Kuda Hura House Reef Project

Four Seasons Resort

Maldives

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Executive summary

The lee side of the Huraa reef system, in North Male' Atoll, presents a fracture of the reef framework, south west of Kuda Huraa. This break corresponds to the outlet of the oceanic swell created current on the reef flat. It brings sand that accumulates in a slope after the break. On this slope are a number of coral patches.

This site is proposed for research on a pre-emptive method to rehabilitate damaged reef. The major sources of degradation at the site, which this project tries to mitigate, are coral bleaching and diver damages.

The overall approach consists in transplanting coral fragments on a bare substrate to enhance natural coral recruitment. This necessitates two steps to be taken before a potential impact. First, a monitoring program should keep a description of the reef updated, for status before the impact, and follow its evolution after the restoration. Second, a sustainable source of coral fragments has to be created.

The present conditions at the site have been described and hypothetical processes have been stated, leading the data collection design and exposing directions for research. The physical settings consist in isolated patch reefs down a sandy slope. The nursery areas, resembling patch reefs, will blend well in the reefscape provided they are deployed on a sandy bottom, away from existing coral boulders. The coral cover, quite low on the upper part of the reef, increases with depth, and is rather good in the deeper parts. The fish fauna is diverse and healthy, which is sign of a solid food chain, denoting a possible input of resources from the sea grass beds on the reef flat.

The monitoring of the natural environment will increase our understanding of the processes taking place. Based on a mapping concept, it focuses on the benthic composition by recording the major coral colonies at the site and describing them with a number of given attributes, and on the structure of the fish fauna, which will be described by way of fish counts at family level.

To provide coral fragments for transplantation, the project proposes to mariculture corals in-situ on artificial reefs implemented as nursery areas. These nursery areas will be made of 10 Reef Balls, which are concrete structure easy to deploy and providing a number of holes and shelters. The initial input of fragments will consist of broken branches broken off colonies by divers. This is thought to be an effective tool for mitigating damages caused by recreational diving. When these fragments grow, they will in turn be used as source of fragments to be transplanted on the substrate left bare after degradation, in an effort to restore the environment to its pre-impact state.

To achieve the objectives of the project, a team, including the resort's marine biologist, dive school staff, and apprentice dive master will join in the research effort and maintain a climate of discovery with the guests. To build the divers awareness, dive trails will be implemented pointing out interesting reef features. This will also enable to direct the flow of the recreational divers, taking the beginners away from sensitive areas, thereby decreasing the risk of damage. To further interest the divers into the research undertaken at the site, they will participate in the data collection by reporting their sightings of popular individuals of flagship species.

To enable the analysis of the information, a database will be created to enter the information rapidly after the data collection, provide maps for the monitoring and take care of the calculations to assess statistical tests. The findings and progress of the project will be reported every year to the government of Maldives, and at the request of the concerned government agencies, the information can be fed into databases dealing with coral reefs.

1. 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 corals 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.

Figure 1: Aerial picture of the reef flat with the site on the left.

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. Surveys immediately after the bleaching on the reef tops of diverse atolls showed that the pre-bleaching coral cover was around 20 times greater than the post-bleaching coral cover. 6 month after, the data was indicating a decrease rather than an increase in live coral cover (Zahir, 2000). This led to the rumour that the Maldivian reefs were dead, which is undeniably a bad publicity among divers concerning the Maldives, as 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. 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 hollow hemispherical 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.

2. Natural reef

2.1 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.

2.1.1 Physical environment

2.1.1.1 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. 2), 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.

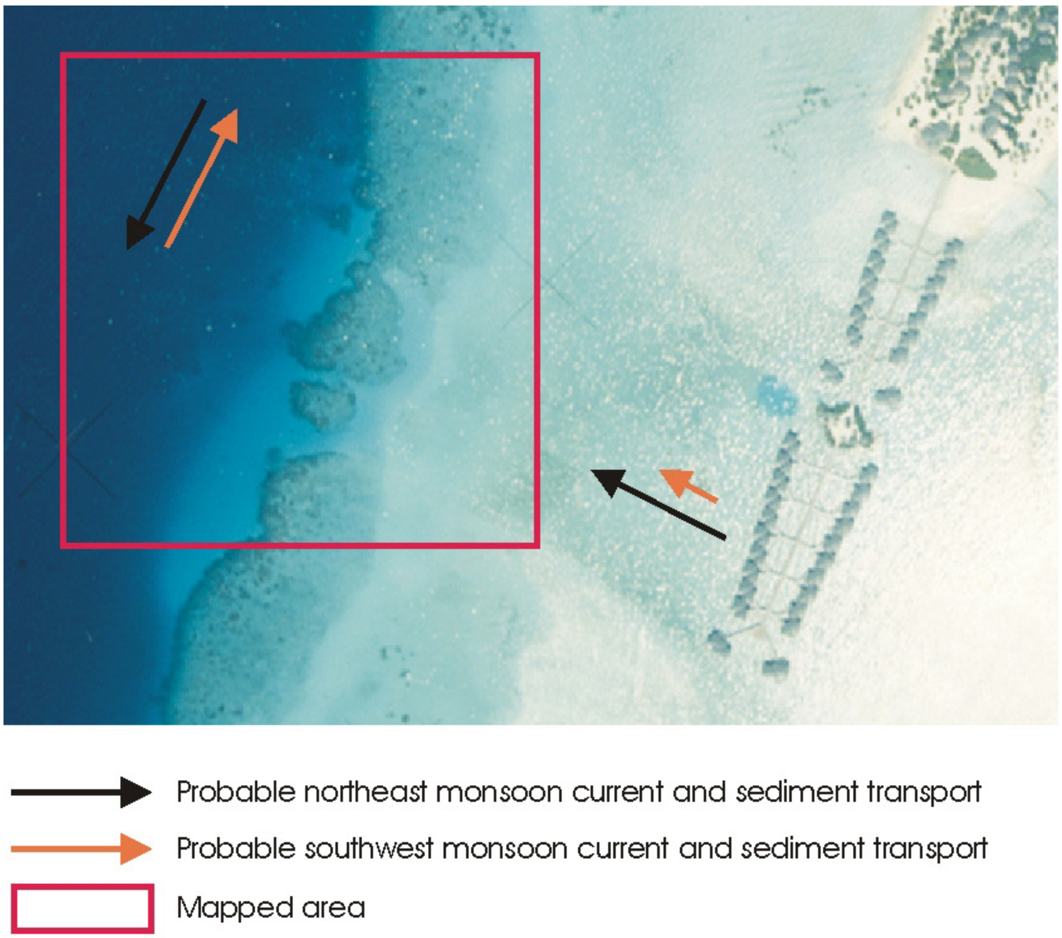
The configuration of the reef, with multiple patches of corals separated by sandy areas, makes it easy to integrate artificial reefs in the landscape. The artificial reef structure would have to "mimic" the natural coral patches in sandy areas.

2.1.1.2 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 south-westerly direction and the sediment supply would be high, as the northeast monsoon wind waves helps the swell created flow to transport the sediment to the lee side. During the southwest monsoon, the flow would have a north-easterly direction, and sediment supply would be low, as the monsoon wind waves hinder sand transport to the lee side.

Figure 2 : Sediment transport at the site.



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.

2.1.2 Benthos

2.1.2.1 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).

2.1.2.2 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 temperatures, 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 species 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.

2.1.3 Fish and mobile invertebrates

2.1.3.1 Present conditions

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 of 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*.

2.1.3.2 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 habitats, 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.

3. Artificial reefs

3.1 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 transplanted 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.

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 are 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, it should be noted that the aim of the study is itself to create a ready supply of donor colonies for a larger operation 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 prior 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 existing 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 life. 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.

3.2 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 0.9 m (3 feet) and a height of 0.6 m (2 feet). These Reef Balls will be constructed in concrete on the island with a mould acquired by Four Seasons. The concrete used is a stable structure, which has a rough surface texture. This will be beneficial to natural recruitment, as it suits scleractinian corals well (Spieler et al., 2001). The special concrete used in the making of the Reef Balls has a pH similar to that of the sea, around 8.3, whereas regular concrete gives a surface pH value of 12, and the low pH makes the Reef Ball more suitable for recruitment of benthic species.

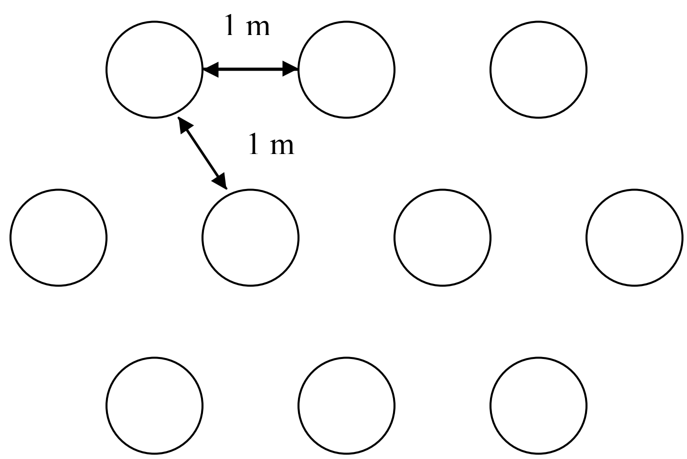
The Reef Balls have a hemispherical shape with a hollow inside and a number of circular openings between the outside and the inside chamber. The number of openings can be chosen, and an increased number of holes increase the ratio of the surface area over the mass. This parameter is of important consideration, as the increased complexity of the structure will increase shelter space. A total of 12 holes will provide a ratio between the mass and the surface area of 71.4 and a volume to surface ratio of 0.028 m. These parameters 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.

Figure 3: Positions of the Reef Balls in a nursery area



The surface area of these reefs is 26 m^2. A distance of 1 m is left between the Reef Balls to allow for coral growth on each 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, controlling their buoyancy 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.

3.3 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 external 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 applicable 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. Transplants onto the Reef Balls will consist exclusively of broken coral fragments found lying.

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. Around half the coral plugs, an area will be brushed regularly to investigate the survival rate and growth 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.

3.3 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 and 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.

4. Dive site

4.1 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.

At the moment, an estimate 1700 dives are carried out yearly at the site. This may seem far from the critical level, but the fact that this is a beginners and orientation dive explains that a number of colonies have been broken.

4.2 Improvement of the diving activity

4.2.1 Increase divers awareness

Education has a significant role to play by increasing environmental awareness of the guests, who would then tend to pay more attention to possible degradations, thus reducing the damaging impacts. Education is therefore an important focus of the project, which proposes to create dive trails to present interesting features gathered by themes to the guests.

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.

4.2.2 Management of impacts

While showing the guests aspects of the reef that often go unnoticed, the dive trails will also reduce direct impacts to the coral reef. This will be achieved by assigning levels of dive experience suited to follow the different dive trails based on the depth it reaches, the length of the dives and the sensitivity of the different areas visited. For example, the least experienced divers can be taken to areas where poor buoyancy control will be of less importance.

Furthermore, using the broken fragments for transplantation to the nursery areas mitigates direct negative impacts by clumsy divers breaking corals. The monitoring will also enable to follow the survival rate of broken coral colonies.

5. Activities of the project

Two types of activities are planned for the site, research activities which will be performed by trained people, and educational and participative activities which are intended for the guests.

The research activities, which concern the study of the benthic community and the study of the fish population, follow a strict scientific protocol to ensure the reliability of the data. This protocol is explained in the next two paragraphs, whereas the activities oriented towards the guests are described in the last two paragraphs.

5.1 The means for the project

5.1.1 Settings

The site, located near the island, is easily accessed from the dive school. The dive school, which provides the diving equipment for the research at the site and facilitates the dives, is an important component of the project. It is therefore a place where a lot of interaction takes place. Apart from this sometimes-hectic place, the project will have the use of a quieter library where books and scientific resources will be made available. This library will also be the place where the research and its progress are displayed, making it possible for the guests to access information on the project and follow the activities at the site.

5.1.2 The team

At least as important as the space devoted to the research, the project relies on a team of people well acquainted with its ways and objectives for its development. A resident team including the marine biologist, the dive school staff and the Maldivian Divemaster Apprentices of Four Seasons' apprenticeship program, who further their education through the project, have started training in the different monitoring techniques. The training is carried out by Seamarc Pvt. Ltd, a Male' based environmental consultancy firm who will lead the scientific research component of the project. A knowledge of the practical scientific approach to reef studies will be added to their day-to-day acquired knowledge of the diving practices at the site. This will be built further as the project unfolds and their contribution in the data collection effort gets more substantial.

The training of the team not only concerns the fieldwork, but also will in time extend to the maintenance of the data and understanding of the scientific analysis procedures. This will enable them to answer pertinently the guests' inquiries and to illustrate their conversation with the information obtained through the research.

5.1.2 Visiting scientists

This research team will also benefit from the visit of guest scientists, who would be interested in this new site-specific research. These scientists, who will spend a period of time on the island, will be able to use the background information at the site, carry out other connect research and give lectures on their respective fields of expertise. Different angles are desirable in this effort, and their input will undoubtedly be valuable.

The climate of dialog and the diversity of opinions will effectively benefit the team and help spread environmental awareness.

5.2 Benthic study

5.2.1 Aim

There are two objectives of the benthic study, in view of the overall aim of achieving a successful restoration of the local environment in anticipation of bleaching events. The first objective, which concerns the natural reef environment, is to provide the necessary background information about the coral community and the reef processes to study the adaptation of the benthic fauna to the main physical influences. This will help in determining appropriate locations for the transplantation of the different coral species to restore the community structure. The second objective is to assess the feasibility of coral nurseries and coral transplantation as techniques for restoring the coral reef environment.

5.2.2 Methodology

5.2.2.1 Overall description

The study of the natural environment will provide an accurate description of the coral community at the site and follow its evolution through a monitoring program. The major coral colonies are mapped and described by a number of standard attributes, and this information is stored in a database. This information can then be analyzed using statistical tests. Mapping helps in representing the information visually to support the intuition while formulating hypothetical tests.

Long-term monitoring of the natural environment will be carried out using Line intercept transects of 10m within the different zones. These transects will be laid out at two depths of 3-8 m and 15-20 m, and will be replicated. The GCRMN codes will be used to record the different benthic categories.

The study of the coral transplants focus on three main aspects affecting the mortality, and the growth of the fragments: the difference between species, the changes in depth, and the influence of competition of other benthic groups. For this last purpose, half the fragments are subjected to a treatment consisting of brushing the Reef Ball surface around the base of the transplant. The fragments are examined monthly, taking different measures and recording different attributes.

5.2.2.2 Procedures and details

5.2.2.2.1 Base map

To enable mapping of the major coral colonies, a base map showing the reef configuration including hard substrate and sandy bottom had to be created. The surveying was conducted using SCUBA. Before going underwater, an outline of the reef was taken using an aerial picture of the area and drawing the contour of the visible reef using AutoCAD. This contour was reproduced onto plastic paper sheets so that they could be utilized underwater.

The surveying procedure involved three people working as a team using a fibreglass tape, a compass and depth gauge. A point on the outline was chosen as a departure point, assigned a letter, and its depth recorded. From this point, the first diver unfolded the tape to the next point, while the other two stayed at the starting point. When an appropriate point was found, the tape was secured in place by the first and third diver, ensuring that it was taut. This point was assigned the subsequent letter, its depth recorded and the length between the two points recorded. The second diver then swum along the tape reading the direction. The tape is then rewound, the third diver joining the other two.

A series of segments was therefore obtained by iterating this process. These were later drawn in the AutoCAD file contour of the visible reef to outline the deeper invisible reefs. This process was reiterated to increase the resolution of the map as much as possible. The refinement can be measured, but approximate visual corrections are less time consuming.

5.2.2.2.2 Zonation

Once the base map is established, a zonation of the reef is carried out. This identifies the major different structures and substrate types of the reefs including:

- Dead coral boulders overgrown with algae
- Stands of a particular species or genus (e.g *Goniopora, Acropora*)
- Area of a dominant life form (e.g digitate, massive, submassive)
- Rubbles with *Acropora* colonies
- Isolated bommies
- Sea grass

For each of the zones delimited on the map, the record will have the following fields:

- Label
- Condition (applicable to the stands of a single species)

  This is assessed with an index on a 1 to 5 scale, which correspond to some visual estimation of the apparent live coral cover as follows:

  0 to 20 %: 1
  20 to 40 %: 2
  40 to 60 %: 3
  60 to 80 %: 4
  80 to 100%: 5
- Description

  A set of descriptors are predefined to allow further computations to give an explanation for the condition index:

  - Bleached

- Disease
- Diver damage
- Sedimentation
- Bite marks
- Number of structural cracks
- Presence of borers
- Presence of corallivores (COT, *Culcita, Drupella* etc.)

- Remarks

5.2.2.2.3 Mapping of the major colonies

To enable the description and mapping of the coral present at the site, the base map is drawn onto plastic sheets to bring them underwater. The focus of the mapping will be towards the colonies that have survived the early stages of settlement, recruitment and early growth, and are therefore most likely to be living in favorable conditions. These colonies are the ones which contribute the most to the live coral surface area and therefore, the influence of leaving aside the small coral colonies in the calculations of the total coral cover will be minimal. However, it may have a consequence when examining the diversity, and some specimens of the less common species should be recorded, even if they are quite small.

When recording a coral colony, an index is represented at its location on the map, and a record on the data sheet is added and the description fields filled. The different fields are listed below with a brief explanation when necessary:

1. Genus
2. Species
3. Depth
4. Diameter

   The diameter is a measure of the size, approximately half way between the length and the width of the colony. This is roughly measured using the fiberglass tape.
5. Height

6. Life form

   The life form categories code is the one in use by the GCRMN and described in the ASEAN manual for reef survey.

7. Condition

   This is assessed with an index on a 1 to 5 scale, which is a mainly determined by the apparent live coral cover as follows:

   0 to 20 %: 1
   20 to 40 %: 2
   40 to 60 %: 3
   60 to 80 %: 4
   80 to 100%: 5

8. Description

   A set of descriptors are predefined to allow further computations to give an explanation for the condition index:

   - Bleached
   - Disease
   - Diver damage
   - Sedimentation
   - Bite marks
   - Number of structural cracks
   - Presence of borers
   - Presence of corallivores (COT, *Culcita, Drupella* etc.)

The site is examined biannually and the changes are added to the database in order to follow the evolution of the reef in time.

5.2.2.2.4 Transplantation experiments

5.2.2.2.4.1 The nurseries

The nurseries consist of artificial reef structures of ten Reef Balls (Model: Bay Balls), deployed with the geometry indicated in the Section 3.2. The dimensions of the Bay Balls are 0.9 m in diameter and 0.6 m in height. Each weighs around 200 kg. On each Reef Ball, 10 in-built plugholes distributed on the surface will be incorporated. To avoid adverse effects of sedimentation, the plugholes will be evenly distributed on the top two thirds of the Reef Balls. These plugholes at a later stage will be receiving plugs on which coral fragments will be glued using marine proof epoxy resin.

All in all, 6 such nurseries will be deployed or 60 Bay Balls in total. To test the coral survival with depth, two replicate nurseries will be located at similar depth. The depths are 4-5 meters, 10 – 12 meters and 20 – 22 meters. One of the replicates will be open for the visit of the divers whereas the researchers will visit the other ones for taking the measurements. This will help in assessing the impacts of recreational diving.

Figure 4: Proposed deployment area for the coral nurseries

The species that will be used to populate the different Reef Balls cannot be determined at this stage as it depends on which fragments are present on the reef. The branching and more fragile corals like *Acropora* are the main victims of diver damage and therefore these genera are likely to constitute the bulk of the transplants. As a general rule, it may be more practical to place the branching, fast growing species on the outside Reef Balls, and encrusting and more massive species on the inside. This will facilitate access to the colonies when taking the measurement of the transplants even after they have grown.

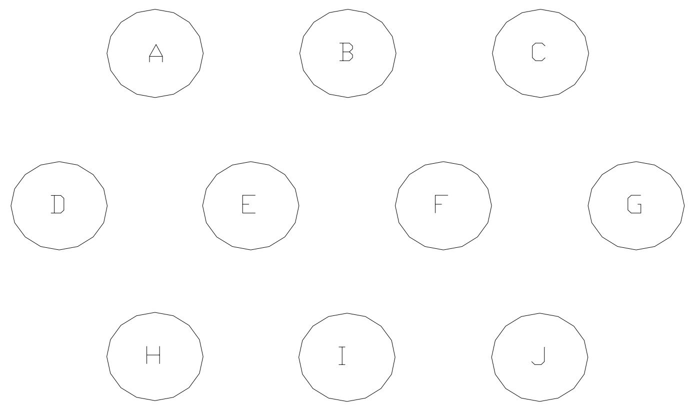
The deployment of the nurseries will be done progressively one nursery area after the other, with a period of 1 month between the deployments of each nursery. After the deployment of the Reef Balls, they will be transplanted with 10 coral fragments each. Therefore 100 coral fragments will be transplanted during each period, and thus 600 fragments will be required in total for the six nursery areas.

5.2.2.2.4.2 The transplantation process

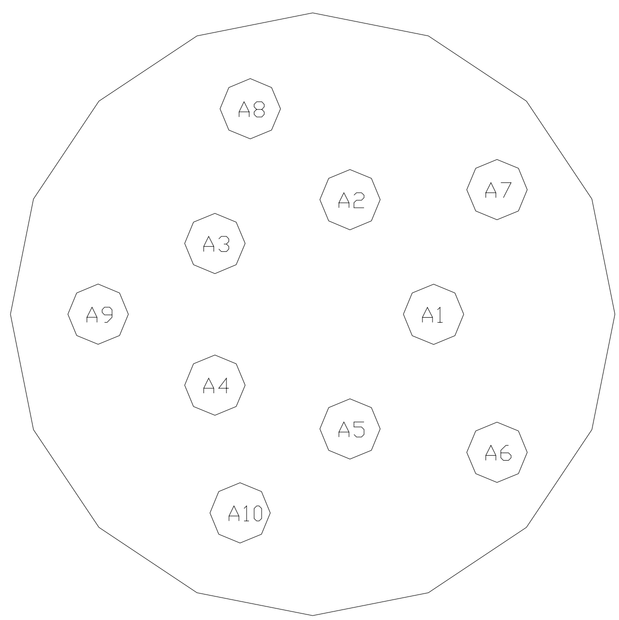
The transplantation of the Reef Balls must obey a rigorous protocol and follow logical steps to avoid losses and enable clear and reliable data collection. The following plan of action describes the steps and stress important considerations for each of them. This plan assumes that ten Reef Balls with ten plugholes each have been built.

Step1: Before deployment it is important to map the Reef Balls and to assign an index to each plughole. This number is written with a marker inside the plughole.

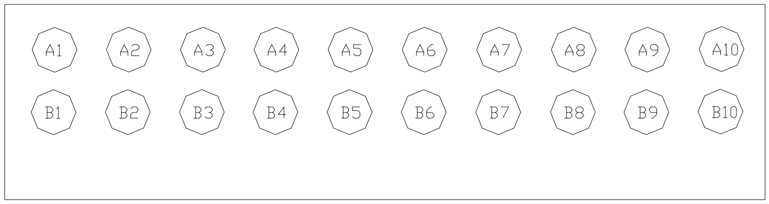
Plan of the nursery



Plan of Reef Ball A



Step 2 : After assigning the indices to the plugholes, they are reported on the tray which will hold the plug with the transplants.



Step 3: The Reef Balls are deployed at the chosen site

Step 4: Transplantation of the broken fragments onto the plugs on the tray. While collecting the broken fragments and setting them on the tray, complete the datasheet with the information as discussed in the next section (Section 5.1.2.2.5) concerning the fragments, ensuring to record the corresponding index on the sheet.

Step 5 : Setting of the plugs in the corresponding plugholes.

5.2.2.2.5 The fragments

Once an artificial reef has been deployed, the Reef Balls are ready to receive the coral transplants. Each transplant is followed individually from the time it is either recovered from the reef. After choosing the fragment, it is glued with some underwater epoxy resin to a plug, which is then carried on a tray. These plugs are given a Reef Ball number and a plug letter to enable identification in the data recording process. The parameters recorded for each fragment are:

1. Genus
2. Species
3. Depth found
4. Depth on Reef Ball
5. Diameter of stem
6. Diameter of basal disc
7. Diameter of colony
8. Number of axial corallites (*Acropora*) or branches (Other genus)
9. Length/Height
10. Status (living, dead, bleached)

The measurements are made using a vernier caliper.

5.2.3 Analysis of the data

5.2.3.1 Coral cover

Diverse parameters can be assessed from the data and among the most general, the total coral cover and the coral cover by species. The map enables the calculation of the total reef area, and therefore the percent coral cover can be calculated. This makes the method compatible with other reef monitoring methods, which usually look at percent coral cover. Any value of percent coral cover is only an approximation of the real percent coral cover, and all methods result in a bias in the calculation. In our case, it is based on the colonies recorded, their size, and their condition.

The sum writes:

$$\text{Total live coral surface} = \Sigma\, S_i\, C_i$$

With S_i being an estimate surface area of the colony i, calculated by its diameter in the case of a stand alone colony;

$$S_i = \Pi/4 * d_i^2$$

and in the case of areas dominated by a species, the surface of this area itself. C_i is the approximate coral cover translated from the condition index:

Condition Index	C_i
1	0.1
2	0.3
3	0.5
4	0.7
5	0.9

This sum, divided by the total hard substrate is an approximation of the coral cover. It is most probably an underestimate of the coral cover estimated with Line Intercept Transects, as the smaller colonies are not taken into account. Their influence in the calculations would be minimal though, as due to their size, they cover a negligible surface area. When they grow and enter the records, they will contribute to the increase in coral cover detected by this method.

With the complementary information, the difference between two censuses can be further defined, as we can link the loss in coral cover calculated this way to the description of the coral colonies. This allows for quantified comparisons between the effects.

5.2.3.2 Coral fragment growth

The different measures on the fragments will in the first instance be treated to look for significant differences using ANOVA (Analysis of Variance). These will be performed to detect differences between species and between nursery areas.

Other important questions like the influence of depth change over growth rate, influence of initial fragment size over growth rate will have to be investigated using regression analysis.

The influence of depth over the colony growth form (e.g. stunted colonies in the shallows and spread out colonies in the depth) will be crudely investigated using ratios between the number of branches (or axial corallites) and the height or diameter of the colony. But due to the slow growth rate of corals this is not believed to be possible in the first years of the experiment.

5.3 Fish Study

5.3.1 Aims

The fish community at the site is an important focus for the study, as it will try to determine which model of community structure, among the "single-species equilibrium", the "multi-species equilibrium", the "recruitment limited", or a mix of the models is the most plausible (Section 2.1.3). It will also investigate whether the influence of the artificial reef structures are attractive or productive.

Moreover a detailed study of the Family Pomacentridae will try to determine the recruitment and post-settlement processes for this family, which represents one of the largest families of fish inhabiting tropical reefs, and numerically and functionally important members of coral reef communities.

This study is one of general interest, as it will increase the knowledge in the cycles followed by the reef fish species, which could have managerial significance.

5.3.2 Methodology

5.3.2.1 Overall description

A number of studies aiming at defining and quantifying the community structures have been carried out using visual census to count the fish at species level (Sale & Douglas, 1984, Tupper & Hunte, 1998). Both these studies found that the size of the reef considered was an important factor influencing the stability of the fish communities, larger area of reefs showing more stability. The choice of the sites must be carefully chosen so that this factor does not bias the study.

The method used will be the visual fish census method using 10m x 5m belt transects. These transects will the same as those used for the benthic study. The community structure at each one of these sites will be described by a fish count grouped by families, dividing the species into 2 categories. The first category contains the more transient families, which roams around and therefore cannot be said to belong to a certain site of the reef. The structure of these families will be described using a fish count during a 5 min period. The second category, comprising the more sedentary species and which territories can be identified as being within a site, will be counted, with no specified length of time. There is no rule of thumb to determine which family is transient or sedentary. The fish count will therefore have two values for a same family if the family has both sedentary and transient individuals. To enable a better description of the community structure, the predominant species for each family will be recorded as well.

5.3.2.2 Choice of the sites

These sites should be representative of common habitats found in the Maldives, such as area of rich coral growth with a dominant species, areas of different geometric complexities (eg: stand of branching corals, sub massive corals, or boulders of massive corals), area of dead corals overgrown with algae and other life forms. Furthermore, all the sites should have an equivalent surface of approximately 25 sq.m to enable comparison of the community structures. This surface of 25 sq.m is approximately the surface area of the artificial reefs that will be deployed, and each of the nurseries will constitute a site for the fish count.

For a further comparison of the sites, the sites should be described by:

- Their size
- Their depth
- Their nature
- The main factors, which could be influencing the area (situation, wave energy, currents, sedimentation regime, isolation...)

5.3.2.3 The fish count

The fish count aims at defining the fish community structure. A number of studies with similar goals have been carried out using visual census to count the fish at species level, and this appears to be the most common method. In our study, there are practical and ecological reasons to justify making a fish count at family level compared to species level. On the practical side, identification at family level is easier and therefore more people would be able to execute reliable visual census. It will also limit the time underwater necessary to do a fish count for a particular site, thus enabling a greater number of sites to be monitored. On the ecological side, this will bring the focus on community change at greater amplitudes. Compared to a count at species level, a count at family level will show more stability in respect to changes. This is due to the fact that generally the species of the same family compete for similar resources and fulfill similar roles. To make sure of this and to not miss important differences in resource use by a single family, the most abundant species will also be recorded. It is therefore expected that the study of the similarity of the fish community structure of two different census (either different sites or different periods) will discriminate major changes in the quality or the availability of the resources.

It is also important to recall the aim of the fish study, which is to determine the possible model shaping the fish community. If it follows a non-equilibrium model, a fish count at species or family level should show some dissimilarity. If it follows the "single species equilibrium" model, with no change in resources, a fish count at species level or family level would show some similarity in time. If the resources fluctuate (with the monsoon cycle for example) then the fish count should fluctuate accordingly. If it follows the "multi-species equilibrium" model, then a fish count at species level could show some dissimilarity while a fish count at family level could show some similarity. Indeed, if similar species are competing for similar resources, the number of members of the same family, which is a group of similar species, is limited by the resource, independently of the species.

The conclusion is that if the family count shows some similarity, but that the dominant species in the family are different, then we can conclude surely that the model is the "multi-species equilibrium". If on the contrary, we have the same dominant species, then it is more likely to be the "single-species equilibrium". If the fish count at family level show no similarity whatsoever, then the "non-equilibrium" or "recruitment - limited" theory is probably the community model. A fish count at species level does not appear as conclusive, as it would show dissimilarity for both the "multi species equilibrium" and the "non-equilibrium" models.

In addition, the family count is also advocated by the GCRMN (Global Coral Reef Monitoring Network) in South Asia, and complying with this will enable easy transfer of the data collected in Kuda Huraa to the Maldivian national coral reef database. In this database, the major families of reef fishes have been chosen, and therefore will be the ones counted in our studies. These are:

- Acanthuridae
- Scaridae
- Chaetodontidae
- Pomacentridae
- Labridae
- Pomacanthidae
- Serranidae
- Lethrinidae
- Lutjanidae
- Haemulidae
- Balistidae
- Carangidae
- Mullidae
- Siganidae
- Caesionidae

There are other families like the Apogonidae or Scorpaenidae, which may be of importance in our site, and this will be estimated at a later stage.

5.3.3 Analysis of the data

Fish density and species richness are two rough indicators that have been utilized to compare fish communities. These are crude indicator of the productivity of the reef sampled and of its diversity. The data issued from the reef count enables the comparison of the community structure at family level among different sites between themselves, in time, two by two or by group. The Percent Similarity Index (PSI) and the mean coefficient of variation (MeanCOV) are important measures which will be computed to assess the similarity of the family structures. The PSI, devised by Sale and Douglas, compares the proportional similarity of the community. It is computed with the following formula:

$$C_{ij} = 1 - 0.5 \Sigma |p_{in} - p_{jn}|$$

Where C_{ij} is the proportional similarity between censuses i and j, and p_{in} and p_{jn} are the proportions of the total number of fish seen in the i^{th} and the j^{th} censuses, respectively, that belong to the n^{th} family. If the two communities do not share any families, then we have

$$\Sigma |p_{in} - p_{jn}| = \Sigma |p_{in}| + \Sigma |p_{jn}| = 2$$

and the coefficient is null. On the other hand, if the number are exactly proportional, then for all the families,

$$|p_{in} - p_{jn}| = 0$$

Their sum is null and the similarity is 1. It needs to be pointed out that this similarity does not take the density into account: two communities, one having exactly twice as many fish in each family per square meters, would have a similarity of 1. Therefore, the density is a value that complements the PSI in the description of the community.

The MeanCOV, used by Tupper and Hunte (1998) is a measure, which takes the density into account in its calculation. When the similarity of the community structure of a group of censuses is studied with this method, the coefficient of variation of the densities for each family over the censuses needs to be calculated independently. They are then averaged to give the MeanCOV. The MeanCOV between censuses finding exactly the same density for each family will then be null, being the average of coefficients of variations that are all null.

The Mean COV, contrary to the PSI, does not necessarily give a good similarity for community structures that would be exactly proportional. These coefficients will be treated using the analysis of variance ANOVA to demonstrate any existing correlation in communities when comparing censuses in time, or test for their dependence to the substrate and other criteria defining the sites.

5.4 Dive trails

The design of dive trails, in cooperation with the dive school, will enable to present specific features of the reef gathered by themes such as invertebrate life or symbiotic relationships to the guests. Some will also give a particular purpose, like coral or fish identification.

These dive trails, being also rated in terms of level of experience, will enable to diminish the impact of recreational diving, avoiding the most sensitive areas.

5.5 Sightings

During our visit two turtles were seen, and napoleon wrasse are reported to visit the site. These individuals are a focus of attention, and it is interesting to follow their evolution and habits. To this purpose the different individuals of flagship species reported to visit the reef will be identified by characteristic markings. Sightings of the different individuals will be recorded and over time from this information may emerge living patterns and habits. This will improve the knowledge of the life history of the concerned species. Sighting information will be concerned with:

- The place of the observation
- The time of the observation
- Remarks on the behavior

6. Information storage and display

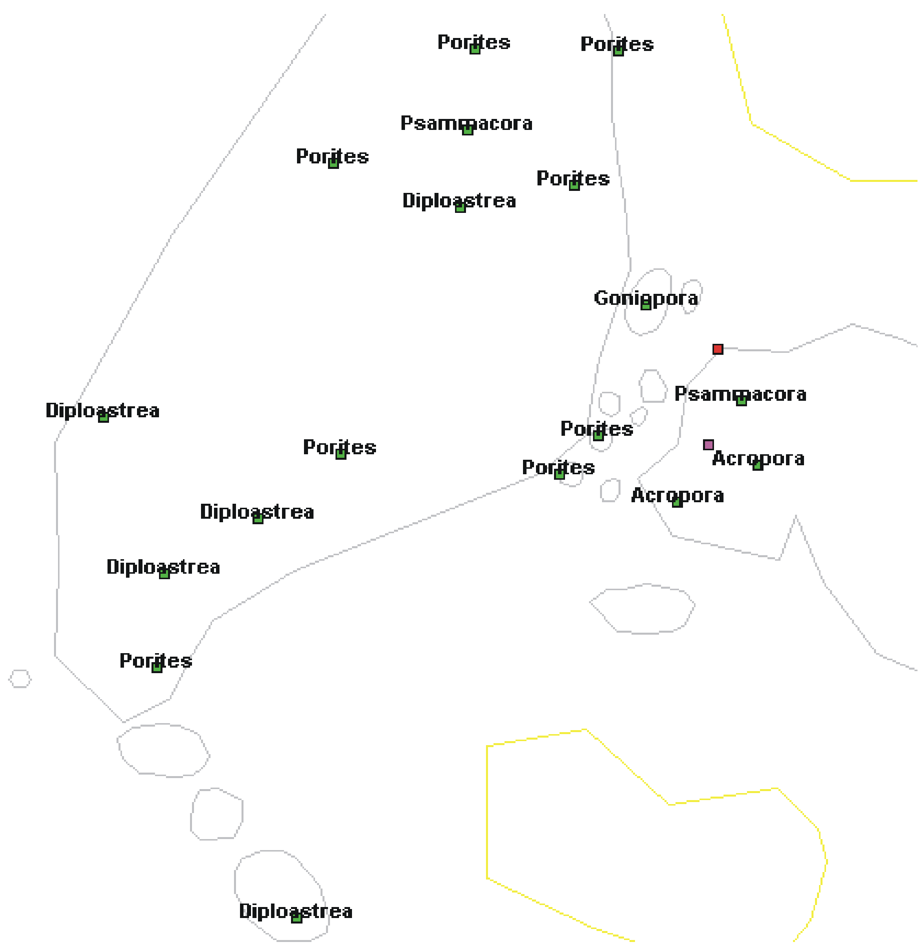
Monitoring the site and collecting data is an important part of the project, but to study the reef processes or follow the reef growth of the transplant, the researcher needs an appropriate tool to extract information from the data. It has been mentioned in the sections concerning the data analysis, that the data will be analyzed using various statistical procedures such as ANOVA. It is therefore paramount to have a data storage, which will enable these calculations. To that effect, a database using a geographical information system (GIS) using a local coordinate system was conceived and partly created. The output maps are the ones in use in the presentation of the preliminary data.

The concepts underlying the database are a good visual display of the data, and user friendliness.

6.1 A tool for monitoring

The user friendliness of such a database makes it possible for people with minimum training to enter data. The information can be entered right after the data collection. The updated and corrected information can then be printed and reported on plastic sheets for further fieldwork.

Figure 5: Partial map of reef with the information used for monitoring



6.2 A tool for analyzing the information

The structure of the collected information in fields and records will enable any type of calculations. All the calculations mentioned in earlier paragraphs would be programmed, facilitating the data analysis. The information can also be queried and the result visually represented to support the investigations of the processes taking place at the site.

6.3 Sharing the information

The data gathered will be made available to any person interested through the Internet. Whether be it a scientist interested in the data or a guest checking out the resorts activities, they will be able to get up to date information on the conditions and the status of the site. Any comments on the project, its methods, its objectives or its findings will be welcome and visitors to the site will have the possibility of taking part in a forum.

Every year, the project is to report on the progress and on the findings to the government. At the request of the Ministry of Fisheries, the database will also provide formatted information to feed directly into the National Coral Reef Database implemented by the GCRMN (Global Coral Reef Monitoring Network) under its responsibility.

7. Conclusion

The project, based in the long term, is devised to improve both the recreational and biological values of the Kuda Huraa house reef. It will improve the diving activity for the guests, providing them with opportunities to learn more about the coral reef environment, to experience it more closely and even to get involved in participatory activities helping with the research. It will also be looking at reducing the anthropogenic and natural degradations impacting the coral reef ecosystem. These include both degradations caused by the diving activities, as well as the more unpredictable degradations like those caused by coral bleaching. These large-scale events are likely to recur in the future.

A pre-emptive approach consisting in growing corals in nursery areas from fragments found broken off by divers at the site is attempted here: it mitigates the impacts of recreational diving and provides a sustainable source of fragments. The nursery areas resembling small patch reefs will blend in the surroundings, which features many of them.

The research will also try and understand the reef processes in their specificities. In particular it seems important to try and answer the following questions: what are the factors influencing coral growth and how are they affected by human activity? Is it possible to help the natural recovery? What are the links between substrate and fish community structure? What are the seasonal patterns of recruitment and migration of fish species?

To achieve this goal, the project document described the scientific protocols, which will be followed for data collection and data analysis. A team of divers devoted to the project will be further trained to carry out the data collection, and a database will also be developed to enable the scientific analysis of the information. With this project, Four Seasons wants to bring eco-tourism one step closer to the environment by developing applied research to mitigate adverse effects, increase knowledge and build awareness. The outcomes will be communicated to the government of the Maldives, and can be integrated in the national effort carried out to manage the coral reefs, in view of sustainable use of the resources and conserving the bio-diversity.

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