Enhancement program of the Kuda Huraa house reef

Introduction

The Kuda Huraa house reef is located on the lee side of the large reef system of Huraa in North Male Atoll. The most important feature on the lee side is a fracture in the reef structure south west of Kuda Huraa. This break usually referred to as the Kuda Hura House Reef, is a preferred dive site for the diving school, especially for beginners and for the orientation dives and thus the project will be carried out at this site. Diving is an important income earner for the tourism industry in the Maldives, and this industry could be affected by a degradation of the bio-physical status of the reefs.

At the site, possible causes of reef degradation include:

- coral bleaching, when corals stressed either by an increase in temperature, salinity, light, sedimentation, aerial exposure and pollutants lose or expel their symbiotic zooxanthellae (Glynn, 1993)
- impacts from diving, when an inexperienced diver breaks coral with their fins
- algal overgrowth, algae and corals competing for space (Hughes, 1994)
- increased nutrient levels due to human presence on the island
- various outbreaks of predators such as the crown of thorns starfish.

Even though anthropogenic activities are partly responsible for reef degradation, the single most important event shaping the reef landscape at present is the 1998 coral bleaching event. Of unprecedented reported scale, it decimated the coral colonies (reference needed), leading very fast to the unfounded rumor that the Maldivian reefs were dead. This has led to a bad publicity among divers concerning the Maldives, and potential visitors may have chosen other destinations for their vacations. 46 % of the tourists polled at the Male' airport said that the marine environment was very important to them (Cesar et al, 2000). With the prediction of global warming, such disturbances are likely to occur again and actions need to be taken to mitigate such large-scale events, the source of which is increasingly thought to be anthropogenic (Glynn, 1991; Brown, 1996; Hoegh-Guldberg, 1999; Wilkinson, 1999). The natural rate of recovery after a severe disturbance is slow and it can take five to ten years to recover from a small, localized disturbance such as a ship grounding and one to several decades for larger impacts such as coral bleaching (Edwards and Clark, 1998).

To remedy this bad publicity, there is a need to counter the adverse effects of coral bleaching and other impacts and to increase the satisfaction of divers. Nowhere in the world is an efficient method to counter bleaching to be found, as the research in this sector is still at its beginning. Therefore a research aspect will have to be incorporated in the project to assess the success and failures as well as to direct the efforts. Spieler et al. (2001), advocate for a research program to be incorporated in every single restoration project until a better understanding of restoration methodology is acquired, as well as a monitoring of the project for at least a period of 5 years. The results of the research and of the monitoring undertaken, as well as the directions followed will then be presented and explained to the interested divers, thereby increasing their potential satisfaction.

The present enhancement program for the site looks at a management strategy to integrate human activities such as recreational diving and pre-emptive reef restoration techniques, in particular in the case of extensive coral bleaching events. Diverse ecological and physical aspects of the reef would also be studied to increase the overall knowledge of the reef ecosystem and increase awareness of the guests.

This project will look at the restoration of the denuded reefs left after the bleaching events, using corals maricultured in a nursery. This technique was first developed by Rinkevich in Eilat in the Red Sea and was called the "gardening of coral reef" (Rinkevich, 1995). In this technique, different types of coral material is used to create either colonies or fragments which can then be transplanted on the bare substrate. It will also investigate the integration in the natural environment of artificial reef structures, which will be utilized as the nursery. These artificial structures will consist of several grouped ReefBalls, which are concrete structures . This implies a monitoring and an understanding not only of the artificial reef structures but also of the natural conditions of the target site for the restoration.

Natural reef

Reef processes

Although coral reefs are receiving more and more research focus, they are still unknown in a number of respects. Studies incorporating the different aspects of coral reefs are lacking and a holistic view need to be adopted to understand the reef processes. The physical conditions on the reef determines to a certain extent the configuration of the benthos, which in turn will provide certain types of habitat suitable for particular species. The interactions on the coral reef are very complex and an understanding of the reef physical, biological and ecological processes in a site such as the Kuda Huraa House Reef will require observation of diverse aspects in a long term study. The knowledge of the natural cycles at this site is a target for the research program and is important for making management decisions.

Physical environment

Present condition

The site is characterized by the presence of interruptions in the continuity of the reef top framework. The presence of this break also corresponds to the area where the current created by the oceanic swell on the reef crest flows into the lagoon due to the presence of Kuda Huraa and Vahboahuraa. The back reef slope also comes to an end at this place and is replaced by a sandy slope forming a flat area inshore close to the reef top, and sloping outwards until it meets the lagoon sea floor.

Along this slope several small patch reefs and isolated bommies are to be found, as well as a wreck (see map). Two slightly bigger reefs are found to the north and to the south of the site. The sandy area in between those patch reefs consists of fine sand and was strewn with dead leaves of seagrass, but it is not known whether their presence is seasonal. From the aerial picture of the site (Fig.) , the sand appears to be gathering at the south of the openings of channel connecting to the reef flat area. The settling of the sand and the distribution of the leaves are both governed by the hydrodynamic regime of the site.

Hypothetical processes operating at the site

The first hypothesis is that the presence of the break in the lee side of the reef and its position between the two islands are related. The currents created by the oceanic swell setup on the atoll rim would be flowing in between the islands of Kuda Huraa and Vahboahuraa. The water flows as if in a funnel and would be increased at the break. The flow could possibly be responsible for the presence of the break, which is in turn supported by the shape of the reef itself. The reef crest line is concave in this area, which induces the idea that the currents would have caused abrasion of the reef framework, enhancing erosion. All the more that the water coming from the reef flat would carry sand and debris created on the atoll rim reef crest.

Where the width of the reef system is greater, such as near Kanifinolhu or Bodu Huraa, this sand accumulates in the lagoon. It is possible that the lagoon present to the north of the reef system was extending southwards in the past, and was filled up after the reefs caught up with Holocene rising sea levels, but this could only be proven by cores or the presence of corals in growth position underneath this sand. A coral microatoll found on the reef flat east of Bodu Huraa was dated and found to be 710 ? 80 years old, but little can be inferred from this value and simply proves Gardiner, who assessed the boulder conglomerates to be 4000 years old wrong (Woodroffe and McLean, 1992). However, the sand has now filled up this lagoon and the loose sediment created by the erosion of coral growth on the atoll rim crest passes through the break forming over time an accumulation on the atoll side of the reef system. The shape of the gentle sandy slope to the sea floor on the inside of the atoll, with more sand accumulation to the south of the openings may be explained by a monsoonal change in the hydrodynamic regime. The hypothesis is two fold, first the direction of the main flow along the atoll side would be influenced by the monsoon, and second the sediment supply is also affected by the monsoon. During the northeast monsoon, the current on the inside of the atoll would flow in a southwesterly direction and the sediment supply would be high, as the northeast monsoon wind waves helps the swell created flow to transport t he sediment to the lee side. During the southwest monsoon, the flow would have a northeasterly direction, and sediment supply would be low, as the monsoon wind waves hinder sand transport to the lee side.

Another important mechanism that could account for part of the physical configuration is the action of borers on the blocks of the upper reef framework, undermining them and making the framework more fragile. This action would have been enhanced by the swell created flow by removing the loose sediments in this place. This in turn could have led the blocks to topple over and fall down the slope. A similar reef front progradation was observed at the Tin Smelter reef in Phuket, South Thailand, by the splitting and the toppling of massive porites colonies and their reestablishment a little further seaward down the fore-reef slope (Tudhope and Scoffin, 1994). The difference there is that the area is a sedimentation area where borers are passive endoliths and vertical splitting of the coral skeleton is facilitated by the abundance of elongate cryptoendoliths parallel to the growth direction (Scoffin and Bradshaw, 2000). In our case, this hypothesis would also account for the concave shape of the reef in that area, (Fig 1), as well as the presence of coral patches down the slope.

Benthos

Present condition

At the site, the overall condition of the benthos was representative of the overall conditions prevailing in the Maldives since the 1998 coral bleaching event. Few living corals are present on the upper part of the reef, which exhibits a bare substrate overgrown with turf algae. The presence of ascidians as well as of coral colonies of the species, *Porites rus*, is also common in these conditions.

The coral growth increases with depth, and the deeper reefs display a good coral cover, with a number of areas dominated by the genus *Goniopora*. The patch reefs are dominated by a number of large colonies of *Porites, Diploastrea, Psammocora* and *Galaxea*. A number of dead colonies form coral heads, which are usually, colonized by an assemblage of diverse benthic species among which are coral species, usually encrusting or branching. Areas of rubble are also present and in these cases, they are often colonized by *Acropora* species. These colonies are small in size, and have probably settled subsequent to the 1998-bleaching event.

Whereas seagrass are found in the vicinity of the island, on both the eastern and the western side, they are absent from the reef flat directly upstream of the break, to a distance of approximately 500 m. Nevertheless, a patch of seagrass of around 40 m^2 at a depth of 4m was present downstream of the channels from the reef flat.

The substrate between the patch reefs is sandy, providing a favourable habitat for numerous sand-dwelling organisms. Blades of seagrass are found on the sand, which could potentially increase the available nutrients in the area. Holothurians, which are detritus or filter feeders, dominated some of the sandy areas. These organisms are important in "cleaning" the sand and digests bacteria and plankton in the organic matter (Coleman, 2000).

Hypothetical processes operating at the site

The benthic composition of a reef is influenced by the physical conditions, like currents influencing recruitment, or sedimentation hindering coral growth. Therefore, the benthic species composition, the condition of the colonies and their shapes will give clues about the physical factors and their influences.

At the Kuda Hura House Reef, the oceanic swell created flow could play an important role on the ecology of the reef by promoting the exchange of species from the outer reef crest to the inside of the atoll. It could also be bringing food to the site, in the form of plankton from the reef flat and crest. Import of species from upstream could also be responsible for the presence of the seagrass patch. The presence of seagrass on the reef flat near Kuda Huraa is possibly due to increased nutrient input into the area as a result of human habitation. The aerial pictures from 1969, prior to resort development does not show any seagrass near Kuda Hura. However, since the establishment of the resort, seagrass has been seen as a problem for the aesthetics of the island. A study carried out in Laamu Atoll found that seagrass was related to an increase in the input of phosphorous into the lagoon (Miller and Sluka, 1999). Phosphorous is one of the common nutrients that are found in the human effluent and thus it is not surprising that the presence of seagrass in the Kuda Hura lagoon has been observed since the habitation of the island. Whether the increase in nutrient levels in the water has had an influence on the benthic communities is not known, and would be difficult to determine as the effects would have been masked by the 1998 coral bleaching event.

Coral bleaching occurs when corals lose or expel a major portion of their zooxanthellae, when the concentration of the photosysnthetic pigments in the zooxanthellae decreases severely or due to a combination of these processes. It is a stress reaction that can be induced by certain stressor including elevated or decreased water temperatures, high fluxes of visible and ultraviolet radiation, prolonged aerial exposure, freshwater dilution and high sedimentation (Glynn, 1991). Responses to bleaching include reduced coral growth and calcification, diminished capacity to reproduce and tissue necrosis. Intense and prolonged bleaching however can cause high coral mortality (Glynn, 1993).

When bleached corals die, the available space is often colonized by non-reef-building organisms. The dead framework act as shelter and grazing surfaces for many potentially destructive organisms such as boring sponges, mussels, sea urchins and fish, leading to higher bioerosion than net carbonate production (Glynn, 1991).

Some coral species are more susceptible to coral bleaching than others. Corals having massive morphologies have been found to be less affected while those with branching morphologies are more susceptible. Marshall and Baird (2000) found that there were significant differences in bleaching response between depths and taxa. *Cyphastrea, Turbinaria* and *Galaxea* were relatively unaffected by bleaching, while most acroporids and pocilloporids were highly susceptible. The hydrocorals (*Millepora* spp.) were the most susceptible taxa, with 85% mortality. Before the 1998 bleaching event, many reef flats in Maldives were dominated by branching acroporids. As these species have very low susceptibility to prolonged elevated tempera tures, high mortality occurred during this event. Many hardy corals such as *Porites lutea, P. cylindrica* and *P. rus* and *Goniopora* spp. seem to have survived the bleaching event.

Recruits of *Acropora* and *Pocillopora* in the 30cm size class were observed at the Kuda Hura House Reef especially in the area of dead coral rubble on the southernmost patch reef. Considering their size, these colonies have probably recruited subsequent to the bleaching event. Some species such as *Stylophora pistillata* and *Seriatopora hystrix*, which were common pre-bleaching but are thought to have disappeared from the northern atolls, were absent at the site.

The structure of the benthic community is an important factor shaping the reef ecosystem. It provides habitats for a large number of fish and mobile invertebrates, which depend on the reef framework for shelter. The way the benthic communities influence the distribution of habitats for the mobile fauna will be a focus of this study (e.g. affinity of certain fish species for certain coral forms or species). The assemblages of fish and invertebrates found on the reef can reciprocally affect the benthos. For example, some species of parrotfishes which are herbivorous fish grazing on algae excavate the substrate, feeding predominantly in the shallow part of the reef, with preferential grazing on convex surfaces such as dead coral stumps. Some of these species have been observed to defecate mainly in deeper areas such as gullies and over the reef base As they primarily feed on convex surfaces and defecate in depressions, they have the potential to reduce the overall topographic rugosity of the reef top (Bellwood, 1995).

Coral polyps, tunicates, sponges, algae and other sessile animals are a source of food for a number of species. Two spe cies of obligate corallivores, *Gobiodon citrinus* and *Oxymonacanthus longirostris*, which were common on Maldivian reefs pre-bleaching have virtually disappeared with the death of the branching acroporids which provided shelter and food for these species.

Fish and mobile invertebrates

Settings

The diversity of fish observed at the Kuda Hura House Reef was very high with 141 species belonging to 90 genus being recorded from the area. The fish community appears to be healthy with an abundance of predators such as groupers, snappers, moray eels and scorpion fish. Cryptic species like *Calloplesiops altivelis*, were seen swimming freely near their crevices. Small carnivores such as apogonids were very frequent, gathering in schools in sheltered space.

Another characteristic of the site is the presence of schools of balistids, such as *Odonus niger* in the water column which are usually not found in back reef conditions, and prefer the currents of the channels. A large number of *Pseudobalistes flavimarginatus*, showing a schooling behaviour was also present.

Omnivores are also well represented at the site, with a number of pomacentrids, chaetodontids, blennids, gobiids and pomacanthids. Among those families, species like *Apolemichtys xanthurus*, *Chaetodon decussatus* or *Gunnelichtys curiosus*, which are quite rarely encountered were sighted.

Herbivorous fish were not lacking either, with all the major families including acanthurids, scarids, kyphosids and siganids present. It appears that in each of those families, large size individuals were frequent. The variety of resources enables the presence of rare species, such as the ornate ghost pipefish *Cheilodipterus artus*.

This diverse fish fauna also sustains a number of fish associated species such as shrimps. Four species o f shrimps were recorded from the site Two of these species *Urocardiella antonbruunii* and *Rhynchocinetes durbanensis* had set up some cleaning stations, while *Stenopus hispidus* was also seen and is well known to clean big predators like moray eels. Other invertebrate fauna include the octopus *Octopus cyanea*, a large number of royal sea cucumber, *Thelenota anax*, on the sandy sea floor, and a few spiny lobsters *Panulirus versicolor.*

Hypothetical processes operating at the site

The site seems is obviously characterized by a diversity of resources. To simplify, resources are usually divided into two broad categories, food and living space (Sale, 1980). The presence of patch reefs down the slope separated by sandy areas provides at least two distinct habitat s, which sustain two different communities. The diversity at the spot is therefore enhanced by the physical settings.

In the scientific literature, evidence that food directly limits number of fish is limited (Sale, 1980), and it is therefore difficult to find grounds for the null hypothesis of this general rule. In our case though, the species richness, the size of the individuals as well as the abundance of secondary transformer tends to show that the food resource is excellent at the site. As mentioned earlier, the role of the current flowing over the reef flat is probably important, but medium to long-term observations are required to establish the interactions within and between these communities. The study concerning the fish and the mobile invertebrates will try and determine the relative roles of competition, predation and abiotic factors in structuring the fish and mobile invertebrate communities.

There are a number of possible theories explaining the structures of fish communities. They can be divided into two classes. The "equilibrium" theories state that there is an equilibrium between the amount of resources like food and shelter and the fish population, and that this limits the number of fish as a whole. The other class, regrouping the "non-equilibrium" theories, does not make the assumption that the amount of resources is a limiting factor for the fish population. Instead they propose that the limiting factor for the fish population would occur during recruitment (Victor, 1983, 1986; Doherty and Fowler, 1994), despite the prodigious fecundity of fishes (Sale, 1977, 1978).

There are two strands among the supporters of the "equilibrium theories". The first school of thought favours the "single-species equilibrium". In this model, the community evolved to create species-specific niches, and therefore, the competition for the limited amount of resources would mostly occur between conspecifics. The second line of thought called "multi-species equilibrium" suggests that similar species would compete for the same resources. The amount of available resources would then determine the total amount of fish, but not the number of individuals in each species.

One last pluralistic theory states that any of the above mentioned models could take precedence in a reef at a given time as the relative population abundances of fish are determined by temporal and spatial variations in recruitment strength, immigration and emigration, predation and competition for shelter sites (Caley, 1993). Therefore it is to be classified among the "non equilibrium theories".

In order to decide which model is closest to reality, the evolution of the fish community will be followed and compared with the predictions of the different models. A highly fluctuating community structure, as noticed by different researchers in Australia (Sale and Dybdahl, 1975, 1978; Sale, 1977; Talbot et al., 1978; Sale and Douglas, 1984; Sale et al., 1994), is in favour of either a non-equilibrium theory, or the "multi-species equilibrium", whereas constant community structure, as noticed in the Caribbean (Ogden and Ebersole, 1981), would favour the "single species equilibrium". Wantiez and Thollot noticed interspecific competition on some 50-year-old artificial structures in New Caledonia, together with post settlement migration of highly sedentary damsel fishes, thus favouring the single species equilibrium.

A monitoring of the reef using a fish count is required over a period of time in order to determine which of these models is applicable to the present situation.

Artificial reefs

Concept of restoration

Coral reefs worldwide are in a state of decline from natural (i.e. storms, predator outbreaks, coral bleaching etc.) as well as anthropogenic causes such as coastal development, pollution and exploitation (Wilkinson, 1999). Unlike in terrestrial environments, the impacts in marine systems are not localized due to high connectivity through ocean currents (Allison *et al.*, 1998). Damage due to natural causes is often widespread and catastrophic and human intervention or restoration is not feasible. However, anthropogenic damage can be prevented by mitigating the impacts and rehabilitating or restoring impacted environments. Artificial substrates have recently become a highly used tool for accomplishing such goals (Spieler *et al.*, 2001). Reef restoration is largely limited by incomplete knowledge of the ecosystem processes (Clark, 2001; Spieler et al., 2001). It is therefore important to build up this knowledge as the project unfolds.

When attempting to restore a reef impacted by coral bleaching and recreational diving, (the two stresses that have been identified as being the major cause for concern in our situation), it is very important to identify the functions that artificial reef structures can have. In some studies, where the reef framework is lost, as in the case of a ship grounding or coral mining, concrete can be used to replace the reef framework in the short term (Spieler et al., 2001). In the case of coral bleaching however, the reef framework is left intact, if we exclude areas of very large stands of Acropora species of the tree type (erect, usually branching projections with a restricted zone of substratum attachment) like *A. cervicornis* or *A. Formosa*, which are reduced to unconsolidated rubble. This rubble is usually unstable and not a favourable substratum for the survival of the recruits, which settle on it. In the long term, coralline algae and internal sedimentation usually consolidate and cement this rubble. Divers mostly impact the more fragile foliose or branching forms, and do not have a significant impact on the reef framework.

Thus, it is understood that the problems faced is the recolonization of the bare substrate by coral species rather than a lack of substrate itself. Natural recruitment is judged to be insufficient for rapid recovery at a human scale (Edwards and Clark, 1998), and therefore this natural process can be accelerated by human intervention, with benefits in certain cases such as the degradation of a popular dive site. This can be achieved through transplantation of corals to enhance recovery.

Edwards and Clark (1998) reviewed the projects, which have been carried out on coral reef restoration and the reasons stated for coral transplantation were to 1) accelerate reef recovery after ship groundings, 2) replace corals killed by sewage, thermal effluents or other pollutants, 3) save coral communities or locally rare species threatened by pollution, land reclamation or pier construction, 4) accelerate recovery of reefs after damage by Crown-of-thorns starfish or red tides, 5) aid recovery of reefs following dynamite fishing or coral quarrying, 6) mitigate damage caused by tourists engaged in water-based recreational activities, and 7) enhance the attractiveness of underwater habitat in tourism areas. The reasons 6 and 7 apply to the present project, which also has an additional pre-emptive aspect in anticipation of a coral bleaching event. So far, cases of pre-emptive restoration include mostly rescue and relocation of corals threatened by human activities (Clark, 2001).

The aim of the program is to enhance the recovery of the Kuda Hura House Reef from bleaching events and diver damage. The objectives are to try in a first phase, to grow coral colonies in nursery areas, which would be less impacted by a coral bleaching event, so that afterwards, the recruitment on the bare substrate can be supported by the transplant of fragments pruned off the colonies grown in the nursery areas.

These types of nurseries have already been tested in the Red Sea for *Stylophora pistillata*, a technique called "gardening coral reefs" (Rinkevich 1995; Rinkevich 2000; Epstein et al, 2001). The different coral material experimented on were fragments, small colonies, coral larvae and coral nubbins, which are fragments of coral colonies consisting only of a few polyps. The two latter ones have been concluded to be expensive techniques not suitable in our case where logistics and manpower would not be sufficient and thus will not be utilised. Small coral colonies will not be taken for transplantation, as they may be recruiting in an area suitable for their growth. Broken fragments of corals are available on the site, either due to natural breakage or from impacts of diving activities, and these will be the preferred choice for transplantation onto the ReefBalls.

Some nurseries will be deployed in areas deep enough to be protected from a bleaching event. Even though deep areas are less affected by higher than normal temperatures, some of these artificial reefs will be deployed at different depths, including relatively shallow areas. This is in part to test the resistance of corals to changes in depth.

In case not enough fragments are available at the site on that day, fragments will be pruned off selected colonies. These colonies will be healthy colonies showing a good phenotype, like fast growth (larger colonies), or adapted to higher temperature (from shallow zones). Some studies have been carried out on the optimal pruning levels and pruning more than 10 % of the branches of a donor coral colony of *Stylophora pistillata* has been shown to decrease survival and reproductive activity of the donor colonies (Epstein et al, 2001). In contrast to *Stylophora pistillata* , acroporid species are known to reproduce asexually by this method, and a limited number of fragments will have to be collected to avoid damaging the donor colonies as well as to avoid reducing the genetic heterogeneity of the genetic pool (Epstein et al, 2001). The details of the deployment and the monitoring of the experiment will be explained in a later paragraph. An in -situ "nursery period" superior to 5 years is predicted for *S. pistillata* small fragments (Rinkevich, 2000), and again, this period may be shorter might be reduced in the case of acropor ids, as asexual reproduction is a natural phenomenon for these species.

A number of projects and studies using coral transplantation have shown some encouraging successes, (e.g. Guzmán, 1991; Bowden-Kerby; 1997; Muñoz-Chagin, 1997; Oren & Benayahu, 1997; Lindahl, 1998, Smith and Hughes, 1998). Based on these studies, as well as their own experience in the Maldives, Edwards & Clark evolved a guideline for coral transplantation (Edwards and Clark, 1998), which is good to consider when planning this type of activity. The major obstacles encountered by researchers stated in their study are: bad water quality, stability of substratum, and presence of a ready supply of donor colonies and fragments. Water quality would not be changed in our case, as the ReefBalls a re made of a stabilised concrete, which do not affect it. The coral reef framework left bare after the bleaching provides a stable substratum and thus the stability of substratum will not be an issue. As for the last point, a few colonies will be pruned in the first part of the program, in case not enough broken coral fragments corals are found, but it should be noted that the aim of the study is itself to create a ready supply of donor colonies for a larger operation at a more critical period when the need arises.

The restoration of the reef by this method is only one a part of the project, as it is well understood that the knowledge of the natural environment, its processes and its community structure before the impact is necessary in order to assess the success of the restoration. Reef recovery can be defined as recovery of the reef to its pre-disturbance state. With a localized impact, recovery can be assessed by comparing with adjacent undamaged areas. However when the impact is large -scale such as with a bleaching event, it is difficult to determine when a reef has recovered, especially if data on pre-bleaching status is lacking. Can we talk about reef recovery if the coral communities exhibit high live coral cover but low species diversity? For example in Florida, reef recovery in terms of live coral cover was achieved within 5 years although the community was dominated by just one species (Shinn, 1976). It is therefore crucial to know what the ecological state of the habitat and of the communities was p rior to the disturbance, which is often lacking in many reef restoration projects (Clark, 2001). A good knowledge of the benthic communities is a key factor in this program, and mapping the present reef as thoroughly as logistically possible will be of great help in order to preserve the structure of the benthic community in the recovery effort after any future disturbances. This point is further discussed in a later paragraph.

When deploying artificial reef structures, their impacts on the already existin g community of the nearby reef must be given as much importance as the engineering aspects including composition, texture, size and stability of the artificial structure. This consideration is important for both the benthic species and the mobile marine li fe. The debate between "attraction", when fishes from the nearby reef migrate to the artificial structures, and "production" when the artificial structures help sustain a larger fish population, as in the case of FADs (Fish aggregating devices), is trying to assess the role of artificial reefs.

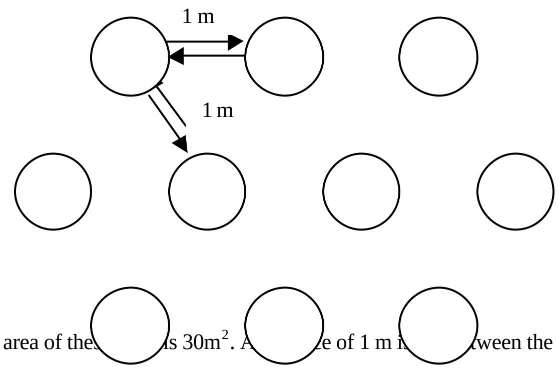
Engineering considerations

The Reef Balls that will be utilised in the present project are the ones of the model Bay Ball with a diameter of 4feet. These Reef Balls will be constructed in concrete on the island with a mould acquired by the Four Seasons. The concrete used is a stable structure, which has a rough surface texture, and which will be beneficial to natural recruitment, as it suits scleractinian corals well (Spieler et al., 2001). The concrete is itself stable and has not been reported to alter water quality in its vicinity.

The Reef Balls have a hemispherical shape with a hollow inside and a number of circular openings between the outside and the inside chamber. The number of openings can be chosen, and an increased number of holes increase the ratio of the surface area over the mass. This parameter is of important consideration, as the increased complexity of the structure will increase shelter space. A total of x will provide a ratio between the mass and the surface area of y, and this parameter will be fixed, so that each reef can be used as a replicate for the measures done, and will not introduce a bias in the statistics.

The shape of the Reef Balls allow for a low centre of gravity, and therefore these structures are fairly stable, and have been used in breaking waves without toppling over. The hydrodynamic conditions at the sites chosen are not this challenging in any way, but deployment of the Reef Balls will be done in the flatter parts of the sandy areas to avoid slipping.

The reef balls will be deployed by groups of 10, which will be considered replicate artificial reefs in the scientific protocols. These 10 reef balls will be deployed in three rows, one of four and two of three on either side of the first, according to the following design.



The surface area of the[illegible]is $30m^2$. A[illegible]e of 1 m i[illegible]tween the reef balls to allow for coral growth on each side sides.

The last engineering consideration is probably what makes most of the success of the reef balls: the ease of deployment. The reef balls are very easy to deploy as an inflatable ball enables the control of its buoyancy. They can be towed behind a boat to the site, and then brought to the desired spot while diving using SCUBA. This method, and the sites chosen for deployment far from any coral growth guarantee that the deployment will be done without any risk of damage to the pre-existing environment.

Benthic

The colonization of the artificial structures by benthic species is of great concern, as this will enable their blending into the natural reef landscape. There is a pattern of succession by different groups of organisms as they colonize a substrate, which depend on their particular strategies and the ext ernal conditions. The focus of the project is on corals as has been emphasized earlier, and the research effort will focus on ways to enhance the colonization of this group over the others.

Edwards and Clark (1998) have critically examined current transplantation approaches and concluded that in most cases, where the degraded area receives sufficient recruits naturally, coral transplantation should be the last resort of a restoration effort. Further, they suggested that slow-recruiting, slow growing massive corals be used when coral transplantation is justified. Spieler *et al*. (2001) retorted that these conclusions highlight the need for an artificial structure, at least in the short term, to replace the structural function of these corals. Indeed, in their restoration program, Edwards and Clark (1998) were looking at the restoration of a reef heavily mined and where the reef framework had been completely removed, leaving only loose sediment on the surface. Thus, their conclusions are far from being applicabl e to all artificial reef structures projects. Typically in the present project that focuses on a bleached reef it is preferable to culture in the nursery corals species which are the most affected by bleaching, such as the ones belonging to the genus *Acropora* or *Pocillopora*. In many instances, fast growing, branching coral species with high metabolic rates were among the first to bleach and die (Glynn, 1992). In the same direction, species of the genus *Seriatopora* , which have been seriously reduced during the 1998 bleaching events and are now commonly seen only in Addu (Hussein Zahir, pers. comm.), present a lot of interest. These fast growing species have already been the subject of most of the research in using coral fragments to reproduce species asexually. Another reason to focus the efforts on these species is that the branching and foliose types of corals are more sensitive to recreational diving than the massive ones. Preferentially, broken coral fragments found lying will be used for coral transplant onto the reef balls.

The broken fragments will be attached to plugs set in the reef ball structure using epoxy resin. Attached fragments show a better survival rate than loose fragments, which are often lost or abraded (Smith and Hughes, 1999). The artificial substrate will also be the object of natural recruitment of other species such as algae and ascidians, which are fast settlers. An area around half the coral plugs will be brushed regularly to investigate the survival rate of corals subject to lower competition levels. Natural recruitment of corals onto the reef balls will also be followed and thus, the benefits of human intervention can be quantified.

Colonization by fish

The colonization of artificial reef structures by fish species has been the subject of a number of studies (Klima and Wickham, 1971; Shulman et al., 1983; Tupper and Hunte, 1998; Sherman et al. 1999; Wantiez and Thollot, 2000). These studies show that the size of the artificial structures, as well as its shape has great importance in determining both the species composition and the stability of the community structure.

Klima and Wickham (1971) reported that the hull of a sunken vessel can cause the aggregation of several species of fish, which are not typical in the area. Therefore artificial reefs of large size would perhaps increase the species diversity. On the other hand, small artificial reefs, isolated by sand or seagrass from natural reefs, attract a fish fauna similar to that found on small isolated patch reefs (Talbot et al., 1978). The artificial reef structures, which will be deployed on the Kuda Huraa House Reef, which will consist of 10 reef balls can be considered as being of middle size compared to the ones described (ships, cars, Reef Balls, cement blocks etc.), but the community is expected to be similar to the one of a small isolated patch reefs.

Several researchers have suggested that the number of species on a reef will be a function of its size, and that the more species from a given species pool that the reef can attract, the more similar will be the fish assemblages on the reef (Ogden and Ebersole, 1981; Sale and Douglas, 1984; Tupper and Hunte, 1983). Given the size of the artificial reefs studied reviewed by Tupper and Hunte (0.25m^2 to 1m^2, 1m^2, 8.25m^2, 100m^2), it appears that the size of 30m^2 structures planned for the artificial reefs in our study, should show some similarity in time, promising some interesting results.

Wantiez and Thollot (2000) found that the repartition of fish on a given artificial structure depended a lot on the geometry of the structure, with complicated areas providing shelters enhancing fish recruitment: if a fish cannot find a shelter when predators attack, it will invariably be eaten. The Reef Balls have a design providing shelters for species, and in the long-term, this aspect can be compared with the different surrounding natural habitats. It is also expected that reef balls with coral colonies growing on them will provide more shelters than bare ones.

Dive site

Impacts of recreational diving

There are limits to how many divers a reef can take without degradation. Dixon et al. (1993) suggest a critical level of about 4500 dives per year before diver impact becomes apparent. In Eilat, despite the tight legislation and management measures that have been employed for years, the reef recovery does not sufficiently compensate for the intense destruction by recreational activities (Epstein *et al.*, 2001). This conflict between recreational diving and the natural environment the sport relies on, is the concern of a large body of literature. Davis and Tisdell (1995) argue that there are critical and biological thresholds above which amenity values are reduced severely, while biological degradation may also become significant. The interrelationships between amenity and biological values are worthy of further research to identify biological and social carrying capacities to formulate suitable management responses to reduced recreational values of the site.

In this context, education has a significant role to play by increasing environmental awareness and reducing the damaging impacts caused by users of the site. The value of the research that will be carried out will therefore be two fold: it increases the recreational aspect of the diving experience, and it helps in maintaining the site in good biological conditions.

Furthermore, using the broken fragments can mitigate localized noticeable impacts caused by a clumsy diver breaking a coral. In case the colony has been severely damaged, a fragment of the same species can be transplanted in its place.

It is also expected that the creation of dive trails will reduce impacts to the coral reef, enabling the divers to take the trail suited to their level of experience, i.e., taking the least experienced ones in less sensitive areas of the site, while showing them aspects of the reef that often go unnoticed.

Dive trails

Dive trails should be designed in cooperation with the dive school.
Certain features of the reefs can be incorporated in the dive trail so that they can be explained beforehand to the divers. Betti, you probably have your own routines and therefore it is important that you participate a lot in this. Apart for the points where the fish species have been identified and the coral colonies de scribed in the mapping of the reef, there is a few interesting features that I have noticed:

- a cleaning station of Anton Bruuni cleaner shrimps (*Urocardiella antonbruunii*) in A (in the fracture of the big bommy) visited by some predators (groupers seen). These stations are similar to the ones set by the cleaner wrasse (*Labroides dimidiata*) but are not as common. In A as well, a possum wrasse (*Wetmerolla nigropinnata*) not often seen because quite secretive and rare among the branches of the psammacora bommy.
- The garden eels (*Heteroconger hassi*) on the sandy areas, which are quite abundant.
- A spiny lobster *Panulirus versicolor* near coral 22 (underneath, see photo)
- In that same area a not so common angel fish *Apolemichtys xanthurus.*
- In G, the ornate ghost pipe fish under the Acropora growing on the deeper side of the porites bommy, you probably know about this one (I was told by the captain). A striped pipe fish in the same area, as well as a couple of Calloplesiops altivelis around the bommy, which are usually secretive and not often seen but are almost in the open there.
- A number of shrimps some unidentified, and banded boxer shrimp (*Stenopus hispidus*) near isolated coral head 31.
- Some durban hinge-beak shrimp (Rhynchocinetes durbanensis) near the wreck, which jump on your hands as you approach them, even though they are not specifically none to set up cleaning station.
- A pipe fish not far from I, which is very easily taken for a stick and whose name I cannot recall (my fish book sadly stayed in Maldives) see picture.
- There was a quite rare goby in J (I think it is called the laser blue goby, my picture of it is bad and I am not sending it), but it was not seen in the following visits.

Sightings

As part of the project, it is planned to record sightings of rar e and flagship species, which visit the reef. Initially the different individuals of the flagship species visiting the reef should be identified. During our visit we have seen two turtles, a fairly large one, as well as a smaller one. Apart from turtles, t here may be some Napoleon wrasse, which visit and usually attract the attention of visitors. It should be possible to identify markings on frequently seen individuals and give them names. The data to be collected, which will be further described in the scientific protocols, will enable the following of their habits. This has to be done jointly with the dive school instructors as they would be doing most of the observations. This data will be entered into the database for processing. Betti, with the help of the dive school people, do you think you can make a list of the possible individuals to follow and identify markings on them?

Activities of the project (will include the scientific protocol)

The surveying and monitoring of the site will use a method based on an inductive approach, and will consist in mapping the reefs according to a protocol using GIS (Geographical Information System) for treating the data. This approach is more adapted than the usual line intercept transect (LIT) treated with biometry for a number of reasons. One shortcoming of the LIT method is in its inability of describing the physical settings of a reef, especially in our case, where there are a number of isolated bommies, which represent different habitats. A precise knowledge of what species is living in which place is important for the achievement of restoration. The LIT method tries to describe the reef from a random sampling, and therefore does not seem adapted in our configuration, where exact positions of species would be required. LIT data is hard to interpret, even for a scientist, let alone the interested tourists, for whom a graphical representation is much more attractive.

The mapping of the reef will encompass three aspects, the reef processes like hydrodynamic regime and sedimentation, the benthic cover, with location of as many coral colonies and species dominated areas as possible, and the fish and invertebrate life. The ecological links between these components will be of foremost importance to understand the reef as a whole.

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