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CORAL SEEDING AS A TECHNOLOGY FOR RECOVERING DEGRADED CORAL REEFS IN THE PHILIPPINES

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ABSTRACT

Philippine coral reefs have degraded at an accelerating rate over the past 20 years, resulting in an interest in the potential use of coral transplantation to rehabilitate disturbed reefs. We selected *Pocillopora damicornis* (Linnaeus) for transplantation because it is an opportunistic species that is ubiquitous and easily maintained under laboratory conditions. Planulae collected in laboratory aquaria from wild adult colonies during five spawning periods showed a mean settlement success rate of 52.9% ± 21.9 % (n = 2714 planulae) and a first week mortality rate of 30.7% ± 14.2%. In comparison, planulae (n = 300) seeded directly onto the reef during June 1997 showed 14.3% settlement success and 81% first-week mortality; none remained after 3 weeks. Monthly growth rates of laboratory-reared juveniles averaged 1.54 ± 0.151 mm (mean ± SE, n = 30) during the first six months after settlement, indicating the feasibility of extended laboratory rearing for this species. We recently transplanted 320 laboratory-reared juvenile colonies from four age/size cohorts (<3 mm, 3–6 mm, 6.1–10 mm, >10 mm; n = 80 for each size class) to the field to examine the relationships between colony size, growth rate, and mortality. Preliminary results indicated decreased mortality with increased size at transplantation (6-week mortality: 82.5%, 60%, 27.5% and 2.5% for smallest to largest size categories, respectively). Growth rates were lower than those observed in laboratory aquaria, but steady. This suggests that rearing juvenile colonies to a minimum of 10mm (six months of age) prior to transplantation to the field will ensure high post-transplantation survival. Our studies indicate that reintroducing corals to a degraded site may be possible by settling planulae in laboratory aquaria, rearing them to a minimum size, and transplanting them onto appropriate substrate.

INTRODUCTION

The accelerating decline in the health of coral reefs throughout the tropics has caused increasing concern among reef workers worldwide since the 1970s. A general consensus is developing that restoration and rehabilitation of degraded systems must require active efforts by scientists, resource managers, and affected communities (Pratt, 1994; Rinkevich,1995; Gomez, 1997; Harriot and Fisk, 1988; Dight and Scherl, 1997). The view that reefs will recover naturally if left alone is no longer a viable assumption in many cases, given the speed at which destruction often takes place and the diverse factors which interact to prevent recruitment of species to an area after the reef has been decimated (Birkeland *et al.*, 1979; Clark and Edwards, 1995). Corals, in particular, may fail to become re-established on a degraded site due to the effects of eutrophication (Wittenberg and Hunte, 1992) and sedimentation on larval settlement (Hodgson, 1990; Wittenberg and Hunte, 1992), competition with encrusting and fouling organisms (Fishelson, 1973; Banks and Harriot, 1996), isolation from other larval sources due to current patterns (Banks and Harriot, 1996; Sammarco and Andrews, 1989), or a lack of living coral fragments for species reproducing predominantly through fragmentation (Tunnicliffe, 1981; Highsmith, 1982).

Coral transplantation as a management/ rehabilitation tool is gaining increasing attention and a diversity of technologies and methods are being developed and tested (see Harriot and Fisk, 1988 for a review). It is appropriate that such a variety of techniques exists, given the diversity of life

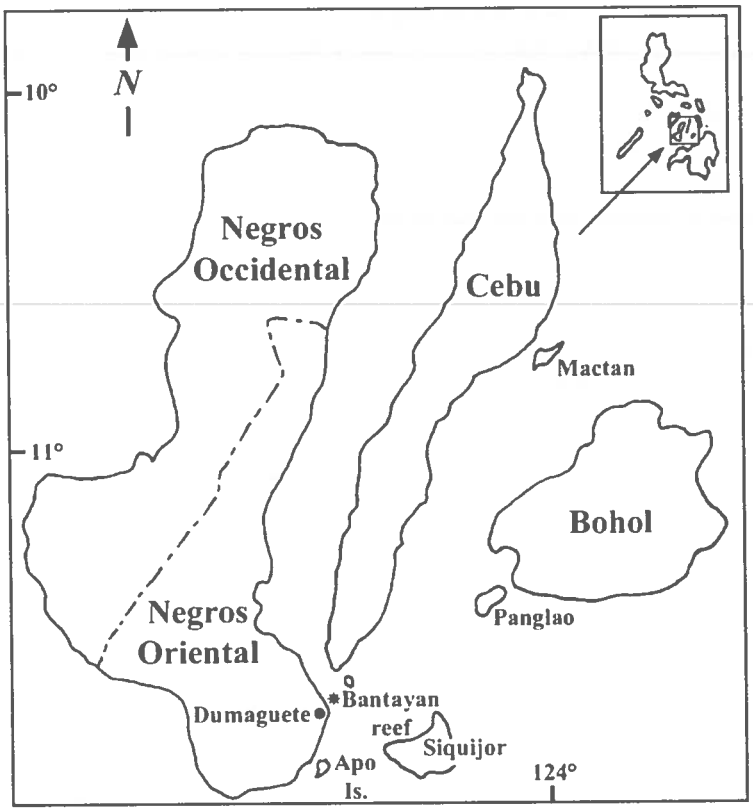

Figure 1 Map of the Central Visayas, Philippines showing the study site at Bantayan reef (marked with asterisk), Dumaguete City. Inset map shows Central Visayas relative to the rest of the Philippines.

histories, reproductive modes, growth forms, and ecological roles that coral species display. In addition, the causes of reef degradation are equally varied, and environmental quality at recipient sites may range from excellent to poor. Rehabilitation technology must, therefore, take into account not only the suitability of a method for the desired species (Clark and Edwards, 1995; Yap *et al.*, 1992), but also its suitability for the site in question and its economic feasibility (Harriot and Fisk, 1988).

In addition, the objectives for transplanting coral must be clearly identified. Efforts by Plucer-Rosario and Randall (1987), Muñoz-Chagin (1997) and Clark (1996) used transplantation to preserve threatened coral communities, by relocating intact coral colonies from areas of high human impact to more protected sites. Results showed highest survivorship of whole colonies transplanted into low-energy environments, indicating that the objective was successful, provided the recipient site was well chosen. Most other efforts have focused on reintroducing coral colonies, or parts of colonies, into degraded areas, to restore some semblance of a coral community. Generally, the results of these studies indicate the following: 1) that differences in life history patterns between species necessitates careful selection of the most suitable species and transplantation method (Clark and Edwards, 1995; Yap *et al.*, 1992; Rinkevich, 1995), 2) that the greatest transplant success has been obtained when the greatest care had been taken with removal, transport and placement of coral colonies or fragments (Birkeland *et al.*, 1979; Plucer-Rosario and Randall, 1987), 3) that survival of transplants was highest in low-energy, protected sites with high water quality (Birkeland *et al.*, 1979; Clark and Edwards, 1995; Clark, 1997; Bowden-Kerby, 1997), and 4) that the cost-effectiveness of a

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project must be considered, as the initial transplantation phase is labor-intensive and post-transplant monitoring is essential to determine long-term success of the effort (Harriot and Fisk, 1988; Clark and Edwards, 1995).

This paper reports the preliminary results of a study using the seeding of juveniles of the scleractinian *Pocillopora damicornis* (Linnaeus) to reintroduce coral onto a degraded site. The purpose of developing and testing this method was to reduce the necessity of damaging intact coral heads by breakage or permanent removal from a source site, while harvesting an abundant source of potential future colonies. Larvae were obtained from wild undamaged adults which were later returned to the reef. *P. damicornis* is particularly suited to such a method because it broods larvae, is ubiquitous throughout the tropical Pacific and is often found in degraded areas. In addition, colonies can be easily maintained in laboratory aquaria. We had two main objectives: to compare settlement success and early survival of larvae seeded directly onto bare reef substrate versus those of larvae settled and reared in laboratory aquaria, and to quantify size-related mortality of laboratory-reared juveniles transplanted onto a degraded reef. We hypothesized that laboratory-reared larvae would exhibit higher settlement and survival and that mortality would decrease with increased size at transplantation. Therefore, rearing of juvenile colonies to a minimum diameter in laboratory aquaria may enhance post-transplantation survival and increase the success of the transplantation effort.

METHODS

The Study Site

This project was carried out at Silliman University Marine Laboratory, Dumaguete City, Central Philippines, and on Bantayan reef (9°18´N, 123°18´E), immediately fronting the laboratory (Figure 1). Bantayan reef is a shallow fringing reef subject to chronic human impact from fishing activity and eutrophication from a nearby polluted stream. Coral patches are found interspersed with seagrass between 5 m and 25 m, with greatest reef development at 15 m. Total hard coral cover was estimated at 33% and rubble/dead coral constituted 42% of substrate type in a recent survey (SUML, 1997). Contamination by *E. coli* was recently estimated to be as high as 194,759 col/100ml (Apao, unpubl.). The fish community is dominated by small pomacentrids and labrids and is marked by an almost total absence of larger predators (SUML, 1997). A shallow nearshore area with a rubble/stone substrate is dominated by small pocilloporids (*Stylophora* spp., *Seriotopora* spp., *Pocillopora* spp.), from which adult spawners were obtained. Deeper reef patches are dominated by *Acropora*, massive *Porites*, and *Millepora*.

Settlement and rearing of *P. damicornis* juveniles in lab aquaria

Spawning of *Pocillopora damicornis* was determined to take place immediately after new moon in the Central Philippines (Raymundo *et al.*, in press). Five adult colonies, >10 cm, were collected from the study reef prior to new moon during February, April, June, July, and October 1997. New spawners were collected each month and the spent ones returned to the reef and reattached using marine epoxy. Larvae were obtained from these adults daily during spawning and settled in laboratory aquaria following methods described in Raymundo *et al.* (in press). Settlement substrate consisted of broken pieces of commercially available coralline tiles (Mactan Stone), conditioned for two weeks in sea water. Four of these pieces were stocked per settlement bowl, providing an average area of 800 cm^2 for settlement, including lateral surfaces. Larvae were settled in the bowls at a density of 20 planulae/500 ml of fresh unaerated seawater at 25–28 °C. Substrates with settled spat were then transferred to aerated rearing aquaria with flowing seawater. Seven-day post-settlement mortality was determined for all larvae settled per month, by censusing settlement plates at one week. Thirty juvenile colonies were selected from the February cohort for weekly growth measurements, using mechanical calipers, for six months. This was determined by obtaining maximum diameter, and diameter perpendicular to maximum.

To compare settlement and survival of larvae settled in the laboratory vs. field, 300 planulae from the June and October cohorts were injected into seeding traps fastened onto bare reef substrate simultaneously with larvae (n=510 for June and n=360 for October) from the same parents settled in laboratory aquaria. Stocking density in the field was 50 larvae per seeding trap. The substrate area available for settlement within these traps was 17.3 cm^2 and the volume of each trap was 700 ml. Water flow through the traps allowed for a higher stocking density than what was considered optimum for laboratory-settled larvae. The traps were left in place for 24 hr, after which they were removed. Substrates in laboratory aquaria and at the field site were censused for coral spat at 24 hr and one week, to determine settlement success and post-settlement mortality.

Size-related mortality of transplanted juvenile colonies

To determine the optimum size at which to transplant laboratory-reared colonies, and test the hypothesis that smaller colonies would show higher mortality, four age/size cohorts (from February, April, June and July) were reared in laboratory aquaria and transplanted in August 1997. It was originally intended that age would determine the grouping of individual colonies, resulting in cohorts of 6 mo, 4 mo, 2 mo and 1 mo of age at transplantation. However, a high rate of fusion between colonies settled in close proximity to each other resulted in an abrupt doubling of size of many colonies. Therefore, size was considered a more appropriate category within which colonies were grouped.

In August, all laboratory-reared colonies were measured with mechanical calipers, to determine maximum diameter and diameter perpendicular to maximum. Four size categories emerged from this census: <3 mm, 3–6 mm, 6.1–10 mm, and >10 mm. Eighty substrate pieces per size category, each containing a single measured colony (for a total of 320 colonies), were labelled with color-coded tags and transported in seawater-filled containers by boat to the transplant site offshore. The site selected was in 5 m of water, 200 m offshore, beyond the area of heaviest wave action during storms and low tide. Three subsites were selected to which colonies were attached: a large overturned table *Acropora*, intact but dead, and two nearby elevated rocks. We selected elevated substrates to reduce the disruptive/abrasive effects of grazing sea urchins abundant in the area. Approximately 27 colonies of each size category were randomly assigned to each of the three areas and fixed in place with Pioneer marine epoxy.

Transplants were censused at two weeks for post-transplant mortality, and at six weeks and four months, for mortality and growth. Additional censuses are planned for six months and one year prior to final analysis using transitional probability.

RESULTS

Planulae of *Pocillopora damicornis* settled in laboratory aquaria showed high settlement success in all months but October (mean ± SD = 52.9% ± 21.9%) and a mean mortality rate of 30.7% ± 14.2% (Table 1). Data suggested some seasonality in settlement success coinciding with numbers of planulae shed, although a large variation was observed each month in total numbers shed per colony (Figure 2). Planulae settled directly onto reef substrate showed much lower settlement success and did not survive in the field (Table 1). During the one-week census in the field in June and October, we observed both an accumulation of coarse sand over the bare rock substrate, and grazing activity by sea urchins. We attributed these two factors to the low survival of settled planulae.

Colonies averaged a monthly increase of 1.5 ± 0.2 mm (mean ± SE) in maximum diameter (Figure 3a) when grown in laboratory aquaria. An acceleration in growth was observed starting at 15 weeks of age (Figure 3b), suggesting that energy allocation for increase in colony diameter is lower prior to this period, when the very young colonies are most susceptible to size-related mortality. Many colonies showed a temporary recession of the growing margin, resulting in a decrease in maximum diameter; we termed this "degrowth". This usually lasted two to three weeks, and all but one colony showed subsequent recovery and a regrowth over the receded margin area.

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Table 1 Settlement success and post-settlement mortarity in *P. damicornis*, (n= 5 colonies per spawning period), laboratory vs. field seeding.

Month	Settl. Succ. (#settled/ #stocked, lab)	Settl. Succ. (#settled/ #stocked, field)	Mortality (#dead in 1 week/ #settled, lab)	Mortality (#dead in 1 week/ #settled, field)
Feb.	320/682 (46.9%)	—	100/320 (31.3%)	—
Apr.	327/500 (65.4%)	—	71/327 (21.7%)	—
Jun.	377/510 (73.9%)	43/300 (14.3%)	182/377 (48.3%)	35/43 (81.4%)
Jul.	400/662 (60.4%)	—	56/400 (11.2%)	—
Oct.	60/360 (16.7%)	30/300 (10%)	23/60 (38.3%)	30/30 (100%)
Mean±SD	52.9%±21.9%	12.15%±3%	30.7%±14.2%	90.7%±13.2%

Several interactions were observed between colonies, including overgrowth of smaller, younger colonies by larger adjacent ones, and ridges forming between colonies of similar size growing up against one another (similar to the "sutures" described by Chadwick-Furman and Rinkevich 1994 and "nonfusion" described by Hidaka *et al.*, 1997). The most common interaction, however, was that of fusion, wherein the margins of two colonies in physical contact with each other would become indistinguishable and the "double" colony would subsequently grow as a single enlarged one. A census of fusion in one-month-old colonies from the February cohort revealed that 43 out of 158 colonies (27.2%) were fusing with adjacent colonies and the average number of colonies per fusion "group" ranged from two to six (mean = 2.69 colonies/group). Periodic observations revealed that fusion continued to occur throughout the six months that colonies were in laboratory aquaria prior to transplantation. Aside from the obvious negative effect of overgrowth on smaller colonies, neither of the other two interactions appeared to have a short-term deleterious effect on either colony involved in the interaction.

Preliminary results of the transplantation experiment revealed a distinct pattern of size-related mortality (Table 2). Mortality was highest within the first two weeks after transplantation in all size

Table 2 Frequency of colonies making state-fate transitions over three sampling periods (State: size category: 1= <3 mm, 2 = 3–6 mm, 3 = 6.1–10 mm, 4 = >10 mm; Fate: 1 = dead; 2 =l ive, growing; 3 = live, exhibiting 'degrowth'; T = total).

	Aug. 11–25					Aug. 25–Sept. 30					Sept. 30–Jan. 9				
	State					State					State				
	1	2	3	4	T	1	2	3	4	T	1	2	3	4	T
Fate															
1	35	26	8	2	71	31	20	13	0	64	12	29	29	23	93
2	45	54	72	78	249	14	26	41	52	133	2	4	29	49	84
3	---not measured---					0	6	17	26	49	0	0	1	6	8
Total	80	80	80	80	320	45	52	71	78	246	14	34	59	78	

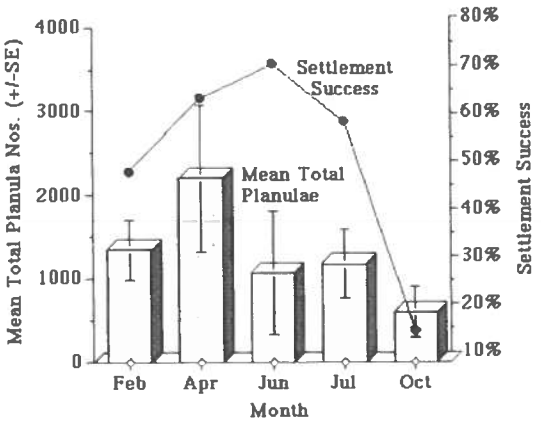

Figure 2 Mean number of planulae released per month (n=5 colonies per month) and settlement success of *P. damicornis* larvae.

groups, but was strongly correlated with size (r^2=99.3% for total mortality at 6 weeks; F=440; p=0.0023; Table 2). Figure 4 illustrates a steady increase in survival from smallest to largest colonies for the first four months. By the third sampling, mortality for the smallest two size categories was almost 100% (97.5% and 93.8% for smallest and next smallest, respectively). Survival continued to be highest in the largest size category, with 55 colonies out of 80 surviving and growing at four months.

Growth data of transplanted colonies was steady for all four size categories, but the largest recruits showed the greatest increase between the six-week and four-month sampling (Figure 5). Colonies in this largest size class resembled the growth form of adult wild colonies (Figure 6) and 25 out of the 55 surviving colonies showed maximum diameters greater than 2 cm. Holloran (1986) found that colonies of *P. damicornis* as small as 2 cm produced viable planulae, although colonies smaller than this were not tested. Based on this figure, the largest of our transplanted colonies may already be of reproductive size, four months after transplantation. Most other colonies would reach this diameter with six months to one year after transplantation. We plan to confirm the production of planulae by the transplants in succeeding months.

We observed an interesting phenomenon which we speculate was a response to transplantation: several colonies showed a decrease in maximum diameter ("degrowth") between measurements made just prior to transplantation and the 6 w measurement. Mortality was inversely proportional to 'degrowth' for the four size categories, with the number of colonies exhibiting 'degrowth' greatest in the largest size category (Table 2). We speculate that this was a response to transplantation stress. 'Degrowth' may enable a stressed colony to lower its energetic requirements, by decreasing colony size. The number of colonies exhibiting degrowth greatly decreased by the third sampling at four months,

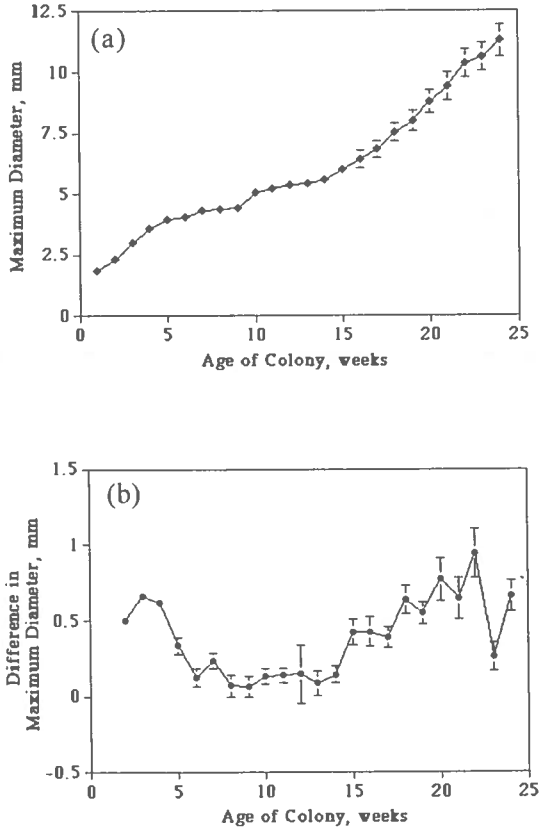

Figure 3 (**a**) Mean growth rate of juvenile colonies of *P. damicornis* (n=30); (**b**) Mean weekly difference in maximum diameter of juvenile *P. damicornis* colonies (mean ± SE; n = 30).

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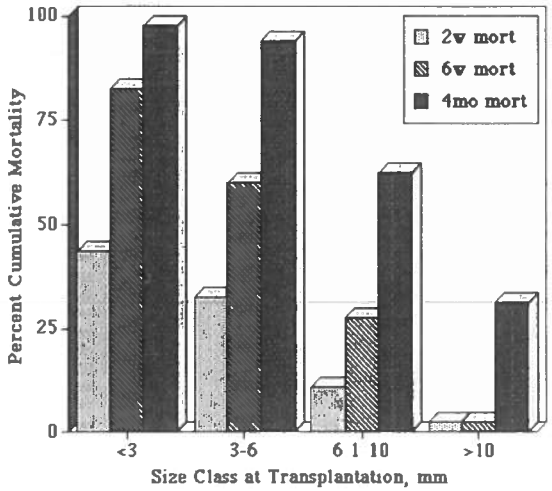

Figure 4 Cumulative size-related mortality of transplanted colonies (n=80 colonies per size class) for three sampling periods of 2 weeks, 6 weeks and 4 months.

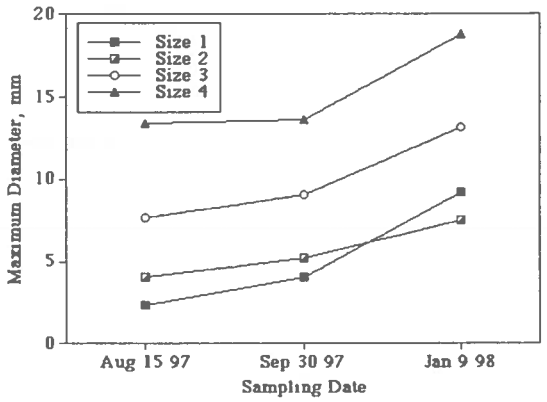

Figure 5 Mean growth of transplanted colonies of four initial size categories (1 = <3 mm; 2 = 3–6 mm; 3 = 6.1–10 mm; 4 = >10 mm).

suggesting recovery from stress by this time. We hypothesized that this response was more common among larger colonies because these were most likely to be able to lose a portion of the colony and still have enough healthy living tissue to remain alive and subsequently recover. Smaller colonies, having less colony surface area, were unable to recover from tissue die-back.

DISCUSSION

Although studies have indicated a high survival rate of transplanted whole colonies (Harriot and Fisk, 1988; Clark, 1997; Muñoz-Chagin, 1997), in many cases of degraded reef areas in the Philippines, it would be both impractical and unfeasible to transplant large, whole colonies. Potential source sites often suffer some disturbance and further degradation by coral removal would be counterproductive. Other intact reefs have been declared marine sanctuaries from which coral may not be removed. Transplantation of fragments may provide a source of asexually-produced colonies, but is best used for branching, broadcasting species, such as acroporids (Rinkevich,1995). Our study has shown that reintroducing small colonies produced from planulae can be successful in terms of survival and potential future reproduction. Early rearing in laboratory aquaria to 10mm diameter increases the probability of survival after transplantation. The rapid growth rate exhibited by this species should result in colonies capable of sexual reproduction within a year after re-introduction. This method, therefore, has the additional advantage of introducing greater genetic diversity to an area via sexually-produced colonies (Rinkevich,1995) which will later reproduce at a fairly small size.

Figure 6 Ten-month-old transplanted colonies of *P. damicornis*, laboratory-reared to six months prior to reintroduction to Bantayan reef. Arrows show position of juvenile colonies.

Coral reef managers and scientists concerned with transplantation as a management option for degraded systems would do well to explore methods and approaches previously developed for terrestrial systems (Rinkevich, 1995; Harriot and Fisk,1988). Analogies between colonial invertebrates and plants have been drawn by many authors investigating immunological systems (Burnet, 1971) and similarities in construction and life history strategies (Harvell and Grosberg, 1988) and the lessons learned in rehabilitating degraded forest areas may well be applicable to coral reefs. The establishment and maintenance of tree nurseries and the use of seedlings to re-establish forest areas are both tried and true technologies which show potential applications to certain species of corals, particularly those of the family Pocilloporidae.

At issue, as well, is the question of what is to be accomplished by a transplantation project. Pratt (1994) makes a careful distinction between restoration, the return of an ecosystem to a pre-disturbance state, and rehabilitation, the re-establishment of specific ecological attributes in a system. Most transplantation efforts would be classified as rehabilitation, rather than restoration. Transplantation would provide increased habitat complexity and genetic and structural diversity. But it would not, in most cases, restore a coral reef to its pre-disturbance condition.

Studies have shown that even a few remaining coral colonies can enhance reef recovery, in terms of both recruitment and survival of new coral colonies (Birkeland,1977; Gittings *et al.*, 1988) and effects on fisheries (Bell and Galzin, 1984; Bowden-Kerby, 1997). Therefore, efforts to reintroduce coral within small-scale protected zones would be justified even though the total amount of coral biomass reintroduced would initially be quite small. A potential target of such efforts might be marine sanctuaries set up by local fishing cooperatives. Coral "planting" or, as Rinkevich (1995) suggested "gardening" would serve to involve local communities in their efforts to manage their resources and increase their fish catch. These communities may, in some cases, be able to provide the large labor investment that many transplantation schemes require in the initial phase and could, with proper training, provide long-term monitoring. Active involvement in management and conservation by the people who use the resources has been consistently shown to be crucial to the success of any conservation effort. Active rehabilitation of coral reefs via transplantation has, in addition, been shown to be one practical solution to the continuing problem of reef destruction.

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