acroporids and 10 young Acroporids were marked with numbers and cable ties and monitored for their survival and growth rate in the same way.
As the growth of the Acroporids and Pocilloporids can be approximated by a negative exponential function (see Results Fig. 10a and b), we categorized small colonies with a fast relative increase in perimeter size as "young" transplants/non-transplants, and bigger colonies that relatively grow slower over time as "adults". An arbitrary line was drawn approximately through the middle of the negative slopes at an initial perimeter size of 40cm, separating the colonies into a "young" and an "adult" group, which were then compared accordingly.
At 'SL' and 'SR', where the concrete structures had been put under water, the reef was monitored for mortality/survival of the transplants and overall health, using the above digital camera. The photos taken of 'SR' (Fig. 8a and b) were put together creating a panorama photo by using the software HP Photosmart Premier 6.0 (Hewlett-Packard Co.).
The whole underwater work, from the placement of the biogenic material to the concrete structures, was undertaken snorkelling and using recreational SCUBA-gear.

To measure and compare the surface areas of the corals, the software CPCe (Coral Point Count with excel extensions, Kevin Kohler) was used. Corel Draw11 (Corel Graphics Suite) aided in photo editing, and with the software STATISTICA 6.0 (StatSoft Inc.) we could undertake the statistical analysis for growth comparisons.

3.3.4 Fish count

In comparison with true rehabilitation or restoration projects, we cannot evaluate "success" by whether the ecological functions of a system have been restored, as we created an artificial reef where there hadn't been one before. In fact, many structural attributes, such as species diversity, become indicators of function when monitored over time. Therefore, we considered the abundance and diversity of dominated reef-associated fishes that inhabited the artificially created reef as an indicator for success of the project over a period of one year.

The fish species were chosen based on their functional association in their reef habitat - herbivores (Scaridae, Acanthuridae), corallivores (Chaetodontidae) and omnivores (Pomacentridae, Labridae etc.). These were checked for their occurrence, abundance and diversity between 9:00 am and 3:00 pm from the inside of the Spa (in front of 'WR' and 'WL') for five minutes each. Newcomers were registered whenever they appeared. Statistical analysis was undertaken using STATISTICA 6.0 (StatSoft Inc.).

3.4 The Coral Nursery

3.4.1 Components of the coral nursery equipment set

A coral processing table and a supporting frame were built for maintaining a total operating weight of 400 kg on the service jetty of the island and are shown in Figure 5a. The table was a simple construction, using GRP (glass-reinforced plastic) laid over a frame of 5-6 mm exterior-grade ply sheet, and coated with a transparent food-grade epoxy resin gel coat. The sturdy supporting frame was a stout timber assembly, with legs of sufficient height to provide a comfortable and safe working level above the deck of the jetty. In order for the corals not to be exposed to direct sunlight while working, we used a protective umbrella; additionally the processing table was covered with two separate wooden frames stringed with a non-transparent plastic material whenever no work was conducted. A 240 V portable generator and a submersible pump (3 m lift;

2000 litres per hour) provided a continuous flow of seawater to the processing table. Running water was fed via a series of pipes. The schematics of water delivery and drainage to the processing table are shown in Figure 6.

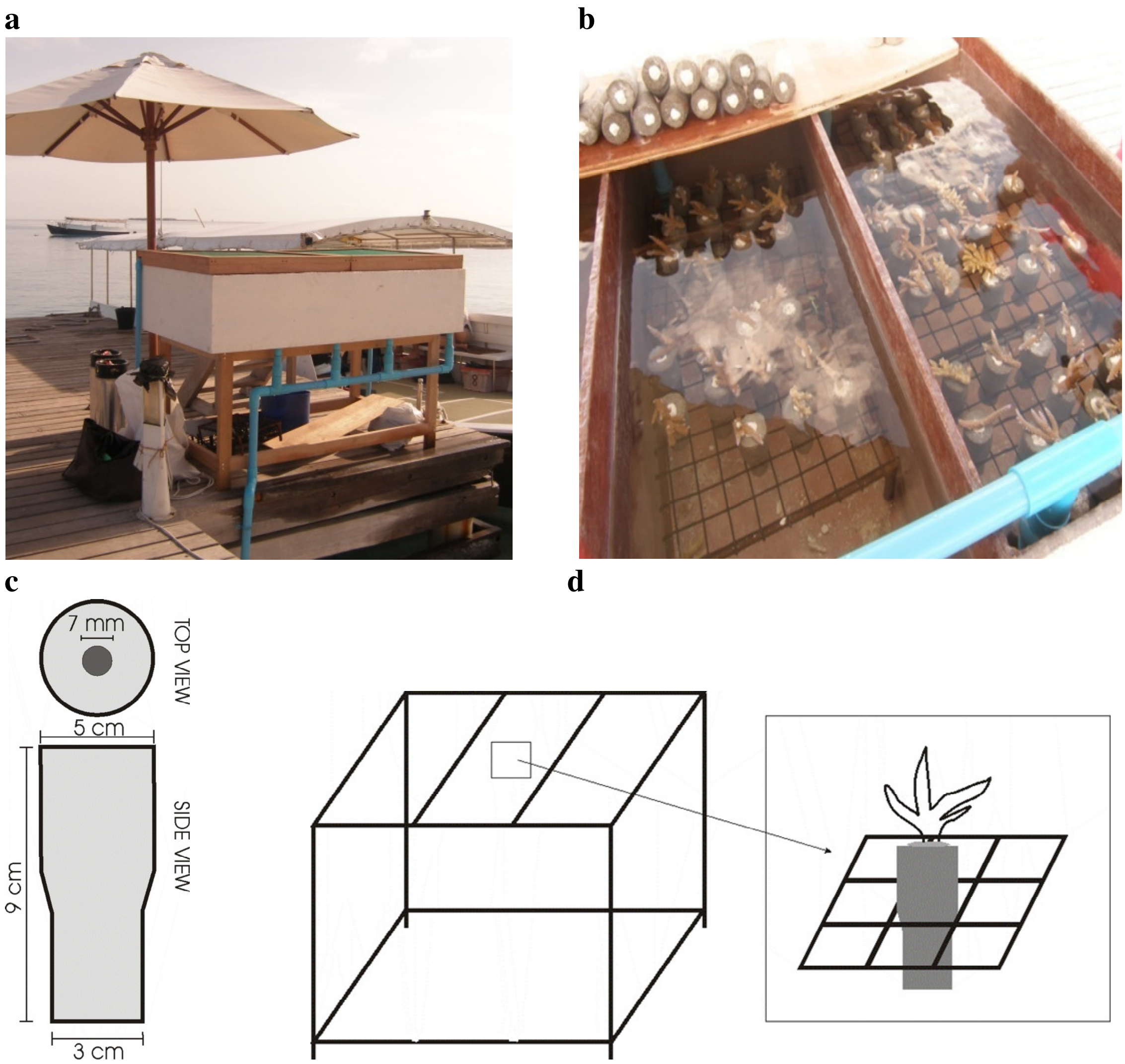


Figure 5. Coral processing material. **a** When no work was conducted, the compartments were covered under wooden frames stringed with a plastic mesh. **b** Compartments with nursery grill trays. **c** Longitudinal view of the concrete plug which the nubbins were attached to. **d** Nursery grow-out table, *square* indicates how the concrete plug with the nubbin was placed on the wire grid

Concrete plugs (Fig. 5c) were produced using simple PVC-pipe reducers (9cm length, reducing from 5cm to 3cm) as moulds, and were then seawater soaked for at least one week to remove possible leaching. A 1cm deep hole drilled into the top side would ensure the corals to be fixed firmly.

For monitoring and husbanding the coral nubbins during their establishment and grow-out phase, grill trays of 40 x 30cm (Fig. 5b) and nursery grill tables of 2m x 1m were constructed. The typical configuration of the nursery table is given in Figure 5d. These tables were made out of steel reinforcing rod (rebar) wielded together for strength, and a wire grid of 5 x 5cm fixed on top was chosen for the concrete plugs to fit in (see Figure 3 for the location of the coral nursery).

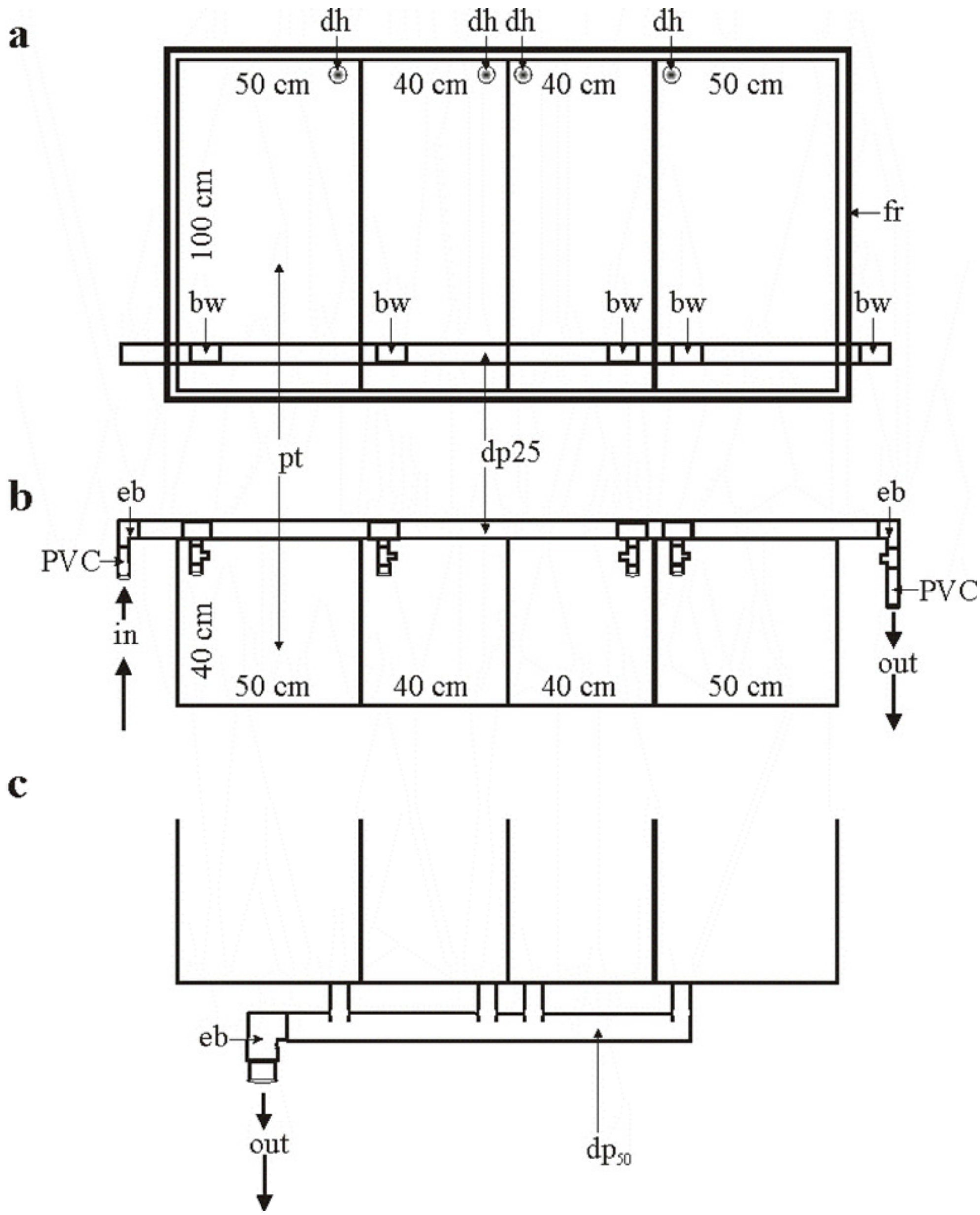


Figure 6. Coral nubbin processing table, pipework. **a** Seawater delivery, top view. **b** Seawater delivery, side view. The delivery pipe lies on top of the table, secured by loop fittings. **c** Seawater drainage, side view. bv ... ball valves; dh ... drainage holes (25mm PVC slip coupling); dp_{25}... PVC delivering pipe, 25mm diameter; dp_{50}... PVC delivering pipe, 50mm diameter; eb ... 90° elbow; fr ... supporting wooden frame; in ... water in (connected by a reinforced flexible hose to submersible pump); out ... water out via flexible hose; PVC ... piece of PVC pipe

3.4.2 *Method and Location*

The coral cultivation was based on the "fragmentation method" (asexual reproduction) where a sub fragment of a coral colony is attached to an artificial substratum and cultivated until the fragment had reattached itself and growth was apparent.

Sources of coral fragments included broken loose species located on the ocean floor resulting from natural damage (e.g. storm, fish) or anthropogenic sources (e.g. snorkellers/divers, fishermen, anchors), as well as directly removed fragments from a natural in situ coral colony to develop the "broodstock". The species most frequently collected included branching and corymbose Acroporidae. Any collection bias towards *Acropora spp.* is offset by their proportionally higher mortality via anomalously high temperatures, wave forcing and/or natural predator numbers. It was of great importance for us to save the donor colonies for the nursery. We required less than 15 percent of coral fragments from any host colony, ensuring survival and continuous growth of the host coral whilst maximizing coral fragment reattachment and growth. The arbitrary figure of 15% is an industry standard that ensures complete recovery of the host colony (Lindsay 2007).

The collected coral colonies were stored in one of the four compartments of the processing table (Fig. 5b). With cutting pliers, sub-fragments of about 5 – 10cm length were broken off and pasted into the hole of the concrete plug, using a non-toxic two-part epoxy resin (EMERKIT, S. Austin Carr. & Co, Auckland, New Zealand). The advantage of the horizontal placement of the nubbin as can be seen in Figure 16a is that the ramet can attach itself easily to the plug because of the increased contact area compared to a ramet which is placed vertically. As this kind of epoxy needed time to expand and set under water, the nubbins were kept in the processing tanks for at least 6 hours until the epoxy was properly set, before they were transferred to the nursery tables into the lagoon.

Transportation to the experimental coral farm, which was situated on the sandy bottom on the northern side of the island lagoon in approximately 2m depth (Fig. 2, Fig. 16b), was undertaken by a small outboard engine-driven boat. Big plastic bins were filled with seawater which the small grill tables carrying the concrete plugs and corals were carefully placed into, and were transported to the grow-out site. There the culturing tables had been moved by a diving boat previously to the transportation of the corals, and had been deployed by free diving and using SCUBA. Care had been taken not to damage any live coral during this process.

3.4.3 Monitoring the coral nursery

Once the nubbins were placed in the nursery tables, periodic husbandry of the nursery was required to remove potential prey or fouling organisms. Our monitoring included a weekly survival check during which dead nubbins were documented and removed from the tables and plugs were cleaned. Photographs were taken as needed. We made sure that in the crowded in situ setup (120-140 fragments per table), the fast-growing coral fragments did not come in direct contact with each other. One combined temperature / light intensity logger ("HOBO Pendant Data Logger 64K") was tied to one of the tables and the data were read out using "Hoboware Lite Software Kit".

3.5 Reef restoration and tourism

To aid the island's house reef by reducing some of its stressors, the coral reef enhancement project was combined with a compulsory education of the tourists who visited the resort from April 2007 onwards. We could compare the knowledge of the average visitor to Huvafen Fushi before the programme on the island had begun (due to an available preliminary study by Brunner 2007) to their knowledge after it by assuming that every guest who had booked a snorkelling trip on the island would know more about coral reefs than before. Every snorkelling trip was escorted by the resident marine biologist, who gave a 20-minutes briefing prior to the excursion and could answer the guests' questions. We considered a briefing necessary as Medio *et al.* (1997) have demonstrated that a single environmental awareness briefing reduced divers' contact to reef substrate. Furthermore, we evaluated the success of employing a marine biologist on the island by comparing the revenues from snorkelling trips before (before April 2007) and after the programme.

4 Results

4.1 Artificial Reef

By February 2007, the first part of the artificial reef with the deployment of four concrete structures, the creation of a limestone basis and the transplantation of coral colonies around the Spa had been completed. It took another six months before this initial reef had extended to an area of about 70m^2, which included the deployment of another two concrete structures and the extension of the Spa reef to the front. Taking into consideration that this project had been planned for the island lagoon, where there had not been a reef before, and where the survival of corals on the sea floor was naturally low due to high sedimentation rates coming from the moving sand bed, we could observe on the two and a half year-old Underwater Spa building that larval settlement in this area was high, tough. Most young recruits around the Spa were found on the vertical walls of the building (Fig. 7) compared to the horizontal top side, and consisted predominantly of pocilloporid species, but also Acroporids and *Tridacna sp.* clams.

a **b**

Figure 7. Recruitment on the side wall of the Spa building, facing south-east

The four three-level structures on the right side of the Spa ('SR') were first completed within three weeks and the result is displayed in Figure 8a. The renovation work took two days and required five SCUBA divers including one marine biologist, two engineers, three staff from our boat crew, who also helped mixing cement, and four snorkelers to take the quick-setting cement down. The result of the renovation after a growth period of 13 months can be seen in Figure 8b.

a

b

Figure 8. The artificial reef which was created in front of the long window on the right side of the Spa ('SR'). **a** In March 2007, the four concrete structures could still be seen. **b** After 13 months, corals have overgrown the structures and are flourishing

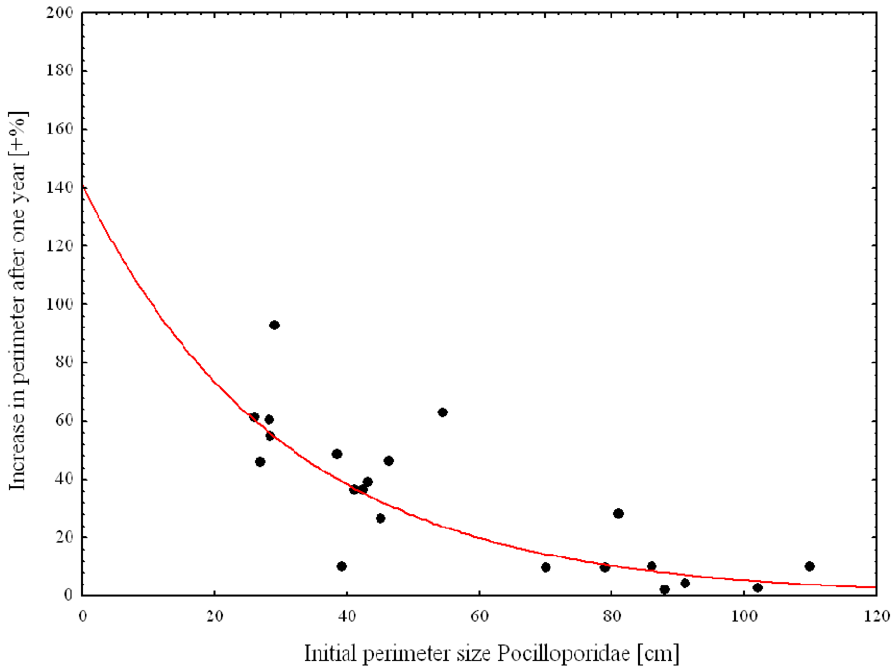
In August 2007, the main renovation work for the artificial reef created on the left side, i.e. removing the previous biorock basis, lowering the structures and filling them with biogenic rock and corals again took only about one week for three divers, two snorkelers and an assisting boat crew. Attachment of corals to the biogenic rock was evident three months after the completion of the transplantation project (Fig. 9).

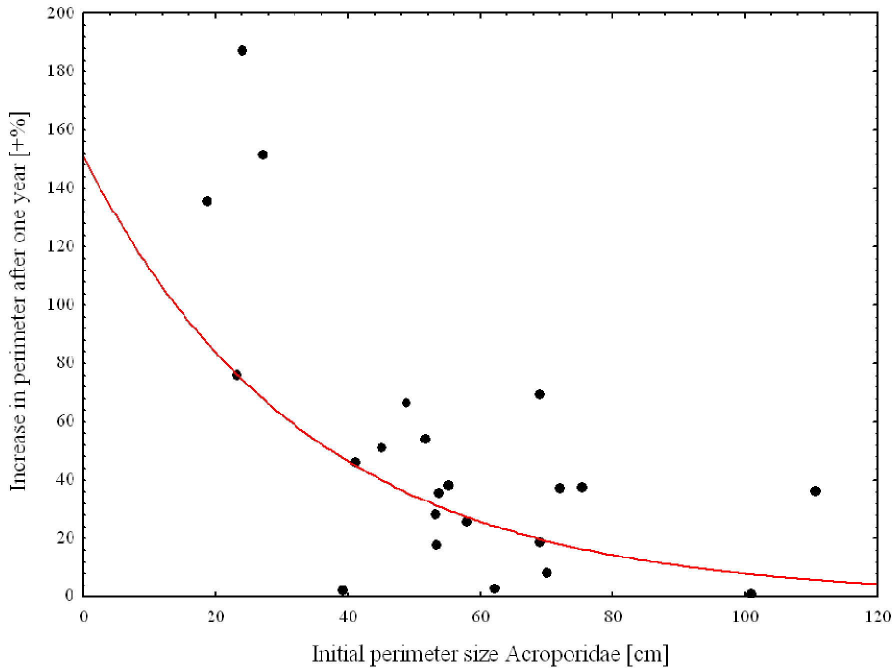
Figure 9. Attachment to biogenic rock of one *Acropora sp.* branch at 'SL', three months after the structure had been topped with rock and corals

4.1.1 Growth monitoring

The growth of all our monitored corals was negatively correlated with their initial perimeter sizes, i.e. small, young corals grew relatively faster than bigger heads in the same period of time (Acropora sp.: Pearson r = -0,626; Pocillopora sp.: Pearson r = -0,779). The correlation between growth and initial perimeter size is displayed in a Scatterplot in Figure 10. Only the "adult" colonies (see Materials and Methods for definition) were used for further growth comparisons between transplants and non-transplants.

a





b

Figure 10. Growth [%] of all monitored coral colonies (young recruits, transplants and non-transplants) around the Underwater Spa and on the house reef, depending on their initial perimeter size [cm], fitted by a negative exponential model. **a** *Pocillopora sp.*, r = -0,78, r^2 = 0,61; **b** *Acropora sp.*, r = -0,63, r^2 = 0,39

Table 2. Growth of monitored young (= <40cm in perimeter) recruits, transplants and non-transplants (= >40cm in perimeter) around the Underwater Spa and the island's house reef. n.f. … not found; n.m. … not measurable; t_0 perimeter … perimeter of the coral measured at beginning of monitoring; t_{12} perimeter … increase in perimeter [%] after 12 months of monitoring

a *Pocillopora sp.*

Location	t_0 perimeter [cm]	t_{12} perimeter [+%]	per month [+%]
Young recruits < 40cm:			
Spa, building	26	61,5	5,1
Spa, building	28	60,7	5,1
Spa, pillar	29	93,1	7,8
Spa, pillar	34	dead	-
Spa, pillar	36	dead	-
House reef	26,7	46,3	3,9
House reef	28,3	55,3	4,6
House reef	38,3	48,7	4,1
House reef	39	10,3	0,9
Transplants > 40cm:			
Spa, WR	41	36,6	3
Spa, WR	79	10,1	0,8
Spa, WL	81	28,4	2,4
Spa, WR	83	n. m.	-
Spa, FR	86	10,5	0,9

b *Acropora sp.*

Location	t_0 perimeter [cm]	t_{12} perimeter [+%]	per month [+%]
Young recruits < 40cm:			
House reef	13	dead	-
House reef	17	dead	-
House reef	18,7	135,7	11,3
House reef	19	dead	-
House reef	19,3	dead	-
House reef	21,3	n. f.	-
House reef	22,3	dead	-
House reef	23	76,1	6,3
House reef	24	187,5	15,6
House reef	29,7	n. f.	-
Young transplants < 40cm:			
Spa, WL	39	2,6	0,2
Spa, WR	27	151,9	12,7
Transplants > 40cm:			
Spa, WR	41	46,3	3,9

Spa, WL	88	2,3	0,2
Spa, WL	91	4,4	0,4
Spa, WR	97	n. m.	-
Spa, WR	102	2,9	0,2
Spa, WL	110	10,5	0,9
Non-transplants > 40cm:			
House reef	42,3	37	3,1
House reef	46,3	46,8	3,9
House reef	50	dead	-
House reef	50,3	n.f.	-
House reef	52	n.m.	-
House reef	70	10	0,8
Spa, building	43	39,5	3,3
Spa, building	45	26,7	2,2
Spa, pillar	53	dead	-
Spa, building	54,5	63,3	5,3
Spa, pillar	60	dead	-

Spa, WL	45	51,1	4,3
Spa, WL	62	3,2	0,3
Spa, WL	69	18,8	1,6
Spa, WL	70	8,6	0,7
Spa, WR	72	37,5	3,1
Spa, WL	101	1	0,1
Spa, WR	117	n. i.	-
Non-transplants > 40cm:			
House reef	48,7	66,4	5,5
House reef	51,5	54,4	4,5
House reef	53	28,3	2,4
House reef	53,3	18,1	1,5
House reef	53,7	36	3
House reef	55	38,2	3,2
House reef	58	25,9	2,2
House reef	69	69,6	5,8
House reef	75,3	38,1	3,2
House reef	110,7	36,4	3

a. Growth of young recruits (< 40cm diameter)

In one year, young *Pocillopora sp.* around the Spa increased their perimeters between +61 and +93%. (+5,1 - 7,8 % per month, n=5). The biggest increase was observed in a colony that was growing all along the vertical PVC pillars (beachwards behind the Underwater Spa) which carried the pathway to the Spa complex. In the first five month, this coral grew five times faster than the other two young recruits monitored in the same location. On the more exposed house reef, a pocilloporid of the same size increased its perimeter at +55%.

Among the young *Acropora sp.* which were monitored on the house reef (n=10), the biggest observed increase in growth was +187,5% (*Acropora selago*). Compared to that, a young transplant at the Spa of about the same size added 152% of skeletal material (Tab. 2).

b. Growth of adult transplants vs. non-transplants (>40cm diameter)

Statistical analyses reveal that there is a difference in growth rates between transplanted Pocillopora sp. colonies and those which have settled naturally (Student t-test; $t = -2.95$, $df = 12$, $p < 0,05$). Transplants would therefore grow slower than non-transplants with an average perimeter increase of +13%compared to +37%. In Acroporids, this could not be confirmed. There, regardless of species, both transplants (+24% mean ± 21 SE) and non-transplants (+41% mean ± 17 SE) would increase in about the same speed (Student t-test, t = -1,88, df = 16, p = 0,08). The fastest growing transplant added 51,1% to its perimeter, the fastest growing non-transplant +69,6%.

Table 3 illustrates how fast four individuals of Acropora tenuis increase their surface area in both locations and an example is shown in Figure 11.

Table 3. Area increase in four compared *Acropora tenuis* species at the Spa (transplants) and on the house reef (non-transplants)

	March 2007	March 2008	increase
A. tenuis N°1, House reef	126 cm^2	342 cm^2	+ 271%
A. tenuis N°6, House reef	156 cm^2	331 cm^2	+ 213%
A. tenuis N°1, Spa	215 cm^2	355 cm^2	+ 165%
A. tenuis N°1, Spa	310 cm^2	525 cm^2	+ 170%

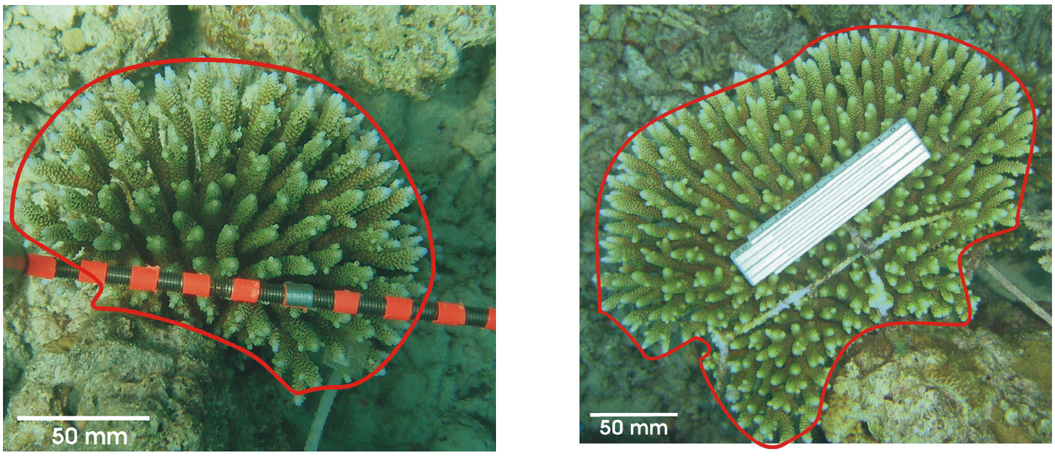


Figure 11. Example of an *Acropora tenuis*(N°1, House reef) increasing its size within one year.

4.1.2 Survival monitoring

a. Survival of young recruits, transplants and non-transplants (Spa 'WR' and 'WL', house reef)

Overall survivorship of transplants around the Spa, non-transplants on the house reef and young recruits on both locations is displayed in Figure 12 and indicates poor survivorship in juveniles that had settled at the Spa (Tab. 2). The highest mortality was recorded from recruits that have settled on the pillars behind the Underwater Spa (*Pocillopora sp.*) - only one out of five colonies had survived one year of monitoring, whereas the fifth developed well at a surprisingly fast rate. The Spa complex seemed to be a better location for recruits, where 100% of the monitored pocilloporid colonies (n=5) survived. On the house reef, young *Pocillopora sp.* survived just as well, by 100% (n=4).

In contrast, young acroporid recruits on the house reef survived by 30% only (n=10), including two colonies which we could not find anymore at the last monitoring, therefore assuming that they had died. Out of the two monitored young *Acropora* transplants on the Spa reef, both had survived well. One grew rapidly whereas the other one showed hardly any growth at all.

Adult acroporid transplants around the Spa (n=10) and non-transplants on the house reef (n=10) survived very well. Except for one colony at the Spa which could not be definitely identified after one year (N°6 "n.f." in Table 2), all adult *Acropora sp.* corals had survived over one year of monitoring. Around the Spa, the adult pocilloporid colonies also had survived very well as well (100%, n = 10), even though they did not grow very fast. In contrast, adult pocilloporid non-transplants on the house reef survived by 67% (n=6), including one colony that we could not find anymore after one year (N°8 "n.f." in Table 2), therefore assuming that it had died. "n.m." in Table 2 are colonies that had survived well but were not measurable due to their location.

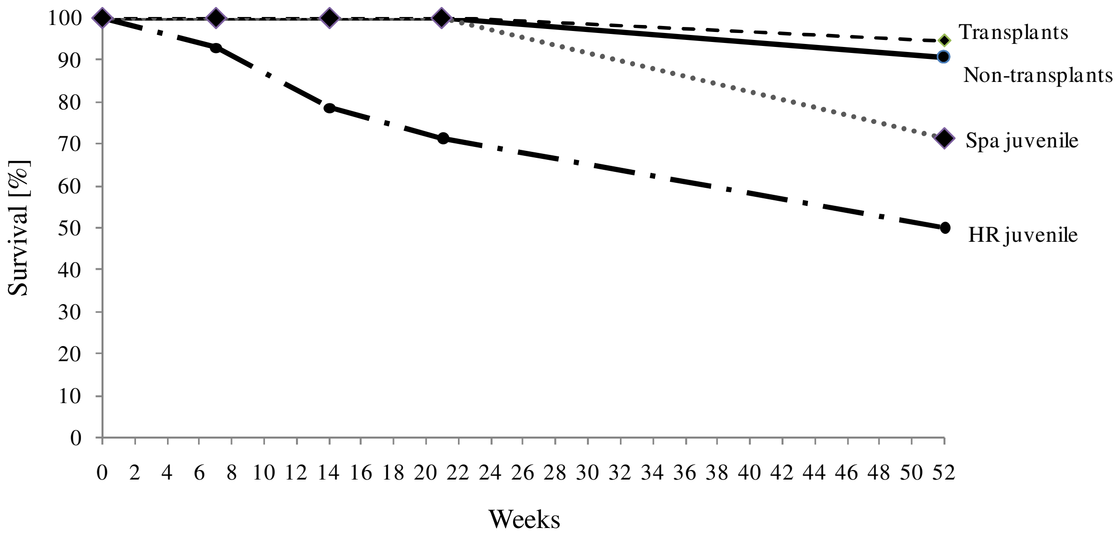


Figure 12. Survivorship of transplanted coral colonies (Spa reef), of non-transplants (Spa and house reef) and of young recruits (also both locations) over one year. Colonies were considered as "young" under an initial perimeter of 40cm (see Materials & Methods). HR … House reef

b. Survival of other transplanted corals around the Underwater Spa

The transplanted corals on the concrete structures and on the remaining area around the Spa survived well as could be observed during a period of one year. As the muricid gastropod *Drupella sp.*, a coral predator, was present on the Spa-reef, it was necessary to remove individuals with tweezers. Some transplants had died either due to corallivores (*Drupella sp., Acanthaster planci?*) or due to algal growth and had to be replaced; or branches covered with algae on several *Acropora muricata* had to be broken off. An example of a dying coral is given in Figure 13.

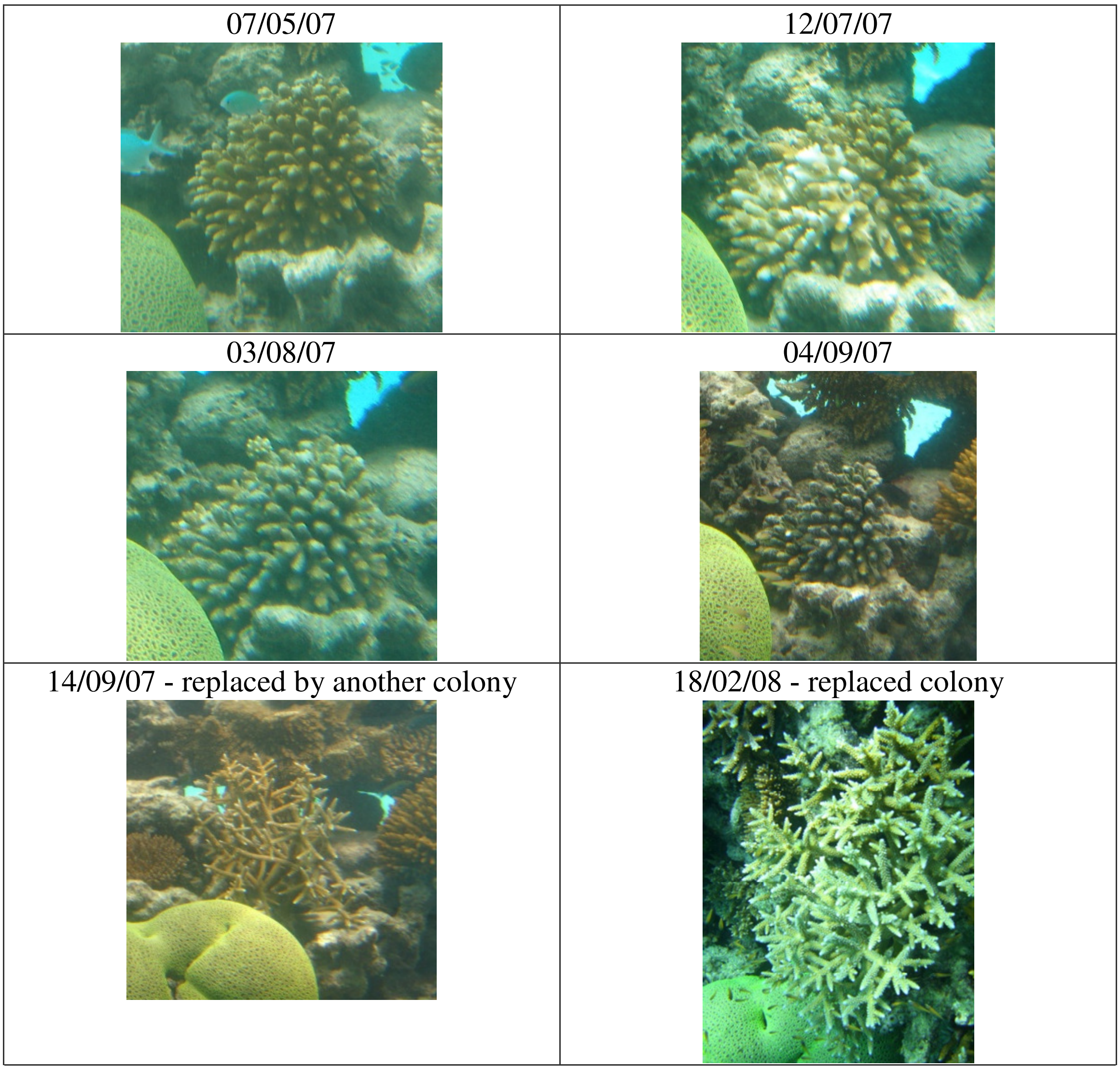


Figure 13. Example of the deterioration in health of an *Acropora sp.* colony which was affected by *Drupella sp*. In May 2007, the coral was in a good condition. In July, more than half of the colony showed feeding marks (white tips) and by September, the coral was dead. It was then replaced by another *Acropora sp.* which grew well in five months, adding new branches and was last monitored in February 2008.

The wall in front of the relaxing area of the spa ('FR' and 'FL' in Figure 3a) is an artificial reef that was created only by a fundament of biogenic rock, topped with coral heads and broken off pieces found on the seafloor (Fig. 14). This small reef was not monitored because it had continuously extended, but we could observe a high fish activity and diversity, including a moray eel inhabiting the small caves and crevices.

Figure 14. In front of the relaxing area of the Underwater Spa, a patch and a wall created by dead coral rock was topped with live coral pieces and loose colonies found on the surrounding sea floor

Fish count

On average, we counted 262 fish of twelve different families within ten minutes at WR and WL. In abundance, fish communities were by far dominated by pomacentrids (Fig. 15).

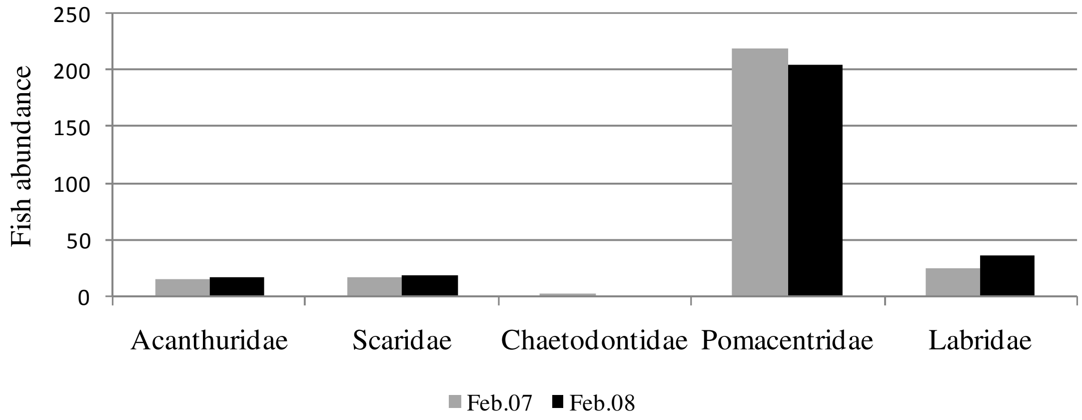


Figure 15. Number of fish counted at 'WL' and 'WR' after the artificial reef was created and one year later

We could not report an increase in fish abundance over time, but a significant difference between the right and the left side of the spa (Wilcoxon-test; $z = 3{,}238$; $n = 26$; $p < 0{,}01$). We also had the impression that there was more fish activity on the left compared to the right side (especially *Chromis sp.* which gathers in schools above the reef). While up to 60 individuals of *Dascyllus aruanus* were found at 'WL' in March 2007, only a few were present one year later in front of 'WR'.

Before the project started, we could observe different fish families high in diversity but low in abundance, dominated by Labridae, Acanthuridae, Pomacentridae Siganidae and Scaridae due to the fouling communities apparent at the Underwater Spa and the few loose coral heads that had been placed into the sand around it. The number and diversity of the coral feeding Chaetodontidae, which had only occurred occasionally around the Spa before the artificial reef was built, were common afterwards. Rudderfish (*Kyphosus sp.*) and Batfish (Ephippidae) passed by frequently, and a moray eel (*Gymnothorax javanicus*) inhabited the rocky reef. One species of Sweepers (*Parapriacanthus ransonneti*, Fam. Pempherididae) was found at the side walls of the Spa at an early stage of the project, but when the big concrete structures on the right side were lowered and topped with corals, a large branching *Acropora sp.* served as a habitat for a swarm of *P. ransonneti*. Six months later, a second school inhabited the two structures on the left side. Another species, *Pempheris vanicolensis,* inhabited the backside of the concrete structures from July 2007 onwards. Cleaner fish (*Labroides dimidiatus*) were present before and after the renovation. When algal growth on the concrete began, Surgeonfish (*Acanthurus spp.*) started grazing on them. One individual of the family Soldierfish (Holocentridae), known to congregate in large open caves or below overhangs of the reef, was seen only one month after the artificial reef had been built, and a group of six *Myripristis vittata* was found under the concrete structures on the left side in February 2008. At the last monitoring of the artificial reef, in April 2008, we again recorded two more new species on the reef, namely *Caesio caerulaurea* and *Lutjanus monostigma.* At dawn, Trevallies (*Caranx ignobilis, C. melampygus*) and Scorpionfish (*Pterois sp.*) hoped for food from the new hand-made reef, and at night we could observe sharks and rays passing by.

4.2 Coral nursery

Within ten days, a total of 875 composite coral fragments from various *Acropora spp.* colonies (14 different species) were produced by a team of two trained marine biologists and several untrained volunteers among the resort staff. In two sessions per day (three working hours each), a biologist and one or two volunteers were capable of making around 100 fragments per day. The mucus which was produced by the corals is an indicator of stress and was automatically removed through the flow-through seawater system in the processing tanks, where the mucus-rich water was continuously replaced by fresh seawater. Figure 16a shows a nubbin which has been prepared for its relocation to the in-situ underwater grow-out tables (Fig. 16b).

a **b**

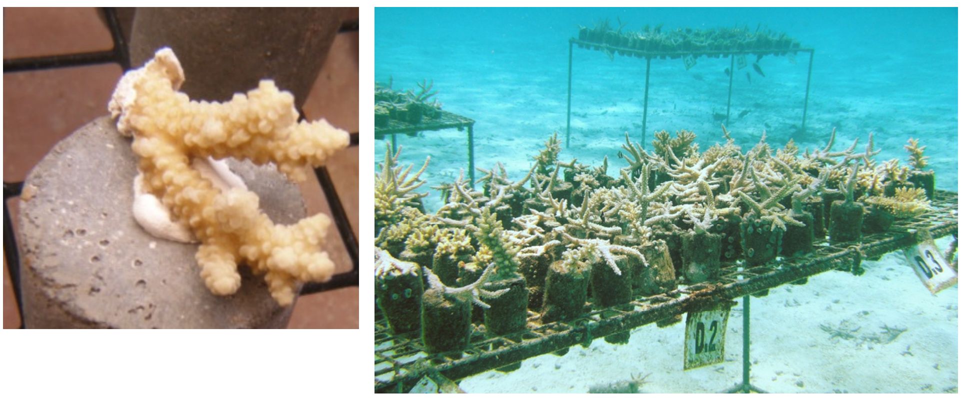
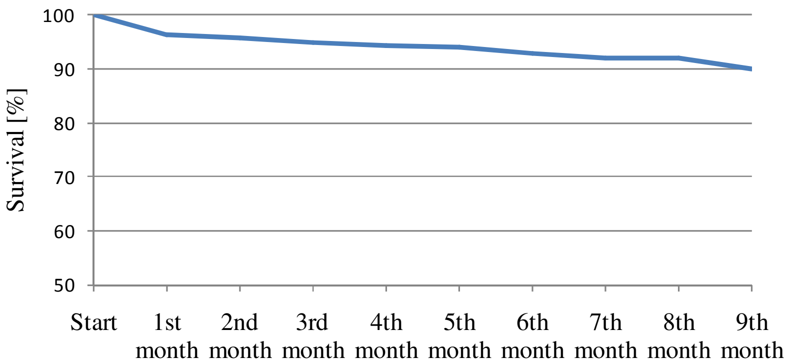


Figure 16. The coral nursery. **a** Photo of a prepared nubbin of about 5cm in length in the processing table. A piece of coral (*Acropora sp.*) was attached to a concrete plug by the help of underwater epoxy. **b** The in-situ nursery grow-out tables, located on a sand bed in 2,1m depth. There, the nubbins were kept for nine months to grow to a size big enough to be transferred to the house reef

4.2.1 Survival and development of nubbins

The survival rate of the nubbins in the first two nursery weeks was 97%. After 6 months, the survival rate declined to 92,8% and after 9 months, just before more than half of the nubbins were transferred to the house reef, to 90,1%, (Fig. 17a).
The seawater temperature at the end of October and in November never exceeded 30,3°C, only the light intensity once raised up to 14.500 Lux at noon on November 3rd 2007.

a



b

Figure 17. a Survival of the coral transplants over a period of 9 nursery months. **b** Attachment of a coral nubbin to the concrete plug after two months in the nursery

All coral fragments that had not died developed into colonies at an impressively fast rate. Within the first month in the nursery, some of the ramets either grew horizontally over the concrete plug heads forming a ring before they grew vertically, whereas others immediately began their length increase, adding one new branch after the other. After two months in the nursery, all corals that were glued to a plug showed attachment to it (815 out of 830 ramets, Fig. 17b). The development of the branching *Acropora horrida* within six months is illustrated in Figure 18. After 9 months, 62% of all nubbins were transferred to the local house reef and were not further monitored in this study.

a b

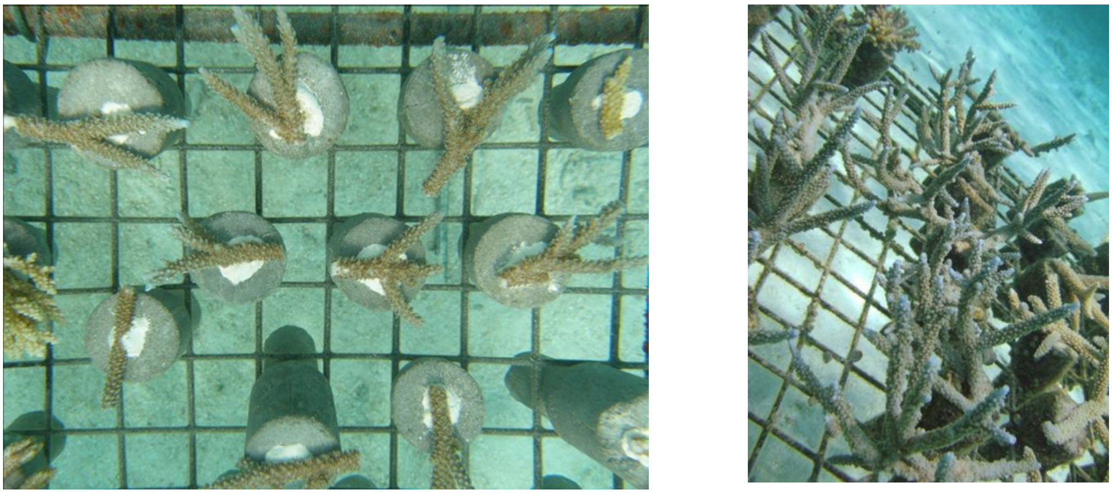


Figure 18. Development of *Acropora horrida*. **a** August 2007 after the pruning compared to **b** six months later. The coral grew from a single- or double branch vertically by adding branches and increasing its length growth

Detached corals were simply fixed to the side of a grow-out table with the help of a cable tie (Fig. 19a). Algae that had started growing on the concrete plugs (Fig. 19b) were efficiently removed with toothbrushes with the help of volunteers, but after about two and a half months the algal growth became less and tunicates (*Didemnum molle*) (Fig. 19c) began to grow until the plugs and the mesh were covered with these invertebrates by the third month after deployment. These animals had to be removed with a brush during the weekly monitoring to prevent them from overgrowing the coral nubbins. Natural removal of algae was performed by resident fish, mostly by schools of *Acanthurus sp*. that appeared immediately after the construction of the nursery. Juvenile Humbugs, *Dascyllus aruanus* and *D. trimaculatus* (Fig. 19d), inhabited some of the branching colonies and Cardinalfish (Apogonidae) were frequently seen swimming between the nubbins.

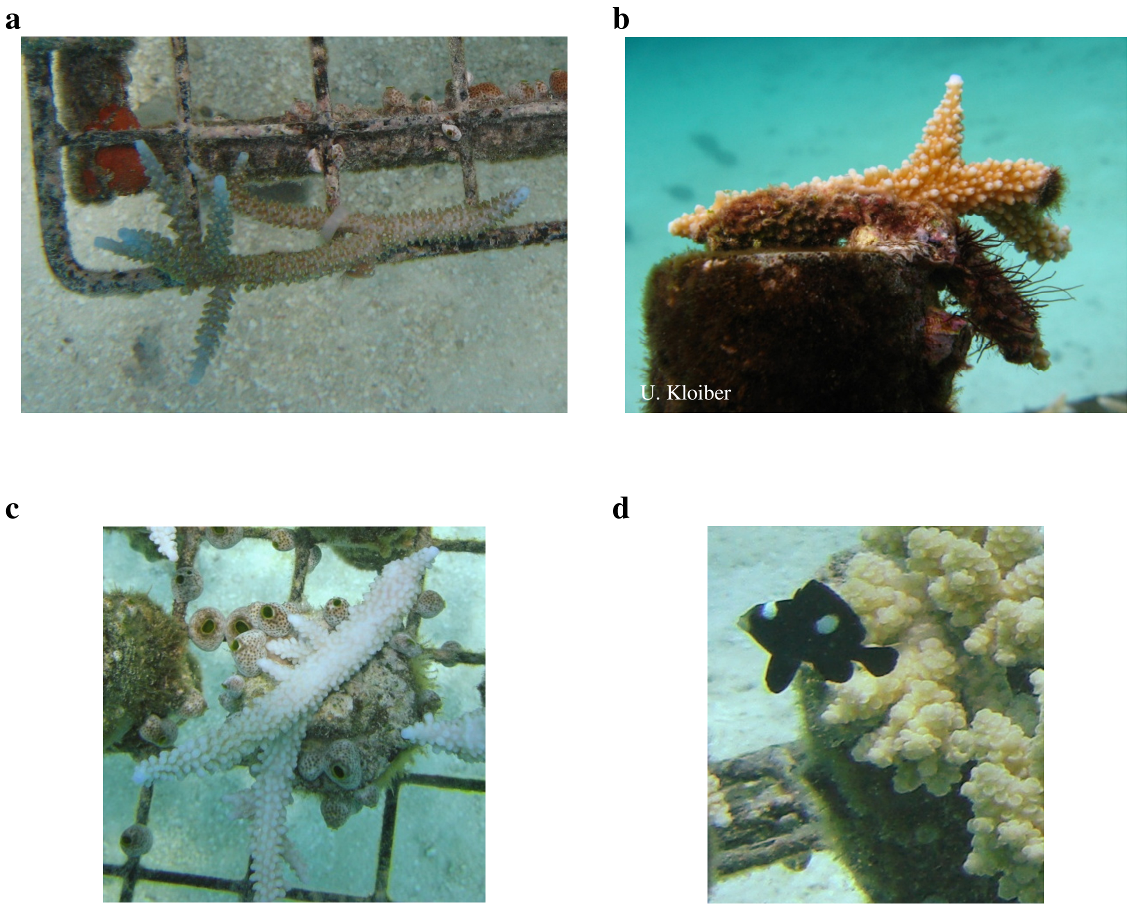


Figure 19. a Loose coral pieces which got detached from the concrete plugs were tied up to the nursery table to continue their growth. **b** Algal fouling on the concrete plug, competing with the coral. **c** *Didemnum molle* growth on the plugs and the mesh. **d** Juvenile *Dascyllus trimaculatus* between the coral nubbins

4.2.2 Costs of the coral nursery

The construction of the nursery cost about 800 USD. Labour was also minimal, but a qualified person was required to overlook the handling of live animals. The survival check for all fragments did not exceed two hours per week, only for cleaning some help from the resort staff was needed.

4.3 Reef restoration and tourism

The ramets created by the coral nursery were made to restock strategic places of the island's house reef. On the other hand, the reef's recovery was speeded by taking the pressure through tourism away from it. This was achieved by a 20-minutes introductory lesson from the resident marine biologist for each guest who has booked a snorkelling excursion either on the local house reef or to a nearby reef.

In 2005/06, where these snorkelling excursions were attended by a front officer only, 563 guests were taken for USD 40.000. In 2006/07, there still was no biologist on the island and 549 guests were taken to the reefs for USD 42.000. But between April 2007 and March 2008 (ongoing), more than 900 briefed guests on Huvafen Fushi were taken on snorkelling excursions by the resident marine biologist. This change resulted in a total revenue of USD 60.000. Comparing the revenues gained from snorkelling excursions 12 months before April 2007 (without a marine biologist) to 12 months later (with a marine biologist), it can be said that revenues were higher after the employment (Wilcoxon-test, $z = 1,96$; $n = 12$; $p < 0.05$). Hence, within one year, 900 people left Huvafen Fushi with some knowledge about corals reefs and the adequate behaviour in the sea. In addition, the guests had the opportunity to learn more about coral reefs and their inhabitants in two different audiovisual presentations twice a week as well as personally from the marine biologist who was there for them to answer their questions.

5 Discussion

As mentioned in the introduction of this paper, the "Spaquarium" project in Huvafen Fushi cannot primarily be classified as "reef rehabilitation" or "reef restoration" rather than the "creation" of a man-made reef where there had not been a reef before. In contrast, the island's house reef required rehabilitation methods due to its poor coral cover, especially on the frequently used snorkel trail on the southern side of the island (Fig. 2, "site 2"), which had suffered under great snorkelling and diving pressure (La Mer 2008).

The present prototype artificial reef and coral nursery address several methodological issues that could be important to reef managers, especially tourist resort managers for the upper market. Major topics are (1) the general shape of the artificial reef and the coral nursery with an eye to working conditions; (2) the substratum used for (a) the elements of the artificial reef and (b) the temporary substratum which the nubbins develop on during the nursery phase; (3) the realistic time that has to be calculated for the establishment of (a) a small-scale artificial reef like ours and (b) a coral nursery like the one we created; (4) the growth and mortality of transplanted vs. non-transplanted colonies and the mortality of the coral nubbins on the nursery grow-out tables. Other aspects such as how and where to transplant the coral colonies, the optimal size for transplantation, rates of mortality/growth in the reef after transplantation and other post-nursery acts were not researched in this study, but are part of another study being undertaken at the moment on Huvafen Fushi. Eventually, I will reflect on the role that tourism plays in Huvafen Fushi (and in the Maldives in general) and discuss about the application of a sustainable approach on high-end tourist resorts in the Maldives.

5.1 The "Spaquarium" - the biggest "in-situ aquarium" in the world

Artificial reef structures are often costly and their deployment time consuming (Clark and Edwards 1999). It is never easy to simulate a natural reef topography and complexity, and only rarely can the artificial structures provide the aesthetic qualities of natural reefs. Sites for deployment and the material have to be selected carefully, minimising the risk of break-up leading to pollution. Nevertheless, in the present study the artificial reef created in the island lagoon of Huvafen Fushi met our expectations, providing shelter, refuge and cryptic habitat and attracted reef fish. Its sediment-free, vertical surfaces will hopefully lead in settlement of coral larvae and other sessile invertebrates and framework builder like crustose coralline algae (CCA).
Coral planulae exhibit strong preferences as to where they will settle and establish themselves (Kaufman 2006). A good deal of research has been done on the suitability of various substrata to surface artificial reef structures and settlement tiles. Throughout the world, early (and perhaps all) hard coral recruits settle preferentially on CCA. Particular species of CCA exude chemical signatures that are particularly attractive. We hope that the use of biogenic rock for the reef around the Underwater Spa will enhance settlement. Dominance of the sessile community by coralline algae is seen within a broad range of light and nutrient levels but often does not occur due to competition from fleshy algae. Indeed, the interactions between macrophytes, crustose coralline algae and hard corals are at the crux of reef conservation and restoration. Intuitively, corallines should do best at the junction of intermediate light level and intermediate grazing pressure. The higher the amount of light and nutrients, the more grazing pressure is necessary to achieve the same effect. Thus, a way of increasing the efficiency of coral gardening would be to terminate fishing for herbivorous fishes. As can be seen in Figure 15, Acanthurids and Scarids were present in about the same abundance after we had

created the artificial reef in front of 'WL' and 'WR' and one year later. Sometimes, small schools of Acanthurids and juvenile Scarids invaded these two sites, fed and left as fast as they had arrived. This grazing pressure implies a positive effect on the artificial reef, which is automatically colonized by algae and fouling organisms and has to be controlled by herbivores. One resident male *Scarus rubroviolaceus* was under suspicion to have scratched the soft Plexiglas windows of the Underwater Spa, but was not removed because it was valued more as an attraction for the guests than for its grazing activities around the Spa. However, large Scarids not only served as herbivorous grazers in our study but were also observed to bite off branches of *Pocillopora pistillata* and branching Acroporids. Miller and Hay (1998) found parrotfish to be an important source of mortality in young corals in an experiment. Similarly, a large rainbow parrotfish (*Scarus guacamaia*) in the Biosphere II ocean mesocosm reversed the anticipated outcome of an experiment by eating the non-caged corals exposed to the "benefits" of grazing (Kaufman *et al.* in preparation). One option for coral gardeners, at least for sessile enemies, is to remove the predators, competitors, and diseased portions of colonies by hand (Miller 2001). In our small-scale man-made reef, the most dangerous non-sessile predator was *Drupella sp.*, and as its outbreaks on coral reefs are feared and recognized (e.g. Morton and Blackmore 2000), we found it necessary to remove them from the reef. Another option to reduce predation is to attract or fore-recruit resident species that will feed on coral predators (e.g. Gochfield and Aeby 1997). It is possible to influence the type of fish attracted to the artificial structures by altering the design. Inclusion of spaces which mimic caves and crevices attracts large numbers of Holocentridae (food fish), Apogonidae (bait fish) and Pempheridae. The two species of Pempheridae that finally inhabited the artificial reef on the right side, shared only one structure - one school of *Parapriacanthus ransonneti* was found in a large branching *Acropora sp.* and another one of *Pempheris vanicolensis* under the three shelves. Edwards and Clark (1992) have obtained similar results from a rehabilitation study undertaken on mined reef flats in the Maldives. They reported a successful re-establishment of the reef fish populations on larger reef structures but also that their community structure was still different to that of unmined reef flats. Large (SHED; Shepard Hill Energy Dissipator hollow concrete blocks) structures had created shaded habitats like the concrete structures in our study, akin to crevices and small caves, and were very attractive to *Myripristis vittata*, *Pempheris vanicolensis, Chromis viridis* and *Apogon apogonides,* which are not usually common in the reef-flat environment.

Only from video documentations can we estimate the diversity of fish that had been present before the creation of the artificial reef. But we could observe that over time more and more fish that had actually lived behind the Underwater Spa came to "visit" the newly created reef. As the building and its associated structures (e.g. PVC pillars which carried the pathway to the Spa) had been lowered three years before the project, a fouling community with its associated fish and invertebrate life had established itself and attracted a diversity of larger fishes, where the Spa visitors could not see them (behind the building). For example, one male *Pterois sp*. was permanently occupying one tyre that was hanging behind the Spa, but at dawn it came out and presented itself together with three to five other Lionfish in front of the windows and was therefore an attraction for the guests inside. The fish count undertaken between February 2007 and February 2008 was probably not suitable to display the increase of fish diversity over time. It rather showed that the abundance and composition of the observed families that had been present after the reef at 'WR' and 'WL' had been completed was the same one year later. For a proper evaluation, fish abundance and species diversity would have to be quantified before the renovation works started.

Even though larval recruitment on the pillars behind the Spa appeared to be good (Fig. 20 and personal observation) which could be due to their shallow, vertical orientation that implies little sedimentation,, we reported the highest mortality of corals of this site. Only one out of five Pocilloporids survived over one year of monitoring but grew very fast, suggesting that the environment there, where sometimes strong currents occur, would be favourable only for already well established colonies which would have successfully competed with weedy algae and other invertebrate settlers. Another possible reason for the high mortality could be the way of labelling these relatively young corals (not more than two and a half years old). Whereas the number, sealed in a plastic foil, is relatively quickly overgrown by the coral, the cable tie offers substratum for algae and tunicates to grow and compete with the corals, which could lead to their death.

Figure 20. Vertical PVC pillars that support the pathway to the Underwater Spa. Note the high density of sessile organisms competing for space

The ideal coral species for transplantation would grow fast, survive the stress of transplantation well, and have low mortality rates once established in its new environment. Unfortunately, such a combination of characteristics is unlikely as life-history strategies tend to involve a trade-off between growth rates and longevity. On the concrete structures 'SR' and 'SL', where all corals were monitored for their survival and mortality, only the number of present Acroporids had changed over time, i.e. within one year of monitoring, only *Acropora sp.* colonies had to be replaced or removed from the reef because they had died (see example Fig. 13), confirming the results of other studies (e.g. Clark and Edwards 1995) that fast-growing species such as Acroporids are highly vulnerable to a suite of transient disturbances. Young acroporid recruits monitored on the house reef survived only by 30%, whereas 100% of the monitored >40cm diameter colonies had survived, suggesting that once established and survived a "critical phase" of competition with other settlers and of buiding up a skeleton hard enough to resist biological forces, Acroporids have a very high chance to survive if other disturbances do not get out of hand.

The reason why we monitored young *Acropora sp.* on the house reef and young *Pocillopora sp.* around the Spa was simply that young Pocilloporids were rarely found on the monitored area of the house reef, and respectively. Acroporids, therefore, seem to be the easiest settlers, taking any possible substratum and growing fast, even on a denuded reef like Huvafen Fushi's with coral rubble accounting for 60% of the benthic substratum in the snorkelling area (Fig. 2) (La Mer 2008).

Thus, we have to make a compromise when restoring reefs, by choosing a mix of fast-growing but vulnerable and less sensitive but slow-growing species, which best represent the coral community prior to disturbance. On Huvafen Fushi, in addition, the artificial reef had to be aesthetically pleasing from the moment it was first deployed, because every day that it was under construction meant a loss in revenue for the management of the Spa. It might, however, take decades for an artificial reef to look like and take on some of the functions of a natural reef. Researchers, however, have discovered methods to hasten the time it takes for a dive site to be aesthetically intriguing. Today, aquascapists design snorkel trails and transplant benthic organisms to artificial or damaged reefs, and underwater sculptors create topographically diverse artificial reefs. The present technology in ocean engineering and construction allows almost any restoration design to be implemented (Precht 2003).

In contrast to mangrove (Field 1996) and salt marsh (Zedler 1984) rehabilitation, reef restoration and rehabilitation based around coral transplantation are still largely at an experimental stage. In this section, some potential adverse environmental impacts (prepared by Edwards and Clark 1998) will be considered.

In general, corals used for transplantation are likely to be taken from adjacent undamaged or less damaged reef areas. These donor areas need to be sufficiently large and rich in coral colonies that they themselves will not be significantly impacted by the removal of transplant material. One aim of our project was not to damage the existing house reef which was low in coral cover anyway, but to reconfigure all existing corals and coral rock that had been moved to the Underwater Spa during its installation. Most coral fragments searched for to establish the artificial reef and the coral nursery were loose or partly buried in sand. Hence, they were normally expected to have a very high natural mortality rate.

According to Plucer-Rosario and Randall (1987) or Yap *et al.* (1992), transplanted colonies tend to have higher mortality rates than undisturbed colonies, and thus the act of transplantation is putting coral colonies at risk. This risk may be small for some species, such as *Pavona spp.* and *Heliopora coerulea*, but may be significantly higher for others, notably fast growing branching species, such as the ones used in our study, namely *Acropora spp.* and *Pocillopora spp.*.In a low-energy transplant site like the one in our study, i.e. an island lagoon in four meters depth, we can not agree on this, at least

during our observation period of one year. On the contrary, our transplants showed the best survivorship results (94%), followed by non-transplants (91%).
However, the stress of transplantation may have less dramatic consequences than death. One such consequence may be reduced growth rates of transplanted colonies compared to undisturbed ones. Clark and Edwards (1995) found that average growth rates of transplanted *A. hyacinthus*, *A. humilis* and *A. cytherea* colonies were significantly slower during the initial seven months after transplantation than thereafter. Yap and Gomez (1985) reported that growth rates of transplanted *A. pulchra* colonies were considerably less than those of undisturbed ones. We can confirm this for *Pocillopora spp.*, where naturally growing colonies (> 40cm perimeter) on the house reef grew faster than transplants. In Acroporids we did not find any difference at genus level.

5.2 The coral nursery - an effort to rehabilitate certain parts of Huvafen Fushi's house reef

Since the mortality of newly settled recruits is principally high (Shafir *et al.* 2006), which is the case in our study too, it may always be worth the effort of growing out corals to the stage of small colonies and then manually securing them to the restoration site. This study demonstrates that a successful nursery can be a simple structure, cheaply built from easily produced material and with only few technical manipulations. Preferably, it should be situated in a protected area since mechanical forces may significantly reduce operational success (Shafir *et al.* 2006).
We found that the first two weeks of the nursery period are critical for reducing the number of dead coral fragments. Therefore, special attention should be given to the preparation of the fragments (separation from the donor colony, attachment to the substratum, placement on the underwater nursery). We guess that much of the loss was also due to mechanical force by stormy weather, by algae and ascidian growth and by bleaching. Weekly maintenance of the nursery (observations, cleaning from algae and tunicates) requires no more than two hours per week. Detachment of nubbins (15 fragments after 94 nursery days) was primarily due to an increased wave action during a storm in October 2007. Two nubbins were accidently detached during a cleaning session. Dead nubbins resulted mostly from bleached or overgrown fragments. Primarly the upper sides of *Acropora microphthalma* were affected in November 2007, whereas

the bottom still harboured symbionts, leading in brown colour. This could be due to an increased sensitivity to stress of this particular species. Another branching and similar-looking species on the tables (*A. muricata*) in contrast, did not show any stress during the grow-out phase. Shafir *et al.* (2006) explain their major loss, recorded for the long and thin fragments of *A. pharaonis* and *A. eurystoma* (41,1% and 40,5%, respectively), that these long branches were probably subjected to increased shearing forces, as the relatively narrowly glued surface areas failed to hold the long branches to attach them. We report a mortality of 5,8% only after 147 nursery days (9,9% after nine months) on our elevated nursery tables in the back-reef lagoon at Huvafen Fushi. In contrast, Shafir *et al.* (2006) reported 13,1% dead and 21,2% detached fragments after 144 nursery days on a floating mid-water nursery which was placed at 6m depth (14m above sea-bottom) within the nutrient-enriched environment of a fish farm. They used 0,5-3cm (height) fragments, attached to plastic pins with super glue.

Thus, we conclude that our method, which does not even require SCUBA equipment or many personnel, is very successful and that no significant environmental impacts are identified that are associated with the components of the project (La Mer 2008).

The crucial experiment of transplanting the nursery-grown corals to the natural house-reef environment with all its additional biological, physical and anthropogenic pressures has been undertaken in May 2008 and is part of a separate study. Continuous monitoring is important because it is easy to define a coral reef restoration project as successful merely on the establishment of coral cover. While some projects may initially appear successful, long-term monitoring has proven that it takes other components (and efforts) than coral cover alone to guarantee the long-term perpetuation of the coral reef ecosystem. In many cases, coral reef restoration projects are not monitored at all for success or failure. Others are only monitored for a short period of time after restoration efforts have been completed because (1) there is insufficient funding to support continuous assessment, and/or (2) legislative regulations do not require monitoring.

5.3 Problems the Maldives currently face most

In the history of the Maldives, coral mining for the construction industry has resulted in widespread degradation of shallow reef-flat areas. Reefs which have been severely mined for corals have shown no evidence of recovery over periods of up to 20 years (Brown and Dunne 1988). "In the 70's and 80's, significant quantities of coral were used in the construction of resort islands. Current tourism regulations discourage the use of corals for building purposes at resorts. Even so maritime structures such as breakwaters, jetties and groins are still constructed using corals. The need for land led to land reclamation programmes. Harbours are dredged to facilitate economic growth in islands. The demand for building materials in the form of coral nodules has increased steadily and coral mining has become a major environmental concern in the country" (Abdulla Naseer, in Brunner 2007).

Furthermore, this little island nation has been facing damages from natural stress factors. The climate anomaly El Niño caused widespread coral bleaching in 1998. Later on in the year 2004, the island nation was hit by the Tsunami. In particular, it caused considerable damage to some of the local coral reefs. Consequently it is correct to state that the Maldivian environment has been facing massive pressures during the past 10 years and is still struggling to recover from them.

5.4 Tourism in the Maldives

In addition, anthropogenic pressure on the Maldivian ecosystem is rising proportionately to the increase in tourism activity and the continuous ascent in population growth. Currently 89 Maldivian islands are in operation as resort islands. Just recently the government has projected further expansion of tourism capacity. The graph below (Fig. 21) illustrates the growth of total tourist arrivals - a constant rise during the past 20 years.

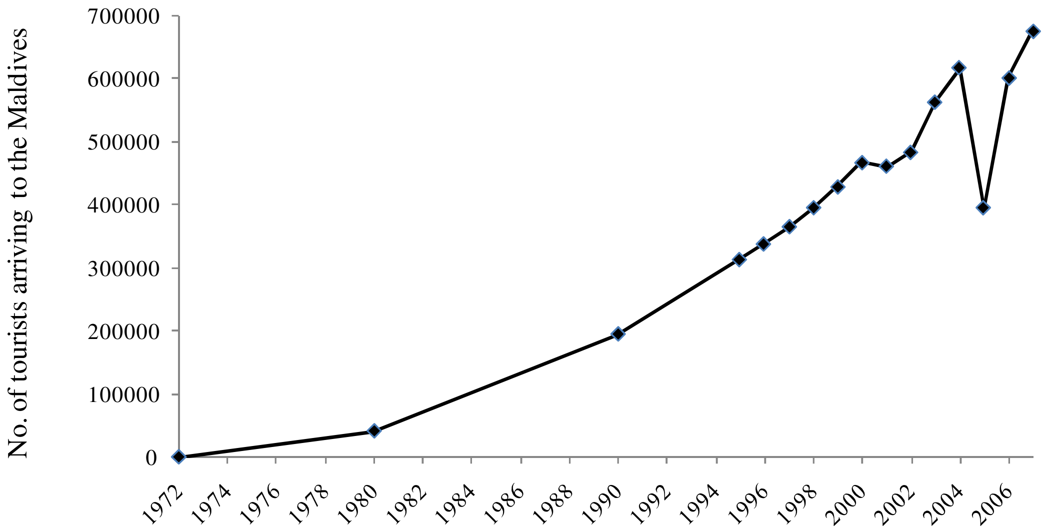


Figure 21. Total number of tourist arrivals 1972, 1980, 1990 and 1995-2007
Source: Tourism Yearbook 2007, Ministry of Tourism and Civil Aviation Maldives

The ministry of tourism has recently given approval for further touristic development of 35 islands. Therefore the environmental impositions certainly will rise notably in the course of the next few years. Besides, the local population continues to grow at a very fast pace.
Thus, it will be important to conserve the Maldivian ecosystem for locals but also for the tourism industry, which is now the principal source of national revenue, generating 27% of the NDP (National Development Plan 2007). In a country where dive-related tourism is the major industry and the corals are the main attraction, aesthetically pleasing reef communities are therefore an important economic resource.

One year ago, Brunner (2007) tried to set an impulse concerning the actual necessity for the implementation of sustainability into business operations for tourism resorts in the Maldives, and conducted her research on Huvafen Fushi. The resort is internationally rated as a five star property and belongs to the up-market resorts in the Maldives. Furthermore, it is a member of the 'Small Luxury Hotels of the World'. The resort concept of Huvafen Fushi encompasses the elements 'natural resources of the Maldives' and 'sustainable development'. The official brochure states: “Set within its very own lagoon. Huvafen Fushi is a naturalist’s wonderland where the stunning environment – above and below the waterline – is an attraction itself." But in this context, a crucial question rises: What does the average Huvafen Fushi visitor actually know about this "stunning environment" below the waterline?

5.4.1 Sustainability on Huvafen Fushi

In her diploma thesis about the LOHAS concept (Lifestyles of Health and Sustainability), Brunner (2007) found out that only 36% of the questioned guests correctly classified a coral as an animal (compared to a stone or a plant). This trend is crucial considering the protection of coral reefs at Huvafen Fushi.

It was Dr. Reinhard Kikinger, marine biologist and lector at the degree-programme "Tourism Management & Leisure Economics" in Krems, Austria, who first designed a concept for an environment-friendly and sustainable programme for Huvafen Fushi, because he believed that the LOHAS-concept "*is an intelligent approach to combine comfort and luxury for tourists, without becoming part of the well known and destructive 'recreational succession'*" (cit. Kikinger in Brunner 2007). This programme included the employment of a resident marine biologist based on the island, who was, amongst other factors, responsible to guide the up-market guests through their snorkelling excursions. Educating around 900 guests on Huvafen Fushi only within one year means that these 900 guests left the Maldives being more familiar with the local environment than before. Almost all resorts offer snorkelling excursions, and on most of them, especially on those of the discount travel market, which is currently declining in the Maldives, many more tourists are taken to coral reefs than on Huvafen Fushi. My personal estimation is that a minimum of 1500 guests on average book a guided snorkelling excursion per resort every year in the Maldives, and in addition, about twice this amount snorkel on the local house reef on their own. Taking into account 89 of the total ~1200 coral islands of the Maldives, this would mean an estimated pressure of around 400.500 snorkelers (including beginners) per year.

In the ideal case, all guests who visit the Maldives would get briefed about underwater life. On Kuramathi Island (Northern Ari Atoll, Maldives), all guests are recommended, but not forced, to listen to a short introductory about coral reefs and snorkelling on the island's house reef. On some other resort islands, only guests travelling with particular tour operators get an introduction to the island and the coral reef by a resident tour guide. Marine biologists are still rare in the Maldives as only about a handful of resorts find it worth employing someone who is competent for underwater life.

If only the tourists who book snorkelling excursions are well briefed about the correct behaviour in the reef and if only 80% of them followed the rules, this will result in a reduction of snorkelling pressure on the corals of roughly 100.000 people per year in the Maldives alone. Divers are not included in these calculations. Whereas one would assume that holders of diving certificates have a common knowledge about coral reefs and behave correctly, results of Brunner's (2007) survey indicate something quite different. According to her study, we can be assumed that holders of a diving certificate do not automatically dispose of any understanding of the biology of corals. An island which focuses on a relaxing middle-class holiday and an intact house reef (e.g. Eriyadu Island Resort, North Male' Atoll, Maldives) records ~ 1500 divers per year (~16.000 dives/year), and a typical "diver's island" (e.g. Vilamendhoo Island Resort, South Ari Atoll, Maldives) records ~2500 divers per year.

Observations were carried out in the Ras Mohammed National Park (Egypt) by Medio *et al.* (1997) to determine the rates of damage to corals by SCUBA divers and to assess the effectiveness of environmental education in reducing these damages. A single environmental awareness briefing reduced the rate of divers' contact with reef substratum from 1,4 to 0,4 contacts per diver and per 7 min observation period. At the same time, the proportion of contacts that were deliberate and conscious, and so mainly directed at non-living substratum, increased to 63,8%. As a result, the rates of contact with living corals (as opposed to non-living substratum) decreased from 0,9 to 0,15 instances per diver and per 7 min.

We believe that the majority of guests who know what a coral is and how long it takes for a coral reef to build up change their behaviour. In order to make them more familiar with corals, we invited hotel guests to help during the coral propagation process, which can be, on the one hand, an income-stream for the resort when guests adopt their own coral and pay a minimal amount for it. And on the other hand, it will certainly create an understanding for marine invertebrates among the tourists. Even the local staff was eager to help and learn more about corals, which turns the coral nursery also into a socio-economic project, teaching Maldivians more about the surroundings they live in. Besides, the Underwater Spa is an ideal place to explain to locals and foreigners what a coral reef is all about, without them getting into the water themselves.

In a nation like the Maldives which depends on its environment, we find it absolutely necessary that every resort island employs a marine biologist or at least a professional environmental manager, who does not only take the tourists to the reefs, but snorkels with them and is able to answer their questions immediately. From the ~ 250 snorkelers I have personally taken on an excursion, I have not experienced anything but positive feed-back. If someone is able to competently give reasons why not to step on or touch any reef organisms, even up-market guests who pay several thousands of dollars for their holiday will not feel confined in their personal freedom and will understand. Many resort owners, especially those of the of high-end hotels, have not fully understood this yet, believing that they can only make money if they let people do whatever they want, even if this means harming the environment.

6 Conclusions

Restoration is a relatively new and rapidly expanding discipline that combines many fields of science including ecology, geology, socioeconomics, and engineering.
In this study we could show that it is possible to construct an attractive, small-scale artificial reef rich in fish life and a coral nursery with simple methods and cost-effective material. Using broken and loose fragments for both the Spa reef and the nursery reduced the pressure on donor reefs. Transplants around the Spa survived well after one year of monitoring, and simply in adult Pocilloporids we could observe slower growth rates for transplants compared to non-transplants. In the coral nursery, a 90% survivorship after nine months can be taken as a successful example for future rehabilitation methods and can be optimised if species vulnerable to propagation are avoided (e.g. *Acropora microphthalma*).
Although the specific goal of restoration is to restore the ecological function of a particular ecosystem, a multi-scale approach is needed to ensure the successful restoration of a site, especially in the case of coral reef restoration. In this multi-scale approach, the influence of tourism should never be forgotten because it is, interestingly, the booming branch of the (sustainable) tourism business that can be used to achieve important benefits to conservation. It may provide a source and serve as an economic justification for financing parks and conservation, offer economically sound and

sustainable alternatives to natural resource depletion or destruction to local people and create an impetus for private conservation efforts.

Resort owners in the Maldives should catch up with the future tourism stream. According to Brunner (2007), we can observe that values and value sets in western societies are changing within shorter periods. Therefore, it can be assumed that values geared towards ecology and health will come to the forefront in the near future. The key demands of the future traveller will be quality, "pleasant transportation, comfort, a diversity of opportunities at the holiday destination and sustainable management - and all together for an affordable price. The 'Lifestyle of Health and Sustainability' concept is a step towards a more sustainable way of tourism. It can not completely prevent negative ecological impacts, like long distance flights, but it can reduce damages to a destination site"(cit. Kikinger in Brunner 2007). Huvafen Fushi is definitely keeping up with this trend.

7 Acknowledgements

I would like to express my special gratitude to Dr. Reinhard Kikinger, who first suggested this topic and the resort to me, and to my Diploma Thesis coach Prof. Branko Velimirov, who happily accepted to advise me throughout the whole project. I am grateful for their continuous support. I thank Universal Pvt. Ltd. and Per Aquum Resorts Spas Residences for their financial support and for enabling me to combine the project with my diploma thesis study. The "Green Team" on Huvafen Fushi, Mr. Stephen Lindsay and Dr. Robert Hilliard essentially contributed technically and physically to the fieldwork.Sincere thanks are expressed to Mag. Ulrike Kloiber, who continued the marine biology programme on Huvafen Fushi, provided valuable monitoring data to me and kindly granted permission to use some of her photographs. In addition, I am most grateful to my teacher and friend Mag. Astrid Schernhammer for reviewing my script, and to my parents for supporting me financially during my studies. For his continuous encouragement, for contributing valuable information to my thesis due to his close connection to the Maldives, and for just being my better half, I thank my dear husband Aboo.

8 References

Allison WR (1996) Snorkeler damage to reef corals in the Maldive Islands. Coral Reefs 15: 215-218

Barker NHL, Roberts CM (2004) Scuba diver behaviour and the management of diving impacts on coral reefs. Biological Conservation 120: 481-489

Bell JD, Galzin R (1984) Influence of live coral cover on coral-reef fish communities. Marine Ecology Progress Series 15: 265-274

Bellwood DR, Hughes TP, Folke C, Nyström M (2004) Confronting the Coral Reef Crisis. Nature 429: 827-833

Brown BE, Dunne RP (1988) The environmental impact of coral mining on coral reefs in the Maldives. Environmental Conservation 15: 159-16

Brunner, F (2007) The Lohas Concept. A case study in Huvafen Fushi Maldives. Diploma thesis submitted at the IMC University of Applied Sciences Krems, Austria

Carpenter KE, Abrar M, Aeby G, Aronson RB, Banks S, Andrew A, Chiriboga A, Cortés J, Delbeek CJ, DeVantier L, J. Edgar GJ, Edwards AJ, Fenner D, Guzmán HM,. Hoeksema BW, Hodgson G, Johan O, Licuanan WY, Livingstone SR, Lovell ER, Jennifer, Moore JA, Obura DO, Ochavillo D, Polidoro BA, Precht WF, Quibilan MC, Reboton C, Richards ZT, Rogers AD, Sanciangco J, Sheppard A, Sheppard C, Smith J, Stuart S, Turak E, Veron JEN, Wallace C, Weil E, Wood E (2008) One-Third of Reef-Building Corals Face Elevated Extinction Risk from Climate Change and Local Impacts. *Science* [DOI: 10.1126/science.1159196]

Cesar HSJ (2000) Coral Reefs: Their functions, Threats and Economic Value, in Collected Essays on the Economics of Coral Reefs, Cesar HSJ (ed.). Cordio, Kalmar University Sweden

Chua CYY, Chou LM (1994) The use of artificial reefs in enhancing fish communities in Singapore. Hydrobiologia 285: 177-187

Clark S, Edwards AJ (1990) An evaluation of artificial reef structures as tools for marine habitat rehabilitation in the Maldives. Aquatic Conservation 9: 5-21

Clark S, Edwards AJ (1994) Use of artificial reef structures to rehabilitate reef flats degraded by coral mining in the Maldives. Bulletin of Marine Science 55: 2-3

Clark S, Edwards AJ (1995) Coral transplantation as an aid to reef rehabilitation: evaluation of a case study in the Maldive Islands. Coral Reefs 14: 201-213

Clark S, Edwards AJ (1999) An evaluation of artificial reef structures as tools for marine habitat rehabilitation in the Maldives. Aquatic Conservation: Marine and Freshwater Ecosystems 9: 5-21

Constanza R, d'Arge R, de Goot R, Farber S, Grasso M, Hannon B, Limburg K, Naeem S, O'Neill R, Paruelo J; Raskin R, Sutton P, van den Belt M (1997) The value of the world's ecosystem services and natural capital. Nature 387: 253-260

Driml S (1994) Protection for profit. Economic and financial values of the Great Barrier Reef world heritage area and other protected areas. Great Barrier Reef Marine Park Authority, Research publications no. 35, Townsville, p. 83

Edwards AJ, Clark S (1992) Rehabilitation of coral reef flats using precast concrete [use of precast concrete structures (Armorflex and SHED) to promote rehabilitation of coral reef flats degraded by mining in the Maldives, Indian Ocean]. Concrete 26: 16-19

Edwards AJ, Clark S (1998) Coral Transplantation: A Useful Management Tool or Misguided Meddling? Marine Pollution Bulletin 37: 474-487

Epstein N, Bak RPM, Rinkevich B (2001) Strategies for gardening denuded reef areas: the applicability of using different types of coral material for reef restoration. Restoration Ecology 9: 432-442
Epstein N, Bak RPM, Rinkevich B (2003) Applying forest resoration principles to coral reef rehabilitation. Aquatic Conservation: Marine and Freshwater Ecosystems 13: 387-395
Fernandes L (1995) Integrating Economics, Environmental and Social Issues in an Evaluation of Saba Marine Park, Netherlands Antilles, Caribbean Sea. Honbue, Honolulu, USA, 60 pp
Field CD (1996) Restoration of Mangrove Ecosystems. International Society for Mangrove Ecosystems, Okinawa, Japan. 250 pp
Franklin H, Muhando CA, Lindahl U (1998) Coral culturing and temporal recruitment patterns in Zanzibar, Tanzania. Ambio 27: 651-655
Gochfield DJ, Aeby GS (1997) Control of populations of the coral-feeding nudibranch *Phestilla sibogae* by fish and crustacean predators. Marine Biology 130: 63-69
Harvell CD, Mitchell CE, Ward JR, Alitzer S, Dobson AP, Ostfeld RS, Samuel MD (2002) Climate warming and disease risks for terrestrial and marine biota. Science 196: 2158-2162
Hawkins DE (1998) The Relationship of Tourism-Related Revenue Generation to Coral Reef Conservation in Coral Reefs: Challenges and Opportunities for Sustainable Management, Hatziolos ME, Hooten AJ, Fodor M (ed). World Bank Publications, Washington D.C., 93 pp
Hawkins JP, Roberts CM, Van't Hof T, De Meyer K, Tratalos J, Aldam C (1999) Effects of recreational scuba diving on Caribbean coral and fish communities. Conservation Biology 13: 888-897
Hilbertz WH (1979) Electrodeposition of minerals in sea water: experiments and applications. IEEE Journal on Oceanic Engineering OE-4(3), 94.
Hughes TP (1994) Catastrophes, phase shifts, and large-scale degradation of a Caribbean coral reef. Science 265: 1547-1551
Jaap WC (1998) Coral reef restoration - a synthesis of information, goal setting and success criteria for coastal habitat restoration. Charleston, SC, January 13-15
Jaap WC (2000) Coral reef restoration. Ecological Engineering 15: 345-364
Jackson JBC**,** Kirby MX, Berger WH, Bjorndal KA, Botsford LW, Bourque BJ, Bradbury RH, Cooke R, Erlandson J, Estes JA, Hughes TP, Kidwell S, Lange CB, Lenihan HS, Pandolfi JM, Peterson CH, Steneck RS, Tegner MJ, Warner RR (2001) Historical overfishing and the recent collapse of coastal ecosystems. Science 293: 629-638
Johns GM, Leeworthy VR, Bell FW, Bonn MA (2001) Socio-economic study of reef resources on Southeast Florida and the Florida Keys. Broward County Department of Planning and Environmental Protection, Fort Lauderdale, FL
Kaufman LS (2006) If you built it, will they come? Toward a concrete basis for coral reef gardening, in Coral Reef Restoration Handbook, Precht WF (ed.) CRC Press Taylor & Francis Group, Florida, p. 126
La Mer (2008) Environmental Impact Assessment Report for Establishing a Coral Nursery at Huvafen Fushi, North Male' Atoll. Land & Marine Environmental Resource Group Pvt Ltd, Male', Maldives
Lindahl U (1998) Low-tech rehabilitation of degraded coral reefs through transplantation of staghorn corals. Ambio 27: 645.

Lindahl U (1999) Low-tech rehabilitation of coral reefs through transplantation of corals: implications for cost-effective management in developing countries. Proceedings of an International Workshop on the Rehabilitation of Degraded Coastal Systems, 19-24 January 1998. no. 20, p. 130. Special publication. Phuket Marine Biological Center. Phuket [Spec. Publ. Phuket Mar. Biol. Cent.].

Lindsay SR (2007) Environmental Impact Assessment: Cultivation of Corals - Kosrae, FSM. Prepared for: Micronesia Management and Marketing Enterprises for the Kosrae State Government.

Lirman D, Miller MW (2004) Modelling and monitoring tools to assess recovery status and convergence rates between disturbed and undisturbed coral reef habitats. Restoration Ecology 11: 448-456

McCulloch M, Fallon S, Wyndham T, Hendy E, Lough J, Barnes D (2003) Coral record of increased sediment flux to the inner Great Barrier Reef since European settlement. Nature 421: 727-730

Medio D, Ormond RFG, Pearson M (1997) Effects of briefings on rates of damage to coral by scuba divers. Biological Conservation 79: 91-95

Miller MW (2001) Corallivorous snail removal: evaluation of impact on *Acropora palmata*. Coral Reefs 19: 293-295

Miller MW, Hay M (1998) Effects of fish predation and seaweed competition on the survival and growth of corals. Oecologica 113: 231-238

Miller SL, Barimo J (2001) Assessment of juvenile coral populations at two coral reef restoration sites in the Florida Keys National Marine Sanctuary: indicators of success? Bulletin of Marine Science 69: 395-404

Miller SL, McFall GB, Hubert AW (1993) Guidelines and Recommendation for Coral Reef Restoration in the Florida Keys National Marine Sanctuary, National Undersea Research Center, University of North Carolina at Wilmington

Morse ANC, Morse DE (1996) Flypapers for coral and other planktonic larvae. Bio Science 46: 254-262

Morton B, Blackmore G (2000) The impacts of an outbreak of corallivorous gastropods, *Drupella rugosa* and *Cronia margariticola* (Muricidae), on Hong Kong's scleractinian corals. Final report to The Government of the Hong Kong Special Administrative Region, China 30 April 2000. Swire Institute of Marine Science, The University of Hong Kong. 48 pp.

Muthiga NA, McClanahan TR (1997) The effect of visitor use on the hard coral communities of the Kisite Marine Park, Kenya, in Proceedings of the Eight International Coral Reef Symposium, Smithsonian Tropical Research Institute, Balboa, Panama, Vol. 2: 1879-1882

National Development Plan 2006 - 2010 (2007) Ministry of Planning and National Development, Male', Republic of Maldives

Oren U, Benayahu Y (1997) Transplantation of juvenile corals: a new approach for enhancing colonization of artificial reefs. Marine Biology 127: 499-505

Petersen D, Tollrian R (2001) Methods to enhance sexual recruitment for restoration of damaged reefs. Bulletin of Marine Science 69: 989-1000

Plucer-Rosario GP, Randall RH (1987) Preservation of rare coral species by transplantation: an examination of their recruitment and growth. Bulletin of Marine Science 41: 585-593

Pratt JR (1994) Artificial habitats and ecosystem restoration: managing for the future. Bulletin of Marine Science 55: 268-275.

Precht WF (2003) Call for abstracts: coral reef restoration and remediation mini symposium 4-20, 10th ICRS. Coral List (October 2003)
Precht WF, Robbart M (2006) Coral Reef Restoration: The Rehabilitation of an Ecosystem under Siege, in Coral Reef Restoration Handbook, Precht WF (ed.). CRC Press Taylor & Francis Group, Florida, p. 6.
Quinn NJ, Kojis BL (2006) Natural Resilience of Coral Reef Ecosystems, in Coral Reef Restoration Handbook, Precht WF (ed.), CRC Press Taylor & Francis Group, Florida, p. 61.
Rinkevich B (1995) Restoration Strategies for Coral Reefs Damaged by Recreational Activities: The Use of Sexual and Asexual Recruits. Restoration Ecology 3: 241-251
Sabater MG, Yap HAT (2002) Growth and survival of transplants with and without electrochemical deposition of $CaCO_3$. Journal of Experimental Marine Biology and Ecology 272: 131-146
Shafir S, Van Rijn J, Rinkevich B (2006) Steps in the construction of underwater coral nursery, an essential component in reef restoration acts. Marine Biology 149: 679-687
Spieler RE, Gilliam DS, Sherman RL (2001) Artificial substrate and coral reef restoration: what do we need to know to know what we need. Bulletin of Marine Science 69: 1013-1030
Tourism Yearbook (2007) Statistics & Research Section, Ministry of Tourism and Civil Aviation, Planning Department, Male', Republic of Maldives.
Tratalos JA, Austin TJ (2001) Impacts of recreational SCUBA diving on coral communities of the Caribbean island of Grand Cayman. Biological conservation 102: 67-75
Wilkinson C (2004) Status of Coral Reefs of the World. Australian Institute of Marine Science, Townsville, Australia
Williams DM, Roth CH, Reichelt R, Ridd P, Rayment GE, Larcombe P, Brodie J, Pearson R, Wilkinson C, Talbot F, Furnas M, Fabricius K, McCook L, Hughes T, Hough-Gulberg O, Done T (2002) The Current Level of Scientific Understanding on Impacts of Terrestrial Run-Off on the Great Barrier Reef World Heritage Area. CRC Reef Research Centre.
Yap HT, Aliño PM, Gomez ED (1992) Trends in growth and mortality of three coral species (Anthozoa: Scleractinia), including effects of transplantation. Marine Ecology Progress Series 83: 91-101
Yap HT, Gomez ED (1985) Growth of *Acropora pulchra* III. Preliminary observations on the effects of transplantation and sediment on the growth and survival of transplants. Marine Biology 87: 203-209
Yap HT; Alvarez RM, Custodio HM, Dizon RM (1998) Physiological and ecological aspects of coral transplantation. Journal of Experimental Marine Biology and Ecology 229: 69-84
Zakai D, Chadwick-Furman NE (2002) Impacts of intensive recreational diving on reef corals at Eilat, northern Red Sea. Biological Conservation 105: 179-187
Zedler J (1984) Salt Marsh Restoration: a Guidebook for Southern California. California Sea Grant Report No. 7-CSGCP-009, 46 pp

9 Appendix: Curriculum vitae

CURRICULUM VITAE

Zu meiner Person

Verena Wiesbauer
Feldgasse 45
2230 Gänserndorf
Tel.: +43 699 / 11 84 83 74
Tel. (Maldives): +960 / 7869666

Geboren am 26. 11. 1985 in Wien
Familienstand: ledig

Ausbildung

1991 – 1995	Volksschule in Gänserndorf, NÖ
1995 – 2003	Konrad-Lorenz Gymnasium (AHS) Gänserndorf, Maturaabschluss
2003 – 2008	Biologiestudium an der Universität Wien, Zoologie, Meeresbiologie

Ausbildung im Bereich Meeresbiologie an der Universität Wien:

04 / 2005	Einführung in die Meereskunde
07 / 2005	Gefährdung und Schutz von Korallenriffen
01 / 2006	Meeresbiologische Laborarbeiten I
06 / 2006	Meeresbiologische Laborarbeiten II
06 / 2006	Meeresverschmutzung, Meeresnutzung
07 / 2006	Einf. in die Fauna und Flora mariner Lebensräume (Auslandspraktikum in Rovinj, Kroatien)
11 / 2006	Biodiversität maledivischer Korallenriffe
01 / 2007	Biologie Rezenter Riffe
01 / 2007	Kanäozoische Scleractinia (Praktikum Korallenbestimmung)
09 / 2007	Korallenriffpraktikum und terrestr. Exkursionen Auslandspraktikum in Dahab, Ägypten
11 / 2007	Biologie des marinen Plankton
01 / 2008	Management gefährdeter Tierarten

Berufliche Tätigkeit und Weiterbildungen

01. – 31. 8. 2002	Ferialaushilfe bei Austrian Airlines: Einkauf und Logistik
01. – 02. 09. 2006	Teilnahme am 1st National Workshop on Resort Reef Management, Male', Malediven
06. 02. – 29. 08. 2007	Meeresbiologin auf Huvafen Fushi Resort, Malediven
19. - 23. 06. 2008	Vorträge über Haischutz an der VS Gänserndorf

Sonstige Kenntnisse

Fremdsprachen	Englisch: Sehr gut in Wort und Schrift Französisch: Maturaniveau Latein: Maturaniveau Dhivehi: Grundkenntnisse
EDV	Microsoft Office; Internet; Corel Draw
Tauchausbildung	PADI Open Water Diver, 2004, Österreich PADI Advanced OWD, 2004, Österreich NITROX Enriched Air Diver, 2005, Malediven
Taucherfahrung	Österreich, Rotes Meer, Malediven; ca. 150 Tauchgänge Wissenschaftliche Arbeitsmethoden Digitale Unterwasserfotografie
Mitgliedschaften	International Society for Reef Studies (ISRS) Pro mare – Verein zur Förderung der Meeresforschung in Österreich
Führerschein	Klasse B

Gänserndorf, am 10. September 2008