Awareness Raising and Feasibility of Reef Restoration through Coral Transplantation in Tuticorin, Gulf of Mannar, India

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INTRODUCTION

The Gulf of Mannar (GOM) contains 21 islands, which form a chain of small fringing reefs on shallow shores stretching 170 nautical miles between 8°46' and 9°14' N latitude and 78°9' and 79°14' E longitude from north of Mandapam to south of Tuticorin. This area is renowned for its floral and faunal wealth. Patterson *et al.* (2004) reported 104 coral species belonging to 38 genera from the area. A large number of traditional fishermen from the mainland use the reefs as fishing grounds. In 1982, the fishery production in the area was 2 375 tons and in 1983, it was 2 150 tons (Venkataramanujam & Santhanam, 1985). Molluscs, holothurians and algae are harvested in large quantities (Patterson, 2002). Although the conservation authorities of Gulf of Mannar Marine National Park have curtailed destructive reef activities considerably, dynamite fishing and coral mining still occurs in the area.

The Tuticorin coast, which is located at the southern most part of the Gulf of Mannar Marine Biosphere Reserve (GOMMBR), consists of five islands (Tuticorin group) of which one, Villanguchalli, now lies 1 m below mean low water level, as a result of excessive coral mining and soil erosion. Five fishing villages, Pudukadarkarai, Thirespuram, Siluvaipatti, Vellapatti and Tharuvaikulam border the Tuticorin coast, and about 7 000 registered fishermen from these villages depend mainly on fishing around the islands for their livelihood.

Although the average live coral cover around the Tuticorin group of islands is about 29%, large areas of the reefs have been degraded by coral mining, destructive fishing and pollution and, as a consequence, there are no pristine reefs in Tuticorin today (Patterson *et al.*, 2004). However, degraded reefs could recover through natural dispersal and re-colonization by larvae from adult colonies elsewhere (source reefs) if favourable environmental conditions were restored and the pressure from human activities reduced. The time required for recovery would depend on the scale of the disturbance and level of stress on the reef system (Loya, 1976; Harriot & Fisk, 1988) and might be as little as 5 years, but it could also take centuries (Harriot & Fisk, 1988; Edwards & Clark, 1998).

Recovery is particularly slow following episodes causing large-scale coral mortality that results in the disintegration of the reef framework to rubble and unconsolidated sediments, which are, unsuitable for settlement, survival and growth of coral recruits and thus inhibiting natural recovery (Done, 1992). For example, reefs that had been mined in the Maldives showed no recovery after 25 years due to lack of suitable substrata for coral settlement and highly mobile sediment after the mining activities (Brown & Dunne, 1988).

The recovery of a reef area can however be stimulated through, for example, the placement of artificial hard substrata on the seabed to enhance the conditions for colonization (Clark & Edwards, 1995; Thongtham & Chansang, 1998) or by clearing or consolidating loose sediment. Transplantation of corals has been suggested as a viable methodology for expediting the recovery of damaged or degraded coral reefs (Rinkevich, 1995). However, transplantation of entire colonies from an undamaged reef area (donor site) to a damaged site is essentially redistributing the damage, since recovery of the donor site may be slow (Lindahl, 1998). Thus, simple, low-tech methods of coral transplantation that are less destructive to donor sites have been investigated for restoring coral cover to damaged low energy reefs, using unattached coral fragments to mimic and accelerate asexual fragment-driven reef recovery processes (Guzman, 1991; Bowden-Kerby, 2001).

Fragmentation is a very important mode of reproduction among many of the major reef building corals and therefore, is important for the recovery of coral communities after disturbance (Highsmith, 1982). Rehabilitation of coral reefs through transplantation of coral fragments could be seen as a way to by-pass the phases of early slow growth and high mortality rates among newly settled recruits (Harriot & Fisk, 1988) by using the corals' inherent ability to reproduce through fragmentation. In determining transplantation effort in a particular area, results from other regions may not be applicable, since both physical and biological conditions for survival and reef development after transplantation vary greatly among localities and species (Guzman, 1991; Smith & Hughes, 1999). Thus, in order to investigate the feasibility and means of enhancing the recovery of reef areas in Tuticorin through coral transplantation, this study aims to test the survival of different species and growth forms (i.e. massive and branching) at different sites in Tuticorin. Further, this project serves to raise awareness of the importance of corals for reefs and fish populations among fishermen and women from Vellapatti village who are, solely dependent on fishing in the degraded reef areas fringing the islands off the Tuticorin coast (Patterson *et al.*, this volume). All coral transplantation studies were conducted in 4 different sites along the Tuticorin Coast (figure 1).

MATERIALS AND METHODS: INVOLVEMENT OF THE LOCAL COMMUNITY

Coral transplantation was performed with extensive involvement of the local fisher community, to establish awareness and understanding of the importance of corals for reefs and fish populations, and also for cost efficiency. Initially, a survey was conducted together with the fisher folk and an ideal patch reef area outside Vann Island and the park area was selected. The substrate of the site had been denuded by illegal mining and the use of dragnets and was composed predominantly of coral rubble. Before coral transplantation and restoration commenced, several awareness-raising meetings were conducted with the villagers in Vellapatti. The benefits of conserving coral reefs, the ill effects and consequences of destroying reefs and the wise use of non-destructive types of net were highlighted. After the completion of the awareness-raising programme, the women were encouraged to participate in the community-based coral transplantation project activities. A core group of the most interested 30 people was selected to participate and were briefed on the objectives and methodology of the project. Participants were taught how to handle and attach the coral fragments (figure 2) prior to the commencement of restoration in order to promote higher survival of the fragments.

PREPARATION OF CORAL FRAGMENTS AND GENERAL TRANSPLANTATION METHODS

Colonies of branching and massive corals, representing about 3–5% of the total coral population, were collected by SCUBA divers in baskets from a donor site with high coral cover and diversity outside the harbour patch reef at 6.5 m depth. The donor site was about 4km from the 4 study sites and the corals were transported by boat in

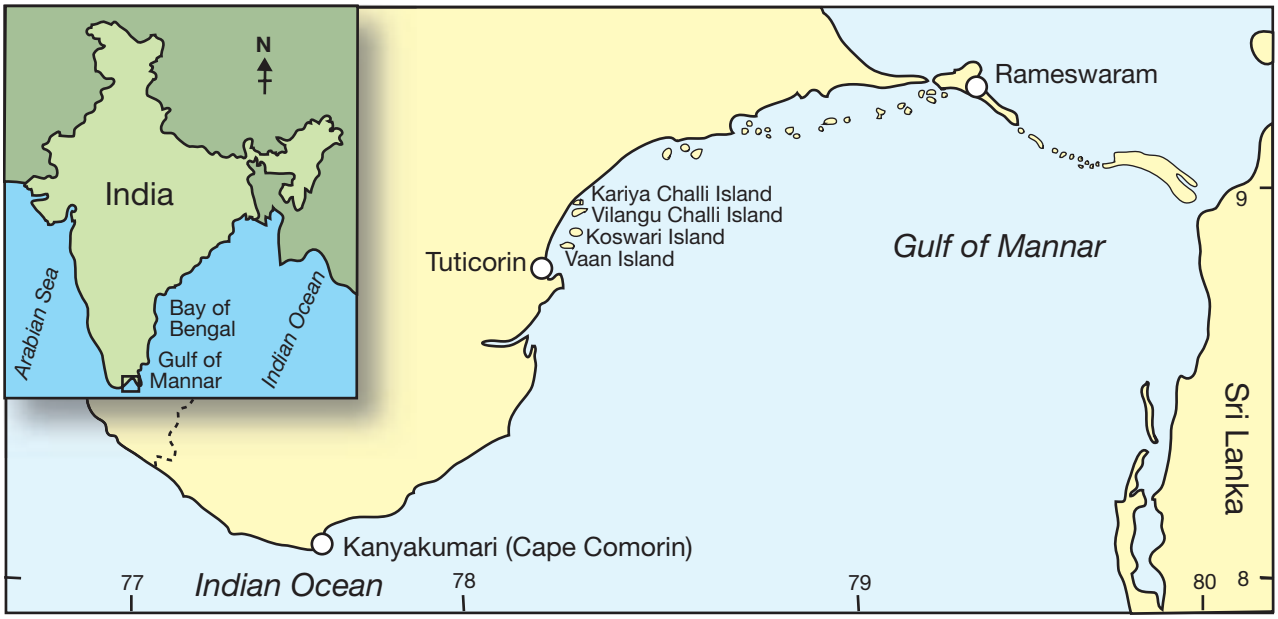

Figure 1. Map showing the study sites.

Figure 2. Training fisher women how to fix coral fragments on ferro-cement slabs.

large fibreglass tanks filled with seawater. During transportation, the fragments were protected from direct sunlight using thick, wet cloth. The water in the tank was changed when the amount of mucus secreted by the corals into the water deemed hazardous to the health of the corals. Colonies of coral with massive, columnar, encrusting, branching, foliaceous and laminar forms were divided into fragments approximately 8 cm in size using a hammer and a chisel and then kept in basins filled with seawater. Fragments were fixed to ferro-cement slabs (20 cm x 5 cm x 1.5 cm) that had been washed in seawater, using nylon ropes or galvanized wires. Initially, the wire was tied tightly around the fragments through holes in the slabs, then around the slab. For each fragment, the firmness of the attachment to the slab was then checked. Loose fragments were retightened before being transferred to the transplantation site. The initial length of each fragment was measured before SCUBA divers placed the slabs on the seabed.

STUDY SITES

Site 1. Tuticorin Port Breakwater

The Tuticorin Port study site is located at Lat. 8°45'N and Long. 78°13'E, encompasses about 1800 m² inside the southern breakwater and is totally free of any anthropogenic activities. The patch reef is dominated by branching corals and provides excellent substrate for healthy growth of corals. A preliminary transplantation study

was conducted between April and July 2002 where 90 fragments of *Acropora nobilis,* 105 fragments of *A. intermedia,* 25 fragments of *Favia palida* and 30 fragments of *Porites lutea* were collected from donor sites and fixed tightly on different substrates like cement slabs, clay pots and stones using nylon strings and were transplanted on dead coral substrate at a depth of 1.5m.

Site 2. Vaan Island Patch Reef

Vaan Island is situated approximately 5 km from Vellapatti fishing village. Fringing reefs are seen on the southeastern face of the island while the intertidal zone supports branching and massive corals. The branching corals include the genera *Montipora* and *Acropora* while the massive coral assemblage is comprised of *Favia, Favites*, *Hydnophora*, *Goniopora* and *Platygyra,* all thriving between 1 m and 3.2 m depth. Transplantation was conducted outside the area of Vaan Island Park in September 2002. Data describing growth and survival was subsequently collected during the period between September 2002 and August 2003. Fragments of *Acropora nobilis* (60), *A. cytherea* (55), *Montipora foliosa* (30 fragments), *M. hispida* (26) and *M. divaricata* (40) were fixed on a concrete frame and deployed at a depth of 5.6 m.

Figure 3. A 12 month old culture of *Acropora intermedia*, *A. cytherea*, *Tubinaria mesentarina* and *T. peltata* growing on concrete frames deployed at a depth of 5.5 m.

Site 3. Harbour Area Patch Reef

The third site was a patch reef 5 km in length situated approximately 1.2 km offshore near the harbour. This site is largely composed of sand with a dense cover of monospecific *Turbinaria* sp. at a depth of 5.5 m. In February 2003, 10 concrete frames, each with a surface area of 1 m^2, were deployed as platforms upon which fragments of *Acropora intermedia* (35), *A. cytherea* (21), *Tubinaria mesentarina* (25) and *T. peltata* (20) were transplanted (figure 3). The concrete frames and transplanted coral covered an area approximately 3 m long and 3 m wide. Data describing the growth and survival of fragments was collected until January 2004.

Site 4. Harbour Area Patch Reef – Fish Houses

At this site, a novel low-tech method for reef restoration termed 'Fish House' was investigated (figure 4). The fish houses were constructed using cement and limestone. This artificial structure was served a dual purpose – to enhance the fish assemblage and as substrate for coral transplantation. Each fish house consisted of 3 or 4 holes

Figure 4. Fish house, constructed using cement and limestone.

and coral fragments were fixed on the structure between the holes using nylon rope. In July 2003, 40 fish houses, supporting a total of 150 coral transplants, were deployed at a depth of 5.5 m over an area of 25 m^2. On each fish house, 3 or 4 fragments of *Acropora intermedia* and *A. cytherea* were fixed. Growth and survival data was collected between July 2003 and June 2004.

Survival and Growth Rate

Initial survival of the coral fragments was recorded 15 days after transplantation, and further subsequent measurements of survival and growth were recorded monthly. Estimates of growth were obtained by measuring the length and width of each fragment using Vernier callipers and recording them on underwater slates. The average growth of each fragment was calculated as the geometric mean diameter (Clark & Edwards, 1995). Data was collected for a period of one year and processed using 2-way ANOVA to find out the difference in growth rate between sites and coral types (branching and non-branching corals). Underwater photographs of the transplanted fragments were taken using a Canon digital camera.

Sedimentation Rates

Heavy sedimentation adversely affects coral recruitment, growth and survival, and can result in fewer coral species, lower growth rates and greater abundances of branching forms and decreased net productivity (Roger, 1990). In this study, the sedimentation rates were estimated by using sedimentation traps (English *et al.*, 1997). Five sediment traps were deployed in two coral transplantation sites (Site 2 – Vaan Island patch reef, Site 3 – Harbour area patch reef) and the contents were collected monthly. The collected samples were sieved to separate particles into different size categories using a sieve shaker and the particle size composition was analysed using Wentworth's scale (1922). Once sieved, each fraction of the sample was weighed and the average sedimentation rate was calculated and recorded.

RESULTS

The preliminary experiment was conducted at site 1 for 4 months and the overall survival of transplanted corals was 75%. Survival of branching corals, *Acropora nobilis* and *A. intermedia,* and non-branching *Favia palida* and *Porites lutea* was 80% and 70% respectively and growth rate was 2.15 cm ± 0.08 and 0.94 cm ± 0.04. respectively. In subsequent experiments conducted at sites 2, 3 and 4, overall survivorship of transplanted coral fragment after one year was 73.84% (figure 5).

Generally, branching corals had formed the second-

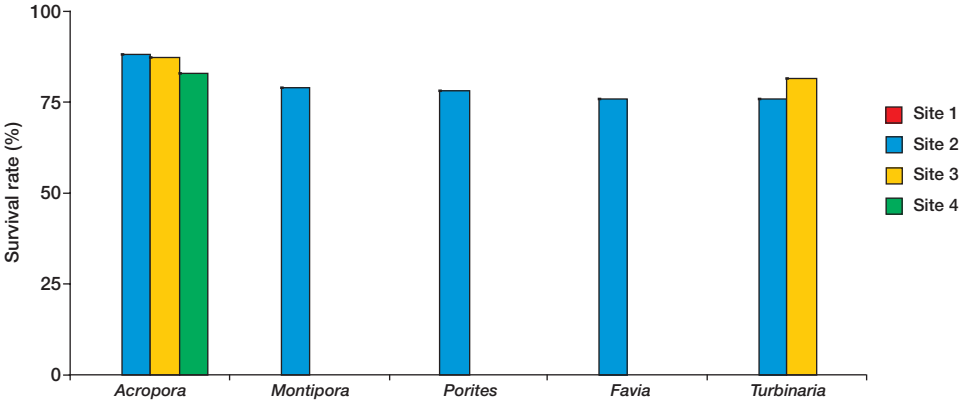

Figure 5. Survival rate of transplanted corals of each genera at each site.

Table 1. Mean annual growth rate (cm·year^{-1}, ± S.E.) of the transplanted corals at different sites

	Site 1	Site 2	Site 3	Site 4
Acropora intermedia (n=60)	–	–	11.75 ± 0.74	9.58 ± 0.31
A. cytherea (n=60)	–	8.17 ± 0.30	9.32 ± 0.80	6.80 ± 0.18
A. nobilis (n=60)	–	4.81 ± 0.18	–	–
Turbinaria mesentarina (n=60)	–	–	1.14 ± 0.09	–
T. peltata (n=60)	–	–	1.98 ± 0.17	–
Montipora foliosa (n=60)	–	2.06 ± 0.09	–	–
M. hispida (n=60)	–	2.65 ± 0.18	–	–
M. divaricata (n=60)	–	1.24 ± 0.04	–	–
Porites lutea (n=60)	–	1.85 ± 0.11		
Favia palida (n=60)	–	1.53 ± 0.08		
Branching coral (n=20)	2.15 ± 0.08	–	–	–
Non-branching coral (n=20)	0.935 ± 0.04	–	–	–

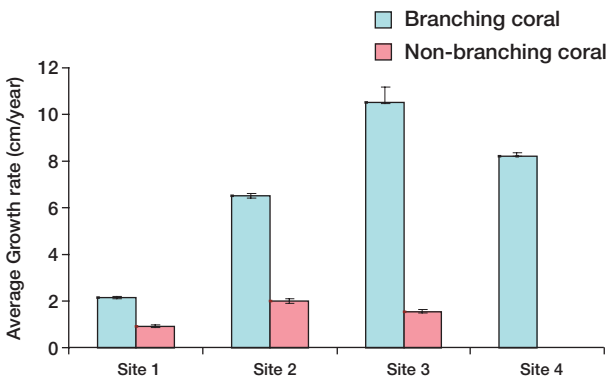

Figure 6. Average growth rate (± S.E.) of branching and non-branching corals at each site.

ary basal disc within 10 to 20 days after transplantation, while non-branching corals required between 20–30 days. All fragments were completely fused to the substrate after 3–5 weeks. A few fragments were toppled by wave action and were subsequently buried by sand killing them.

The growth and survival rate of the different species of corals at the different sites is presented in table 1. The fastest growth rate was recorded for *A. intermedia* transplanted at site 3. At all sites, branching corals showed higher growth rates than the non-branching corals (figure 6 and 7). The results of 2-way ANOVA showed that the difference in the mean growth rate of the branching

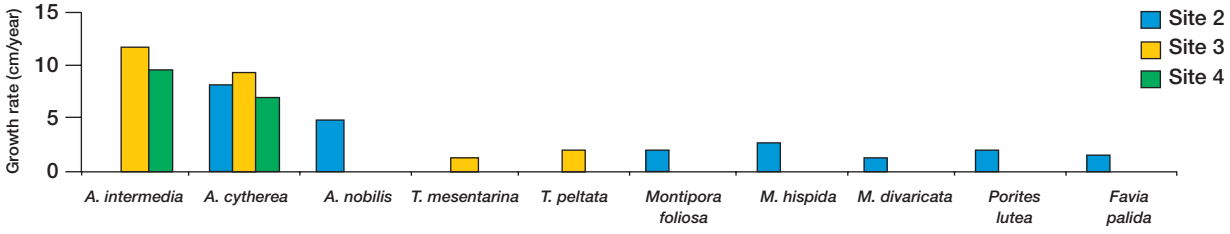

Figure 7. Average growth rate of each coral species at sites 2, 3, and 4.

Table 2. Summary of results of 2-way ANOVA investigating differences in the rates of growth of branching and non-branching corals at different sites after one year

ANOVA *Source of Variation*	*SS*	*df*	*MS*	*F*	*P-value*	*Level of Significance*
Between coral types	65.49974	1	65.49974	10.19812	0.04958	P<0.05
Between sites	20.63327	3	6.877755	1.070846	0.478225	P>0.05
Error	19.26819	3	6.422729			
Total	105.4012	7				

Branching corals (*Acropora intermedia, A. cytherea, A. nobilis*) and Non-branching corals (*Turbinaria mesentarina, T. peltata, Montipora foliosa, M.hispida, M. divaricata, Porites lutea, Favia palida*)

Table 3. Analysis of sediment collected at sites 2 and 3

Sediment size	Site 2 (Vaan Island patch reef)	Site 3 (Harbour area patch reef)
Medium sand (%)	22.17	54.34
Fine sand (%)	30.28	32.98
Very fine sand (%)	47.28	11.38
Average sedimentation rate (g/month)	212.17 ± 34.63	202.45 ± 33.0

and non-branching corals did not differ significantly between the sites (table 2) but that the growth rate of branching corals was significantly greater than non-branching corals.

Sediment Analysis

Medium sand

An average of 54.34% medium sand was found at site 3 due to the sandy bottom and high wave energy. Site 2 had 22.17% medium sand and is characterized by a sandy bottom with rubble, dead coral and algae.

Fine sand

An average of 32.98% fine sand was found at site 3, followed by site 2 with 30.28%. The higher percentage at site 3 may be due to the action of water currents.

Very fine sand

An average of 47.28% very fine sand was found at site 2, followed by site 3 (11.38%) which exhibited a greater composition of coarse particles.

Sedimentation rate

Site 2 showed an average sedimentation rate of 212.17 g·month^{-1} (± 34.63), followed by site 3 (202.45 g·month^{-1} ± 33.0). The highest (299.75 g·month^{-1}) and lowest (162 g·month^{-1}) sedimentation rates were recorded at site 2 during July (2003) and April (2003) respectively.

The composition and rate of sedimentation at sites 2 and 3 is summarised in table 3.

DISCUSSION

Large coral fragments often have higher survivorship probabilities (e.g. Hughes & Jackson, 1985; Done, 1987; Smith & Hughes, 1999), but obviously, it is a trade-off between size and numbers of fragments that can be generated from a single donor site. With the techniques used in this study, fragments of only 8 cm showed rela-

tively high rates of survival. For example, the survival rate of transplants in this study was 73.84% after one year and was considerably greater than the 40% survival of larger transplants used in a study at Sumilon Island, Philippines after the same period (Alcala *et al.*, 1982).

Edwards and Clark (1998) argue for less focus on transplanting fast-growing branching corals, with relatively high mortality rates after transplantation and generally quite good natural recruitment rates. Instead, when transplantation is justified at all, they recommend slow growing massive corals, with high post-transplantation survival, and low natural recruitment rates. On the other hand, branching *Acropora* corals can provide structural stability binding reef elements, thus enhancing the habitat for other sessile organisms (Gilmore & Hall, 1976; Connell & Keough, 1985; Lirman & Fong, 1997). Further, post-transplantation mortality rates are highly site and species specific (Edwards and Clark, 1998), including between species of *Acropora* (Clark and Edwards, 1995), and relatively good post transplantation survival rates have been shown for example by *Acropora intermedia,* a species suggested to be relatively well adapted to fragmentation as a natural reproduction strategy (Smith & Hughes, 1999). This species showed the highest growth rate among the transplants in this study. Furthermore, this experiment generally showed a slightly higher rate of survival of fragments of *Acropora* than of other genera, which also have been shown by Alcala *et al.*, (1982). We thus suggest that when natural recruitment is inhibited, for example by unconsolidated rubble unsuitable for settling and survival of recruits, transplantation of *Acropora* corals can be appropriate, although the particular species used should be selected with care.

In the present study, the experiments were carried out based on the findings of the pilot study indicating that nylon rope may be more suitable than the galvanized wire to secure the fragments. Further, the concrete slabs were found to be the most suitable substrate on which to transplant fragments. This information can be used to enhance future restoration efforts in the area and may be useful in determining the needs for subsequent rehabilitation actions to enhance fragment survivorship. Further, Rinkevich and Loya (1985) found that contacts between fragments of *Stylophora pistillata* from different colonies resulted in reduced rates of growth and reproduction. Therefore, the described method of coral transplantation would probably work best if fragments that are attached to the same string section originate from the same colony. The faster growing genus *Acropora* accreted to the concrete substrate within 2 months while massive corals took longer to accrete. Highest growth rates occurred in fragments of *Acropora*, a genus of relatively fast growing corals.

In the transplanted fragments, the polyps and proto branches started developing from the second month onwards because early basal disc formation consumes some time before vertical growth begins. The main problem faced by transplants was competition for space on the substrate because some gastropods routinely occupy the area, minimizing the opportunity for the transplanted corals to expand horizontally. The present study indicates that the sedimentation rate is minimal, and affects the corals to a minor extent only. An exception is the colonies of *Turbinaria* spp. at site 3, where sediments accumulate inside the cup shaped structure of the colony, which may lead to the slow mortality of the coral.

Coral transplantation by the fragmentation method using cement block substrata is a relatively labour intensive method, compared to for example the 'seeding' of unconsolidated coral fragments on the seabed. However, in our view, the higher survival rates compensates for the increased labour of fixing the coral fragments to solid substrates, and also spares donor sites from repeated collection to replace dead fragments. Also, transplantation on the cement frames helps to protect the fragments from sedimentation. Thus, this method for restoring damaged coral patches may in the long term and conducted at larger scales be a viable way to rehabilitate a damaged coral reef environment and restore the marine life in specific areas along the Tuticorin Coast.

The involvement of local community in the reef restoration work created awareness among the fisher folk of

the need for conserving corals and associated resources. Also, the fisher folk improved their understanding and skills in communicating issues about their environment and resources. This participatory involvement in resource management is considered vital for the protection and conservation of corals by the fisher folk themselves.

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