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PRESERVATION OF RARE CORAL SPECIES BY TRANSPLANTATION AND EXAMINATION OF THEIR RECRUITMENT AND GROWTH

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ABSTRACT

Three rare coral species found in Guam's only commercial harbor, which is undergoing a slow degradation caused by harbor pollutants, were transplanted into a bay and a lagoon unaffected by pollution. Each new habitat had three sites located at three depths (1.5 m, 4 m, and 10 m). Three transplant methods were used, fully grown coral heads of different sizes, broken shards, or branches scattered in large numbers, and coral nubbins attached to terra cotta bricks. Growth and survival were recorded over a 12 month period. Results showed that transplanting heads (regardless of size) was the best method for percent survival, mortality, growth rate and cost effectiveness. Controls showed the highest survival and growth rate for all species. The deepest sites had the least mortality for both habitats. Survival at the shallowest sites, which had the greatest mortality, was affected by wave action and light intensity.

The expanding population and economy of Guam are placing increased demands on its coastal regions and marine resources. Economic development of coastal areas and in Apra Harbor, Guam's only deep water port, has caused environmental degradation to these areas. The biological portion of a study sponsored by the U.S. Army Corps of Engineers (1977) identified three species found in Apra Harbor and nowhere else on Guam. These species are *Pavona cactus* Forskal, 1775, *Leptoseris gardineri* van der Horst, 1921, and *Montipora pulcherrima* Bernard, 1897.

Observations of the coral mounds located at the western end of Piti Channel on 8 September 1977 revealed that most of the *Pavona cactus* colonies, as well as other species of corals, were in a state of stress. The stress appeared to be caused by heated water discharged by the Piti and Cabras power plants combined with the effects of a series of low spring tides that occurred during mid-day insulation. Subsequent observations of these coral mounds revealed that the stressed condition occurs annually during the late summer months. After each period of stress, many of the *P. cactus* colonies fail to recover.

At the present level of thermal stress, the *P. cactus* coral mounds located at the western end of Piti Channel will probably be destroyed within a few years. The cumulative or synergistic effects of further development in Apra Harbor could place the other two rare species of corals in jeopardy, particularly since the only locations where they are known on Guam at present are also the areas of the harbor most likely to be affected by future development.

By transplanting rare corals to habitats away from development sites, it may be possible to save them from local extinction. Birkeland et al. (1979) employed three methods of transplanting corals at Tanguisson Point, Guam, to determine whether or not a coral reef community could be reestablished in a power plant thermal effluent area. The Birkeland et al. study showed that transplanted coral colonies in high energy environments lack stability. To test transplant success in lower energy environments, a limited number of *P. cactus* colonies from Piti Channel in Apra Harbor were transplanted to the protected waters of Cocos

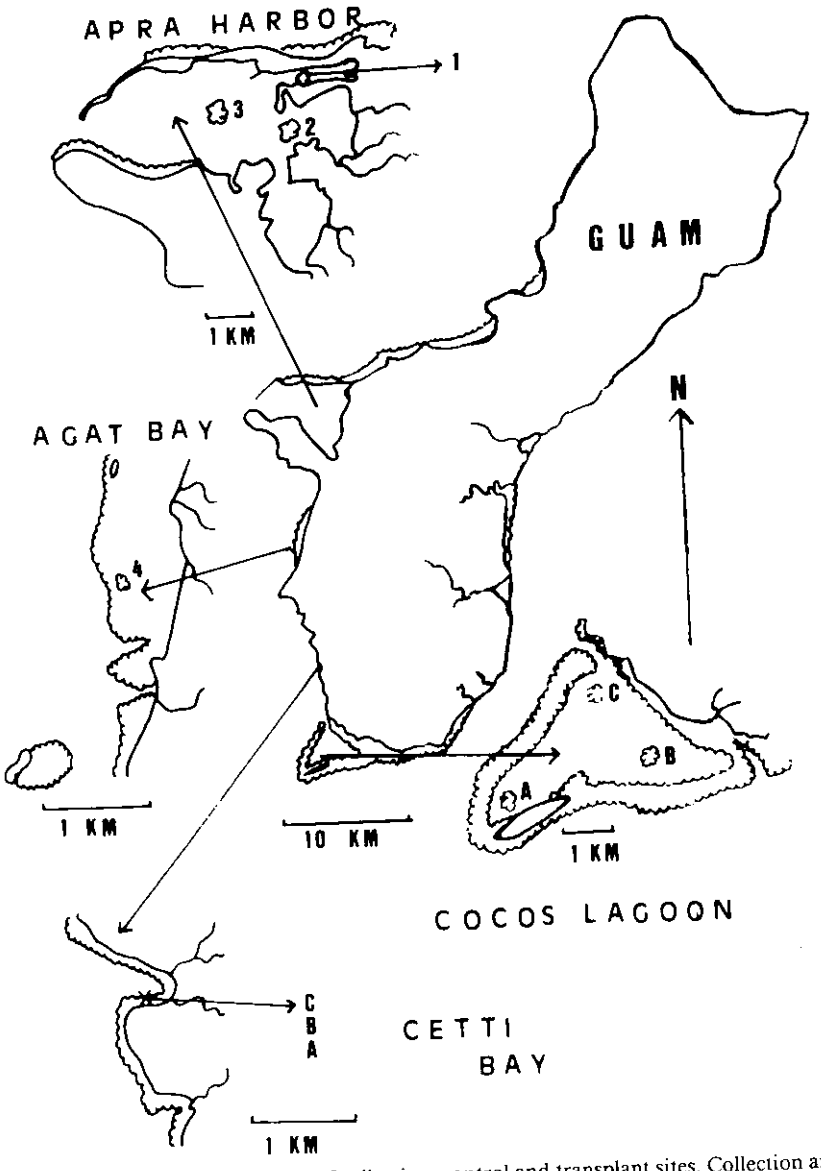

Figure 1. Map of Guam with insets of collection, control and transplant sites. Collection and control sites: (1) *Pavona cactus*, (2) *Montipora pulcherrima*, (3) *Leptoseris gardineri*, (4) *Acropora echinata*. Transplant sites: (A) shallow, (B) intermediate, (C) deep.

Lagoon. This preliminary study revealed that transplanting *P. cactus* was successful even though only a few whole colonies were transplanted.

Other studies on coral transplanting have been conducted in Kaneohe Bay, Hawaii, by Maragos (1974) and in central Visayas, Philippines, by Auberson (1982). Both of these studies were principally designed to preserve and shorten recovery time of coral reefs damaged by human activities.

In this study specimens of rare coral species were transplanted to Cocos Lagoon and Cetti Bay along the southwest coast of Guam (Fig. 1). The purpose of the

study was to determine whether or not these corals could be successfully established in habitats where they presently are not found, before they are eliminated from their natural habitats in Apra Harbor and near Nimitz Channel by stress related to economic development. The project took place from June 1981 to May 1982.

Materials and Methods

Transplant Species.—Three of the transplant species proposed for this study, *Pavona cactus, Montipora pulcherrima,* and *Leptoseris gardineri,* are found only in Apra Harbor. Although a fourth species, *Acropora echinata* (Dana, 1846), is widely distributed throughout other Indo-Pacific reef systems, it is only known to occur as a few isolated patches along the southwest coast. For this study it was collected from a small reef-flat hole near Nimitz Channel. Since this location has been proposed for the development of the Agat Bay Small Boat Marina, this coral is under similar threats of environmental degradation as the other transplant species from Apra Harbor.

Transplant Collection and Control Sites.—*P. cactus* is found at the western end of Piti Channel at 1–4 m in depth where it forms scattered monospecific mounds 1–2 m high. *M. pulcherrima* is found in patches and as isolated colonies on the slopes of patch reefs 3–10 m deep in the western part of Sasa Bay. *L. gardineri* is found in isolated patches along with individual colonies on the deep slopes of the Western Shoals patch reefs at 10 to 40-m depth. *A. echinata* was found as a single large patch on the sandy floor of a reef-flat hole at 5-m depth about 200 m north of Nimitz Channel along the southwest coast. The transplant collection and control sites are shown in Figure 1.

Transplant Sites.—The corals from various locations in Apra Harbor and the reef-flat hole north of Nimitz Channel were transplanted to six sites, three in Cocos Lagoon and three in Cetti Bay (Fig. 1). At Cocos Lagoon, Site A is located at the western corner of the lagoon in water 1–2 m deep on a rubble and sand veneered reef rock substrate, Site B is located at the eastern corner of the lagoon in water 3–5 m deep on a rubble and sand floored depression on the surface of a small patch reef, and Site C is located at the northern corner of the lagoon in water 10–12 m deep on the upper surface of a low mound composed of coral rubble. At Cetti Bay the three sites are located on a reef slope situated along the south side of the bay at depths and on substrates comparable to those described for the Cocos Lagoon sites (Site A as the upper, Site B on the middle, and Site C on the lower reef slope). At all six transplant sites, habitats were selected where existing communities of corals are currently found.

Transplant Methods.—In an attempt to discover what size each coral must attain before being relatively safe from factors that cause mortality or prevent recruitment, we transplanted each of the four coral species in a series of sizes to each habitat using the three methods described by Birkeland (1976) and Birkeland et al. (1979). These methods are: (1) to transplant fully grown coral heads of different sizes; (2) to transport heads to the site, then break them up and scatter the shards, chips, or branches in large numbers into an area; and (3) to transplant coral nubbins attached to terra cotta bricks.

Ten coral heads of each of three size classes (5–10 cm, 10–15 cm, and 15–25 cm) of *P. cactus, M. pulcherrima,* and *L. gardineri* were transplanted to each of the six sites. Only five of each size class of *A. echinata* were transplanted because of its very limited distribution. The coral heads were removed from the control sites, placed in a large plastic tub of seawater, and transported by boat to the transplant sites. After a period of acclimatization (1–3 months) at least six heads of each species at each site were stained in situ in plastic bags using Alizarin Red S bone stain (Birkeland, 1976). The stained corals were then marked by attaching a length of plastic coated wire to the basal parts of the colonies. For controls, a total of 46 *P. cactus,* 40 *M. pulcherrima,* 24 *L. gardineri,* and 5 *A. echinata* heads were treated to similar periods of boat transport and then replaced at the control sites, and then at least 10 of each species (six of *A. echinata*) were stained in situ.

Seven terra cotta bricks with eight attached coral nubbins were prepared for *P. cactus, M. pulcherrima,* and *L. gardineri,* and then placed at each transplant site. Only two bricks with eight attached pieces of *A. echinata* were placed at each site. Preparation of the bricks necessitated transporting coral heads from the collection sites to outdoor concrete holding tanks at the University of Guam Marine Laboratory. One day was allowed for the heads to acclimate, then they were stained in the tanks with Alizarin Red S bone stain for 5–7 h. The following day they were broken into nubbins (3–6-cm-sized pieces) and attached to terra cotta bricks using "Sea Going Epoxy Putty." The next day they were returned to the plastic tubs and transported by boat to the transplant sites. Four bricks of each species (two only for *A. echinata*) were similarly treated and transported to the control sites.

Shards of each coral species, except *A. echinata,* were scattered about in the vicinity of the heads and nubbins at all of the transplant sites. Colonies were collected from the control sites and transported in plastic tubs by boat to the transplant sites where they were then broken into 2–4-cm-sized pieces. Two hundred shards were then scattered about over a 5–15 m^2 area at each site.

Monitoring.—Each site was monitored twice a month, alternating between Cocos Lagoon one week and Cetti Bay the next. Vitality or health of the transplanted corals was recorded on a relative scale as follows: 0 = healthy, 1 = stressed-slight discoloration of soft tissues, 2 = stressed severe discoloration of soft tissues, 3 = <half of colony dead, 4 = ≥half of colony dead, 5 = entire colony dead, and X = colony missing.

Since transplanting times of each species occurred on different dates scattered over a 3-month period, each was monitored a different number of times. Where particular conditions caused a coral's survival or death, it too was noted. Shards were recounted only once at the conclusion of the project. Statistical analyses were performed on the health data and on mortality data (dead vs. living).

Growth Measurements.—At the conclusion to the project, all surviving stained heads and nubbins were returned to the laboratory and bleached. Growth was measured from the leading edge of the stain to the tip of the coral. When possible six replicate measurements were taken for each individual head and nubbin.

Results and Discussion

Numerous treatments were tested in this project: four coral species, three methods of transplanting the corals, two bays in which they were transplanted, and three depths within each bay. These treatments are analyzed separately in this section.

Coral Species.—*P. cactus* showed the greatest health (as rated on the scale 0 = healthy through 5 = dead) and lowest mortality (dead vs. living) at all depths, bays, and for all methods (Table 1). The only exception was that the *M. pulcherrima* shards had a higher percent survival at Site C in Cocos Lagoon. Although survival was high in all treatments it was highest in Cocos Lagoon at Site C, using the head transplantation method. It should be noted that this species had the second highest number of missing heads; however, of those that were found, survival and health were far greater than for any other species.

A. echinata had the second lowest mortality and highest health over all treatments. It also had the fewest number of missing heads and nubbins at the conclusion of the project, and was the only coral which did not show an early major decline in survival. *A. echinata* showed a preference for the deeper sites, Cocos Lagoon, and the head transplant method.

M. pulcherrima and *L. gardineri* both had extremely high mortality through all treatments. Both had a higher survival in the deep site (C) of Cetti Bay using the head method of transplanting.

All corals except *A. echinata* showed an initial sharp decline in survival, which then tapered off to a more gradual decline. *P. cactus* showed this decline in the shallow sites (A) but where there was a high survival (sites C and sometimes B) the decline was more gradual and occasionally nonexistent.

Methods.—There was a large difference in coral mortality between methods. All species showed a greater survival using the heads method, and this was true regardless of depth or bay (Table 1). This was tested using only those corals which were identifiably dead or alive; all missing corals were discounted. Most missing corals were heads. This would be expected since nubbins were attached to bricks, and although a few nubbins were broken off and lost, only five bricks were lost. Throughout the duration of the project, it was noted that when a coral died, it soon became indistinguishable from the surrounding coral rubble because of filamentous and encrusting algae. This tended to mask many corals which, although "dead," had to be labelled "missing," thereby decreasing the number of "dead" corals. Although the actual number of living corals was higher for the heads method, this method would show lower mortality, as many missing corals were actually dead, and by discounting them, the final mortality figures were skewed.

Table 1. Percent survival of transplanted and control corals. Control and mean percent survival placed in the column for Site A for convenience. N = nubbins, H = heads, S = shards, NU = method not used. G statistic (Sokal and Rohlf, 1969) computed from a 3 way anova (non-parametric). df = degree of freedom, * $P = 0.025$, *** $P = 0.005$

Site	A			B			C		
Method	N	H	S	N	H	S	N	H	S
Pavona cactus									
Cocos Lagoon	64.2	26.6	6.0	53.5	56.6	33.5	98.2	86.6	15.0
Cetti Bay	14.2	40.0	15.0	37.5	20.0	3.0	57.0	83.3	8.5
Mean	54.1	52.1							
Control site	100	89.1	NU						
	df = 2 Depth/Mortality					G = 38.64***			
	df = 1 Method/Mortality					G = 31.14***			
Montipora pulcherrima									
Cocos Lagoon	0	10.0	0	9.6	26.6	3.0	32.1	73.3	21.5
Cetti Bay	1.8	10.0	0.5	8.1	43.3	4.5	0	50.0	1.5
Mean	8.6	35.5							
Control site	83.4	50.0	NU						
	df = 2 Depth/Mortality					G = 39.98***			
	df = 1 Method/Mortality					G = 154.58***			
Leptoseris gardineri									
Cocos Lagoon	0	0	0	0	16.6	0	21.4	76.0	11.5
Cetti Bay	14.2	36.6	0	10.7	13.3	2.0	12.5	30.0	4.5
Mean	14.7	34.5							
Control site	98.8	83.3	NU						
	df = 2 Depth/Mortality					G = 28.92***			
	df = 1 Method/Mortality					G = 124.64***			
Acropora echinata									
Cocos Lagoon	81.2	46.0	NU	25.0	46.0	NU	75.0	93.3	NU
Cetti Bay	0	13.3	NU	12.5	53.3	NU	37.5	6.6	NU
Mean	46.2	43.0							
Control site	75.0	70.0	NU						
	df = 2 Depth/Mortality					G = 8.83*			
	df = 1 Method/Mortality					G = 11.1***			

It would not be valid to assume that all missing corals were dead, so looking at mortality as a test of a superior method would not be useful. Percent survival data would, however, show which method was superior, and showed that the heads method, with 39.88% survival, was higher than that of nubbins (27.75%), and shards (7.22%). For a more detailed breakdown of percent survival for each treatment, see Table 1.

Size.—The heads were transplanted in three size classes. When resulting mortality was statistically analyzed, no significance was found for the treatment ($\chi^2_{(2)} = 3.48$).

Bay.—The two corals which showed the lowest mortality, *P. cactus* and *A. echinata*, both showed their lowest mortality in Cocos Lagoon. *Montipora pulcherrima* and *L. gardineri*, which had the highest mortality, showed somewhat lower mortality in Cetti Bay than in Cocos Lagoon. However, this is only when discounting missing corals. Many more corals were lost at Cetti Bay, so few were found dead. There were actually more living corals of these two species in Cocos Lagoon, but so many were present and dead that testing living against dead gave a skewed

result. Total number of surviving corals was higher for all species in Cocos Lagoon (Table 1).

Depth.—The deepest site (C) had the lowest mortality for all species and methods. In both bays Site A showed the greatest mortality, caused by strong currents and wave action which scattered the corals, causing most to be lost, and the rest to be severely broken up and scoured. Also, *M. pulcherrima* and especially *L. gardineri* showed a great sensitivity to light intensity at all depths, particularly the shallow sites (A). In Cocos Lagoon, only *P. cactus* nubbins survived well at this depth; almost all other nubbins at this site were killed (Table 1). In Cetti Bay only those corals lodged in crevices survived the currents. It was even more important for *M. pulcherrima* and *L. gardineri* to be lodged and shaded, as those lodged in a crevice but open to sunlight died.

Growth.—Table 2 compiles mean growth rates per month for all treatments. Many of the stained corals died or were missing at the end of the project, but only *P. cactus* heads from Site C in Cocos were obviously adversely affected by the stain. Most of them were more than half dead within 2 weeks of being stained, though all recovered. Only from *P. cactus* were growth measurements obtainable for all treatments. The lack of measurable growth in many of the samples (designated as "0" in Table 2) was a result of the stain not showing a distinguishable line from which to measure growth. This could be attributed to either of two reasons: during staining the corals did not grow sufficiently to incorporate enough stain; or, some stain was incorporated, but there was a lack of sufficient growth after the stain was incorporated. In most cases, stain was clearly not picked up in sufficient quantity to distinguish a pink line from which to measure growth. In no sample was a stain line visible without accrued growth. In a few cases, new growth had obviously occurred even without a stain line, such as covering the epoxy or growing over the brick.

The corals were stained after they had been in the field a number of weeks and were presumably no longer under extreme stress. All corals were stained over a 24-h period, which should be sufficient (Birkeland, 1976). The controls were stained in the same manner, yet picked up sufficient stain. Therefore, the transplanted corals in Cocos Lagoon and Cetti Bay must have been under stress even after being in the field a few weeks, which slowed their growth, restricting their incorporation of stain. This point is also apparent when noting that corals from sites A and B had fewer samples with measurable growth than those from Site C. The shallower sites also had lower survival rates in most cases than Site C for all corals. *P. cactus* had the highest growth rate, followed by *A. echinata, L. gardineri,* and *M. pulcherrima* (Table 2). It should be noted that the same order of corals was shown in survival and mortality data. None of the transplanted species had growth rates equivalent to the controls; all averaged approximately ½ to ¾ of the control growth rates. *P. cactus* was the only coral whose nubbins grew consistently faster than its heads; all other corals had faster growth of their heads. This data is in accordance with survival data between methods. All species except *M. pulcherrima* grew faster in Cocos Lagoon than in Cetti Bay.

CONCLUSIONS

Using percent survival, mortality and growth rate as indicators, the method of transplanting heads, regardless of size, was shown to be a better method than transplanting nubbins or shards. This method also takes fewer man hours, as no time is spent bringing corals to the lab, breaking them into nubbins and attaching

Table 2. Monthly mean growth rate of stained corals. Control growth rates and mean growth for the coral species are placed in column A for convenience. -0- indicates no samples with measurable growth, A, B, and C transplant sites, N = nubbins, H = heads. Growth in millimeters. Numbers in brackets beside growth rates give standard deviation

	Transplant Site	A		B		C	
	Transplant Method	N	H	N	H	N	H
Pavona cactus	Cocos Lagoon	1.35 [0.85]	0.66 [0.07]	1.48 [0.88]	0.84 [0.23]	1.29 [0.40]	0.62 [0.31]
	Cetti Bay	0.78 [0.38]	-0-	0.50 [0.36]	0.33 [0.09]	0.68 [0.30]	0.50 [0.25]
	Mean	1.01 [0.52]	0.59 [0.19]				
	Control site	2.26 [0.68]	1.73 [0.62]				
Montipora pulcherrima	Cocos Lagoon	-0-	-0-	-0-	-0-	0.50 [2.1]	0.65 [0.32]
	Cetti Bay	0.35 [0.10]	-0-	-0-	0.75 [0.21]	-0-	0.55 [0.17]
	Mean	0.43 [0.15]	0.65 [0.23]				
	Control site	1.05 [0.53]	0.99 [0.46]				
Leptoseris gardineri	Cocos Lagoon	-0-	-0-	-0-	1.19 [0.27]	0.81 [0.03]	1.21 [0.53]
	Cetti Bay	-0-	-0-	-0-	0.61 [0.16]	-0-	0.81 [0.05]
	Mean	0.81 [0.03]	0.96 [0.25]				
	Control site	1.39 [0.48]	1.64 [0.28]				
Acropora echinata	Cocos Lagoon	-0-	1.49 [0.57]	-0-	-0-	0.64 [0.28]	2.27 [0.58]
	Cetti Bay	-0-	-0-	-0-	1.24 [0.65]	-0-	-0-
	Mean	0.64 [0.28]	1.66 [0.60]				
	Control site	1.20 [0.74]	2.00 [0.88]				

them to bricks, nor is it necessary to break up large corals into small shards. Since there is no need to buy bricks or epoxy, it is also far less expensive than the nubbin method. With the head size being unimportant to survival, future transplanting projects would not need to break up heads into particular sizes, saving time as well as stress on the coral. Heads could be taken intact and transplanted. Where space is limited (in the transportation used), small heads could be chosen exclusively.

It is apparent that different coral species react differently to being transplanted. *P. cactus* was the fastest growing coral, and had a higher survival. The other corals grew more slowly and showed a higher mortality. In all cases the controls showed the fastest growth and highest survival. Where possible, environments similar to the home site should be chosen for the transplant sites. Both *P. cactus* and *A. echinata* originally grew in shallow clear waters, and except where strong currents were found, did relatively well at all sites in both bays. *M. pulcherrima* was found in shallow highly turbid water (caused by suspended particles), and when transplanted only did well where shaded from direct sunlight or where deep enough to live in well filtered sunlight. *L. gardineri* is found at 30 m in depth where light is very dim. Consequently, it too showed survival only at the deep sites, or when shaded within a crevice. Often, the top sections would die, while living tissue was found by turning the coral over. In effect, *L. gardineri* used itself to shade living polyps. Where only areas with strong currents or wave action are available, either tying them to an immobile surface, or lodging them in crevices is necessary.

The two main problems encountered in this project were the lack of stain incorporation in some coral species, and the great number of missing coral heads. Both problems could easily be rectified in future projects of this kind. A test of stain incorporation should be performed to evaluate the amount of time necessary for a particular species to pick up the stain. This staining should be performed at the home site before transplantation, greatly reducing stress on the coral, with transplanting of the stained corals occurring a week or two later. When using the heads method, the heads should be tied down to a permanent or artificial substrate (Birkeland et al., 1979; Maragos, 1974; Auberson, 1982). This would not only keep the corals in place, but make them identifiable after death when they tend to blend in with the surrounding rubble. Although this would add man hours to using this method, future evaluation of survival would be greatly simplified. This would not be necessary when there is no need for future statistical evaluation since survival is high even without this precaution. Survival would be enhanced by choosing the right environment for the coral species, as was also noted in Maragos (1974) and Auberson (1982).

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