Resilience of Zooxanthellae to Bleaching Stressors:

An Experimental Study

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ABSTRACT

Resilience, in the context of the capacity for populations of zooxanthellae to recover after coral bleaching, is a little-studied but crucial aspect of coral responses to bleaching stressors. This study investigated resilience to experimental bleaching induced by elevated temperature and darkness in the scleractinian species *Porites cylindrica*. Resilience, as assessed by changes in densities of zooxanthellae on termination of the stressor, was influenced by the nature and duration of the stressor. Zooxanthellae in corals subjected to relatively long durations of darkness were more resilient than those in corals treated for shorter durations. The opposite trend was evident for zooxanthellae in corals exposed to elevated temperature. The basis for these contrasting results may lie in different endodermal processes occurring during treatment with the two stressors. Localised coral bleaching occurs in response to a range of stressors, and this study has strong implications for recovery of corals in the field after natural bleaching incidents. The relevance of these experiments on resilience to field bleaching events is discussed.

INTRODUCTION

Bleaching, the paling of zooxanthellate tissues resulting from the drastic decline in densities of zooxanthellae (e.g. Hoegh-Guldberg & Smith, 1989) and/or the loss of photosynthetic pigments (e.g. Kleppel *et al.*, 1989; Szmant & Gassman, 1990) has long been recognized as a generalised response of corals and allied marine Cnidarians to stress (Glynn, 1993; Brown, 1997). As such, it is elicited by a variety of environmental and laboratory stressors. Greatest emphasis has been placed on identifying the physiological determinants of bleaching in response to elevated seawater temperatures. This is due to the fact that elevated sea surface temperatures (SST), often combined with increased solar radiation (Glynn, 1993; Rowan *et al.*, 1997; Brown *et al.*, 2002), has led to the mass bleaching and mortality of reef corals after the 1980's (Glynn, 1993; Brown, 1997; Hoegh-Guldberg, 1999), with severe impacts to tropical coastal communities (Hoegh-Guldberg, 1999; Wilkinson, 1999). Nonetheless, localised bleaching in the field has been reported to occur in response to a range of stressors, including sedimentation (Bak, 1978), oil pollution (Guzman *et al.*, 1991), reduced salinity (Goreau, 1964), reduced water temperature (Kobluk & Lysenko, 1994) and aerial exposure (Yamaguchi, 1975). The underlying mechanisms of bleaching in response to the majority of known environmental triggers remain poorly defined (Douglas, 2003). For any given zooxanthellate symbiosis, the different triggers of bleaching are predicted to have different impacts on the zooxanthella, the animal host, and symbiotic interactions between the two partners (Douglas, 2003). Thus, the mechanisms and symptoms of bleach-

ing are likely to vary with the specific trigger. Consequently, recovery processes are also likely to be influenced by the nature of the bleaching stressor.

Two bleaching-stressors that have been widely used to induce bleaching in laboratory studies are elevated seawater temperatures (e.g. Gates *et al.*, 1992; Warner *et al.*, 1996; Perez *et al.*, 2001; Ralph *et al.*, 2001; Dunn *et al.*, 2002) and prolonged incubation under darkness (e.g. Wang & Douglas, 1998; 1999; Titlyanov *et al.*, 2002; Lewis & Coffroth, 2004). Bleaching arising from exposure to elevated temperatures has most frequently been attributed to damage to the photosynthetic apparatus of the zooxanthellae (Iglesias-Prieto *et al.*, 1992; Warner *et al.*, 1996; Warner *et al.*, 1999; Jones *et al.*, 1998; Jones *et al.*, 2000). Laboratory investigations have also demonstrated damage to host tissues, particularly in the endoderm, during periods of exposure to elevated seawater temperatures (Gates *et al.*, 1992; Dunn *et al.*, 2002). These findings are consistent with reports describing the histology of corals in the aftermath of natural temperature-mediated bleaching incidents (Lasker *et al.*, 1984; Glynn *et al.*, 1985; Hayes & Bush, 1990). In contrast, prolonged exposure to darkness is not known to cause direct damage either to the photosynthetic machinery of zooxanthellae or animal tissues.

The onset of bleaching is thought to be a function of cumulative heat stress, i.e. not only is the magnitude of the stressor (e.g. positive SST anomaly) important in the incidence of bleaching, but so too is the duration for which it persists (Gleeson & Strong, 1995; Podestá & Glynn, 1997; Winter *et al.*, 1998). High values for indices assimilating duration and overall magnitude of the bleaching stressor, for example degree heating weeks (Gleeson & Strong, 1995) and degree heating days (Podestá & Glynn, 1997), were shown to correlate well with the incidence of bleaching. Critical values for such indices have been proposed as thresholds in excess of which bleaching may occur at the respective locations (Gleeson & Strong, 1995).

The major aim of the experiments described here was to investigate the influence of the nature of the bleaching stressor on recovery of populations of zooxanthellae in

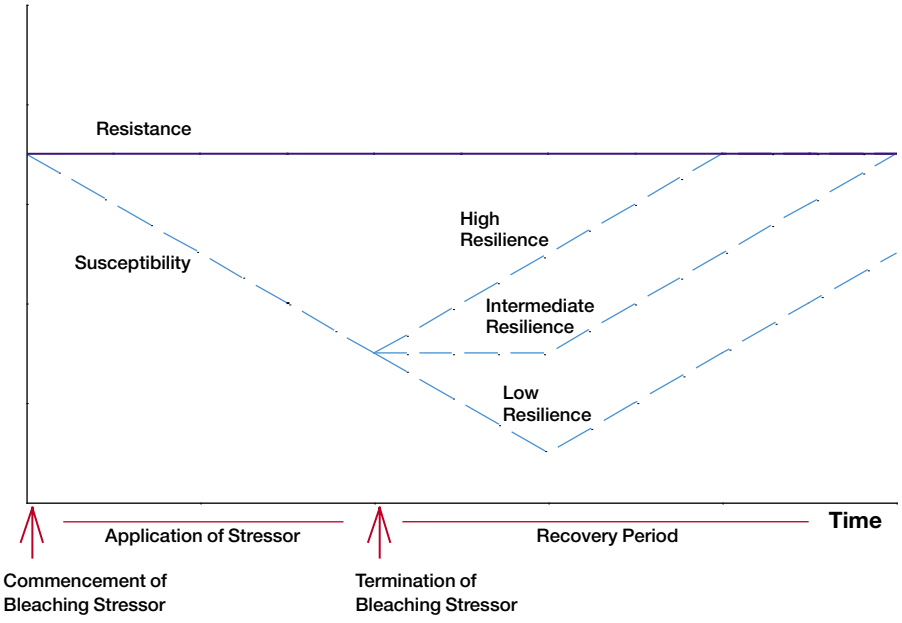


Figure 1. Key responses of the populations of zooxanthellae of coral colonies to bleaching stressors.

bleached corals. Specifically, does the nature of the bleaching stressor influence resilience, i.e. the capacity to recover from bleaching? For the purposes of this study, resilience is defined as the capacity of populations of zooxanthellae in a bleached coral colony to recover from a decline in population density after the application of an external bleaching stressor is terminated. Faster recovery is characteristic of greater resilience whereas slow recovery is a feature of diminished resilience. This is illustrated in figure 1. Elevated seawater temperature and prolonged darkness were selected as bleaching stressors based on the different impacts they have on zooxanthellae and animal hosts, and on their widespread use in laboratory studies on bleaching. A secondary aim was to establish whether the duration over which a stressor is applied influences resilience to bleaching.

MATERIALS AND METHODS

Coral Collection and Maintenance

Experiments were conducted in Mombasa, Kenya. The coral species utilised was *Porites cylindrica* Dana 1846, collected at low tide at a depth of 0.3 m from Kanamai Reef (3.97°S, 39.58°E). Colonies selected for study were separated by at least 5 m. Fragments measuring approximately 4–5 cm in length were broken off parent colonies and transported to the laboratory submerged in a shallow tub of seawater. Coral fragments were glued (Superglue, Alpha Techno Co., Japan) at their base onto dead coral stones. Fragments were maintained indoors, under natural light (12 hour dark/light cycle) in plastic seawater tanks, each with a capacity of 10–12 l. The seawater in the tanks was aerated continually and exchanged daily. Filamentous and turf algal growth were periodically scraped off the bases of coral fragment using a soft bristle toothbrush, and the walls and bottoms of all experimental tanks were similarly cleaned regularly. The positions of tanks were changed weekly. All fragments were maintained in these conditions for at least one week before experiments commenced, in order to allow corals to acclimate to laboratory conditions, and to identify any diseased or damaged fragments, which were removed.

Measurements of Zooxanthellae Density

The density of zooxanthellae, expressed as number of cells per square centimetre of coral skeleton, was determined using the 'aluminium foil' technique of Marsh (1970). The average number of dividing cells for two separate counts of 500 cells was made in order to determine the percentage of dividing cells. Measurements of the density of zooxanthellae and division rates commenced approximately two hours after dawn.

Experimental Designs

Experiment 1 was carried out in May–July 2003. Dark-treatments were commenced on different days, but terminated on the same day, allowing for simultaneous measurements to be made on designated days post-exposure to light on fragments from all treatment tanks. Eighty fragments of each of two *P. cylindrica* colonies were collected from Kanamai, and 10 randomly selected fragments of each colony were divided into 8 tanks. After an initial acclimation period of 7 days, 2 tanks were selected as 'controls', and 2 tanks were dark-treated for 21 days. Seven days and 14 days later, 2 tanks were dark-treated for 14 days and 7 days respectively. Dark treatment required enclosure in opaque heavy-duty black polythene, with no changes to aeration and seawater exchange. Immediately on removal of the polythene sheet (day 0), the density of zooxanthellae and the percentage of dividing cells in one fragment from each colony in each treatment tank was recorded and again on days 7, 21 and 42. One fragment per colony in each control tank was assayed at the start of the experiment, and at four-week intervals thereafter.

Experiment 2 was carried out in May–August 2003. Sixty fragments from each of 2 coral colonies were collected from the reef, and 10 randomly selected fragments from each colony were divided into 6 tanks. After an acclimation period of 24 days, 2 tanks were selected as

'controls', and the coral fragments in 2 'treatment' tanks were transferred to a water bath for 96 hours. The temperature in the water bath was gradually raised over 4–6 hours from ambient (approximately 28°C) to 32.5°C using a filament immersion heater. Aeration and seawater exchange was maintained throughout treatment. Two days after the experiment started, the coral fragments in the remaining pair of 'treatment' tanks were temperature-treated in the water bath at 32.5°C for 48 hours. Treatment was terminated simultaneously for both durations of temperature-treatment, and the fragments were transferred back to their respective 'treatment' tanks. Immediately on termination of temperature-treatment (day 0), the density and percent of dividing zooxanthellae in one fragment from each colony in each treatment tank was measured, and again on days 7, 21, 42 and 63.

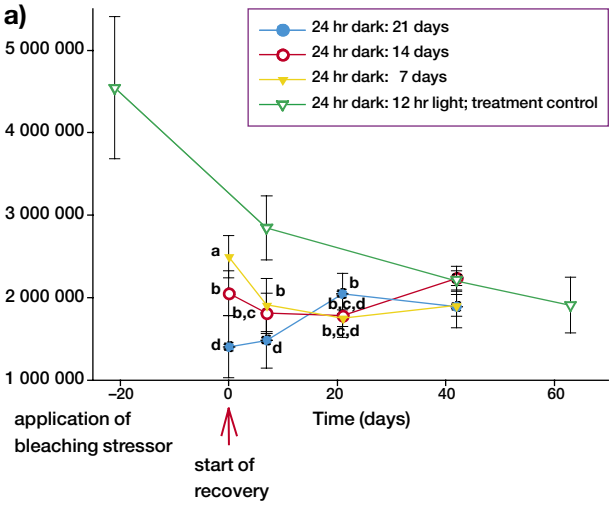
Statistical Analysis

Data were tested for assumptions of *normal distribution* and *homogeneity of variances* respectively, before applying ANOVA, followed by post-hoc analysis with Fisher's LSD test. Percentage data were arcsine-square root-transformed prior to conducting ANOVAs. Significant differences were tested for at the p = 0.05 level. Statistical analyses were performed using MINITAB (Version 10.1) software.

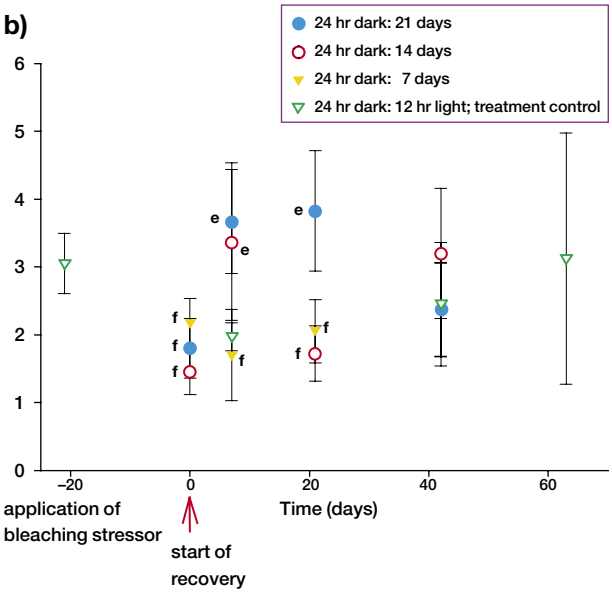
RESULTS

Experiment 1: Resilience of Zooxanthellae to Bleaching Induced by Darkness

Treatment corals underwent a progressive loss of zooxanthellae (and corresponding pigmentation), relative to control corals, with increased duration of darkness (figure 2). The density of zooxanthellae in corals that had been maintained in darkness for the longest duration (i.e. 21 days) was approximately 39% of that in control corals at the end of the dark period. Changes in the densities of zooxanthellae during the first 21 days of recovery were dependent on the number of days that corals were



Factor	D.F.	F Ratio	P value
Treatment	2	6.58	<0.01**
Time	2	2.47	0.103
Interaction	4	6.60	0.001***
Error	27		



Factor	D.F.	F Ratio	P value
Treatment	2	9.72	0.001***
Time	2	8.61	0.001***
Interaction	4	7.22	<0.001***
Error	27		

Figure 2. Densities of zooxanthellae (mean values ±1 SD) (a) and the percentage of dividing zooxanthellae (b) in corals recovering from bleaching elicited by varying durations of darkness (24 hr dark: 21 days, 14 days, 7 days) and in control corals (12 hr light: 12 hr dark, 21 days). Arrows indicate when the treatment was terminated. Results of a two-way ANOVA comparing changes in the density of zooxanthellae and percentage of dividing cells over the recovery interval of 21 days after corals were returned to ambient light are shown below the respective graphs. Measurements of the percentage of dividing cells in treated corals were arcsine-square root transformed prior to conducting the analysis. Letters indicate homogeneous subsets from post-hoc analysis with Fisher's LSD test.

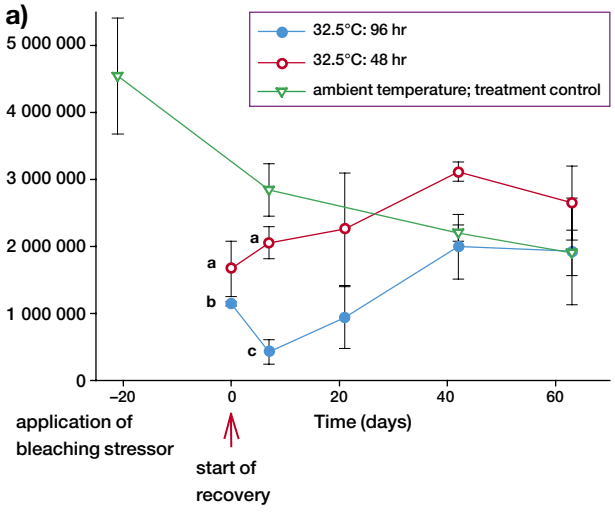
maintained in darkness (two-way ANOVA, interaction term p = 0.001). The least resilient zooxanthellae were those in corals maintained in darkness for 7 days. These underwent a further decline in zooxanthellae densities between recovery days 0 and 7 (2.50 x 10^6 cells cm^{-2} to 1.91 x 10^6 cells cm^{-2}, p<0.001), with no significant changes thereafter. Corals treated for 14 days did not exhibit significant changes in the densities of zooxanthellae over the recovery period analysed. Corals held in darkness for 21 days displayed significant increases in the densities of zooxanthellae between recovery days 7 (1.47 x 10^6 cells cm^{-2}) and 21 (2.05 x 10^6 cells cm^{-2}), showing the highest resilience of zooxanthellae populations of all treatments.

Percentages of dividing zooxanthellae, which varied between 1.5% and 3.8%, are shown in figure 2b. A two-way ANOVA was carried out on cell division data for the first 21 days of recovery. Results show that the rate of cell division over the period analysed was dependent on treatment (interaction term p <001). Corals maintained in darkness for 7 days did not display any significant changes in the percent of dividing zooxanthellae, remaining near control levels of approx. 1.5–2%. Those subjected to 14 days of darkness exhibited an increase in the percent of dividing cells at day 7 (3.4%), followed by a decline to 1.7% on day 21. Those subjected to 21 days of darkness exhibited an increase in the percent of dividing cells at days 7 and 21, to 3.7 and 3.8%, followed by a decline to <2.5% on day 42.

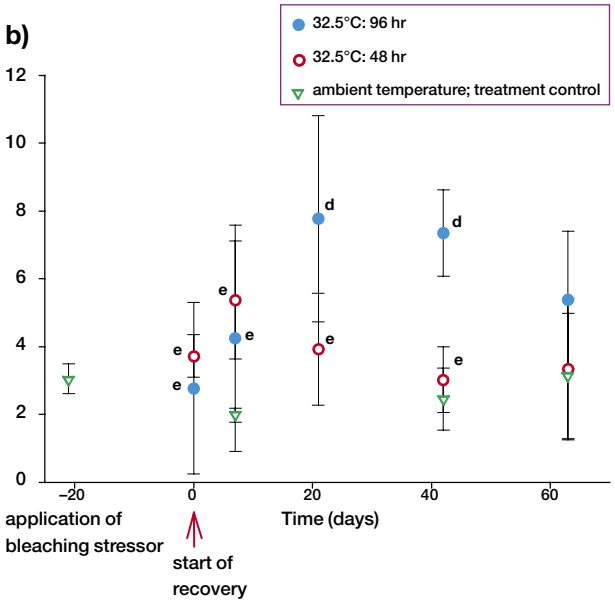
Experiment 2: Resilience of Zooxanthellae to Bleaching Induced by Elevated Seawater Temperature

At the start of recovery, treatment corals had densities of zooxanthellae that varied between approximately 47% (for 48 hour treatment corals) and 32% (for 96 hour treatment corals) of that in control corals (figure 3 on next page). There was a highly significant interaction for the first 7 days of recovery: zooxanthellae in corals treated for 96 hours displayed a significant decline in density between days 0 (1.15 x 10^6 cells cm^{-2}) and 7 (0.43 x 10^6 cells cm^{-2}), while there were no significant changes to the density of zooxanthellae in 48 hour-treated corals. This suggests that changes in the density of zooxanthellae in the initial period following exposure to ambient temperature was dependent on the length of time during which corals were exposed to increased seawater temperatures. However, over a longer recovery phase (days 0–21), two-way ANOVA showed non-significant interaction between treatment and time ($F_{2, 18} = 3.34$, p = 0.058, data not shown). By day 42 of recovery however, the 48 hour treatment corals had significantly higher densities of zooxanthellae than either the 96 hour treatment corals or control corals, both of which did not differ significantly at that stage (one-way ANOVA: $F_{2, 9} = 15.86$, p <0.01).

The percent of dividing zooxanthellae is shown in figure 3b. The interaction between treatment and time in the two-way ANOVA ($F_{2, 18} = 2.90$, p = 0.081) was not significant for the recovery days 0-21. When data were analysed for recovery days 0–42 however, there was a significant interaction term. The percent of dividing zooxanthellae increased markedly for corals treated for 96 hours, from a mean of approximately 2.8% (± 2.5 SD) on day 0, to a mean of approximately 7.8% (± 3.0 SD) on day 21. These were more than double the maximum division rate observed for Experiment 1 (maximum mean of



Factor	D.F.	F Ratio	P value
Treatment	1	70.71	<0.001***
Time	1	1.72	0.215
Interaction	1	18.85	0.001***
Error	12		



Factor	D.F.	F Ratio	P value
Treatment	1	2.24	0.147
Time	3	2.24	0.109
Interaction	3	4.37	<0.05*
Error	24		

Figure 3. Densities of zooxanthellae (mean values ±1 SD) (a) and the percentage of dividing zooxanthellae (b) in corals recovering from elevated temperature-induced bleaching (32.5°C: 96 hr, 48 hr) and in control corals (ambient temperatures). Arrows mark the start of the recovery period, i.e. when treatment was terminated. Results of a two-way ANOVA comparing changes in the density of zooxanthellae in treatment corals during the first 7 days recovery after returning to ambient temperatures are shown below the respective graph. Percentage data were analysed for the first 42 days of recovery and were arcsine-square root-transformed prior to the use of ANOVA. Letters indicate homogeneous subsets from post-hoc analysis with Fisher's LSD test.

3.8%) for dark-treated corals. The division rates of 48 hour-treated corals did not change significantly over the period for which the analysis was performed.

DISCUSSION

Processes in Recovery from Bleaching

Corals that have undergone bleaching may recover their zooxanthellae through three mechanisms:

- an increased rate of cell division in zooxanthellae, as has previously been reported for bleached corals (Fitt *et al.*, 1993; Jones & Yellowlees, 1997), in combination with:
- the division of infected host cells and redistribution of their resident zooxanthellae to daughter cells (Berner *et al.*, 1993; figure 4a); and/or
- the expulsion by exocytosis of zooxanthellae from infected endoderm cells into the gastric cavity, and their subsequent uptake by uninfected host cells (Jones & Yellowlees, 1997). These could be vacant cells that had lost zooxanthellae during bleaching but that remain competent (i.e. can be reinfected), and/or newly differentiated from stem cells replacing host cells lost during the bleaching event (figure 4b).

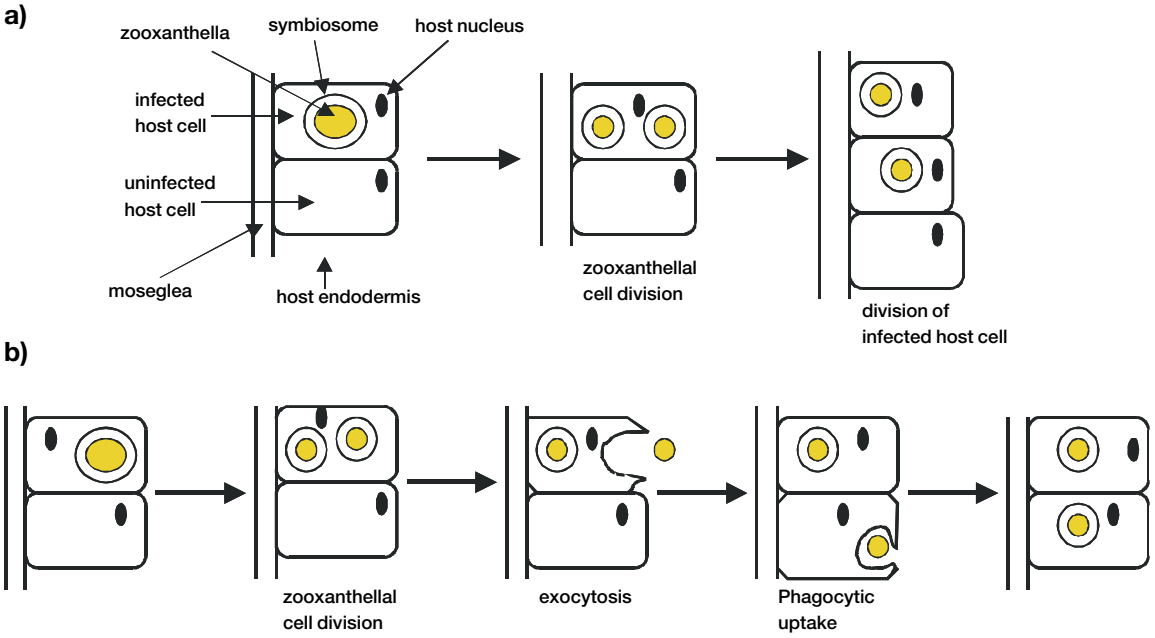


Figure 4. Processes occurring in the host endodermis during recovery from bleaching. a) The division of host cells and distribution of their resident zooxanthellae to daughter cells. b) The division, expulsion and subsequent uptake of zooxanthellae.

Recovery from Bleaching Induced by Darkness

An important consequence of prolonged exposure of corals to darkness is the reduction in cell division rate of residual zooxanthellae, without a corresponding decline in the growth and division of host cells. This is indicated partly by the variation in the rates of division of zooxanthellae in corals subjected to different durations of darkness, immediately on their return to ambient light. For instance, in Experiment 1, the zooxanthellae in corals treated with darkness for a relatively short period had a higher proportion of dividing cells on day 0 than those treated for longer periods (7 days: mean 2.2%;14 days: 1.5%; 21 days: 1.8%). The primary outcome of the contrasting effects of darkness on the division of host cells and zooxanthellae is predicted to be a change in the ratio of uninfected host cells to residual zooxanthellae. The longer the exposure of corals to darkness, the larger this ratio is likely to be (figure 5 on next page).

Factors that influence the rates of division of zooxanthellae include the availability of space (Smith & Muscatine, 1999), host-derived nutrients including nitrogen (Falkowski *et al.*, 1993; Muscatine *et al.*, 1998) and/or possibly carbon (Douglas, 1994), and light. These experiments were conducted indoors, where the light levels, albeit unmeasured, were low in comparison to that which corals are likely to have experienced in their natural environment. The extent to which these factors limit the division of zooxanthellae is directly related to the density of zooxanthellae in coral tissues. In turn, zooxanthellae density, as a consequence of the inhibitory effect of darkness on zooxanthellae division, was inversely proportional to the length of exposure to darkness. It follows therefore, that the rate of zooxanthellae division in corals subjected to relatively short durations of darkness (occurring at relatively high densities) would undergo a decline, thereby bringing about a *density-dependent* reduc-

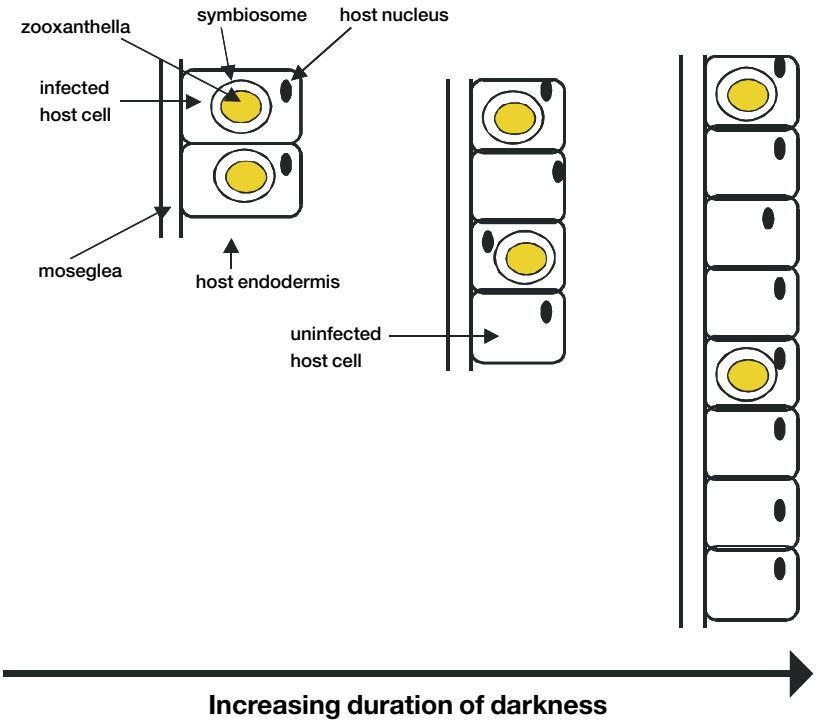


Figure 5. The predicted impact of duration of darkness on the ratio of uninfected host cells to zooxanthellae.

tion in zooxanthellae densities. Conversely, the above-mentioned factors, and in particular available space, i.e. the ratio of uninfected host cells to residual zooxanthellae, would not have limited the division of zooxanthellae in corals that were kept in darkness for relatively long periods (occurring at relatively low densities). Under these conditions, zooxanthellae would proliferate. Their release into the gastric cavity, and subsequent uptake by uninfected host cells would bring about the repopulation of bleached tissues, as would an elevation in the rates of division of infected cells. The observed data on the division of zooxanthellae during the early stages of recovery are consistent with this explanation. For instance, in Experiment 1, the percent of dividing zooxanthellae significantly increased between days 0 and 7 in corals subjected to treatment with darkness for 14 days (mean of 1.5% to 3.4%) and 21 days (mean of 1.8% to 3.7%), but declined, although not statistically significantly, for those in corals incubated under darkness for a period of 7 days (mean of 2.2% to 1.7%). In the context of the present study using darkness as a bleaching stressor, the observed changes in zooxanthellae density for the different levels of treatment would have been defined as elevated (21 days) or diminished (7 days) resilience. Resilience however, may not be an appropriate term to describe the *density dependent regulation* of zooxanthellae populations during exposure of corals to darkness, as the observed dynamics might not relate precisely to the capacity to recover from bleaching. This can be developed into a testable hypothesis.

Recovery from Bleaching Induced by Elevated Temperature

The responses of zooxanthellae populations to treatment with elevated temperature displayed the opposite trend to those of zooxanthellae subjected to darkness. Not only

were the zooxanthellae in corals that were exposed to elevated temperature for a relatively short duration (48 hours) more resilient to bleaching than those exposed for a longer duration (96 hours), but they also exhibited an 'overshoot' of populations relative to treatment controls (see figure 3). In contrast, zooxanthellae in corals treated for 96 hours continued to undergo a decline in population density on their return to ambient temperatures. The zooxanthellae densities of corals exposed to increased temperatures for 96 hours did not exceed those in control corals at any time during the experiment.

Damage to the photosynthetic apparatus of zooxanthellae is widely believed to be the primary determinant of bleaching during exposure to elevated seawater temperatures (Jones *et al.*, 1998; Warner *et al.*, 1999; Jones *et al.*, 2000). Primary cellular mechanisms for the ensuing decline in zooxanthellae densities include the degradation of zooxanthellae *in situ* and the release of zooxanthellae into the gastric cavity by exocytosis (Brown *et al.*, 1995). Some laboratory studies have recently challenged this perspective. Notably, the study by Dunn and colleagues (2002) using the sea anemone *Aiptasia* sp., demonstrated that the swelling and rupture of host endodermal cells caused by tissue necrosis during hyperthermal treatment was a key factor mediating the release of apparently healthy zooxanthellae into the gastric cavity. The authors pointed out that an implication of necrotic damage (as opposed to programmed cell death, PCD) was that it was extrinsically mediated, and not under direct host control. Necrosis and PCD of zooxanthellae, resulting in their degeneration *in situ*, did however accompany damage to host tissues after prolonged exposures to elevated temperatures. Similarly, another laboratory study (Ralph *et al.*, 2001) indicated that the zooxanthellae released by the coral *Cyphastrea serailia* during temperature mediated bleaching (at 33°C) were photosynthetically competent, and only suffered from impairment to photosynthesis after the temperature was greatly elevated (to 37°C). The tissue necrosis of host endoderm indicated by laboratory studies on temperature mediated bleaching has also been observed during histological examination of corals that had undergone elevated temperature-mediated bleaching in the field (Lasker *et al.*, 1984; Glynn *et al.*, 1985). Zooxanthellae of normal appearance were observed in all but the most affected specimens (Glynn *et al.*, 1985).

An alternative mechanism by which the structural integrity of host endodermis can be compromised is the detachment and release of intact endoderm cells with their entire complement of zooxanthellae into the gastric cavity. This has been proposed, based on laboratory experiments, as a dominant mechanism for temperature-induced bleaching (Gates *et al.*, 1992; Sawyer & Muscatine, 2001). A combination of epifluorescence and electron microscopy were used to detect detached viable host cells enclosing symbiosomal membrane-bound zooxanthellae (Gates *et al.*, 1992). The host membranes surrounding zooxanthellae disintegrated shortly thereafter.

In the present study, the underlying mechanisms and symptoms of temperature mediated bleaching were not identified. However, immediately on termination of treatment, the zooxanthellae in corals subjected to increased seawater temperatures for 96 hours were dividing at a mean of 2.8%, not significantly different from those in corals exposed to elevated temperature for 48 hours. This rose sharply to 4.3% by day 7 of recovery, and further still to a maximum mean of 7.8% on day 21 (significantly higher than that of 48-hour treatment corals; see figure 3b). During the same period zooxanthellae densities in these corals significantly declined between days 0 and 7, before slowly increasing. This recovery profile is not consistent with damage to the photosynthetic machinery of the zooxanthellae, but is in line with the continued disruption of host endodermis and subsequent release of zooxanthellae into the gastric cavity in the period immediately after return to ambient temperatures. The exceptionally high proliferation rates of zooxanthellae on day 21 suggest that a large proportion of zooxanthellae counted were inside the gastric chamber and free of host suppression of their growth and division (Suharsono & Brown, 1992; Douglas, 1994; Jones & Yellowlees, 1997), although this was not established.

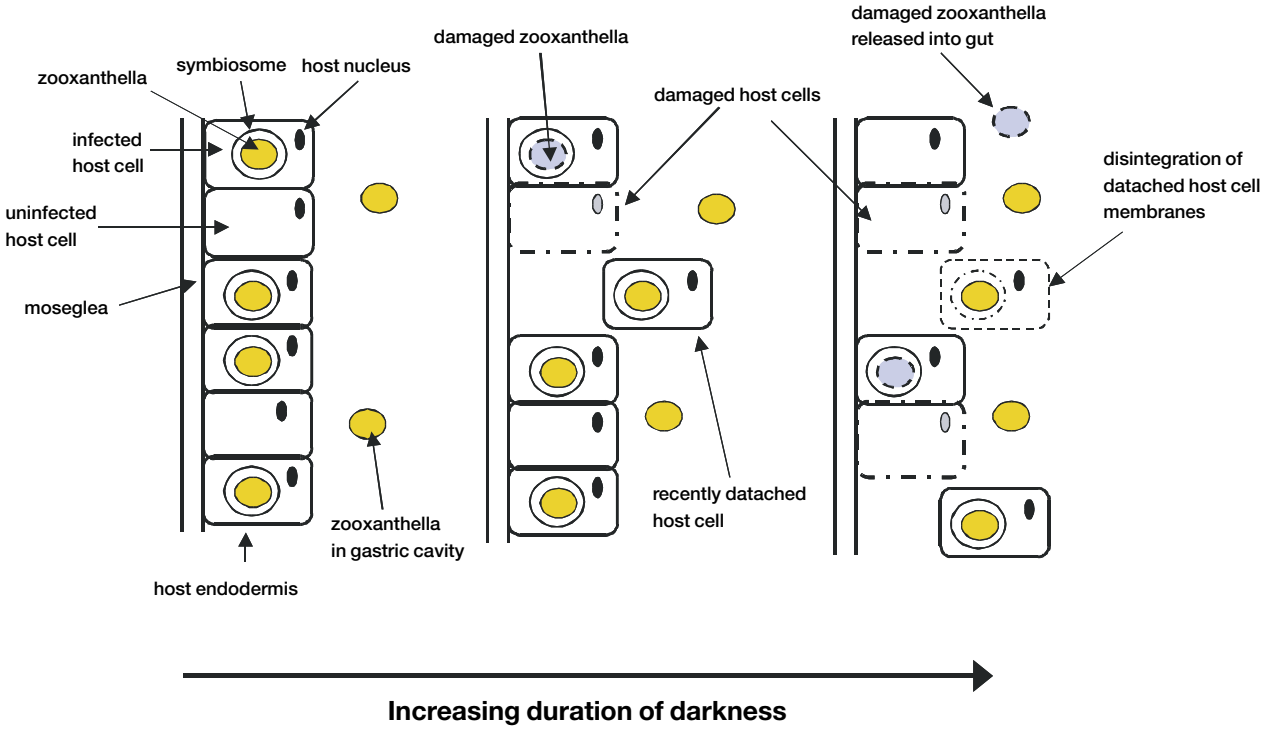


Figure 6. The theoretical impact of duration of elevated temperature on the availability of competent host cells and competent zooxanthellae in a section of coral endoderm tissue.

It is not disputed that damage to photosynthesis occurs when corals are subjected to elevated seawater temperature, especially during prolonged (Dunn *et al.*, 2002) or extreme (Ralph *et al.*, 2001) exposures. Incontrovertible too, is the fact that host tissues, particularly the endodermis, undergo damage during hyperthermic treatment. Frequently, inadequate consideration is given to repair processes in host tissues when attempting to understand factors that either promote or retard recovery of zooxanthellae populations after bleaching. These are almost certainly not instantaneous, and might take days and perhaps even weeks to occur under favourable conditions. Figure 6 is a diagrammatic representation of the theoretical impact of the length of exposure to elevated seawater temperature on host cells and the residual zooxanthellae in a section of the host endodermis.

After a relatively short exposure to elevated temperatures, not only are there a greater number of competent zooxanthellae to proliferate but there are also a larger number of competent host cells available to acquire the dividing zooxanthellae. On the other hand, the longer the period of exposure to elevated temperature, the more vulnerable the host endodermis is to structural damage, exacerbated by photosynthetic damage to zooxanthellae, and the greater the delay in recovery of zooxanthellae-populations, i.e. diminished resilience.

Localised bleaching of reef corals is known to occur in response to a range of environmental stressors, and these experimental studies provide indirect evidence that the resilience of zooxanthellae populations of bleached corals in the field are likely to be influenced by the nature and the duration of the stressor.

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Community-Based Monitoring of Coral Reef Resource Use

in Agatti Island, Union Territory of Lakshadweep, India

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key words: coral reef, reef fishery, resource use, participatory monitoring, Agatti Island, Lakshadweep

INTRODUCTION

Agatti is an atoll island in the Indian Union Territory (UT) of Lakshadweep, a coral archipelago off the west coast of India at the northern end of the Laccadive-Maldive-Chagos ridge. Located at 10° 51' N and 72° E it is the westernmost island in the UT Lakshadweep (Dept of Planning and Statistics, 2000). The island stretches 7.2 km in a roughly north-south direction, with a width varying from 1000 m at its widest point in the north to less than 100 m at its narrowest point in the south. A lagoon, which is wider and deeper (c. 2–5 m at low tide) on the western side than on the eastern side, is enclosed by a coral reef which surrounds the island (figure 1 on next page) (Hoon *et al.*, 2002). The total estimated land area is 2.7 km^2, lagoon area 12 km^2 and reef flat area 14.4 km^2 (Bahuguna & Nayak, 1994).

In the year 2001, Agatti had a total population of 7 072 and a population density of 1 842 km^{-2} (Dept. of Planning and Statistics, 2002)[1]. A detailed socio-economic assessment from the area, covering livelihood aspects, fishing methods, resource governance patterns, indigenous knowledge, site use and resource perceptions, shows that use of reef resources, such as reef gleaning and fishing, still constitutes a subsistence income for more than 50% of the population on the island and provides about 90% of the protein intake (Hoon *et al.*, 2002; Hoon, 2003). In addition to the reef around Agatti and Kalpitti, the traditional fishing and land rights areas of the people of Agatti include the submerged atoll Perumal Par to the northwest of Agatti, and the Bangaram lagoon, encompassing the islands Bangaram, Tinnakara, Parelli I, II, and III. Parrelli III was washed away during a cyclone in 1974 (Hoon *et al.*, 2002). All the areas are used extensively.

In an effort to conserve and protect coral reefs and reef resources, the Department of Environment and Forests of India and the Administration of Lakshadweep issued notifications in July and December 2001 restricting use of a number of marine species (Lakshadweep Gazette, 2001a, b). The July 2001 notification bans all extractive use of scleractinian corals, antipatharians, gorgonians, milleporids and *Tubipora musica*, and also several other key resource species such as all sharks and rays, 52 species of mollusks, and sea cucumbers which are listed as Schedule I species[2].

[1]The census data includes Kalpitti, Bangaram, Thinakara Parelli etc. in the total area of Agatti. This gives a total surface area of 3.84 km^2 and a population density of 1 842. However, because virtually all people live on Agatti Island itself the population density on the island is closer to 2 600.

[2]The wildlife protection act states that harming endangered species listed under Schedule 1 of the act is prohibited throughout India. Hunting or collecting other species requiring special protection (Schedule II), big game (Schedule III) and small game (Schedule IV) is regulated through licensing. A few species classified as vermin (schedule V) may be hunted without restriction.

Figure 1. Agatti Island and the surrounding lagoon. The map is drawn using information provided by Goa Diving (base map and dive sites) and from discussions with fishers regarding the location of Chals (Hoon *et al*., 2004).

This notification was amended in December 2001, returning some of the molluscs commonly collected to schedule IV, which allows licensed collection.

However, enforcement of the notifications is weak. The islanders value the reef and lagoon as a safety net and recognize that the reef provides vital protection against storms and waves, but consider replenishment of reef resources sufficient and thus do not support the restrictions issued by the administration. Many of the reef resources listed on Schedule I continue to be exploited. At the same time, fishermen admit that both catch size and the size of individual fish have declined (Hoon *et al.*, 2005).

There is considerable uncertainty regarding the sustainability of resource use in Agatti, as well apparent inconsistencies between opinions voiced and trends observed. Further, the many conflicting views and opinions

means there is an obvious risk for increased conflict over resource use and access. At the same time, very little information on status and trends in reef resources and utilization patterns is available for the Lakshadweep. A survey on the distribution and abundance of corals, sea weeds, echinoderms and gastropods, conducted on the eastern reef flat of Agatti Island in 1992 and 1993, reports low coral abundance on the reef flat and classifies corals as endangered (Rodrigues, 1996). The Fisheries Department collects some fish catch data, focusing primarily on commercially important species such as Tuna, but information on most subsistence and lagoon activities is scarce.

In view of this, a monitoring programme was initiated in 2003, driven by local residents and stakeholders, that aimed to collect detailed information describing reef use, particularly the differences in resource use between the lagoon and reef area as well as within these; particular 'hotspots'; seasonality in different activities; spatial overlaps in resource use and conflicts that arise out of this; and, finally, illegal resource use.

This paper presents the results of one year of data collection and describes in detail the characteristics and patterns of resource use, with some additional data on resource extraction. In addition, this paper provides recommendations on further needs in reef resource and resource use monitoring in Agatti.

METHODS

Activity Descriptions and Estimated Resource Extraction

An inventory was made of all the reef related activities on the island using participatory resource appraisal methods such as focus group discussions, a variety of visualization tools, and interviews with practitioners (IIRR, 1998; Bunce *et al.*, 2000). Information describing a number of aspects of the activities, such as seasonality, location, importance ranking, value, and average catch size and composition was collected. Local taxonomy and terminology was used for the sake of accuracy and local relevance. Reef areas and sites used for different activities were located on a resource map and ranked according to preference by local stakeholders.

Estimates of the resource extraction by activity, such as average fish catch and catch composition using a certain gear, were obtained through observation and interviews. For each activity at least five separate interviews were conducted with practitioners, and where possible data recorders participated in the activities. Fisheries Department staff who collect fish landing data were also consulted. The data was validated through focus group discussion with 10 expert fishermen from Agatti. This method, while not precise, provided reliable indicative estimates of resource use and catch per unit effort.

Reef Use Monitoring

Reef use monitoring was carried out to estimate average daily pressure from human activities on coral and reef based resources, in different parts of the island and at different times of the year. The island was divided into eight zones as shown in figure 2 on next page. Beach-based data recorders made observations on the number of people carrying out each activity and taking notes on field datasheets listing common activities such as reef gleaning, octopus hunting, tuna baitfish collection, various forms of net and line fishing, and collection of boulder, shingle and sand for construction purposes. Data was recorded four times daily in each zone: at beginning of high tide; high tide; beginning of low tide; and low tide. This sampling strategy was developed through consultation with practitioners and was designed to capture all uses regardless of their dependence on tides. For example, the relationship between tides and the movements of fish means many fishing activities coincide with the change of tides (e.g. some fish are known to enter the lagoon with an incoming tide and leave with the start of low tide).

While this sampling strategy provides data on every type of reef related activity every day, it must be seen as an estimate of total number of reef users. However, it was viewed as appropriate for the objectives of this study, providing reliable information on the pressure on the

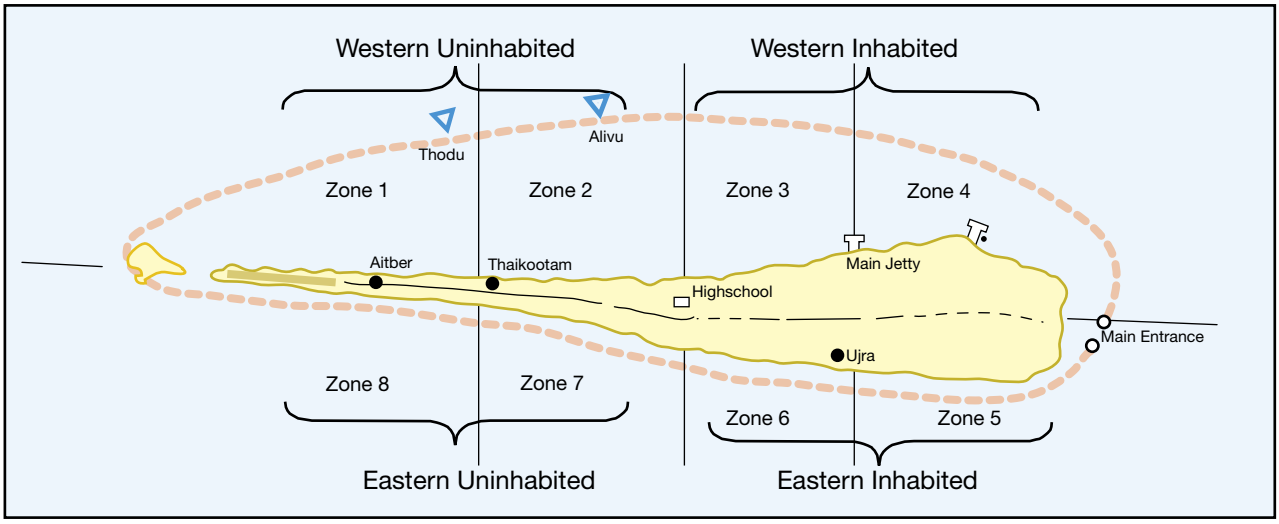

Figure 2. Monitoring zones on Agatti Island defined by the project.

reef and identifying potential problem areas, and it goes considerably further than any previous efforts on Agatti.

In analysing the data the eight original zones have been merged into four zones defined by location in relation to human habitation and lagoonal conditions. Thus zones 1 and 2 have been merged to become the Western Uninhabited zone; zones 3 and 4 became the Western Inhabited zone; zones 5 and 6 became the Eastern Inhabited zone and zones 7 and 8 became Eastern Uninhabited zone. Merging these zones was supported by the data, which did not exhibit significant differences in reef use between the zones that were merged.

Information describing non-extractive reef use in the form of scuba diving was obtained from the Goa Divers dive centre operating out of Agatti Island Beach Resort. The dive centre keeps a daily log of the number of divers they take out and sites visited. Dive site descriptions and locations were also provided.

RESULTS AND DISCUSSION

Most use of reefs and reef resources is carried out to fulfill basic needs. Activities can be classified into three major groups based on what the activity provides:

- collection of construction materials for houses;
- subsistence fishing, providing food and protein as well as some cash income for the household of the individual;
- dive tourism and snorkeling, which is a recently introduced category.

These different activities, their characteristics and use patterns are described and discussed in the sections below.

Collection of Construction Materials

Coral boulders, shingles (coralline rubble) and sand are, in addition to palm trees, among the few building materials available to atoll islanders. On Agatti they are still widely used, in spite of bans and/or restricted use and an increasing supply of materials from the mainland. It is important to note that construction materials imported from the mainland have a monetary cost, even when subsidized, as opposed to materials that can be collected locally.

Boulder Collection

Coral boulders are used for laying foundations of houses. They are normally collected for private use and not sold.

People wade through the shallow lagoon that separates the island from the reef and break off boulders, live or dead, with crowbars. Four to five people are involved in each operation, removing around 100 kg per person per day. If there is not enough manpower to haul whole boulders to shore they are broken into smaller pieces in the lagoon before transportation (figure 3).

Although this activity is prohibited, coral boulders are collected throughout the year all along the eastern side of the island, although at higher intensity closer to the human settlements to reduce transportation distances. Collection increases considerably during the fair season (especially December to March) as this is the season for house construction when the weather is more favorable (figure 4). The wide lagoon on the western side of the island restricts access to the reef and thus prevents extensive collection.

Figure 3. Coral boulders collected for construction. Both live and dead colonies are broken off the reef using iron rods. *Photo:* JERKER TAMELANDER.

Based on the data gathered an estimated 92 metric tons of live and dead coral boulders were collected between June 2003 and May 2004. When compared with the approximately 98 tons collected in a six-month period from July to December 2001 (Hoon *et al.*, 2002) it appears that there has been a reduction in boulder collection. This could indicate that the ban on coral boulder collection is having an impact.

However, there are also indications of bursts of increased boulder collection at times when periods of stricter enforcement of legislation is predicted or expected, illustrating that people are willing to break the laws in order to get the resources needed, when this can be done with a lesser risk of punishment.

Shingle Collection

Shingle is coral rubble that accumulates on the beaches and in lagoons. With cement as the binding material it is

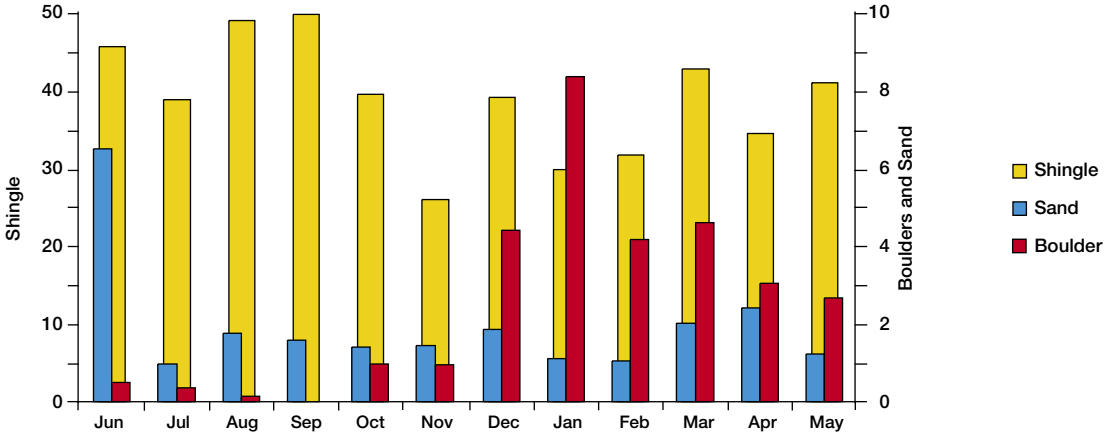

Figure 4. Boulder, shingle and sand collection, presented as average daily effort (man-days) by month. NB all zones have been merged.

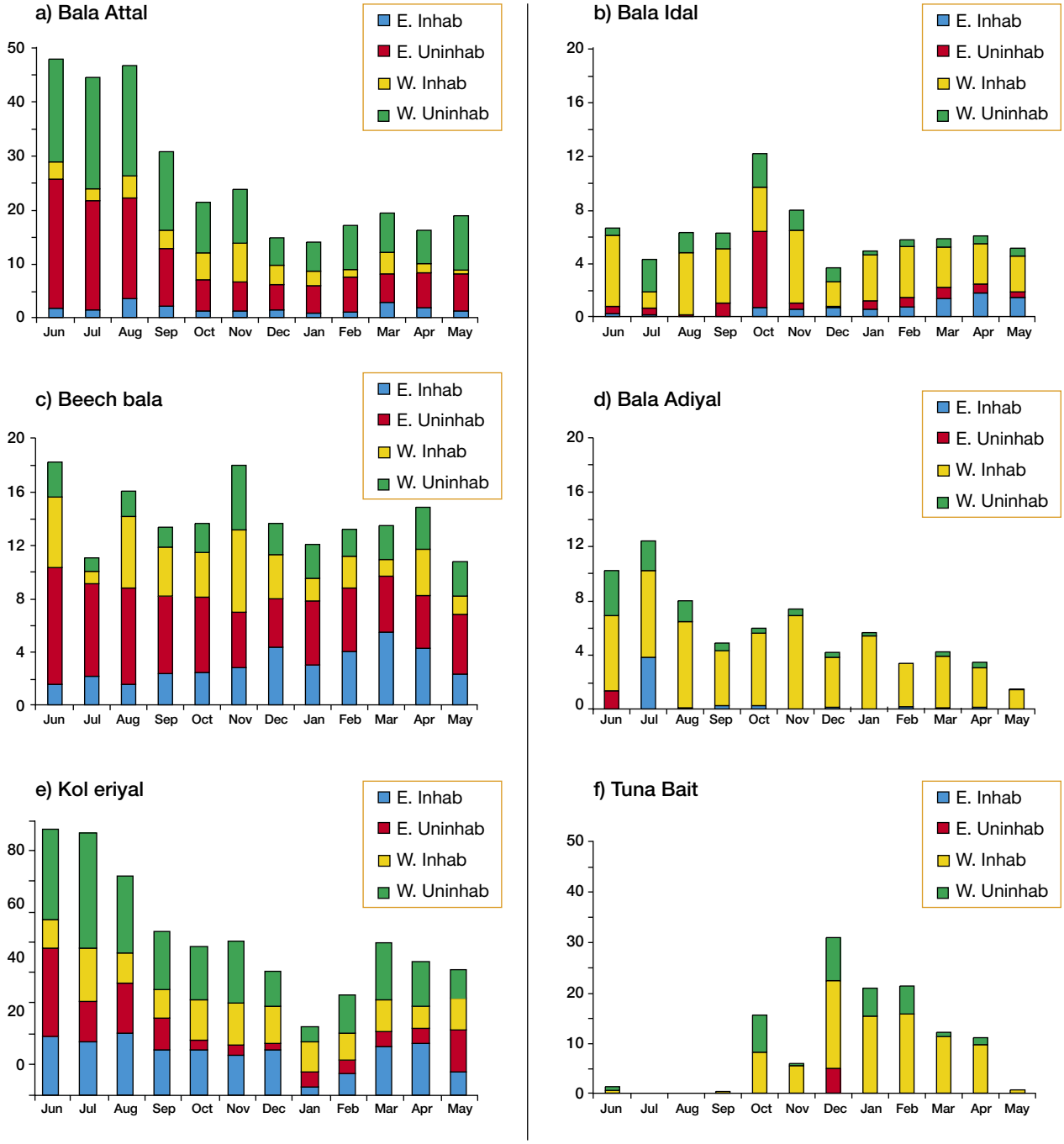

Figure 5. Average daily fishing effort in the four zones by gear and month. Effort is given as the number of people engaged in a certain activity during one day. a) Bala attal, purse seine; b) Bala idal, gillnet in lagoon; c) Beech bala, cast net; d) Bala adiyal, shore seine; e) Kol eriyal, handline; and f) Tuna bait. Note differences in scale on y-axis.

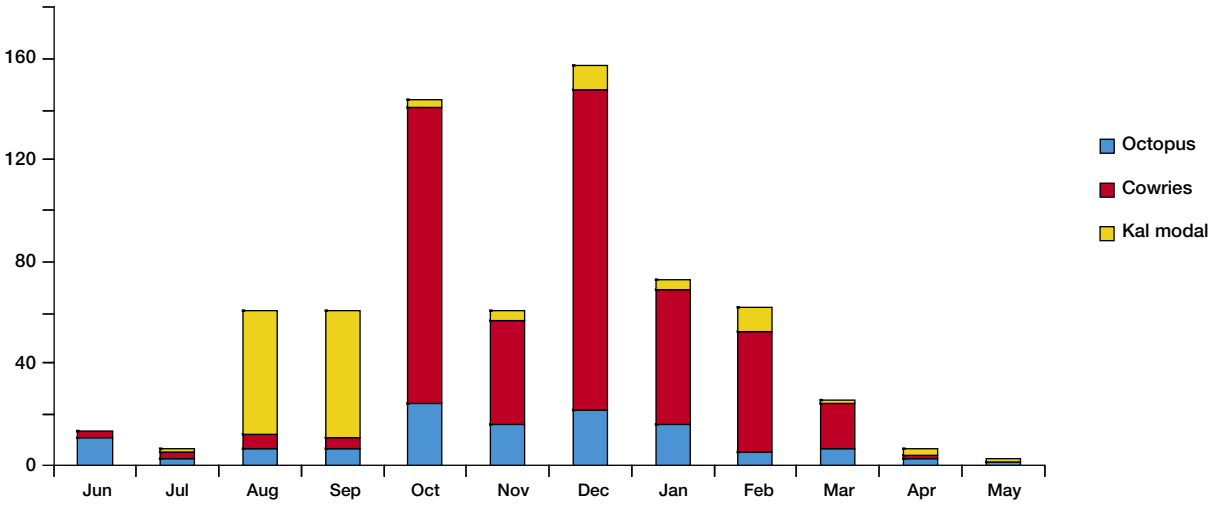

Figure 6. Gleaning pressure on the reefs in Agatti. Cowry collection and octopus and kal modal fishing presented as average daily effort (man-days) by month. *NB* all zones have been merged. Almost all gleaning takes place in the eastern lagoon.

used to make blocks for construction of house walls. It is also used in house foundations and floors. Shingle collection is a regulated activity under permit from the Environment Warden's Office. Those who have a permit must deposit a fee of five Indian Rupees (approximately 10 US cents) per bag of shingle collected.

The permit records show that no applications to collect shingle on Agatti had been lodged since 1998 (Hoon *et al.*, 2002).

In spite of this shingle is collected from all over the island both during the monsoon and fair season (figure 4). Most collection takes place in the inhabited part of the island on the eastern side, as well as in the Kalpitti area in the southernmost portion of the island. Based on the total number of shingle operations recorded and an estimated daily harvest of c. 15kg per person approximately 200 tons of shingle was collected during the monitoring period. This is at the same level as was recorded in 2001 (Hoon *et al.*, 2002).

Sand Collection

Sand, mixed with cement to make concrete used in building construction, is primarily dug out from low sand dunes along the shore, but also collected from the beaches. Collection takes place all around the island and throughout the year (figure 4). In the southern uninhabited part of the island tractors and tillers are used to collect and transport the sand, typically 1.5 and 0.5 tons per load respectively, while in the inhabited part sand is collected in bags, circa five 20 kg bags per person per day. The impact on beaches and dunes is obvious, resulting in loss of vegetation and loss in height.

Subsistence Fishing

Fish for household consumption is caught in the lagoon and on the coral reefs using a variety of gears. In the past the fish catch was shared between households and never sold. However, increasing demands as well as increased purchasing ability and refrigeration possibilities have meant surplus catch is now sold and reef based fishing is conducted for financial gains, in addition to supplying food for the family. Fishing methods range from single person gears such as hook and line or cast net, to large operations involving 30–40 people such as the *bala fadal* drag net. Gears and catches are described in some detail below, with graphs of average daily use (figure 5, 6 and

Figure 7. Local women gleaning the reef of cowries, octopii and other food items. *Photo:* VINEETA HOON.

Table 1. *Bala fadal* (drag net) catch composition expressed as a percentage of the total number of fish caught

English Name	Local Name	%
Snapper	Metti, Phulariyam	4
Carangids	Bangada, Kuluval	1
Parrot fish	Shandi	1
Others, each ≤5%		2
Unicorn	Karakam	
Surgeon fish	Neithala	
Trigger fish	Pallli	
Gar fish	Oola	

7), catch compositions and information on average catches and catch per unit effort (tables 1, 2 and 3).

Shal Kakal

Shal kakal is a gill net with a mesh size between 12 and 14 cm, set at the *chals,* or channels in the reef. Used mainly during the monsoon season, nets are set at the time of new moon, i.e. during spring tide when tidal flushing is at its highest. The reported average catch is around four kilograms (table 1) and consists mostly of red snapper and some groupers. This is not a commonly used gear, with a total of 30 records during in the whole year. The activity is to an extent self-regulatory since it can only be carried out for six days per month around new moon,

Table 2. *Bala adiyal* shore seine catch composition, expressed as a percentage of the total number of fish caught

English Name	Local Name	%
Carangids	Bangada, Kuluval	2
Half Beaks	Mural, Bacchala	2
Mojarra	Furachi	1
Goat fish	Manakkam	1
Others, each ≤5%		2
Mullets	Thithira, Balmeen	
Rabbit fish	Onam	
Gar fish	Oola	

Table 3. Main fishing gears used around Agatti (Gear), number of people involved in each operation (#fishers), average catch per operation (Avg catch), daily catch per person (CPUE), total number of times each operation has been recorded in the year (#events) and total annual catch in metric tons (Annual catch)

Gear (local name)	Gear (English)	# of fishers	Avg catch[1]	CPUE[1]	# of events	Annual catch[1]
Shal Kakal	Gillnet in reef channels	2	4	2	30	0.12
Bala Attal	Purse seining	2	4	2	2 266	9
Bala Idal	Gillnet in lagoon	2	4	2	9 560	38
Bala Fadal	Dragnet in lagoon	30	250	4	30	8
Beech Bala	Cast net	1	1	1	5 124	5
Bala Adiyal	Shore seine	4	8	2	2 161	17
Kol attikal/eriyal	Rod Fishing/Handline	1	1	1	23 313	23

[1]Data on catch and CPUE is based on reports from fishers and observation and is indicative only.

and is restricted to the limited number of natural sites that are available, which are located in the uninhabited section of the western lagoon.

Bala Attal

Bala attal, or purse seining within the lagoon, is a relatively common gear. It is used throughout the year and all around the island, but at higher frequencies during the monsoon months of June, July and August. The zones on the uninhabited southern side of the island are favored, apparently due to availability of suitable sites. Average catch reported is around 4 kg (table 1), consisting mostly of carangids, snappers and garfish (figure 5a).

Bala Idal

Bala idal is a gill net with a mesh size of 12–14 cm. The net is set and anchored in the lagoon close to coral boulders and checked for catch every two or three hours. The gear is used mainly in the inhabited section of the western lagoon, although at low levels in all zones. It is used at similar levels throughout the year (figure 5b). Bala idal nets are owned by 150 families, but used by only around 30 families on a regular basis. The average catch is around 4 kg and consists mostly of carangids and snapper (table 1).

Bala Fadal

Bala fadal is a drag net operation involving 25–30 persons. The team is divided into two groups. One group stays on the shore spreading out the *chandalibala*, a rectangular net 20–40m long and 2–3m high, with a mesh size of 5–6 mm. The other group lays a 100 m long rope with coconut fronds tied to it (the *olabala*) over the reef forming an arc. This aggregates the fish, which follow the *olabala* as it is pulled towards the shore. The *chandalibala* operators then quickly circle the fish with the net and haul them up. The gear is used only during the monsoon, two to three times per week, and almost exclusively in the uninhabited zone near Kalpitti, although occasionally in the northern end of the lagoon. There are two *bala fadal* units on the island, but only one operates at a time. The estimated average catch per operation is around 250 kg, including many juveniles. During the monsoon season in 2003 the drag net operation took place 30 times (c. twice a week between May and August). This means approximately 7 500 kg of reef fish were caught in four months using this gear alone (tables 1 and 2).

Beech Bala

Beech bala, or cast netting from the shore, is a one-person operation (table 1). It takes place throughout the year and in all the zones with only limited variation, although slightly more frequently in the eastern lagoon (figure 5c). The gear is primarily operated from the shore and thus not in the immediate vicinity of coral patches. Fish caught are primarily shallow water and near shore fish such as carangids, goat fish and half beaks.

Bala Adiyal

Bala adiyal, or shore seining, is a popular fishing method used around the year mainly in the western lagoon (figure 5d). Primarily used as the tide changes, it targets fish that aggregate in shallow water at these times. The nets, 15–20 m long and 2–3 m deep with a mesh size of 15–25 mm, are usually operated by four people. The net is laid in a broad arch and hauled back to the shore. Towards the final stages of hauling the footrope is manipulated in such a way that it reaches the shore prior to the head rope without rising from the bottom. The catch size is around 8 kg per operation (table 1), with carangids making up around a quarter of this (table 2). A total of c. 2 000 operations were observed during the one-year monitoring period, meaning approximately 16 tons of fish were caught using this method (table 3).

Kol Attikal and Eriyal

Kol attikal and eriyal, fishing with rod or hand line, is a common practice and pastime for the male population of Agatti. Used mainly as a leisure activity in the free time throughout the year, the intensity of hand line fishing increases during the monsoon when many other ac-

tivities are reduced (figure 5e). Simple hand lines, monofilament with a hook and a sinker, rolled around a piece of wood, are used about four times as frequently as rods. While the most popular rod fishing areas are in the inhabited areas, from the jetties in the western lagoon as well in the eastern lagoon, geographic patterns are less clear for hand line, reflecting the impromptu and opportunistic character of the operation (figure 5e). Popular areas include the north shore, jetty areas, Thodu and the bar area around the reef. Fish caught are mainly red snapper and other snappers, carangids, emperors and goat fish.

Chadum Pork

Chadum pork, or harpooning, is carried out in the outer reef area along the eastern side of the island, predominantly in the uninhabited zone, as well as to a certain extent in the inhabited section of the western lagoon. It is mainly a fair season activity although practiced also on clear days during the monsoon period. Fishers go out in traditional boats generally fitted with outboard engines. There are 8–10 groups of one to three members each, depending on the craft. No powered spear guns are used. Large fish such as seer and rays are targeted. While fish are consumed fresh rays are cut into small pieces that are sun dried.

Chala Pidika

Chala pidika, fishing bait for the tuna fishery, is carried out using fine mesh nets on sandy bottoms in shallow lagoon areas. Collection of baitfish is limited to the times tuna is fished and so almost exclusively collected during the fair season, although there are instances of bait collection and tuna fishing during the monsoon (figure 5f). For example, it is known Agatti fishermen started tuna fishing in August in 2001, which falls within the monsoon season. On Agatti, baitfish are collected only in the western lagoon, primarily in the inhabited portion. However, it seems likely this is minor compared to the collection that takes place in other areas, such as Perumal Par, in association with tuna fishing trips. Another type of bait collection on Agatti includes digging out worms and crabs from the seashore and from the sand shallow areas within the lagoon for the rod and hand line fishery.

Reef Gleaning

Reef gleaning is both an important past time and subsistence activity for the Agatti islanders. Traditionally carried out by women as a means to obtain a disposable income, it now involves women as well as men and children. People walk on the exposed and shallow reef areas looking for cowries and other resource shells as well as octopi (there is also a target fishery for octopus). Iron rods are used to prod, break and overturn coral boulders. Fish are caught by placing nets around small coral boulders, which are then shaken or beaten to drive the fish out and into the net. While there is some specialization gleaning is an opportunistic activity and any reef gleaner will take any target species found. Reef gleaning is carried out monthly throughout the year during the six to seven days of spring tide (figure 6). At its peak over 400 reef gleaners have been counted on the eastern reef flat in a single day (figure 7).

Scuba Diving and Snorkeling Tourism

The dive industry is still in its infancy in Lakshadweep. Commercial/tourist scuba diving at Agatti Island was introduced with the opening of a dive center in September 2003. Dive sites have therefore only recently been explored, but tourists are taken to both lagoonal and outer slope sites, the most frequently used being a site for introductory dives within the lagoon and 'Japanese garden' on the eastern reef. As most of the guests staying at Agatti Island Beach Resort, the only tourist hotel on the island, stay only 2–3 nights few end up doing more than 2 dives. However, there is a lot of potential for development. While the 1998 coral bleaching and mass mortality reduced coral cover by an estimated 70–90% recovery is now seen in several areas, although it is patchy (Rajasuriya *et al.*, 2004). Abundant recruits indicate there is a sufficient supply of larvae. The fish populations are less depleted than many mainland areas, turtles are ubiquitous

and reef sharks are seen frequently, all factors that attract recreational divers.

SUMMARY AND DISCUSSION

Monitoring the different types of reef related activities carried out on Agatti Island provides information on both the frequency of efforts and average harvest, as well as on trends in the use of traditional gears, adaptation or development of gears and practices, and on the importance of reef related activities for food, livelihoods and island culture.

Fishing, whether as a commercial activity or a hobby, is ingrained in the culture and people of the islands. Men take 'leave' from regular jobs to join in fishing activities, and young boys spend their vacations fishing during the fair season. This is reflected in the average daily number of reef users (i.e. number of people involved in direct extractive activities on any given day), which is around 300 and slightly more during the fair season than during the monsoon. Despite many developments and modernization, several of the traditional and indigenous methods of subsistence reef fishing are still used and constitute an essential part of people's lives. Indigenous knowledge of reef resources is still prevalent in Agatti, and with so many practitioners knowledge and skills can be passed down to future generations.

The data gathered during one year provided an estimate of the amount of fish caught through subsistence or recreational reef based fisheries. During the sampling period more than 100 metric tons of fish were caught using these methods, a significant catch that is not recorded in other data systems, such as that being maintained by Fisheries Department. Thus this study provided the only information obtained to date on the size of reef fisheries and their importance to the island, and provides a baseline for studying future trends.

While the eastern lagoon and reef in the inhabited zone is the most utilized, with high levels of harvesting of all types of reef resources, trampling, breakage and overturning of coral boulders and so on, the entire reef and lagoon area is under considerable stress and there are signs of over exploitation and resource depletion. The main local driving force is the increase in human population on the island and continued high dependence on extractive uses. In 1951 the population of Agatti was less than 2 000. In 2001 the population had increased to over 7 000, more than tripling in half a century. This growth coupled with modernization of the society and equipment used has put great pressure on the limited land, fresh water, and lagoon-reef resources. For the long-term sustainability of the area it is therefore extremely important that the reefs and reef uses are managed well. Reliable data on resource use and resource abundance is therefore essential, and the activities reported here will be revised accordingly.

Given the scarcity of information available on reef related activities and the lack of studies describing and quantifying reef fisheries and other resource use in Agatti, the method and approach used have been both appropriate and necessary. However, for more detailed statements and analyses of trends in both resource use and resource abundance a more targeted sampling strategy is needed. This will be developed during early 2005, field-tested and put into operation with the involvement of the local monitoring team, including fishermen and other resource users, during a phase-in period.

Development and expansion of protocols will benefit from the data collected thus far, which can be used to identify where sampling effort should be placed to best reflect the situation on the ground and to provide more rigorous data with higher statistical significance on aspects that currently can only be described in a cursory way. A higher resolution can be attained without losing sight of overall patterns and without increasing the actual sample size. For example, the existing data provides indications of seasonality, which can be used as justification for focusing sampling on one or a few intense periods in each season rather carrying it out continuously throughout the year.

The zones, initially defined arbitrarily and only to a certain extent based on natural or physical character-

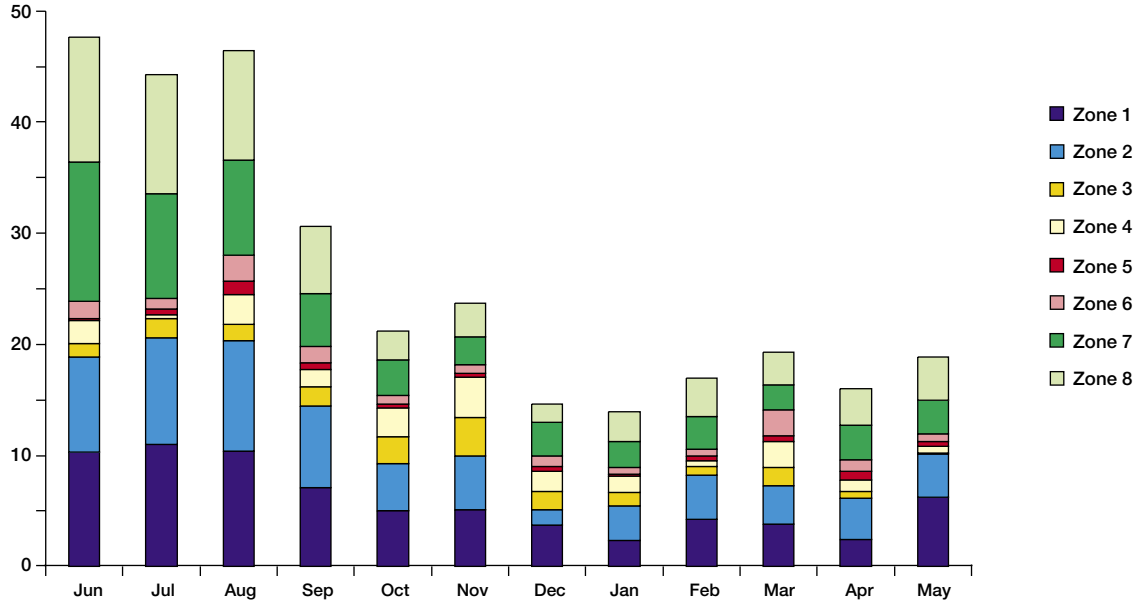

Figure 8. Example of resource use (Bala attal, purse seine) in the originally defined eight zones. Zones that were merged are illustrated in similar colors, e.g. zones 1 and 2, which were merged to become the western uninhabited zone are presented in shades of blue.

istics, were already redefined as observed patterns provided a justification for this. Field observations indicate that while there is a marked difference between the western and eastern lagoons in terms of hydrography and structure etc., they are quite homogenous internally. This is supported by the resource use monitoring data. However, the resource use monitoring data further indicates there is a clear difference in use between the lagoon area adjacent to the inhabited portion of the island and the area adjacent to the uninhabited area within a lagoon (figure 8). Thus differences in resource use patterns between lagoons reflect lagoon characteristics, structure, accessibility and availability of target species, whereas differences in resource use patterns within the lagoons primarily reflect proximity to human settlement, although certain features such as reef channels also play a role. Seasonal rather than monthly variation in most gears indicates using sampling periods (fair, monsoon and the two transition seasons) might be sufficient to show patterns of use and record changes in catch and effort.

The participatory approach taken in setting up the activities means stakeholders benefit both from their direct involvement in the activities and from the monitoring data, which is collected with needs of the local population in mind and presented to them and discussed through regular seminars. This partnership with local resource users is constantly evolving, as are the issues identified by them as important to include in the monitoring activities. In particular, linking ecological and resource monitoring with resource use and catch monitoring will help to illustrate the relationship between destructive reef use or over exploitation of resources and reef health, how multiple stresses such as resource use, coral bleaching and cyclones affect the environment, as well as how this impacts on resource availability. This is an important awareness tool, and will also be used to strengthen the capacity of stakeholders to increasingly take part in man-

agement of the resources on which they rely. Further, the project will continue to organize regular awareness raising activities among fishers as well as other stakeholders such as children (Hoon & Kanvinde, 2005).

The only obvious source of conflict relating to resource use identified during the monitoring is between government and legislation on the one hand and local populations on the other, primarily due to differences of opinion regarding resource management. However, as legislation is rarely enforced, this conflict has been largely dormant. The data gathered does not indicate there is conflict between different resource users, e.g. between tuna bait collectors and cast net fishers or between different groups gleaning the reef area. However, should current legislation be enforced strictly without considerations to livelihood options for the islanders, it seems obvious conflict between resource users and government will become more heated, and could possibly also increase conflict between reef users. In particular, introduction of new reef uses that are seen to benefit outsiders more than local populations may aggravate the situation. This highlights the importance of reliable information on changes and trends in reef ecosystem health and resource abundance, as well as the importance of awareness of these issues among local stakeholders and a willingness and capacity to participate in resource management.

For example, there are indications a grouper fishery in the archipelago will develop further, selling chilled and frozen fish to the mainland and foreign markets (Fisheries Director pers. Comm.). The grouper population in the Lakshadweep appears healthier than in many other parts of Asia, where overexploitation has reduced abundances considerably (e.g. Bentley, 1999). The high market value of the fish is a driver for repeating this pattern. Reliable data can help identify risks for population crashes and stakeholder participation in resource management can help prevent them from occurring. Similarly, increased collection of ornamental fish seems a likely development. A fish hatchery is about to start operations on Agatti, and while this could in the longer term reduce exploitation of target species it will need initial stocks as well as regular replenishment, which will be obtained from the area. Further, it will only have a capacity to breed a certain number of species, but the infrastructure and logistics surrounding it may promote harvesting and export of additional ones, thus introducing a new reef activity that can be destructive to the area. However, if carried out in accordance with sound principles, following e.g. standards set by the Marine Aquarium Council (www.aquariumcouncil.org), it can provide a sustainable source of income for the island. The institutions behind the initiative have indicated they wish to take this path.

The indiscriminate collection of coral boulder, shingle and sand from all around the island and particularly on the eastern side of the inhabited area is a cause for concern. There are indications of increased shoreline erosion, and through a government-led initiative cement tetra-pods have been deposited in huge numbers to reinforce shoreline stability. The efficiency of this intervention is questionable as it does not address the causes of erosion. Further, with each tetra-pod unit costing 1 200 Rupees (~20 Euros) the monetary cost is enormous. The actual sand and rubble budget of the island is unknown, but it seems unlikely the island can sustain the present rates of extraction, especially given the degraded state of the surrounding coral reefs. This issue requires additional and sound information, and a concerted effort from both government and local populations to reduce the drivers behind increased shoreline erosion, while minimizing erosion that is already taking place (figure 9 on next page).

Lastly, the monitoring has identified that a number of activities are carried out illegally, either targeting species under Schedule I protection, or harvesting resources without necessary permits. While the restrictions put in place by the government are designed to protect key species and resources, they have had little impact in Lakshadweep as they are not actively enforced. At the same time strict enforcement would deny islanders use of traditional resources that are still important for their sustenance. A process where resource use is regulated and supplemental sources of income developed can help en-

Figure 9. Cement tetrapods and other modules deployed to prevent erosion. A cyclone in 2004 caused significant loss of beach sand and infrastructure damage. *Photo:* JERKER TAMELANDER.

sure preservation of both key resource species and of cultural practices in the archipelago, for the benefit and enjoyment of future generations. The islanders, the stakeholder group most dependent on the reefs, and partly but not solely responsible for their degradation, must be seen as central in any such efforts.

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Alternative Livelihoods as a Tool for Sustainable Coral Reef Management in Sri Lanka

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INTRODUCTION

As an island nation, Sri Lanka's economic development has always been closely linked with the coast and the marine environment. Coastal ecosystems such as coral reefs, mangroves and seagrass beds provide significant socio-economic benefits, especially in the form of food security and livelihood options for over one million people in the country. The coral reefs of Sri Lanka have not been comprehensively mapped, but three types of reef habitats have been identified: true coral reefs; consisting of fringing and patch reefs, and sandstone and rocky coral communities. The major reef formations are found on the continental shelf within the 30 m depth contour. An estimated 2–3% of the coastline has fringing reefs, with larger reef areas occurring offshore in the Gulf of Mannar and west of the Kalpitiya Peninsula (Rajasuriya *et al.*, 2002; Bakus *et al.*, 2000) (figure 1).

The main economic use of coral reefs in Sri Lanka is reef-associated fisheries, constituting up to 15% of the total fish landing (Rajasuriya *et al.*, 1995). The country also provided 5% of the marine ornamental fish and 8% of the invertebrates exported worldwide during 1997–2002 (Wabnitz *et al.*, 2003). Spiny lobsters, groupers, sea cucumbers and shark are the other coral associated species with high export demand (Perera *et al.*, 2002).

Tourism, which is the fifth largest income earner in

Figure 1. Recorded Coral Reef Locations in Sri Lanka (White & Rajasuriya, 1995).

Figure 2. A fishing net entangled on a reef. *Photo:* NISHAMANI JINADASA.

Figure 3. Mined sea coral piles at Rekawa beach. *Photo:* NISHANTHI PERERA.

Table 1. Major types of direct and indirect stresses on coral reefs in Sri Lanka (modified from White & Rajasuriya, 1995.)

Factors and Examples	Total Relative Impact at National level*
Direct	
• Live coral reef mining: Direct removal of live coral from shallow coastal areas for the lime industry.	**5**
• Direct smothering by sediments, solid wastes and oil: Shallow reefs on the south-western coast experience high sediment loads during the monsoon season.	**5**
• Anchor damage: Encountered in areas of intense fishing (e.g.Weligama and Madiha-Polhena), intense tourism (e.g.Hikkaduwa and Pigeon Island) and ship anchorages (e.g.Pitigala Reef, located near Colombo harbour).	**4**
• Blast fishing: Continuous blasting have severely damaged Rumassala Reef and is a serious problem in the Eastern Province.	**4**
• Storms and cyclones: Coral reefs at Pigeon Island were severely damaged by a cyclone in 2000.	**2**
Indirect	
• Global Warming: Live coral cover is reduced due to coral bleaching and subsequent mortality (during the 1998 El Niño event coral cover was reduced zero in some areas – e.g. in shallow areas of Bar Reef Marine Sanctuary). There are indications of a shift toward algal domination in many areas.	**5**
• Over-exploitation of species and use of destructive fishing gear: The destruction of Kandakuliya Reef was accelerated with the introduction of bottom-set gill nets to harvest spiny lobsters.	**4**
• Predation and diseases: Predation by *Acanthaster planci* has been recorded at Bar Reef, Kandakuliya and Rumassala.	**3**

*=5 high to 1=low

the country, also depends on clean sandy shores and the attraction of healthy coral reefs.

The coral-based lime industry provides another livelihood to poor coastal communities in the south-western, southern and eastern coastal belts, where there is easy access to near-shore fringing reefs. The minimum economic value of coral reefs in Sri Lanka has been estimated to be between US$ 140 000 and US$ 7 500 000 per km^2 of reef over a 20 year period (Berg *et al.*, 1998).

Yet in the past few decades, many coral reef ecosystems that have taken thousands of years to develop have been severely degraded, and some have been destroyed entirely. According to the Reefs at Risk Assessment (Bryant *et al.*, 1998), 86% of Sri Lanka's reefs are at risk due to human activities such as near-shore live coral mining, destructive fishing practices, uncontrolled harvesting of reef biota, increased pressure from tourist-related activities and land-based source pollution (table 1). High coral mortality was recorded during the 97–98 El Niño-related bleaching event and as a result some reefs are now covered by dense algal growth (Rajasuriya, 2002).

The country has adequate laws to protect its coral reefs, and legislation seems to provide a solid framework for prevention of physical breakage of corals, over harvesting of fishery resources and pollution. Also, the marine protected area (MPA) concept has been in use in Sri Lanka since the 1940s (De Silva, 1997). However, management of the nation's coral reef areas has been poor as policy makers and ground level managers rely on incomplete knowledge of the status and ecology of the reefs. Enforcement of regulations remains weak and complicated. For example, reef-based fishing and live coral mining activities are done mainly on a small scale and are widely scattered along the coastline. Table 2 summarizes some weaknesses in existing regulations and socio-political aspects affecting the implementation of existing laws and policies.

Policy makers are now realizing the importance of a strong commitment from the local community for effective management of reefs. In order to motivate a community to protect resources, the management strategies implemented should be able to provide direct benefits to them. One such management option is the provision of appropriate alternative livelihoods, which can financially compensate for income lost when populations are giving up destructive resource use patterns (ICRI, 1999).

Sri Lanka's Coastal Zone Management Plan (CZMP) has evolved since 1990 to include greater levels of com-

Table 2. Summary of reasons for management failures in Sri Lanka.

- In Sri Lanka, both inland fossilized coral as well as live coral from the sea are used in the lime industry. Mining of coral from the sea is prohibited under the Coast Conservation Act (CCA), the jurisdiction of which is limited to the coastal zone. However, implementation requires close coordination between Coast Conservation Department (CCD) and Geological Survey and Mines Bureau (GSMB), which issues permits for inland coral mining (CCD, 2003), as both fossil and live coral is burned in kilns located far from the coast.
- Sustainable management of a resource should be a process, not a project, which is often the case in Sri Lanka. For example, at the end of a donor-funded project, implementation of Special Area Management Plans at Hikkaduwa and Rekewa ceased due to lack of government commitment. People quickly returned to destructive activities and now a new donor funded project is addressing the same issues (Rajasuriya *et al.*, 1998).
- In order to address destructive fishering practices, the government recently established Fisheries Management areas at the Great and Little Basses Reefs off the south coast. Due to political interference, there was partiality in the issue of permits for harvesting of chanks (*Turbinella pyrum*) in this area, which resulted in the collapse of the management regime (Rajasuriya, 2003).
- An attempt by the government to ban the export of live fish was abandoned due to protests by exporters who claimed that around 50 000 people would loose their livelihoods if the ban was implemented (Öhman *et al.*, 1993).

munity participation in resource management. The 1997 CZMP highlights the importance of developing alternative and lucrative economic opportunities in the coastal area as optional employment for those dependent on depleted fisheries and coral mining. This was tested at a pilot scale through the implementation of Special Area Management (SAM) Plans, a community-based collaborative process involving residents and government departments that allows for comprehensive management of coastal resources in a defined geographic area. The SAM Plans for Rekawa and Hikkaduwa highlight the links between poverty, lack of livelihood opportunities and illegal livelihood activities such as live coral mining, cutting of mangroves and collection of turtle eggs. The third iteration of the country's CZMP is in its final stages of development and the SAM process is set to remain a central element (CCD, 2003; Anon., 1995; Anon., 1996; Aeron-Thomas, 2001).

In view of the above, a study was carried out to assess the practicalities of using alternative livelihoods as a

Table 3. Synthesis of reasons for turning to and continuing destructive activities in selected coastal areas

Destructive activity and Location	Reasons
Sea coral mining at Rekawa (Banda, 2002)	By the late 1940s, with the transition to market economy, people of the Hunu cast traditionally involved in the lime production industry were completely replaced by the dominant Karawa cast, who had previously considered lime burning as an inferior occupation. During the 1970s to mid 1980's, prolonged droughts drove poor traditional farmers into coral mining and lime production to earn a living.
Sea coral mining at Passikudaha (Dharmarethanam & Kirupairajah, 2003)	Civil unrest restricted movement of migratory fishermen and farmers, who instead turned to coral mining and exploiting lagoon resources for their livelihood.
Dynamite fishery at Rumassala (Weerakkody, 2002)	Two influential local residents control the activity, supported by several spotters and collectors. They are fully aware of the long-term effects of their actions, but high financial gains and the maintenance of social hierarchy motivates the continuation of the activity.
Overharvesting of ornamental fish at Unawatuna (Ranasinghe, 1996)	Collection has increased due to the expanding export market and the good income earned. Around 72 divers are involved in collection and earn an average of Rs. 500/– per day
Overharvesting of sea cucumbers on the eastern and northwestern coasts (Brown, 1997)	Traditionally, harvesting was limited to estuarine environments, but external market demand has lead to divers engaged in the collection of ornamental fish to also collect sea cucumbers from coral reef habitats using SCUBA. Presently there is no monitoring of catch or exports.
Overuse of reef resources for tourism at Hikkaduwa National Park (Anon., 1995; De Silva, 1997)	Considerable damage is caused by the large number of glass-bottom boats running over shallow coral patches. Food such as bread is also used indiscriminately to attract fish. There is no demarcation of park boundaries and no restriction of entry of boats.
Visitor Pressure at Pigeon Island National Park (MENR, 2002)	Free movement of people due to the cease-fire agreement signed in 2002 has resulted in around 3000 people visiting the 4.6 ha Pigeon Island every weekend. It is estimated that around 15–20 boats are operating in the area, often damaging the shallow coral reefs. Due to lack of awareness and enforcement, live corals are often collected as souvenirs.

management tool to mitigate coral reef and other nearshore resource degradation. The main objective of the review was to synthesize experiences gained in the past in providing alternative livelihood options for coral reef resource users (miners, fishers, etc.) to minimize reef degradation and to develop a set of recommendations specific to the Sri Lankan context. The review and recommendations were compiled in a book entitled *Alternative Livelihoods Through Income Diversification: An Option for Sustainable Coral reef and Associated Ecosystem Management in Sri Lanka* (Perera, 2004). The book will act as a resource guide for policy makers and ground level managers on factors to be considered when introducing new livelihood options to coral reef and other coastal resource users. The project, funded by CORDIO and the South Asian Cooperative Environment Programme (SACEP), was initiated in April 2002 at the inaugural session of the Sri Lanka Coral Reef Forum, a joint venture of SACEP, CORDIO, the Global Coral Reef Monitoring Network (GCRMN) and the National Aquatic Research and Resources Development Agency (NARA). The main findings of the study are discussed below.

FINDINGS AND DISCUSSION

Reefs and livelihoods

The reliance on reefs for livelihood and food vary between locations, depending on the accessibility of reef resources and the socio-cultural background of the user community (Ranasinghe, 1996). The present review revealed that the actual number of people involved in destructive activities and their level of dependence are either not well documented or the data are outdated. For example, comprehensive studies on coral miners were conducted between 1980 and 1995 and therefore do not capture or address more recently emerging issues. However, studies have indicated that poverty, lack of other employment opportunities and short-term financial gains drive people to unsustainable methods of harvesting or illegal mining of the reefs (table 3). Another important factor is the fact that coral reefs are open access resources except in protected areas. Thus, people tend to turn to them for food and income when they are displaced from other traditional livelihoods, e.g. due to civil conflicts, loss of arable land or loss of jobs. Further, at times, local communities become victims of unsustainable activities by tourism developers and external fishers, often with conflicting interests, which may drive them towards unsustainable resource use. The stress on coral reef resources caused by this situation has become more apparent as the population increases.

As shown in Case Study 1 on next page, a community's opinion on how a coral reef should be managed depends on the perceived benefit of the reef, whether it is directly and immediately affecting income and survival, as well as on policy implemented by the government.

Successes and failures of alternative livelihood projects

Situations under which alternative livelihoods have been introduced as a management tool can be categorized under four headings: when certain activities are prohibited under new laws and regulations (e.g. illegal sea coral mining, use of certain types of destructive fishing gears etc); when an area is legally designated as 'protected'; to reduce pressures on natural resources that are not legally protected; and to empower communities in decision making process. The following sections will briefly discuss findings of several initiatives targeting different resource users under the above conditions.

Prohibition of activities under new regulations

In Sri Lanka, the legislation surrounding coral mining has had a difficult and complex history. A total ban on live coral mining was imposed under the provisions of the Coast Conservation Act No. 57 of 1981 and its Amendments of 1988 and 1996. These bans were selectively enforced, especially in areas with a multiplicity of reef use, such as tourism-related activities (Brown, 1997). Prohibition of live coral mining in the coastal zone led to

Case Study 1

Tale of two cities: Unawatuna and Kandakuliya (adapted from Weeramunda, 1999)

The two communities Unawatuna and Kandakuliya, located on the southern and northwestern coast respectively, represent contrasting demographic and economic situations. Unawatuna is highly urbanized, has a heterogeneous social composition, and depends principally on tourism for its economic survival, having given up traditional fishing to a large extent. Kandakuliya, on the other hand, is rural, has a relatively homogenous social composition and still depends on fishing.

A crucial factor influencing the perceptions of coral reef conservation needs among these communities is the importance attributed to the coral reefs for the local economy. The people of Unawatuna have identified reefs as a resource bringing direct financial returns through tourism, and have taken steps to protect the reefs by setting up two conservation societies and even openly opposing visitors who harm the reefs, especially when they are collecting reef biota as souvenirs. People in Kandakuliya do not consider the reefs to play such a important role, suggesting that they do not perceive the direct connection between fish catch and reef health. This can largely be attributed to social context. Economic backwardness and poverty in Kandakuliya, with minimal education, female unemployment, gender imbalance, and indebtedness during the fishing off-season are important factors influencing people's perspectives on resource management. It was also noted that the economic value of a natural resource alone is not sufficient to guarantee management with a long-term perspective. The resource will not be well cared for by those who profit from unsustainable use in the short-term unless good policy decisions on realistic alternative livelihoods are taken, such as promotion of ecotourism.

the loss of livelihoods of several thousands of people, and the CCD, the implementing agency, was responsible for providing alternative livelihood options to those affected. As a consequence, the south-western coastal zone has been the geographical focus of CCD's activities since 1978. Undoubtedly, the most popular solution was the proposal that the miners should turn to fishing. However, experience has shown that this is not a good alternative as in many cases when miners were given boats to earn more income from fishing, the boats were instead used for more efficient coral mining (Hale & Kumin, 1992; Premaratne, 2003). Another strategy used was to relocate the miners to new geographical locations and encourage them to earn a living through agriculture. Case Study 2 describes a relocation programme in Hikkaduwa Divisional Secretariat in 1989.

Studies have revealed that finding alternative employment for people involved in the lime industry depends on several factors, including level of occupation (i.e. miner, kiln operator, kiln owner, etc.), skills and experience of individual workers, the socio-economic viability of the proposed livelihoods and acceptance among target communities (Hale & Kumin, 1992; Ginige, 1997; Premaratne, 2003). Coral mining can be either a primary or a supplementary income generating activity. Thus, where coral mining is a primary income source, new employment ventures must be as financially rewarding as coral mining, or more, in order to be viable and success-

Case Study 2

Provision of agriculture lands for miners in the Monrovia Estate, Hikkaduwa (Hale & Kumin, 1992; Wickramasuriya *et al.*, 1999; Andrahennedige, 1995)

In 1989, the Government initiated a pilot relocation programme targeting 100 coral mining families (33% of the coral mining families in the area) of Seenigama, Totagamuwa and Werallana areas of the Hikkaduwa Divisional Secretary's Division. The project was aimed at providing beneficiaries with agricultural land in Monorovia Estate, located about 16 km away from their native place. Other facilities such as housing loans, food stamps, seedlings and agricultural training were also included to assist the families to adjust to their new living conditions. The funds and other inputs for the project were provided by several government and semi-government organizations such as Hikkaduwa Assistant Government Agent's (AGA) Office, the Land Commissioners Department, Department of Agriculture, National Housing Development Authority (NHDA), Coconut Development Board, Department of Education, Deutsche Gesellschaft für Technische Zusammenarbeit GmbH (GTZ) and the Coast Conservation Department (CCD).

Out of 386 applications received, 93 families were selected as beneficiaries by Grama Seva (GS) officers of the respective divisions, and final approval was given by the AGA Hikkaduwa. As a result of the absence of clear selection criteria and due to political interference, some non-eligible families (e.g. businessmen and farmers) initially received land, which then had to be re-allocated when the irregularity became known. The entire land area of the estate consisted of 97 blocks (acres), out of which 42 contained coconut, 40 rubber and 15 consisted of bare land. The coconut and rubber lands were distributed among 82 families while 11 families received one acre of bare land each. Two acres of bare land were designated as a cemetery. At the time of programme initiation, 80% of the coconut palms were bearing nuts and most of the rubber trees were at the stage of tapping.

A study conducted in 1995 revealed that 48% of the people joined the programme due to fear of a total ban on coral mining while 10% joined to obtain land as they did not own a permanent homestead and their income level was also lower than that of other coral miners (as they were collectors of coral debris from the beach or workers in the lime kilns). After five years, only 22 families remained on the estate, 12 of which on coconut lands and 3 on bare lands. Among those resettled, only 12 families have abandoned coral mining as an income generating activity and were engaged in activities such as agriculture, fishing, day labour and self-employment. Around a third of the beneficiaries that remained on the estate continued coral mining while also receiving additional income from activities such as small businesses, carpentry and hired labour. Of those families who returned to there original homes, around 27% went back to coral mining as the sole income generating activity. Four families leased out their lands to non-coral miners living in the vicinity of Monorovia Estate before returning.

The following factors contributed to the low success of the programme:

- Conflict: The relationship between settlers and villagers in the estate area was damaged as the villagers felt the settlers deprived them of benefits such as pasture land and a source of firewood (the estate was previously used for these purposes by the villages).
- Insufficient income: The income from agricultural activities at the estate was far below the anticipated

level (less than Rs. 2 500 per month) and around 26% of the beneficiaries discontinued the programme as they earned no income from the land.

- Lack of training: Settlers on bare lands could cultivate according to their preference, but settlers on coconut and rubber lands had no choice but to take up these activities. Settlers on rubber lands suffered due to lack of experience in latex tapping and processing and therefore out of the initial 40 only 7 families remained. The two-day training in agriculture and one-week training in skills for rubber tree tapping provided before the resettlement was not sufficient for the settlers to acquire the necessary skills.
- Lack of facilities and funds: Basic facilities such as transport (the estate was located 4 miles away from the bus route), health and schooling were not sufficient.
- Lack of capacity: Most government organizations involved in implementing the programme faced difficulties in undertaking activities allocated to them as they lacked the necessary financial and human resources. For example, the NHDA could provide housing loans for only half of the beneficiaries and the loans were not sufficient to construct houses. Regular monitoring of the programme was not possible due to lack of staff.

ful. Where mining is a supplementary income generating activity, people must be encouraged and assisted to develop their primary income sources (such as fishing, self employment in small businesses, etc.), or to take up alternative strategies on a smaller scale. Kiln workers who are poorly paid tend to be more willing to accept new livelihood ventures, while providing alternative income options to kiln owners is more problematic as their income is significantly higher.

Another example can be drawn from the protection of the turtle nesting area in Rekawa. Turtle egg collection is prohibited in Sri Lanka under the Wild Flora and Fauna Protection Ordinance, section 30 B. In order to involve local communities in the implementation of a law that is difficult for the authorities to enforce, the Turtle Conservation Project (TCP) employed 17 former turtle egg poachers as nest protectors, who were later trained as nature tour guides with the support from the Ceylon Tourist Board and the Sri Lanka Hotel School. The aim of this programme was to provide a valid tourist guide license to the trainees so that they could make an income from their natural resources in a manner that was not destructive. In a rural poor community like Rekawa where there is a lack of services and facilities, a conservation project can increase the commitment to conservation among the community by also addressing socio-economic issues. Therefore, activities such as English classes, health clinics and maintaining a library has assisted the TCP to achieve high community involvement in the programme while also assisting to increase the well-being of the community as a whole. This project also highlights the need for partnership building, collaborative management efforts that involve the community and the key departments and institutions for long-term support and wider outreach (Kapurusinghe, 2001).

Declaration of Marine Protected Areas

One aim of MPAs is to reduce pressures on coastal and marine resources by restricting extractive and other uses by legal means, allowing the habitats to regenerate and thrive in perpetuity. Although still in its infancy in Sri Lanka, many countries use alternative livelihoods through economic diversification as a fisheries management tool or for the conservation of biodiversity within MPAs. For example, at Komodo National Park (KNP) in Indonesia, new livelihood options such as fish culture, the use of fish aggregating devices and the promotion of ecotourism has created many opportunities to engage

and educate local communities and private sector industries on best practices and ecological and economic sustainability of well-managed MPAs. Experiences from a KNP fish culture project shows that full-cycle farming (i.e. which does not require the capture of wild brood stock) of some high value reef fish (such as groupers) is possible, but for many species the technology and knowledge is still lacking. This programme has also realized the importance of educating policy makers on the necessary shift in perceptions regarding aquaculture. Rather than simply producing large quantities of fish, a well-designed mariculture venture can create maximum community involvement and benefits with minimal ecological impact (Sinhleton & Sulaiman, 2002; Pet-Soede, 2003).

In Port Honduras Marine Reserve of Belize, a grassroots community-based organization has been granted co-management of the MPA. Here alternative livelihoods such as fly-fishing, micro-enterprise and ecotourism training are provided to overcome the immediate concerns of the villages have about making an income after sacrificing fishing areas (Wil Maheia, pers. comm.). In the Tubigon Municipality, Philippines, grouper culture was successfully introduced as an alternative to unsustainable fishing methods, such as use of cyanide and dynamite. There are now around 141 grouper culturists in the region. However, two key factors impacting on the ability of fishers to adopt aquaculture are the limited supply of wild brood stock and trash fish for food (Haylor *et al.*, 2003).

Reduce pressure on natural resources that are not legally protected

In 1993, a micro-credit scheme was introduced in Sri Lanka under the Asian Development Bank (ADB) funded Fisheries Sector Development project to strengthen fishery management and reduce pressure on the resource, by diverting the fishing community to land-based income generating activities. It provided around 1590 employment opportunities combined with loans, out of which 71% were non-fishery based enterprises such as production and sales of consumer goods and services. These included bakeries, beauty parlors, tailoring, day care centers and fish processing and trading. Of the borrowers, 465, or 36%, were female, which is higher than past credit schemes. The scheme was operated by the National Development Bank through a wide network of participating credit institutions (PCI). Due to low disbursements recorded at the beginning of the project the ADB and the Government pressurized the PCIs to improve the disbursement ratios and activate the programme, with the result that large-sized loans were given to the best customers. Credit demand, however, was mainly for small loans, and even with small loans most people in the fishing communities were unable meet the collateral requirements of commercial banks and, as a result, defaulted on payments. Therefore, micro-credit institutions with grassroots level links are better suited to serve poor fishing communities (ADB/MFARD, 1999).

Another option in aiding recovery of a depleted resource is reduced harvesting pressure in combination with rehabilitation. The WorldFish Centre is developing and testing a model that links farming of giant clams and restocking of reefs in collaboration with 30 small-scale farmers in the Solomon Islands. The farmers are given 2–3 batches of about 1000 seed clams each year. When the clams reach market size, the farmers set aside 2% of their produce for restocking the reefs. Placement of clams on coral reefs is done to maximize survival, growth and reproduction. Thus, pressure on the reef resource is reduced through farming and recovery is aided by restocking (ICRIForum, 2004).

Empower communities in decision-making processes

The impacts on resource stability can come from external sources, such as through investors who do not live in the area concerned and who may not be sensitive to local traditions regarding access, tenure and resource use. In such instances, it is important to empower communities to manage their own resources. For example, in Rekawa, a low-income traditional coastal community was motivated to unite and self-regulate fishing pressures in the lagoon, so that the whole community could benefit.

United and coordinated action prevented outsiders from encroaching on the lagoon for prawn farming (Ekaratne *et al.*, 1998).

Community empowerment can also address gender issues. Under the Small-scale Fishery Project of the Bay of Bengal Programme, three pilot projects were initiated to promote the skills of women in a fishing community and thereby improving their social and economic conditions. Coir fiber processing, tailoring and lace (beeralu) making at Ulhitiyawa, Mirissa and Kudawella respectively, were selected after a stakeholder workshop revealed that the small-scale rural industrial sector provides scope for promoting women's skills and employment. Initially, many women in the community showed a reluctance to participate in coir processing as this enterprise, like fish drying and vending, has traditionally been associated with poverty and lacks social and economic status. However, a later study revealed that the Ulhitiyawa coir fiber processing centre was functioning well and the earnings had increased due to the improved market demand, while the Mirissa tailoring centre, on the other hand, faced difficulties due to high availability of cheap imported factory made garments in the local markets (Drewes, 1985). While this has strengthened the role of women in society, it also illustrates that economic realities can supersede common perceptions regarding livelihoods.

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE INITIATIVES

Introduction of new alternative livelihoods is an activity that is embedded within a complex system comprised of social, ecological, economic and technological dimensions. For new livelihood options to be adopted by the target communities and continued in the longer term, it is essential to identify the factors that threaten sustainability and to address them in an integrated manner. An activity promoted as an alternative livelihood option must, in addition to being environmentally sustainable, also be financially feasible from the perspective of the target community as a whole as well as the individual. For example, this is an important factor to consider when addressing the dynamite fishery or sea coral mining, where a person can earn a very high income within a day compared to many other locally available livelihood options such as agriculture. Therefore, if the introduced option does not make financial sense, participation will be poor unless some other financial incentives, such as direct subsidies (e.g. Food stamps), are offered.

However, it must also be noted that target communities often have highly unrealistic expectations in terms of income and other benefits from donor funded projects, and therefore, the benefits from projects have to be estimated at a conservative level and expected outputs should be clearly explained to the community. Managing the expectations of communities is as important as managing the resources they rely on. Contributions, inputs and efforts expected from the beneficiaries need to be explained and agreed on at the start of any intervention, and non-participation of individuals for whatever reason in any given intervention should not be seen as a loss of economic opportunity within the community. Social mobilization at the community level should be ensured to enable participants to understand that pilot projects initiated with a limited number of clients, when successful, could be more equitably distributed throughout the community (e.g. CEA/ARCADIS, 2003).

Some of the main recommendations for future alternative livelihood ventures, as identified by the review, are summarized here. For further detailed information, see Perera, 2004.

- Strong commitment from the central government is vital to end any destructive activities that are degrading coral reef resources. The government should support and promote economic diversification as a management option while firmly implementing the existing laws.
- The introduction of new livelihoods should be a part of a wider programme of intervention in coastal resources management (e.g. SAM plan), involving resource users and all other relevant stakeholders. Small-

scale income diversification approaches should be linked with national poverty reduction strategies such as the Samurdhi Programme, or with line agencies such as the National Design Centre to achieve better results.

- More than 30 government agencies have sectoral responsibilities for coastal resources management in the country. If each agency acts in isolation to implement their own work programme without consulting the other agencies, long-term sustainability of a resource will be compromised. For example, in Rekawa, the number of sea coral miners increased due to decreased agricultural productivity caused by poorly planned irrigation. Therefore, cooperation between seemingly unrelated departments such as Irrigation, Agriculture and Coast Conservation, as well as the farming community, is necessary for the rehabilitation of agricultural activities.
- When introducing new technologies through training programmes, educational backgrounds of the participants should be taken into consideration. The younger generation living in the coastal belt has a reasonable level of education and aptitude to learn. Presently, many are employed in activities such as repairing boat engines and diving equipment, but without any technical training. These capabilities can be improved by providing opportunities to enter into vocational training centres, in which enrolment standards should not depend on formal education alone. This will increase the chances of finding jobs, but also improve the quality of work and safety. Training in fields such as electronics, motor mechanics and computing would also put people in a position to venture into 'modern' livelihood options that are not directly depended on natural resources. Skills development in areas such as carpentry and masonry can be promoted to meet market demand for trained personnel.
- The process of obtaining an agreement from a community regarding the possible types of alternative livelihood schemes requires enough time to allow people to discuss different options, negotiate disputes and develop the necessary level of consensus. Effective implementation of the scheme also depends on the process of information exchange, building of rapport and trust between the intervening agency and various stakeholders. Non-governmental agencies and community-based organizations such as fisher folk organizations and women's groups can play a vital role in this. Before an alternative livelihood programme is introduced to an area, such organizations should be identified and strengthened.
- A good understanding of the demographic and social dynamics of coastal communities is needed before introducing a new employment venture. For example, in situations such as Rekawa where women mainly carry out the near shore illegal sea coral mining, it is essential to be aware of gender specific roles in designing projects.
- Similarly, natural or political externalities that may affect a project need to be assessed and taken into consideration. These could include, for example, seasonal weather patterns and infrastructural development plans.
- Rather than trying to introduce new concepts, promoting and upgrading economic activities that already exist within that area is more sustainable. For example, the coconut industry is well established in a few coastal areas. Various coconut-based activities such as production of copra, oil, fiber and arrack distillation, and small-scaled traditional industries such as coir rope, toddy, and mat production, are already well established within rural households. These ventures can be made more economically viable through introduction of new technologies for increased quality and quantity of the final product and by assisting in identification of existing or new markets. Local products can be promoted in the international market by value added approaches such as using attractive packaging to highlight the fact they are locally grown or made. At the same time, new products such as bricks and flowerpots using coir can be promoted.
- Provision of financial services such as revolving funds,

micro-credit facilities and community development funds especially designed for poor communities is essential for long-term sustainability. These financial mechanisms should be flexible to changes occurring in the economic ventures they support as well as market forces.

- Constant monitoring and periodic evaluations of progress of new livelihood ventures with the assistance of independent evaluators is essential to appropriately respond to changing conditions, solve problems, and manage environmental impacts.
- Experiences and lessons learned from projects should be documented and disseminated to policy makers and ground level managers. As the principles of community based management of natural resources vary from case to case, it is important to ensure that policymakers can and will consider each new venture as a different entity, but based on previous experience. This will also assist them to make relevant changes in legal frameworks and supporting policies. In some instances, institutional reforms should take place, giving more authority to local agencies to manage resources. Also, networking among similar ventures carried out nationally or internationally will assist in duplicating positive results and evading the negative impacts.
- Public awareness programmes should go hand in hand with the implementation of alternative livelihood ventures to ensure success. It is important to make the public aware of the values of coral reefs, the factors affecting them and the ways they can be protected and used in a sustainable manner. Both primary and secondary resource users may damage coral reefs inadvertently if unaware of the long-term importance of healthy reefs, but through outreach they can become partners and key players in management initiatives.
- Many alternative livelihood approaches are primarily based on existing natural resources, and therefore the sustainability of such ventures depends on both environmental factors as well as the level of resource use induced by the alternative livelihood venture. Tools such as certification for environmentally sound practices and green labels for products can be introduced to manage this, as well as to aid marketing.

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Bandaramulla Reef of Southern Sri-Lanka: Present Status and Impacts of Coral Mining

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key words: Sri Lanka, coral reefs, coral mining

ABSTRACT

Bandaramulla Reef is an isolated reef on the southern coast of Sri Lanka where the activities of tourists, fishermen and coral miners are completely unregulated. As a result, the overall health of the reef is gradually becoming degraded. This paper describes the present status of the reef and highlights the impacts of mining activities. At present, the coral community is dominated by *Pocillopora, Goniopora* and *Podabacia*, which are known to thrive in highly turbid waters, while the reef fish community is comprised primarily of herbivores. Questionnaires and direct interviews determined that 81% of coral miners were between 15 and 25 years old and that each miner earns Rs. 375 per hour. In total, these miners remove approximately 60 tons of coral each month, averaging 50 coral bags per day. In order to find sustainable solutions to the degradation of Bandaramulla Reef, recommendations for awareness programs, alternative livelihood options, alternatives for coral lime production and improvements in law enforcement are proposed.

INTRODUCTION

Sri Lanka is a tropical island situated between 5° 55' and 9° 55' N latitude and 72° 42' and 81° 52' E longitude and south of the Indian sub-continent (figure 1). Sri Lanka

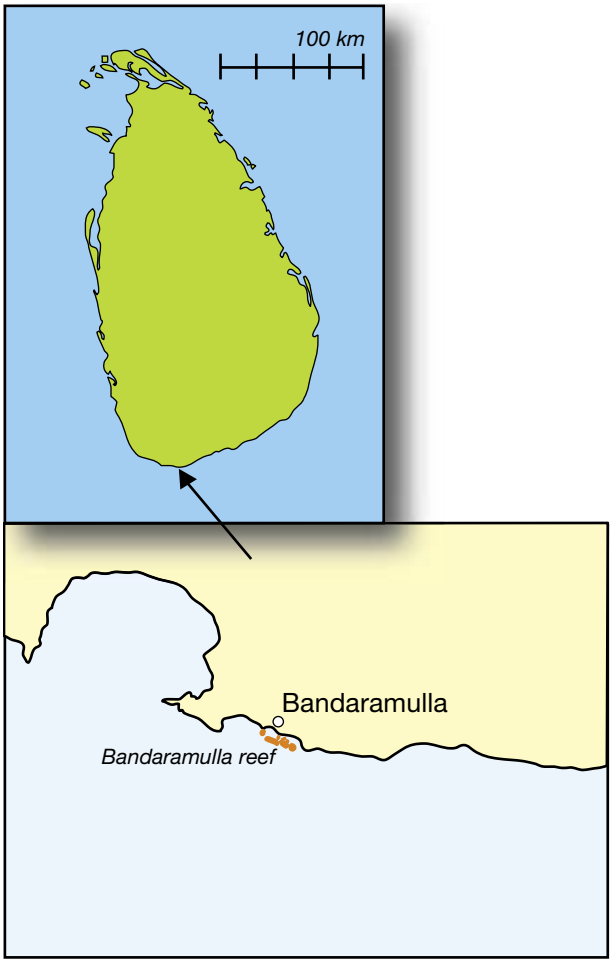

Figure 1. Map of Sri Lanka showing the location of Bandaramulla Reef.

has 1 740 km of coastline and a relatively narrow continental shelf, particularly along the southern coast. Fringing reefs that have formed on rock or limestone substrate abound in the coastal waters off the western, south-western and southern coast of Sri Lanka. In addition, there are a few true coral reefs which tend to be small and isolated fringing reefs (Rajasuriya & De Silva, 1988). During the 1998 El Niño event, corals on about 90% of the reefs in Sri Lanka bleached (Wilkinson *et al.,* 1999) causing considerable mortality. Recovery since the 1998 El Niño has been very slow, moderate or patchy and has been retarded by destructive anthropogenic activities such as dynamite fishing, coral mining, pollution, human settlement, mineral mining, shipping activities and intensive fish collection for the live fish and the aquarium trade. Although coral mining is illegal in Sri Lanka, mining of corals for building materials (Souter & Lindén, 2000) and to produce lime for agriculture and industry still occurs and the resulting degradation of Bandaramulla Reef from intense coral mining is alarming to local fishers.

Coral reefs around the world are incredibly diverse hosting a large proportion of known marine animals and plants. In 1998, it was estimated that the minimum economic value of coral reefs in Sri Lanka was approximately USD 140 000–7 500 000 per km^2 over a 20 year period (Berg *et al.*, 1998). The economic value of coral reefs can be divided into two major components, namely the extractive value and the non-extractive value. The extractive value is derived from the sale of resources harvested from coral reefs such as corals from coral mining, ornamental and food fish and sea cucumbers. Although these extractive activities can cause irreversible damage to coral reefs when conducted in an uncontrolled and unsustainable manner, they provide a short-term profitable source of income for the people involved.The non-extractive value includes the aesthetic qualities of the reef and the white coralline sand beaches that attract thousands of tourists annually and also their essential role in protecting coastlines from erosion by waves (Souter & Lindén, 2000).

Coral mining of living reef is an age-old activity in Sri Lanka, particularly along the southern coast. For centuries, these mined corals have been used for building houses, temples, tombstones and parapet walls to demarcate boundaries. However, these traditional uses have been forgotten and, during the last 20 years, corals have been mined solely for the production of lime for the building and agricultural sectors. In addition to the illegal coral mining conducted on shallow reefs, mining is also carried out on fossil reefs located inland, which supplies most inland areas with lime for building cement. This type of coral mining is legal and is regulated through the issuance of permits.

STUDY SITE

Bandaramulla Reef is located 6 km west of Matara and supports one of the oldest artisanal fishing communities in Sri Lanka. It is a fringing reef which extends for about 500 m across Bandaramulla Bay forming a shallow reef lagoon (figure 2). The depth of the lagoon ranges up to 3 m. The lagoon is occupied mostly by large dead *Millepora* boulders and mounds of *Acropora* rubble. The eastern part of the reef has been completely mined producing considerable quantities of coral rubble and exposing the sand bed during the last four years. Until recently, the central and the western part had not been mined because of the pressure from the fishermen and some of concerned villagers. Unfortunately however, in July 2003, a group of people supported by local gangsters started mining the central part of the reef, especially the reef top (figure 3).

Resources extracted from Bandaramulla Reef lagoon include finfish e.g. jacks (Carangidae), emperors (Lethrinidae), snappers (Lutjanidae), groupers (Serranidae), spiny lobsters (*Panulirus* spp), sea cucumbers (Holothuroidea) and also variety of fish, molluscs, crustaceans for ornamental purposes. Other important fish caught within the lagoon are *Selar crumenophthalmus* (Scads) *Sardinella brachysoma* (Sardinella) and other herring species. In particular, the scad fishery is very important for fishermen as it provides high profits even though fishermen use only traditional fishing gears such as pole and line and hook and line. This fishery is seasonal and exists

Figure 2. Eastern side of the lagoon formed behind Bandaramulla Reef.

Figure 3. Western side of the lagoon formed behind Bandaramulla Reef. Recently mined patches of reef are visible in the foreground as pale areas.

only during particular months of the year. In addition, seaweed culture has been established in the reef lagoon as an experimental trial and is carried out with great enthusiasm by the villagers.

PRESENT THREATS TO THE REEF

Bandaramulla Reef lagoon is an ideal place for traditional fishermen to fish. Unfortunately however, they use large granite boulders to anchor their boats, which crush and destroy everything on the bottom. In addition, the use of gill nets and the trampling corals when casting nets cause severe damage to the reef, especially to delicate corals such as *Montipora* and other newly settled corals. Usage of moxy nets and spear guns, and breakage of corals using crowbars further worsen the situation. Therefore, the low coral cover and diversity in the lagoon is a direct result of such unsustainable destructive fishing practices.

Off site developments cause serious threats to coral reefs because of their sensitivity and the interrelated nature of these ecosystems (Spurgeon, 1992). In addition, the rate of reef recovery from a disturbance will be largely dependent on the anthropogenic impacts and the environmental conditions encountered by newly settled coral recruits. On Bandaramulla Reef, high sediment influx from a nearby part of the shoreline which has been eroded causes severe impacts on coral larval settlement. As a consequence, the recovery rate of is very low while other reefs along the southern coast show promising signs, with large numbers of new coral recruits in many places.

METHODOLOGY

Coral mining activities at Bandaramulla Reef were monitored between July and September 2004. The numbers of bags collected and the number of people involved in mining and transporting mined corals were recorded secretly. In addition, on-site personal interviews were held with coral miners and selected villagers to collect data on the number of trips transported per week, the date of transport, the transportation time, number of bags loaded on the lorry and income levels. On each visit to the reef, the contents of ten randomly selected coral bags were examined. All dead corals within the bags were identified to the highest level possible and the number of live corals in the sample were identified and counted.

The benthic community was recorded using five line intercept transects 20 m in length. Transects were laid parallel to the reef crest and the linear extent of all coral colonies bisected by the line was recorded (English *et al.*, 1994). The cover of each substrate type was calculated as

a percentage cover of the total coral cover and then categorized into percent cover classes (see table 2 for details). Fish communities were surveyed along the same 20 m transects. All fish within a 2 m wide band along the transect were counted. Time taken to record each transect was approximately 15 minutes.

RESULTS

Mining Activities

The commencement of mining activities each day varied in order to avoid the attention of police and local villagers and also as a response to tidal variation. Most commonly, mining was conducted very early in the morning around 5 am, and early afternoon around 1 pm or 5 pm. Initially, miners collect robust branching and massive corals from the shallow reef top. Then they break up other larger coral boulders into manageably sized pieces using iron bars. The broken pieces were then placed into polythene bags and lifted onto air filled tyre tubes, which are used to transport the corals ashore. The coral bags are then stored in the shallow water (<1 m) in order to conceal them from villagers and police until they can be loaded for transportation to kilns.

Age Distribution of Coral Miners

Almost all miners are early school leavers within the age group from 15 to 30 years (figure 4). During the non-monsoon season (November to April), they are ornamental fish collectors, hook and line fishermen or are engaged in other shallow water fishing activities. In the Bandaramulla area, some of young fishermen switch to coral mining activities only during the monsoon period (May to October) when the sea is rough and turbid enough to restrict all other fishing activities.

In each ten bag sample examined, dead massive corals predominated, namely *Goniastrea, Porites, Leptoria, Favia, Favites*, *Pavona* and *Platygyra*. The most common live corals found in bags were *Pocillopora, Podabacia, Leptoria, Favia, Favites, Goniopora, Hydnophora, Montipora* and *Galaxea* (table 1). The average number of live colonies in each ten bag sample was 19.44 (±7.29 S.D.). However, these live colonies were relatively small and were usually attached to the large dead boulder corals.

The number of coral bags mined per day is a function of the number of people involved and the time during which mining is permitted by the tidal cycle. The average extraction rate is 55.33 bags per day and the mean weight of each bag is 40.15 kg (±28.55 S.D.) giving an estimated total weight of coral mined within the month surveyed of 66 645 kg. Assuming similar amounts of coral are mined throughout the year, this translates into an estimated annual coral extraction rate of 799 metric tons.

Lorries, trucks and sometimes bicycles are used to transport corals. Loading, unloading and all transportation activities are only done early in the morning be-

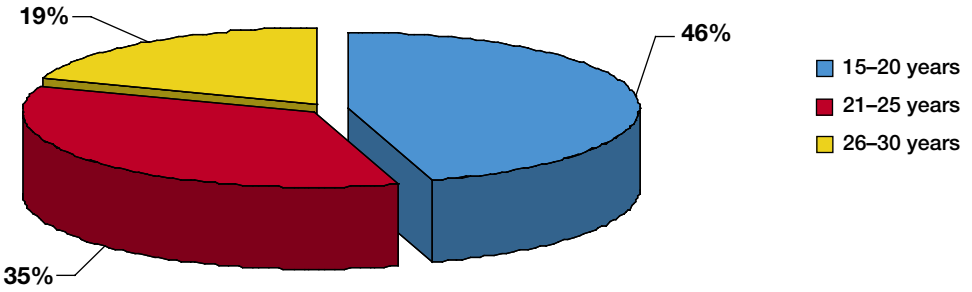

Figure 4. Age distribution of coral miners.

Table 1. Numbers of bags containing live corals transported to lime kilns per month

Date	Number of bags transported	Number of live corals counted in each 10 bag sample	The most common live corals contained in bags of mined coral
03/08/2004	170	24	*Pocillopora, Podabacia, Leptoria*
06/08/2004	155	11	*Pocillopora, Hydnophora*
10/08/2004	180	23	*Podabacia, Porites, Favites, Platygyra*
13/08/2004	140	-	
15/08/2004	140	13	*Galaxea, Montipora*
21/08/2004	190	26	*Pocillopora, Podabacia, Favia, Leptoria*
23/08/2004	160	17	*Pocillopora, Podabacia, Porites*
27/08/2004	175	8	*Goniopora, Podabacia*
01/09/2004	185	26	*Pocillopora, Pavona, Leptoria*
03/09/2004	165	27	*Leptoria, Favia*

tween 0300 and 0530. The middlemen engaged in transportation buy mined coral at the mining site for Rs. 45 per bag and then sell it to the lime kiln for Rs. 75 per bag, thus earning Rs. 30 per bag. The average number of coral bags transported per trip is 166 (±17.44 S.D.) with a value of about Rs. 12 450. The truck owner earns 40% of the total value and the remainder is shared between the miners and those involved in transportation. One single miner earns approximately Rs. 750 per day, which is only about two hours work.

The most abundant live coral species are *Pocillopora damicornis, Podabacia crustacia* and *Goniopora* spp. (table 2). Live coral abundance and cover is extremely low on Bandaramulla Reef primarily because the reef was severely affected during 1998 El Niño event and the recovery since has been very low. Large colonies of *Acropora formosa, A. hyacinthus* and *Millepora* sp. were completely bleached and died. Most remaining corals are less than 15 cm in diameter except colonies of *Goniopora, Porites, Platygyra* and *Leptoria.* Even though baseline data describing the pre-bleaching coral diversity are not available, it is clearly evident that there is a shift in the coral community composition when the existing community is compared with the composition of remaining dead coral colonies. The time needed for the 'original' species composition to be reestablished is extremely unpredictable and will depend

Table 2. Categorised percent live cover of each coral species recorded during surveys of Bandaramulla Reef

Family	Species	Percent cover
Pocilloporidae	*Pocillopora damicornis*	***
	Pocillopora verrucosa	*
Fungiidae	*Podabacia crustacia*	***
	Podabacia spp.	*
Agariciidae	*Pavona* spp.	*
Merulinidae	*Hydnophora minuta*	*
Acroporidae	Acropora hyacinthus	*
	Montipora aequituberculosa	*
	Montipora spp.	*
Poritidae	*Porites* spp.	**
	Goniopora spp.	***
	Alveopora spp.	*
Faviidae	*Favites pentagona*	*
	Favites spp.	**
	Goniastrea spp.	*
	Favia spp.	*
	Platygyra spp.	*
	Leptoria phrygia	**
Oculinidae	*Galaxea fascicularis*	**

* 1– 5%
** 5–10%
***10–15%

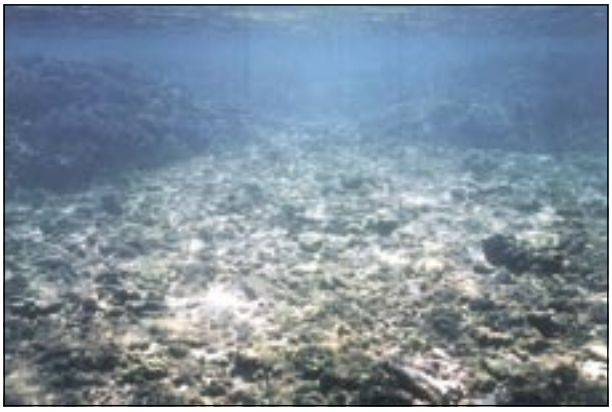

Figure 5. Barren substrate caused by mining activities.

on the extent of the damage and the capacity of surviving species to recover (Tamelander, 2002). In addition, unsustainable and destructive fishing practices used in the lagoon, such as moxy nets, spear fishing, and most importantly coral mining have also reduced the coral cover and diversity in the lagoon (figure 5).

The relationship between reef fish diversity and habitat is likely to be a complex phenomenon. The total number and diversity of reef fish were relatively low in shallow waters when compared with the deeper sites of the reef (table 3). The diversity of fish is relatively high along the reef slopes of mined areas compared with the reef top and bottom substrate. It is well known that there is a positive correlation between reef fish communities and live coral cover (Bell & Galzin, 1984). Reductions in coral cover on Bandaramulla Reef caused mainly by mining activities and destructive fishing methods has also caused concomitant declines in the reef's fish diversity. The absence of butterfly fish (Chaetodontidae) during surveys suggests that these fishes could be used as sensitive indicators of the health of coral reefs (Reese, 1981). Detritivorous and carnivorous fish diversity and abundance were greater at the newly mined sites whereas herbivore diversity was the highest at sites that had been subjected to intense mining activities some time ago. Herbivorous pomacentrids and acanthurids dominate the counts.

Table 3. Abundance of each fish species recorded during surveys of Bandaramulla Reef

Family	Species	Abundance
Muraenidae	*Gymnothorax javanicus*	*
	G. undulatus	*
	Echidna nebulosa	*
Serranidae	*Cephalopholus argus*	*
	Epinephelus merra	**
Scorpaenidae	*Pterois volitans*	*
Syngnathiformes	*Fistularia commersonii*	**
Balistidae	*Rhinecanthus* sp.	*
Pomacanthidae	*Pomacanthus annularis*	*
Diodontidae	*Diodon hystrix*	*
Ostraciidae	*Arothron meleagris*	**
Tetraodontidae	*Canthigaster solandri*	*
Pomacentridae	*Stegastes fasciolatus*	***
	Plectroglyphidodon dickii	***
	Plectroglyphidodon lacrymatus	****
	Abudefduf sexfasciatus	**
Pempheridae	*Pempheris* sp.	*****
Acanthuridae	*Zanclus cornutus*	*
	Acanthurus striatus	***
	Acanthurus triostegus	*
	Acanthurus lineatus	**

Number of fish:
* 1– 5
** 6–10
*** 11–15
**** 16–20
***** >20

CONSEQUENCES

While the Bandaramulla area is blessed with the rapid increase of coastal tourism in the southern region, coral mining and other destructive fishing activities hinder this development. Net economic losses in potential tourism and the coastal erosion caused by coral mining, has been extremely high over the past few years. Both ornamental fish collection and the reef food fish industry are in danger of imminent collapse. As a result, tourist visits would gradually decrease due to the reduced aesthetic value of

Figure 6. Small coral fragments resulting from mining activities and the disintegration of coral skeletons after bleaching are highly mobile and have a high potential to abrade and damage almost all bottom dwelling organisms.

the reef caused by coral destruction and ornamental fish removal. In addition, loss of coral reefs in the southern parts of Sri Lanka would drastically affect the people who directly depend on the coral reefs for their income.

Sedimentation, increased beach erosion and pollution caused by mining activities along the coast might result in an array of environmental problems. For example, coral mining has increased beach erosion along the west coast, south of Colombo and along the south coast of Sri Lanka (Wilhelmsson, 2002). The dead coral branches and rubble produced by coral mining are very mobile and their movements cause severe damage to sessile organisms such as sponges, octocorals, anemones, hard corals and all other soft bodied organisms dwelling on the bottom (figure 6).

More than 42% of the bottom surface of the lagoon was covered with sand and silt. There is a large probability that the increased mining activities will expand this sand and silt area. As a result, newly settled corals and other remaining live coral colonies may be subjected to mechanical abrasion and even smothering due to high suspended particle content and vigorous water movement across the damaged reef.

Permanent damage to the reef, the low availability of larval influx, the effect of environmental conditions such as increased current velocity, sediment level and competition with fast growing algae, caused as a result of mining activities would further impede the recovery rate of the reef. In addition, sedimentation and high water currents in the lagoon reduce the abundance of appropriate habitats for targeted fish species restricting artisanal fishing activities which have been practiced for centuries. The abundance of reef fish and all other reef dwelling organisms is dwindling threatening the livelihood of ornamental fish, lobster and sea cucumber collectors.

SOLUTIONS

There is an awareness of the extensive damage caused to the coral reefs from coral mining and other destructive activities. However, miners are poor and not in a position to stop their activities unless there is an acceptable alternative source of income. Therefore, it is a prime target of the government to provide suitable and satisfactory income sources to coral miners. Expansion of present seaweed culture, provision of alternative livelihood options in various sections of the growing tourist industry would be well-accepted solutions.

It is recommended that enforcement of the existing ban on coral mining be improved with better capacity and tools. Corrupt enforcement officers, including police, lack of arrests, delays in bringing cases to court and lack of or improper sentencing are major problems in controlling coral mining. The establishment of a task force with full potential and power to monitor and control all coastal destructive activities around the island, including coral mining, would help in controlling the situation. In addition, finding alternatives for coral lime through surveys for inland lime deposits is needed. Although inland mining activities are practiced, there are number of problems associated with it, such as the pale colour of the lime extracted, the inadequate quantities in the deposits to make the industry economically feasible and low demand. Research for finding new formulations

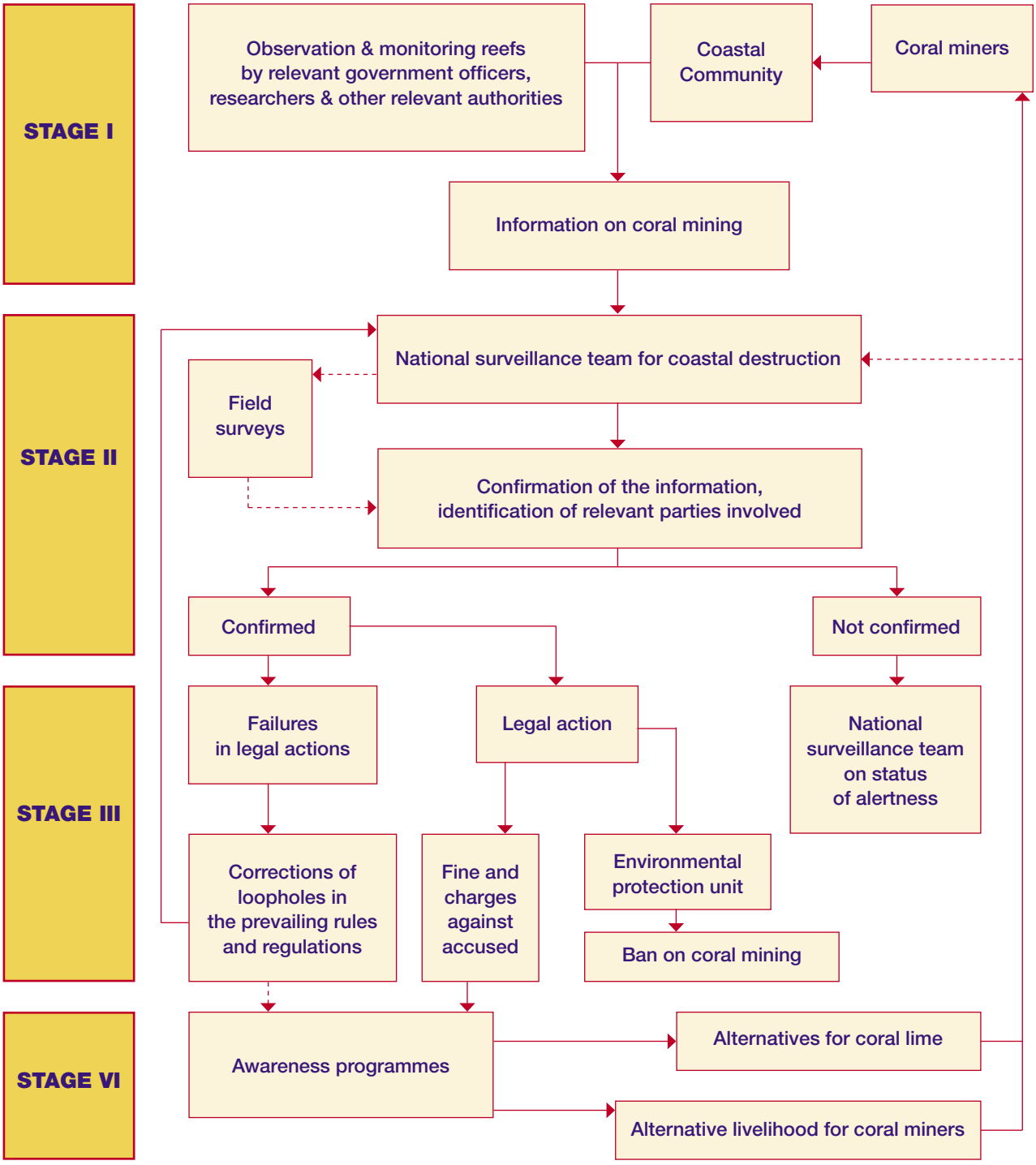

Figure 7. Action plan in the case of coral mining (Adapted from De Silva, 1998).

as a substitute for coral lime provides reasonable solutions to the problem (figure 7).

Mining activities have decreased in some places due to the increased law enforcement efforts and the vigilance of some stakeholders. However, the fines for such destructive activities are relatively low when compared to their income. On the other hand, there are a number of loopholes in existing regulations which make it difficult for law enforcing authorities to bring the accused to the court. Whatever the situation, the government is responsible for strengthening the existing legislations with higher fines, formulating sound regulations and improving enforcement. Various institutes, such as universities, governmental departments, and non-governmental organizations, coral miners, lime kiln owners, inland coral miners and community representatives, should be encouraged to participate in a multi-disciplinary, multi-stakeholder process to formulate a well constructed national policy to solve the coral mining problem.

Finally, there are a number of isolated reefs located around the country that have escaped the attention of scientists, the government, universities, non-governmental organizations or other relevant parties. The biodiversity of those reefs is very high and provide an excellent calm lagoon environment both for animals to live and human to conduct various activities. There should be a programme to identify these places of importance and manage them by legally gazetting them as a natural reserves or marine parks. Bandaramulla Reef is such an unidentified reef but it has been exposed to various threats over the last centuries.

CONCLUSION

Bandaramulla Reef supports a considerable number of fishermen and, during the last two years, has seen an expansion in the tourism industry. However, the reef itself is in great danger due to the low recovery rate after the degradation resulting from elevated sea temperatures caused by the 1998 El Niño event and anthropogenic activities, particularly vigorous coral mining activities that have started during the last couple of months. In order to control the situation, an awareness raising programme organized for the coastal communities on the importance of corals and the implications resulting from their destruction would be beneficial. In addition, alternative livelihoods such as seaweed culture; career opportunities in the tourist industry for coral miners and alternatives for coral lime are some of the possible solutions to the current situation. Strengthening and enforcing existing legislations assuring proper implementation, Sound and strict rules and regulations with high fines for all persons engaged in mining activities and other coastal destructive activities are also necessary. In order to implement the law, necessary facilities, power and acceptable wages for all coastal governing and enforcement officers are essential. Finally, formulation of a permanent national policy to terminate all destructive coastal practices is the final goal for a sustainable usage of non-recoverable natural resources including those extracted from coral reefs.

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

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key words: reef restoration, coral transplantation, fish houses

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

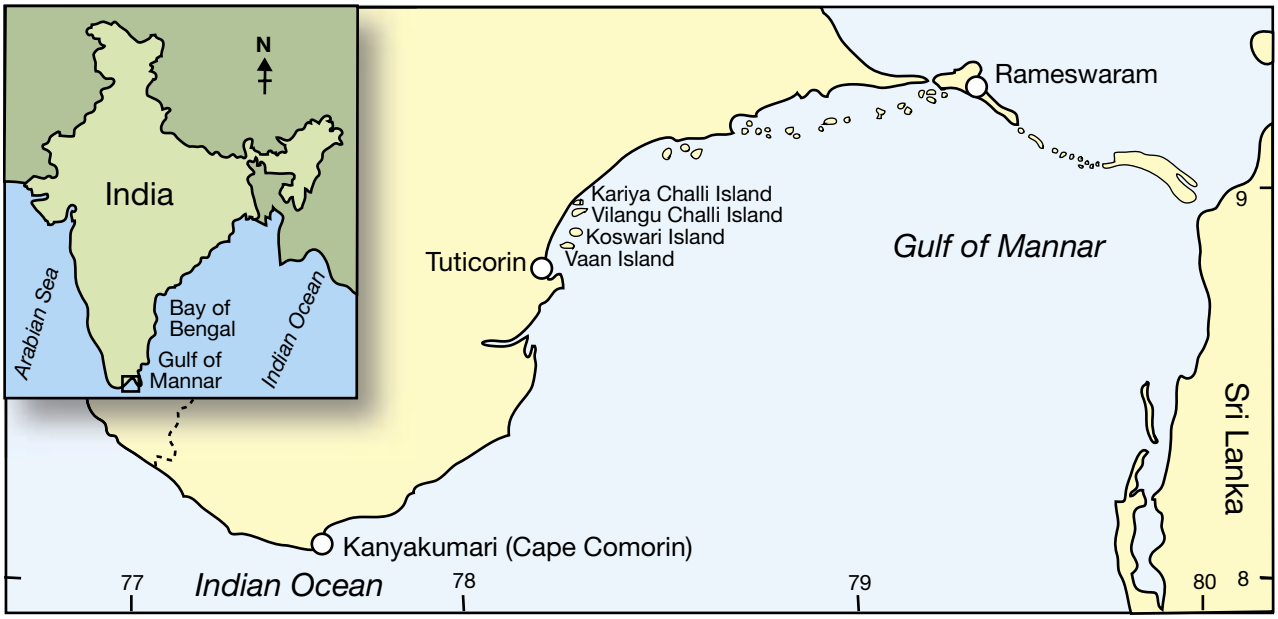

Figure 1. Map showing the study sites.

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-

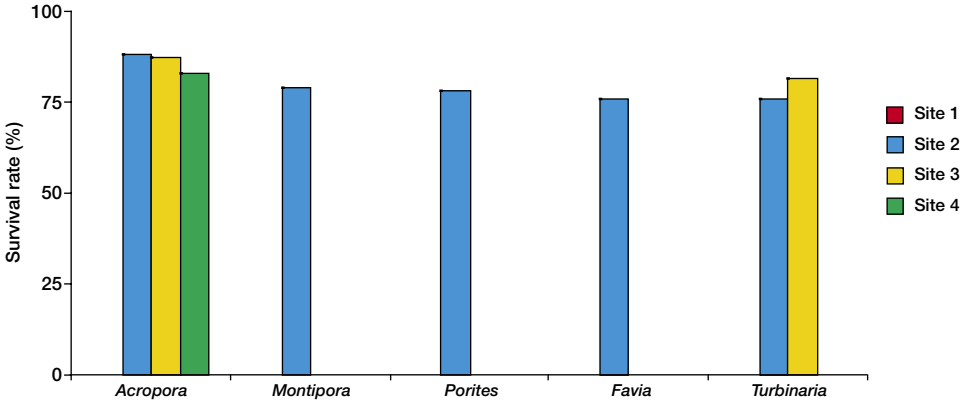

Figure 5. Survival rate of transplanted corals of each genera at each site.

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	–	–	–

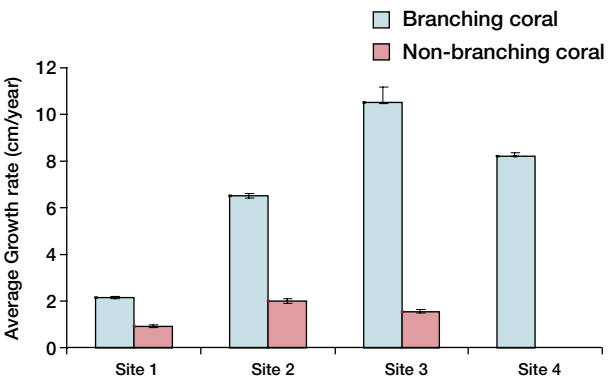

Figure 6. Average growth rate (± S.E.) of branching and non-branching corals at each site.

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

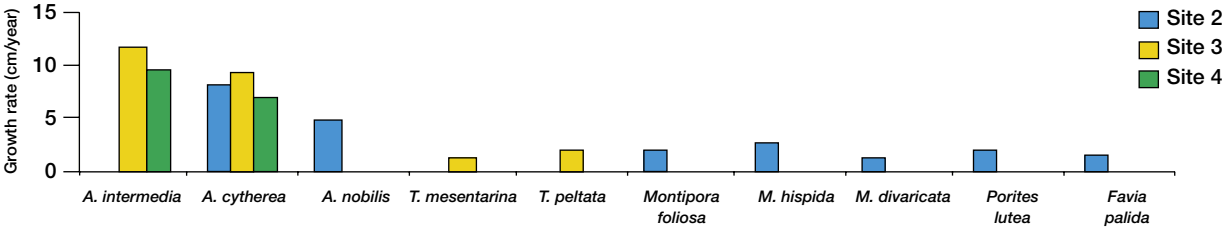

Figure 7. Average growth rate of each coral species at sites 2, 3, and 4.

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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Improving Living Conditions for Reef Dependent Fisher Families

in Tuticorin, Gulf of Mannar, Southeast coast of India

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INTRODUCTION

The Tuticorin Coast is the most environmentally stressed coastal area in the Gulf of Mannar (Patterson, 2002). Population increases, lack of other employment opportunities, and low literacy levels force local villagers to depend mainly on the marine resources that can be harvested from around the four coral reef fringed islands off the coast. As most of the fishermen do not have adequate financial support for large vessels, they are restricted to reef areas that are easily accessible with small boats. Strained by decreasing fish catches, they are often compelled to use more effective and also destructive fishing methods, which reduce the productivity of the reefs even further. Overfishing and the use of destructive fishing methods have been prevalent for many years. Coral mining has been practiced for the past several decades, and many poor fishermen are involved in this illegal practice for their daily livelihood (Patterson, 2002). The number of boats involved in mining varies with the fishing season. Although this practice is now considerably less common, it still persists. Cyanide fishing is used to catch reef fishes and the use of various types of destructive fishing nets such as beach seine nets and trawl nets are causing harm to the benthic environment in Tuticorin. Further, a small section of fishermen are also involved in dynamite fishing using gelignite sticks to kill shoaling fishes which, in turn, destroys the whole reef habitat. Lack of awareness and adequate literacy, limit the villagers understanding of the long-term value of the resources. The development of many industries along the coast, destruction of mangroves for saltpans, and disposal of domestic sewage also pose considerable impact to this ecosystem and the dependent coastal folk (Easterson, 1998; Murugan & Patterson, 2000).

Suganthi Devadason Marine Research Institute (SDMRI) has implemented series of activities to make coastal communities in five selected villages along the Tuticorin coast less dependent on the coral reef resources by providing opportunities for income diversification and alternative livelihoods. Further, efforts have been made to raise the awareness of increasing problems. In order to reduce pressure on the reefs, and make people less vulnerable to changes in the supply of food and income from these ecosystems. This report summarizes the findings and results achieved to date through the following projects:

- Assessment of the socio-economic and fishery status in the villages;
- Creating awareness on the sustainable use of the marine resources;
- Introduction of alternative and supplementary sources of food and income to fisher families.

SELECTED VILLAGES

The Tuticorin Coast in the Gulf of Mannar is the core region of the southern part of the Marine Biosphere Reserve. Five villages namely Tharuvaikulam, Vellapatti, Thalamuthu nagar/Siluvaipatti complex, Thirespuram and Inico Nagar are dependent on the adjacent reef areas for the fin and shellfishes.

Tharuvaikulam (population: 10 085) is located about 15 km from the main town of Tuticorin.

Vellapatti (population: 2 138) is located about 11 km from Tuticorin. The village is unique as the crab fishery is a major occupation. Recently, a few families have started to operate other gears for trapping of finfishes.

Thalamuthu nagar/Siluvaipatti complex (population: 13 951) includes six fishing villages namely Siluvaipatti, Thalamuthu Nagar, Sameer Vyas Nagar, East Kamaraj Nagar, Anand Nagar and Jesu Nagar. They have a common landing site at Siluvaipatti. The villages are situated close to each other and are located 5 km away from Tuticorin. The chief fishery of these villages is shrimp but it is augmented by small-scale seasonal fishing for cephalopods, emperors and siganids.

Thirespuram (population: 19 368) is located about 1 km north of Tuticorin. It is one of the oldest fishing settlements in this district and the fishermen have migrated to other places.

The total population in Inico Nagar – called Pudukadarkarai (New shore) until 2002 – is 2 189. The major fishery is sardines. On the southern side of this village, there is a small estuarine complex which is lined by stunted *Avicennia marina*. Sometimes the fisher folk also engage in collecting shrimps by hand picking in the mangrove areas.

FISHING ACTIVITIES

All these fishing villages depend mainly on fishing on the reef areas around the Tuticorin group of islands; Vaan, Koswari, Vilanguchalli and Kariyachalli. At Tharuvaikulam, boats leave the village by 3 pm and return by 8 am the following day, while at Vallams, boats leave by 4 am if the target species are finfishes and return by 8 am the same day.

A wide variety of species are landed at Tharuvaikulam, while other villages have more specific target species. In Tharuvaikulam, all 7 gears (table 1) are effective enough to bring in good catches and there are no trawling activities carried out in the village. The whole set up is very healthy and the fishing is sustainable. Good catches of emperors, groupers, jacks, skates and snappers are obtained using maya valai which, along with nets like 5 no valai, 2 no valai, and the irupuri valai, are modified gill nets. Nandu valai is a modified bottom set gill net used to catch crabs. The annual catch of crabs at this village was 104 tons, 90% of which was blue swimming crabs (*Portunus pelagicus*), 7.5% mud crabs (*Scylla serrata* and *S. tranquebarica*), 1.5% crucifix crab (*Charybdis ferriata*) and 1% three spot crab (*Portunus sanguinolentus*).

More than 31 species of gastropods were obtained as by-catch and were usually utilized for shell industries. A variety of fish species were available in the particular fishing village. The landing centers display some reef fishes

Table 1. The type of fishing gear used by fisherman in each of the selected villages along the Tuticorin Coast, Gulf of Mannar, India

Village	Gear
Tharuvaikulam	Paru valai, 5 No. valai, 2 No. valai, Maya valai, Crab nets, Hooks and lines, Irupuri valai
Vellapatti	Crab nets
Thalamuthu/Siluvaipatti	Push nets, Shore seines
Thirespuram	Maya valai, Mural valai, Nandu valai, Paru valai, 2 no valai, Disco valai, Irupuri v Chala valai, Singhi valai, Kola valai and Trawls like Thallumadi, Ola valai, Kara valai, Hooks
Inico Nagar	Chala valai

that are also landed as by-catch in many of these nets. Some species like butterfly fishes, angelfishes and trigger fishes are consumed locally as well as exported to the neighbouring Kerala state.

At Vellapatti, fishing occurs just once a day. The nets are set around 4 pm and are retrieved at 5 am the next morning. The catch is brought ashore at 9 am and all auctions take place where the catch is landed. Almost 293 tons of crabs have been landed annually, mainly blue swimming crabs, three spot crab, crucifix crab and mud crabs.

At the Thalamuthu nagar/Siluvaipatti complex, fishing is conducted only once per day. The fishermen leave during the night or early in the morning and return around 10 am. In Thalamuthu nagar complex, push nets were used to catch 60 tons of shrimps and associated by-catch of, gastropods, bivalves and crabs. Shore seines targeting emperors, siganids, crabs and cephalopods have produced 11.89 tons annually.

In Thirespuram, fishermen leave by 5 am and return before midnight with catches comprised mostly of both shell and fin fishes. At Inico nagar, the major fishing activity is focused on capturing shoaling sardines. The fishermen leave around 1 am and return by 8 am.

Different types of fishing gears are used in each selected village (table 1). In Tharuvaikulam and Thirespuram, a wide variety of gears are used, ehereas in Vellapatti and Inico nagar, fishermen practice only crab and sardine fishing respectively. In the Thalamuthu nagar complex, only push nets and shore seines are used.

Fishermen from these villages also use different types of vessel. The most common vessels used at Tharuvaikulam are both the large boats that operate gill nets and vallams, which are indigenous country crafts. At Vellapatti, on the other hand, only vallams are used for fishing related activities. Fishermen in Thalamuthu nagar and Thirespuram also have vallams but fish for reef fishes like emperors, groupers and snappers. At Inico nagar, the vallams are used only to catch sardines.

ASSESSMENT OF SOCIO-ECONOMIC STATUS

Questionnaires were used to acquire pertinent household, socio-economic and fishing related information. Interviews were then conducted with focus groups such as the village administration and fisher folk of either sex.

The majority of the coastal families in the five villages depend solely on the income generated through fishing activities for their livelihood. Many fishing families are poor and lack the basic facilities such as clean drinking water, sanitation and electricity. Health and education seem to be the immediate issue in parallel with poor sanitary conditions. The five villages have different modes of fishing with a variety of gears. Illegal coral mining is considerably less common and more efforts to raise awareness of the damage this activity causes in the area can eradicate this occupation.

Annual Income of Fishermen

Tharuvaikulam: The average annual income depends on the type of vessel used by the fisherman. Fishermen who are involved in fishing with small boats earn about Rs. 30 000–45 000 annually, while those involved in fishing with traditional vallam earn between Rs. 25 000–30 000 annually. The poorest fishermen are those that operate small 'vathai', which are generally used to transport goods and fishermen from the small boats to the shore.

Vellapatti: Fisher folk earn average annual income of between Rs. 30 000 and 45 000, although there are seasonal differences throughout the year. During peak seasons, they are able to earn Rs. 1 000 per day while during the lean season only Rs. 50–100 per day is earned.

Thalamuthu nagar: The fishermen are able to earn about Rs. 35 000 to 45 000 annually. During peak seasons, they earn around Rs. 1 000 per day while during the lean seasons they are satisfied with a meagre Rs. 75 per day.

Thirespuram: The average annual income of fishermen in Thirespuram varies according to the species targeted or the type of fishing they are engaged in. Chank divers earn up to Rs. 500 per day during the peak seasons while sometimes, they do not even earn a single rupees. Gill net operators, earn around Rs. 600–800 per day during

the peak season and only Rs. 50–100 during the lean season. Fishermen who are employed as deck hands on trawlers, work in shifts with one day on and one day off and earn around Rs. 150 per working day.

Inico nagar: The average annual income of fishermen in the sardine fishery is estimated to be around Rs. 15 000–21 000, with monthly incomes fluctuating, between Rs. 750–2 000 depending upon the season.

The Role of Self Help Groups

The Self Help Groups (SHGs) in all villages play a major role in the generation, saving and wise use of financial resources. The Government is encouraging SHGs in order create confidence among the women. In Indian culture, the women at home play an important role in maintaining the family and also it is believed that the women would be more reliable in repayment of borrowed funds and so it would be easy to sustain any programmes with their involvement. The majority of the women SHG's are under the control of the Tuticorin Multipurpose Social Service Society (TMSSS) run by the Roman Catholic Diocese. The Bishop of Tuticorn District is the president and is assisted by several members. There are 98 SHG's under the administration of the TMSSS in all the coastal villages of Tuticorin with a total of 2 019 members. The main objectives of the TMSSS are to:

- bring socio-economic changes by organizing technical programmes;
- develop skills for income generating programmes;
- improve the sense of saving;
- remove illiteracy among children below 14 years of age.

The number of SHG's in each village varies with the population of the respective village. Each SHG consists of a president, secretary, treasurer and 17 members. In each village, all the SHGs are managed by a single coordinator who meets with the groups once a month to assess and co-ordinate their activities. The SHG's play a leading role in the generation and administration of saved funds. The amount saved by each varies but ranges between Rs. 50 000 and Rs. 100 000 (US$ 1 064 and 2 128). The total savings of all 98 SHGs of Tuticorin up to March 2002 was Rs. 5 030 843 (US$ 107 039) (TMSSS Annual Report 2001–2002). Each group deposits their savings in a bank and the related original papers are lodged at the TMSSS office. Each SHG meets once in a week in order to discuss the wise use of funds, repayment of loans and the plan for the coming week.

The savings were loaned to SHGs for various purposes, so that they could avoid borrowing from moneylenders at high interest rates, which was found to be one of the reasons for the continued poor economic status of the households. In order to rectify this situation, women within the villages were encouraged to increase their savings to enable them to use the available funds for income generating activities. On behalf of each SHG, TMSSS takes a loan that is three times the amount of the total saved by each group and distributes the money to the members of respective groups based on their contribution. Each member is required to pay back the amount loaned in monthly instalments within 21 months at 9% interest. The women use these loans mainly to help their family members (husband/sons) to buy fishing materials or for family functions. In addition, women belonging to SHGs are empowered in social and economical domains and actively participate in decision making and planning processes, linking them with micro-enterprises and banking institutions (Patterson, 2003).

The livelihood of fishermen is jeopardized by declining reef resources resulting from overexploitation by growing populations and an ever-increasing number of fishing boats, which are employing increasingly destructive methods to catch fish. In addition, all fishing activities within these villages tend to be controlled by middlemen who offer loans to fishermen for boats and nets in return for a certain portion of their catch to be sold to them at a low fixed price. The inability of fishermen to sell their entire catches at fair market prices has hindered the economic development and financial security of many coastal fisher folk. For example, at Inico Nagar, all

the auctions are carried out through middlemen who get a commission of 6–7%. As a result, the fishermen are forever indebted to these middlemen who grow wealthier while the fisher folk who carry out all hard work obtain only meager prices for their catches. The basic reasons behind the problems are lack of awareness and alternative livelihoods.

CREATION OF AWARENESS

In 2001, a survey to assess the awareness of fisher folk about corals determined that only 29% of men and 3.1% of women were aware of the ecological significance of corals (Patterson *et al.*, 2002). Thus, SDMRI has conducted series of awareness programmes in these villages, to promote the importance of corals, healthy fishing practices and the need to curb illegal coral quarrying and destructive fishing practices (figure 1). Mainly fisher women were targeted as they play a very important role within the family and social set up. By explaining to the women the ill effects of coral quarrying, the loss of habitat for many fin and shellfishes and loss of potential fishery zones in the near future, the message subsequently reached the ears of active male fishing representatives in their family. The awareness programmes also focused on families actively involved in removing live and dead corals from the offshore islands and, as a result they have now started to argue against destructive activities in all villages. In Vellapatti, coral quarrying has stopped totally, and the fishermen have also adopted less destructive fishing methods. The fisher women in Tharuvaikulam are strongly opposing coral mining and destructive fishing which has curbed these activities considerably. The practice of dynamite fishing using gelignite and amatol sticks has ceased completely in Thirespuram village, once famous for this type of illegal fishing. The women fisher folk have turned out to be the most effective educators of the male working members of their families. They have also informed their Self Help Groups (SHGs) that conservation should be practiced by them in order to maintain the resources for future generations. Following the completion of this series of awareness programmes, another survey of the knowledge about ecological significance of corals among male and female fisher folk determined that awareness levels had increased beyond 80% and 20% in males and females respectively. Through our awareness programmes, the basic knowledge about the need of conservation of the coral reef ecosystem was increased substantially.

Figure 1. Coral reefs awareness programme in Tharuvaikulam village in Tuticorin coast.

ALTERNATIVE LIVELIHOOD SCHEMES

In order to improve the living conditions of fisher folk and to reduce the pressure in the marine ecosystem, alternative livelihood schemes were introduced to empower the women under Self Help Group (SHG) to earn extra income on their own, to help their family to enhance their socio-economic status.

Apart from short-term training programmes on pickle preparation from marine fishes and shrimps, no viable

alternative livelihood programmes have been implemented in the past. SDMRI has involved in the capacity building especially on vermi-composting, crab fattening and development of value added products from underutilized resources such as gastropod meat with support from CORDIO and other agencies.

Vermi-Composting

Vermi-composting is a simple technique of converting biodegradable wastes into value added biofertilizer using earthworms. Earthworms breakdown degradable waste and consume it along with the soil. Further, the breakdown is taking place in the intestine of the earthworms by the microorganisms and digestive enzymes present in the intestine. The digested materials are expelled in the form of granules called *worm casts*, which are seen in the top layer of soil. The worm casts along with the urine and other secretions of the earthworms, dead adult worms and enormous quantities of beneficial microorganisms are collectively called *Vermi-compost*. The vermi-compost contains all the micronutrients, humus and organic matter, essential for soil health and plant growth.

Vermi-Compost Preparation

A pit of 2 m x 0.5 m and 1 m deep is dug in the soil and a 5 cm layer of broken bricks or pebbles is spread at the bottom. Thereafter, a thick layer of sand is spread over the pebbles to drain excess water. A layer of soil is spread on top of this, and, after being moisturized, the soil is inoculated with locally collected earthworms. Small lumps of cow dung are placed over the soil and covered with bio wastes like for example dry leaves. This process of spreading alternate layers of cow dung and bio waste is repeated until the pit is filled. Water is sprayed liberally until the entire contents of the pit are moist but not wet. The pit is then watered and monitored regularly for about 25 days, and kept covered with coconut or palmyrah leaves to prevent disturbance of the vermi-bed by birds. After 25 days, the appearance of juvenile earthworms is a healthy sign. Water management is the most important criteria in vermi-culture, as worms require moisture for their survival. Once a week the contents of the pit should be turned upside down for uniform conversion.

As the compost is getting ready and the change of refuse into a soft, spongy, sweet smelling, dark brown compost is noticeable, no additional water is added which compels the worms to move into the vermi-bed. This will facilitate the harvesting of the compost without much damage to the worms. The harvested compost is placed in the form of a cone on a solid ground in bright sunlight. This will facilitate whatever worms still present in the compost to move to the lower layer. We can recover the worms from the lower layers of the compost and transfer them in a new composting unit.

Benefits

The organic wastes generated every day, which otherwise can cause environment and health problems can be recycled. The use of vermi-compost will reduce the quantity of the chemical fertilizers. This reduces the input costs for cultivation. And there are no ill effects when using vermi-compost excessively unlike with chemical fertilizers.

The wastelands will be improved when the application of vermi-compost and the introduction of earthworms improve the soil properties. Vermi-compost will change the structure of the soil and provide oxygen to the roots of the plants. Further, an enhanced disease resistance will be developed in the soil.

Vermi-compost increases the quantity and quality of the products. It provides plant growth promoting substances and other essential nutrients to the plants. The taste and quality of the products will be improved and the keeping quality and shelf life period will be enhanced.

It prevents the soil erosion and water evaporation. It improves the soil pH. It enhances the growth of beneficial microorganisms.

Vermi-composting does not require sophisticated instruments that need to be maintained.

It creates job opportunities to rural, coastal and urban populations. The sale of vermi-compost and earthworms

Figure 2. Training programme for coastal fisher women in the preparation of vermi-composts.

provides additional or alternate sources of income to women and unemployed youths thereby improving their livelihoods.

Training of Fisher Women

SDMRI has initiated training programmes on vermi-composting through CORDIO, particularly to coastal fisherwomen belonging to the SHGs of Thirespuram, Punnakayal, Vellapatti and Tharuvaikulam (figure 2). The training programmes were organized as an awareness raising activity because the sources of organic waste available are comparatively large in these areas (seaweeds, sea grasses etc in the shores and dry leaves of shady trees). The women who attend to household work can take care of the vermi-compost pits in their leisure time.

Twenty women from Vellapatti village were trained at a commercial vermi-composting farm at Puliuthu where they obtained practical experience in large-scale vermi-composting methods (figure 3). At Vellapatti, the soil is sandy in nature and unfit for the preparation of the pits. Therefore, through CORDIO programme, 13 vermi-composting pits were constructed for trained families with brick walls to avoid sinking of the pits and SDMRI

Figure 3. Local fisher women gaining practical experience in large-scale vermi-composting methods.

Figure 4. Harvested vermi-compost ready for sale.

provided technical back up. Regular monitoring of the pits and technical advice is provided freely to the villagers. Effective composting has continued since the initiation of this vermi-composting programme. SDMRI has arranged buyers for their bio-fertilizer and every pit owner is earning about Rs. 1 500 to 2 000 per crop. The women of Thirespuram have started to prepare vermi-composts in their own in their backyards, and are now able to harvest rich yields of both compost as well as worms that can be utilized for the next filling. Once the bio-fertilizer is ready to be harvested, SDMRI arranges buyers on behalf of the women (figure 4). After the second training programme in Tharuvaikulam in 2004, women started to venture into vermi-composting in their own village. This is an economical improvement for the coastal people and also a viable alternative/additional livelihood option especially to the fisher women.

Vermi-composting has become very popular income generative activity because of its low investment, less time consuming and promising market value. This activity is fast spreading among other villages and SDMRI is keen to provide training to other villages.

Crab Fattening

All crustaceans undergo 'moulting', a process by which their exoskeleton is shed in order to grow. In recently moulted crabs, the carapace is very soft and are locally known s 'water crabs' and do not fetch attractive prices at the market. Usually, they are discarded. Culturing these crabs until the carapace hardens is called crab fattening. The mud crab (*Scylla serrata*) takes 21 to 24 days for fattening but the swimming crabs *Portunus pelagicus* and *P.sangunolentus* fatten within 7 to 9 days. The fattened crabs generate a normal market price just like other crabs.

Benefits

Crab fattening is simple process and it can be used as one of the viable alternate livelihood programmes for earning additional income by the fisherwomen. The crab fattening saves the resource and gives an additional income a SHG of between Rs. 1 000 to 1 500 per month.

Training to Fisherwomen

The daily economic loss for fishermen due to 'moulted crabs' was unavoidable until recently when the crab-fattening process was initiated. Groups of fisherwomen representing the coastal villages were trained in the process of crab fattening by SDMRI during 2002. Responding to the interest put forth by the fisher women of the crab-fishing village Vellapatti, a one-week training programme was organized by SDMRI under the CORDIO programme. The training covered all aspects of fattening from choosing the moulted crabs, fattening, feeding the molted crabs with inexpensive baby clams, *Donax faba* and the harvest of fattened crabs (figure 5). They were trained to fatten the mud crabs and blue swimming crabs.

After the training programme, a proposal was prepared for the construction of a fattening unit exclusively for the SHG women of Vellapatti fishing village. Five SHGs volunteered to take up the responsibility of the entire operation from stocking to harvesting and selling. The district administration sanctioned a grant for the

Figure 5. Fisher women feeding crabs held in cement holding tanks with baby clams.

construction of the crab-fattening shed. After the construction of the fattening shed, all the five SHGs, involving around 60 women, were successfully carrying out the fattening programme. Regular monitoring and technical back up was provided by SDMRI as a part of CORDIO programme.

The local women fisher folk of Vellapatti fishing village have taken up crab fattening process to generate income as an alternate livelihood scheme. Initially, the costly and export oriented mud crabs were preferred for fattening, as they are exported in live condition and there is a demand for them throughout the year, and crab stocking was carried out in all tanks. However, the fattening period for mud crabs was found to be as long as 3–4 weeks. Thus, instead of mud crabs, the blue swimming crabs are being fattened for a period of 7 to 9 days with higher stocking density. The moulted blue swimming crabs are purchased for 1 rupee per crab and sold for an attractive price approximately Rs 7–9 per crab. The crab fattening is a viable alternative/additional livelihood programme and could effectively be practiced in Tuticorin coast by SHG fisherwomen in the other villages.

Crab fattening has become very popular, as it is highly viable with good market value. Other funding agencies have also come forward to provide training to coastal folk in crab fattening. However, in order to provide more hands on trainings to fisher folk, a training unit in one of the coastal villages in Gulf of Mannar is essential. This training unit could also help to give proper guidance and monitoring of the fattening activity by the villagers.

Development of Value Added Products from Under Utilized Marine Resources (Gastropod Meat)

Background

Seafood, primarily in the form of fin fishes, crustaceans and molluscs, has been source of protein since time immemorial. In India, the cost of the seafood (fin fishes and crustaceans) is increasing rapidly due to the high demand in local and export markets making it unaffordable to people in poorer sectors of society. Hence, there is a need to promote an alternative and cheaper source of nutritious food to meet the needs of poor people. In the molluscan group, the cephalopods, bivalves and gastropods form important fishery resources next to crustaceans. Meat from molluscs is rich in protein and they can be an inexpensive source of nutrition. In India, gastropod meat is not popular like other seafood due to lack of awareness combined with the conventional food habit of the people. As direct consumption of gastropod meat may not be appeal to the public, the incorporation of dried meat into some value added products was thought to be more acceptable.

Benefit

The available gastropod resources can be utilized wisely without any waste. The development of value added products from the under utilized gastropod resources with low technology would help the fisher women to earn extra income during their free hours. The women can also start their own small-scale cottage unit for the preparation of value added products. It would also help to promote an alternative and cheaper source of nutritious food to meet the needs of poor people

Training to Fisherwomen

A total of 25 fisherwomen from Vellapatti village participated in the training programme. Crab fishing is the main fishing activity in Vellapatti village, however huge quantities of gastropods are also landed as by-catch. The gastropods were used only for their beautiful shells and operculum, but the meat was wasted without knowing its nutritional value. During the training, the fisherwomen were made aware of the value of the resources and were taught to prepare value added products such as pickles, soup powder, chutney powder and other common local products using gastropod meat. They were also taught how to hygienically handle the meat to enhance the quality. The follow-up survey conducted after the training programme showed that the villagers started consuming the gastropod meat. Development of value added products from these under utilized gastropods is the first of it kind and will serve as better alternative protein source in the near future. Now the nearby villagers (Tharuvaikulam) are also asking to conduct such kind of programmes. The villagers are also willing to take up small-scale cottage industry to prepare the products from gastropod meat to earn additional income.

The training on the development of value added products using under utilized gastropod meat has created awareness among the fisher folk of Vellapatti village to utilize the meat and also the neighbouring villagers to ask for such training. However, in order to market the developed products locally, the villagers need to set up small-scale unit, which they cannot afford. It would be worth providing such small units in 2 or 3 villages in Gulf of Mannar, so that additional income could be generated by the fisher women through the wise utilization of gastropod meat, which has, by enlarge, been neglected.

CONCLUSION

The people living along the Tuticorin Coast of the Gulf of Mannar mainly depend on the reef resources for their livelihoods. The lack of awareness and viable alternative livelihood programmes are major hindrances to improving their socio-economic status and also threatens the sustainable use of the reef ecosystem. This 'demonstration project' focusing on awareness and alternative livelihood programmes showed good results among the fisher folk and is now a role model to other coastal villages of the maritime states.

The creation of awareness coupled with alternative livelihood programmes in these villages has created considerable interest among the people to protect, conserve and manage the reef resources for the coming generations. Such a level of awareness and viable options for income and food generating activities should be replicated at a larger geographic scale in order to sustainably use reef resources. SDMRI already plans to initiate similar efforts in other villages in Tuticorin in the near future and throughout Gulf of Mannar in the longer term, and additional donors have showed their interest.

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Building an Integrated Coral Reef Monitoring Network

– Lessons from the GCRMN South Asia

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ABSTRACT

The Global Coral Reef Monitoring Network (GCRMN) has been operating in India, Maldives and Sri Lanka since late 1997 with the goal to establish a regional network of people and institutions to collect coral reef information for integrated and poverty-oriented reef management planning and policy-making. This paper briefly summaries the activities and experiences of the 'GCRMN South Asia' from its first five years of operation, including a capacity building framework developed to assist identify, collect and use coral reef information to inform and influence management and policies. Important messages of the paper are that effective coral reef monitoring and management structures need to consider first and foremost the needs of the people who depend on the reefs for their survival. Secondly, it is critical that information of all types (ecological, socioeconomic, cultural, political and institutional) is available in a range of formats to develop holistic policies and management solutions. Through the activities presented below, a set of lessons relating to gathering, organizing, and disseminating that critical information to end-users have emerged, which may be useful in future work within and outside the region.

INTRODUCTION

Recent studies show that coral reefs underpin the livelihoods of millions of people worldwide, especially in Asia, the Pacific, East Africa and the Caribbean (Whittingham *et al.*, 2003). In some areas, particularly small island states, the dependence is extremely high. Many of these people are very poor and regularly depend upon the reefs as a *keystone resource*. Others depend on the reefs as a *safety net* at certain times of the year to ensure they escape the worst of poverty. These people are extremely vulnerable to reef degradation and many are starting to become poorer (IMM, 2003a).

In recent decades, however, the coral reef ecosystems in South Asia have come under increasing pressure from environmental stress, unsustainable fisheries and harvesting methods, climate related coral bleaching and diseases, land-based sources of pollution, sedimentation, dredging and coral mining, and from inappropriate coastal development caused by insufficient planning, management, and policy decisions (Rajasuriya *et al.*, 2004). These negative impacts erode the livelihoods provided by healthy coral reefs to local people. The impacts vary among stakeholder groups, but in general the poorest stakeholders are finding that their livelihoods are declining more than other coastal stakeholders and they are the least able to respond to this change.

If coral reef management are to be successful on the longer-term, it has to effectively address the needs and aspirations of the poor people depending on reefs, ensuring the benefits are equitably distributed among all

stakeholder groups. Almost any form of resource management will affect the way people interact with reef resources, and dramatic changes in their access to reefs are likely to influence their livelihoods. And where people's livelihoods are marginal and subjected to stress and conflict, this will likely seriously affect their ability to pursue a sustainable livelihood. To avoid this situation, informed and holistic reef management that address the concerns of local reef users is vital.

Building capacity for integrated coral reef monitoring, aiming not only to collect ecological and socioeconomic data on status and trends, but also synthesise and disseminate this information into planning and policy processes, is an important step in achieving this goal.

This paper briefly presents the activities and experiences of the GCRMN South Asia, including the project approach, which has evolved from a mainly environmental focus to a more holistic development-environment approach, and presents some experiences that may assist further coral reef monitoring and management planning.

GCRMN SOUTH ASIA PURPOSE AND PROJECT SET-UP

In 1995, the Global Coral Reef Monitoring Network (GCRMN) was formed by a range of international organisations and institutions to raise awareness on the global reef decline and provide better information on reef status and user practices to managers and policy makers.

The GCRMN South Asia (GCRMN SA) was formed in 1997 as a regional node of GCRMN by the governments of India, Maldives and Sri Lanka in response to the International Coral Reef Initiative's 'Framework for Action' (ICRI 1995) addressed at a regional ICRI workshop in Bandos Island, Maldives.

Addressing the close linkages that exist between the health of coral reef ecosystems and the welfare of poor coastal communities that rely on them, the overarching goal of GCRMN South Asia were to *'reduce poverty amongst coastal communities in South Asia*', with the specific project purpose to *'inform and influence management planning and policies towards more sustainable and equitable exploitation of coral reefs*' (For a detailed definition of the concepts of 'equity' and 'sustainability' used by GCRMN South Asia, please refer to DFID 1999).

To achieve this purpose, the project set out to deliver the following specific *outputs*:

(i) Enhanced capacity among national and regional partners to develop integrated coral reef monitoring programmes;
(ii) Monitoring systems for the ecological and socioeconomic aspects of coral reefs operational at target sites adapted for local and national use;
(iii) Processes for more effective use of coral reef monitoring information to contribute to coral reef management planning;
(iv) Increased regional awareness and understanding of issues related to sustainable use of coral reefs.

Training in ecological and socioeconomic reef monitoring, tailored information dissemination and regional networking have been facilitated by a succession of GCRMN Regional Coordinators from a project office based in Colombo, Sri Lanka working in close collaboration with National GCRMN Coordinators appointed in India (based at the Ministry of Environment & Forestry with Zoological Survey of India, ZSI), Maldives (based at the Marine Research Centre, MRC, Ministry of Fisheries) and Sri Lanka (based at the Natural Aquatic Resources Agency, NARA, Ministry of Fisheries).

Financial support, including a regional coordinator position, has been provided by UK Department for International Development (DFID), and technical and managerial support provided by the Intergovernmental Oceanographic Commission (IOC) of UNESCO and IMM Ltd (a UK based development and policy group acting on behalf of DFID), with local administrative assistance from the IUCN Sri Lanka office. Additional guidance has been received from a range of sources, in-

cluding the Global GCRMN Coordinator and DFID technical advisors.

GCRMN South Asia Capacity Building Framework

Building capacity to achieve above four outputs has been the focus of GCRMN SA over its first five years. Consultations, training, pilot monitoring, awareness raising, and formal and informal networking have contributed to the establishment of a regional network of institutions and skilled people across the region. Between late 1997 and 2003, more than 150 people from national agencies and NGOs were involved in 26 planning meetings, training workshops and field activities across the region. A capacity building framework has been developed to provide the skills to produce and use coral reef information to inform and influence management planning and decision-making (figure 1 on next page). It involves four interrelated requirements:

1. Understanding Information Needs

Government agencies, NGOs or local communities may all be responsible for particular aspects of coral reef ecosystems, and it's rarely a single entity that oversees and understands all aspects of managing the resource. All the stakeholders need information to fulfil their role in the decision-making processes, and they often need it in a different format to help them achieve their specific objectives. *Therefore*, in order to effectively inform each different stakeholder, the following must be specifically recognised: Who needs to be influenced? What information is required? What is the best information format? How is the information effectively disseminated?

2. Building Capacity to Collect and Analyse Information

Coral reef management presents decision makers with complex issues relating to the status of both the ecosystem itself, the diversity of stakeholders using it, and the institutions governing the resource. Information about each level of complexity must be collected, analysed and presented in a form that is accessible to decision makers. *Therefore*, the network partners need capacity, skills and knowledge to collect and analyse information that effectively represents both environmental, social and economic status and trends.

3. Developing Information Systems

Information management systems such as databases and websites assist reef managers in storage and exchange of monitoring data and information, but integrated reef management also needs formal and informal linkages and conduits between institutions and people to enhance information flows. *Therefore*, to effectively inform and influence management planning and policy making, the GCRMN SA network must have *both* the data systems to store, manage and analyse monitoring information, *and* the networking capacity and human and institutional relationships that enables effective dissemination of this information.

4. Informing and Influencing Reef Management

Coral reef decision makers represent different sectors; have different objectives and differing levels of understanding of coral reef ecosystems and their stakeholders. A variety of reef management information is therefore required in a range of different formats. Very often, however, it is left to the information 'producer' to decide what information to collect, its format and dissemination, without always realising the requirements of the information 'user'. As a result, much reef information informs a too narrow range of stakeholders. *Therefore*, the GCRMN SA partners need the skills and understanding to produce and disseminate a range of information to a range of different users, in tailored formats, at strategic times, if they are to effectively inform and influence management planning and decision-making.

Understanding Information Needs in Reef Management

Planning meetings, consultations and skills in monitoring and analysing local ecological, socioeconomic and cultural conditions surrounding reefs and their use, including stakeholder's different needs and aspirations, has

Poverty reduction among coastal communities in South Asia

Information that effectively informs and influences resource use, management and policy making at local, national and international levels enabling equitable and sustainable coral reef use

Building capacity to produce and use information on environmental and socio-economic conditions of coral reefs and their use

4. Develop skills to use coral reef status information to inform and influence reef management planning and policy making

- Training in informing and influencing management and policy processes
- Link information providers with end users
- Promote the use of Informing & influencing strategies

2. Develop capacity to collect coral reef information

Provide training and guidance in:

- Ecological monitoring (survey designs, dive training, taxonomy)
- Socio-economic monitoring and reef livelihood assessments
- Data analysis & interpretation

Support pilot ecological monitoring and reef livelihoods assessments at demonstration sites

3. Develop systems for information sharing

- Facilitate networking among institutions and people
- Develop coral database in consultations with all stakeholders
- Establish national Coral Reef Fora
- Communicate via website, newsletter, other media
- Distribute publications
- Education and awareness raising in local language

1. Understand information needs in effective management planning

Through workshop and consultations, build understanding of:

- Processes governing the management and use of coral reefs
- Diversity of stakeholders in these processes and their information needs
- Local and national institutions and decision structures relating to coral reefs

Figure 1. GCRMN South Asia capacity building framework.

gradually enhanced the partners understanding of the information requirement of integrated reef management and the decision-processes governing coral ecosystems.

To help understand the political and institutional aspects of coral reef planning and decision-making, GCRMN SA commissioned national studies in each country (Cattermoul et al, 2003) identifying key information needs and institutional planning and decision-processes. The studies contain information on: (i) Current policies and policy instruments for the management of reef ecosystems at the national, and community levels; (ii) A description of the institutions, and their specific roles, that are responsible for the formulation and implementation of policies, legislation, and projects; (iii) The sorts of decisions that are made by these different institutions and the type and form of information needed by those institutions to plan and implement their roles in relation to reef ecosystems management; (iv) The information systems these institutions use to generate, store, analyse, use and disseminate the information; (v) The gaps in the current systems including: information quality and quantity; information detail; its appropriateness for use; and the skills, attitudes, and knowledge to implement systems; (vi) Recommendations on how skills and systems might be improved to satisfy these needs during a future phase of GCRMN SA. It is recommended to undertake similar studies in order to design and effectively utilise monitoring efforts in a given geographic area.

Key Lessons Learned

- It is essential that information provided to decision makers is provided in a format that decision makers can utilise. Implementing a study of decision-making processes in the early stages of developing an information network will provide a valuable framework for planning other initiatives such as skills enhancement, management information systems development, and dissemination strategies.
- Decision makers are influenced by many factors beyond scientific evidence. These may include wider government policy, political gain, economics, and social welfare.
- Participatory monitoring (both ecological and socioeconomic) can be an effective way of enhancing local community's understanding of coral reef ecosystems and their use, thus enabling them to play a more active role in management, policy, and decision-making processes. Likewise, local communities and stakeholders often have valuable information that should be incorporated in the policy and management planning processes.

Building Capacity to Collect and Use Coral Reef Information

Coral reef management presents decision makers with complex issues relating to the status of both the ecosystem itself, the diversity of stakeholders using it, and the institutions governing the resource. Information about each level of complexity must be collected, analysed and presented in a form that is accessible to decision makers. The GCRMN SA delivered training workshops and guidance in both ecological monitoring and socioeconomic monitoring.

Ecological Monitoring

Training in ecological monitoring techniques, coral taxonomy, scuba diving, survey design and data analysis were provided in India, Maldives and Sri Lanka in 1998–1999, followed by pilot monitoring at demonstration sites in each country (figure 2). Emphasis was placed on using the common GCRMN survey method and data formats (English *et al.*, 1997), allowing comparison between sites. More recently, the less labour intensive ReefCheck survey method (Hodgeson *et al.*, 2004) have been introduced and are now commonly used for routine monitoring across the region, complementing detailed GCRMN monitoring surveys at selected permanent sites.

GCRMN SA assisted formulation of national Monitoring Action Plans, with strategies for supporting and

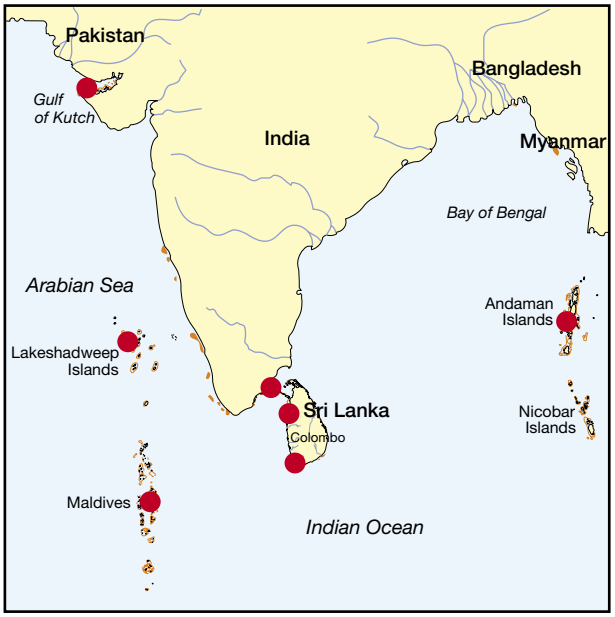

Figure 2. GCRMN South Asia training and monitoring demonstration sites indicated in red circles; *India:* South Andaman Island, Gulf of Manar, Agatti Island (Lakshadweep), Gulf of Kuchch; *Maldives:* Male Atoll, Vavuu Atoll; *Sri Lanka:* Unawatuna, Kandakulya. Training and demonstration site monitoring is an important step in raising the awareness of reef issues at both local and high levels. India, for example, where coral reef monitoring and management had previously been very limited, now has developed a national reef monitoring program (ICRMN) and scientific centres across the country. In Sri Lanka, the training helped further develop and consolidate previous efforts.

implementing reef monitoring activities, in consultation with government departments in each country. These have been implemented only partly, though, and ecological monitoring has been undertaken by government agencies at varying levels of intensity through valuable collaboration with programs such as CORDIO ('Coral Reef Degradation in the Indian Ocean' supported by SIDA-SAREC), which has supported routine monitoring in the region since 1998. The utilisation of early GCRMN training, skills and networking in other regional projects is a good example of collaboration and cost-effective sharing of competences and resources. Support for ecological monitoring to GCRMN partners has also been provided by AusAID, Asian Development Bank (ADB), and recently the Global Environmental Facility (GEF).

Socioeconomic Monitoring and Reef Livelihood Assessments

Socioeconomic reef monitoring on people's interaction with reefs represents a key requirement for implementing strategies for sustainable and equitable resource use, and has been a core focus of GCRMN SA. The common GCRMN Socioeconomic Monitoring manual (Bunce *et al.*, 2000), which was partly developed at a large regional workshop at Kadmat Island, India, September 1998, has been used as a key training resource in South Asia. Training in participatory monitoring surveys, site selection and development of protocols tailored to the local conditions where held in Gulf of Mannar and Sri Lanka, followed in 2000–2001 by training at demonstration sites in Sri Lanka, Maldives, South Andaman Island and Lakshadweep Islands, India. 12-month pilot surveys were undertaken by local groups funded by GCRMN SA at sites where ecological reef monitoring were already taking place, bringing together multidisciplinary information for use as baselines for longer-term monitoring.

Participatory monitoring was also used to raise awareness among local stakeholders and enable their participation in management decision processes. In Mahatma Ghandi Marine National Park, Wandor, South Andaman Island, for example, an important goal of the socioeconomic monitoring was to stimulate greater involvement of local communities in future conservation strategies, and a major outcome of site-specific surveys was the development of dialogues with the local communities. In Agatti Island, Lakshadweep, socioeconomic surveys recorded knowledge on traditional reef use practices from senior generations.

Findings from these surveys are reported in a series of papers and reports, of which some has been translated and distributed in local dialects (Hoon, 2002; MRC, 2003; Singh *et al.*, 2002). The information also contributed to the IMM-implemented, DFID-funded *Reef Livelihoods Assessment* project on how different local communities benefit from reef resources and how they assess those benefit flows in terms of their wider livelihoods (reported in 'Poverty & Reefs', Whittingham *et al.*, 2003).

Key Lessons Learned

- Socio-economic monitoring and ecological monitoring should be viewed as an integrated activity. But appropriate institutions to undertake for socioeconomic and ecological monitoring are not likely to be the same. It is therefore essential that dialogue and collaboration between different institutions are established at the outset of monitoring to ensure information is closely integrated. A division between socioeconomic and ecological disciplines is unlikely to be perceived as meaningful by local stakeholders and could lead to confusion.
- Developing the capacity of national government institutions to provide in-house training and guidance can assist fulfil the long-term training requirements of a constantly changing workforce. Providing a readily accessible supply of training material that caters to different levels of skills and knowledge can complement national training efforts.
- Participatory monitoring requires incentives for local participants both on the shorter and longer term. In the short term, financial incentives may be used, but the impact and sustainability of such inputs must be carefully considered. In the long term, the demonstration of effective impacts of monitoring is an important aspect of participation.
- Participants should not just be seen as a source of information but as the actors determining the agenda for monitoring and analysing the results of that monitoring.
- It is rarely possible or constructive to recommend one uniform approach to socioeconomic monitoring. Social and economic conditions and the patterns of reef use will vary among locations, and an approach that suits one location may not work in another.
- Using locally-based institutions with a pre-existing role and relationship with the community will assist establishing a monitoring programme and help ensure that information feeds into the policy process or management efforts more effectively. The more precisely the monitoring meets the information requirements at the local and national levels, the more likely is it used and will receive long-term national support.

Principles for Poverty-Oriented Coral Reef Monitoring and Management

Over the evolution of GCRMN SA, the project approach evolved from an initial mainly environmental (ecological monitoring) focused to a more holistic development-environment approach, addressing the purpose of 'poverty reduction' by promoting holistic and people-centred reef monitoring and management (for further background and theory, see IMM, 2003a, b). The following principles were adopted, which are recommended always to consider in development of a poverty-oriented monitoring network:

- The probability of achieving a sustainable future for coral reef ecosystems is greatly reduced in areas where poverty persists. The network therefore *aims to be Poverty Focused*: (i) It recognises the coastal poor as a very important sub group of coral reef stakeholders; (ii) It understands linkages between poverty and coral reef exploitation; (iii) It recognises the need to include the very poor and marginalised in reef management processes.
- The network seeks the views of the local resource stakeholders in the management process and therefore *aims to be People-centred*: (i) It understands the diversity of stakeholders, their needs and aspirations; (ii) It understands the impact of policy and institutional arrangements upon resource users; (iii) It fully involves people and respects their view; (iv) It defines success not only in terms of international and nation-

al development objectives but also in terms of the priorities of vulnerable reef-dependent stakeholders; (v) It recognises the inherent potential of the poor (indigenous knowledge, skills, attitudes and relationships) and builds upon this.

- The network seeks to *promote Micro – Macro Linkages*: (i) It aims to develop linkages between macro level policy and institutions to community level organisations; (ii) It aims to ensure that high-level policy making processes involve the local communities and consider local social, cultural, economic, and environmental conditions; (iii) It aims to ensure that high-level policy is informed by lessons learnt and insights gained by donor projects, management initiatives and other interventions at the local level.
- The diversity of stakeholders that affect and are affected by the benefits from coral reefs covers a wide spectrum of sectors, ranging from fisheries and tourism to agriculture and industry. All of these sectors must be engaged in the process of change if coral reef management initiatives are to meet with success. The network therefore *aims to be Holistic*: It embraces the complexity of the issues facing coral reefs and reef dependent communities that exist across a diversity of sectors.

Figure 3. a) Socioeconomic training workshop, Andaman Islands; b) Socioeconomic survey, Andaman Islands; c) Parrot fish for sale at a local market, Chennai, India; d) Pricing the crab catch, Gulf of Mannar, India; e) Andaman Islands, India; f) Ecological reef monitoring; g) 'A Tomorrow of our Coral Reefs', IUCN exhibition, Colombo, Sri Lanka.
Photo: EMMA WHITTINGHAM, PHILIP TOWNSLEY, K. VENKATARAMAN, JOS HILL and OLE VESTERGAARD.

- The issues facing coral reef ecosystems and their stakeholders are complex and characterised by a wide diversity of stakeholders; they will not be solved with isolated interventions. The network therefore seeks to *promote Partnerships*: It recognises the need for multi-agency cooperation, including representatives from both the public and private sectors, as well as and community organisations.

Developing Systems for Information Sharing

Effective systems for sharing and using reef status information in management planning and decision-making entails not only a database and a set of information products; institutional networking and personal linkages that develops through local, national and regional level collaboration, trust and sharing are integral to an effective information system, as briefly highlighted below:

a. Local, Regional and International Networking

Formal and informal networking and sharing of expertise among network partners, government departments, NGO's, private sector and stakeholders at both local and national level is required for effectively producing and disseminating socioeconomic and ecological informa-

tion into management and policy processes. The structure of GCRMN SA is designed to facilitate transfer of information for use in management planning by local and national partners, as well as to inform international coral fora (figure 4). By collaboration at training workshops, national and regional meetings, and international fora such ICRI meetings and scientific symposia, a growing level of cohesion has developed among the network partners, representing a valuable platform for developing and implementing management activities. Through serving as a common focus for coral reef-related activities, the GCRMN SA project has brought together a large group of stakeholders and created synergies with other coral reef initiatives and coastal management projects. For example, early GCRMN monitoring in Kandakulya and Unawatuna, Sri Lanka guided the ADB Coastal Resource Management Project (CRMP) in development of local management strategies. In Maldives, the ecological monitoring established with the Marine Research Centre assisted work of AusAID on marine protected areas in Addu Atoll.

Figure 4. GCRMN South Asia logo *Act locally, Inform globally*. Coral reef status information is disseminated via national status reports and the biannual global GCRMN status reports (e.g., Wilkinson 2004), CORDIO status reports, project documents and scientific papers. Networking with international coral reef research and management communities have been established by partners attending international fora such as the International Coral Reef Symposia (Bali 2000, Okinawa 2004); ITMEMS II (Philippines 2003); or ICRI general meetings and regional workshops (Cebu 2000, Maputo, 2001, Cancun 2002). Logo designed by Prasaana Weerakody, Sri Lanka.

b. Database Development in Consultation with Users and Stakeholders

GCRMN SA partners early expressed a need for a coral reef database to store and exchange reef monitoring information across the region and to serve as a repository for documents, training material, survey protocols, details on related projects and as a contact directory for regional coral reef experts, NGOs, and agencies working with coral reef issues.

The development process involved extensive and in-depth participation of data providers and users from each country to determine the required content, structure and functions, aiming to develop a system tailored national requirements. The final database structure is 90% similar between the three countries, but certain features are adapted to specific national terminologies and features. The prototype version has features such as a protocol for socioeconomic survey data and geographical mapping functions. Manuals and training has been provided in all three countries and data entry of existing data (e.g. fisheries statistics) has been commissioned at government agencies. The prototype version can be downloaded from the GCRMN SA website. It is not yet fully functioning in the region and further progress requires coordination support and establishment of infrastructures for regional dataflow and technical support. One step further has been taken in India, where the database has been further adapted to national needs and is now hosted at the Ministry of Environment & Forestry in Delhi.

The fact that a regional database infrastructure has not yet been fully implemented is due partly to the extensive resources it requires, but also the time needed to build strong relationships and mutual trust between network partners at a level where they are willing to share detailed data. However, engaging several institutions in

the early design process has helped build such relationships and should facilitate future database development and data exchange.

c. National Coral Reef Stakeholder Fora

In 2002, the GCRMN SA, jointly with the South Asia Cooperative Environment Programme (SACEP) and CORDIO South Asia, initiated a national Coral Reef Forum in both Sri Lanka and Maldives, serving as fora for discussions and learning among a broad spectrum of coral reef stakeholders, including resource users, NGOs, researchers, government departments, international donors and private sectors (e.g. hotel owners, dive operators and aquarium fish traders). The fora have met 1–2 times per year. At its second meeting, held in November 2002, the Sri Lanka Coral Reef Forum received official endorsement by the 1st Secretaries of the Ministry of Environment and Natural Resources and the Ministry of Fisheries and Ocean Resources, respectively, and support and strong commitment was expressed to integrate efforts between departments and sectors (see further details in 'Forum News' on the website). For these expressions of good will to develop further, the national fora can be useful instruments to generate future collaboration and activities.

d. Information Products and Publications

GCRMN SA has produced a large amount of information to inform and influence individuals and organisations about coral reefs and related management and policy issues, and has facilitated interaction with stakeholders through a range of information products, including:

(i) a *project website* serving as regional information centre with news, documents and contacts (www.gcrmn.org);
(ii) a *project library* with handbooks, scientific papers, technical guidelines, project reports and awareness material on coral reef issues and coastal management compiled in the project office, Colombo. A bibliography is available from the project website and hardcopies of documents can be forwarded upon request;
(iii) a *project Newsletter* with updates on project development and international coral reef news presented in a regional newsletter and national 'Forum News', printed and distributed to partners across the region;
(iv) *Local language reports* with findings and results of socioeconomic assessments translated into local dialects (e.g. Hoon, 2002) for dissemination to local managers, officials, school teachers, NGO's and wider public.

e. Education and Awareness Raising

Awareness raising and education materials to inform local reef users as well as schoolchildren include message boards, leaflets, exhibitions, field guides and presentations at meetings. A national mobile school exhibition – *A Tomorrow for Our Coral Reefs* – touring schools in Sri Lanka with posters and videos in local languages and a research colloquium and national art competition for school children was organised in 2001 by IUCN Sri Lanka, jointly with GCRMN SA and CORDIO SA, in association with the Ministry of Ports, Shipping and Fisheries, to raise awareness on the status of coral reef ecosystems, their value and vulnerability, and the need for equitable and sustainable management.

Key Lessons Learned

- There is a tendency for organisations and individuals to work in isolation. A motivating external, neutral entity can bring people and institutions together who would otherwise not interact naturally.
- Much information produced is not disseminated widely enough to fulfil its potential. Systems such as a database, a regional document library, and an organisation work directory can help, as well as informal networks between people and institutions.
- When developing a database, equal emphasis should be given to the systems and skills needed to collect, enter, transfer, manage, and use the information. A weakness in any part of this process is likely to halt the entire system.

- It is likely that external support will be required to assist both the development and the establishment of a database. National governments will need to recognise its value before they commit national resources to it.

Developing Skills in 'Informing and Influencing' Management and Policy Processes

Building skills in *using* reef monitoring information to 'inform and influence' coral reef management and decision processes is essential to achieve the overall purpose of better informed reef management.

In three national GCRMN SA workshops, participants explored the complexity of producing different types of information and how to respond systematically to the complexity of information requirements in terms of informing and influencing a diversity of stakeholders with different backgrounds and objectives, and developed case-specific strategies for different coral reef issues. Through parallel work of IMM Ltd on a DFID-funded 'Sustainable Coastal Livelihoods' project, an 'informing and influencing framework' was developed and subsequently tested in the national GCRMN SA workshops. The framework includes a series of stepwise considerations: (1) Are key stakeholder groups involved? (2) What is their role or stake in the management objectives? (3) Is there any action or change required by the stakeholders? (4) Is there information required to achieve this change? (5) What is the best media to address specific the information needs? (6) Does this information already exist and, if so, where?

Reports with experiences from the three workshops are available from the GCRMN SA website, with further theory and background in IMM 2003c.

Key Lessons Learned

- In many situations, a wide range of reef-related information exists, but is not used effectively. Given the high cost of collecting and analysing data, every effort should be made to maximise the use of existing knowledge before embarking on extensive monitoring efforts.
- If information generated by research is to bring about change in policies and policy implementation, it needs to be made available in many different forms tailored the diversity of different stakeholders involved.
- Informing and influencing strategies should be considered as an integral part of a research-planning process. Using a framework to cope with complexity in a structured way can greatly improve the effectiveness of the project / research outputs.

SOME CONSIDERATIONS FOR FUTURE DEVELOPMENT

After five years of operation, the national network partners conducted a comprehensive review of the impact of the GCRMN SA activities on reef monitoring in the region (see GCRMN South Asia Review, 2003). It concluded that important progress was achieved towards raising awareness and building capacity to provide information on equitable and sustainable coral reef management issues in the region. Partners concluded that coral reef issues are being more seriously considered at both local and national levels and that the network objectives appear to be more firmly anchored in national policy agenda's. Over the years, GCRMN SA has progressively evolved to address different information requirements of reef management in South Asia and is slowly becoming driven by the countries themselves.

An important learning aspect of the first years of activities is that it indeed took five years to just establish the GCRMN SA as an institution, or process, within the region. That is how long it takes to build respect and confidence among the wide range of people and institutions the project has worked with. And a key output from the activities are primarily increased dialogues between partners and formal and informal networking in the three countries, which are currently laying the foundation for new coral reef efforts. The acceptance of GCRMN SA as an institution serving national and local needs, rather than an isolated project fulfilling primarily international priorities, is fundamental to sustaining this

impact. It is hoped that future coral reef initiatives in the region can build on the participation and ownership established. Continued support for collaborative efforts, for example through the national Coral Reef Fora, would be useful to further integrate reef management and policies.

Still there is scope for increasing the government support for routine ecological and socio-economic monitoring in all three countries, in particularly to address poverty issues in a natural resource management context. The project review recommended first and foremost to further evolve reef monitoring that takes fully into account the needs and aspirations of the poorest reef users. Emphasis on holistic approaches, training in socio-economic monitoring, support for reef livelihoods assessments and development of alternative livelihoods are important priorities. A people-centred approach to resource management is likely to increase the chance of management success. Resource management should be viewed as an instrument within a larger framework of coastal development with poverty reduction as the overall goal. Otherwise there is a tendency for the poor to be viewed as an obstacle, rather than as part of the solution. Developing a wider appreciation of the linkages between poverty and the status of coral reef, and how healthy coral reef ecosystems can contribute to national objectives of poverty reduction, may further commitments from governments towards reef monitoring and management.

It appears that the efforts and outputs of GCRMN SA and related projects have had some influence on the regional and international policy climate towards poverty issues within coral reef management. Along with the development of GCRMN and CORDIO, the regional intergovernmental body for environmental affairs, SACEP, has expressed increasing will to engage actively in coral reef issues, including addressing local people and livelihoods aspects. Similarly, calls for pro-poor strategies in reef management have been expressed in recent documents of ICRI partners, most notably in the ICRI statement 'Global Vision for Local Action' (ICRI CPC, Seychelles, April 2005). These are all positive developments. It is important to note, however, that the local reef users will feel little change in their situation unless the good words and intentions are followed up with action on the ground.

Guidance and training in integrating local reef users and pro-poor aspects in the planning, design and implementation of marine protected areas would be a useful step to ensure equitable and sustainable management outcomes. As part of this, future efforts could aim at refining and implementing approaches for targeted information dissemination to reef stakeholders, managers and policymakers. Further, national studies of policy and institutional aspects of coral reef planning and decision-making processes may be useful in this work, including addressing the diversity of stakeholders associated with reefs and build further awareness of the complexity of coral reef issues.

There still is a need for technical guidance and a modest regional coordination to drive these efforts. Further interaction with international coral reef efforts such ICRI, developing efforts of SACEP, as well as the global coral reef data repository ReefBase, may stimulate further commitments of the Governments of South Asia to address coral reef issues. Emphasis should be placed on *two-way* communication, ensuring new knowledge and useful tools are feed back into national and local coral reef activities.

Today, GCRMN SA activities are being continued with coordination support through CORDIO South Asia and IUCN Global Marine Program from IUCN's Asia Regional Office in Colombo, Sri Lanka. Support is provided to continue ecological monitoring at permanent sites in the region, as well as part of the previous socioeconomic assessment initiated in Lakshadweep Reef, India. With the momentum achieved through the DFID-IOC/UNESCO implemented GCRMN South Asia Project, the National Coral Reef Fora will be continued to maintain dialogues between local authorities, NGOs, researchers and the private sector, and to further the development of a regional coral reef database system.

Learn More

Documents available from the GCRMN South Asia project website at www.gcrmn.org include:

1. GCRMN SA Informing & Influencing Strategy – Guidance for Future Interventions (2003)
2. Understanding Information Needs – Country Reviews of Information Needs for Coral Reef (2003)
3. GCRMN SA Planning Framework
4. GCRMN SA Coral Reef Database overview
5. GCRMN SA Partner Review (2003)
6. Agatti Island, Lakshadweep, Socioeconomic study (Hoon, 2003)
7. Vaavu Atoll, Maldives, Socioeconomic study (MRC, 2003)
8. Wandor, South Andaman Island, Socioeconomic study (Singh *et al.*, 2002)
9. Whittingham, E., Campbell, J., & Townsley, P., (2003) *Poverty and Reefs*. DFID-IMM-IOC/UNESCO.

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Most recently, the regional monitoring expertise and network capacity has contributed to rapid assessments of the impact of the Indian Ocean tsunami on 26 December 2004. The joint coordination of the IUCN Regional Marine Programme, CORDIO and GCRMN was key in mobilizing coral reef assessment teams throughout the region, and regular reports to policy makers, scientists and the general public were issued from early January 2005. The IUCN/CORDIO/GCRMN network also contributed significant sections to the regional report prepared by UNEP and to the development of a methodology for assessment of tsunami impacts on coral reefs for ICRI and ISRS. In addition to the networking and coordination mechanism, the reef monitoring capacity built and the baseline information gathered in the region through GCRMN and CORDIO activities since the 1990s has proven invaluable after the tsunami. Many times the only information available originates in these initiatives and their collaboration with government and non-government institutions such as MRC, NARA, SDMRI and RWMC. This reemphasizes the need for continued strengthening of monitoring capacity and

programmes, and importantly also provides an impetus to further develop GCRMN as an inclusive and efficient network of institutions and individuals in the region.

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