THREE METHODS OF CORAL TRANSPLANTATION FOR THE PURPOSE OF REESTABLISHING A CORAL COMMUNITY IN THE THERMAL EFFLUENT AREA AT THE TANGUISSON POWER PLANT

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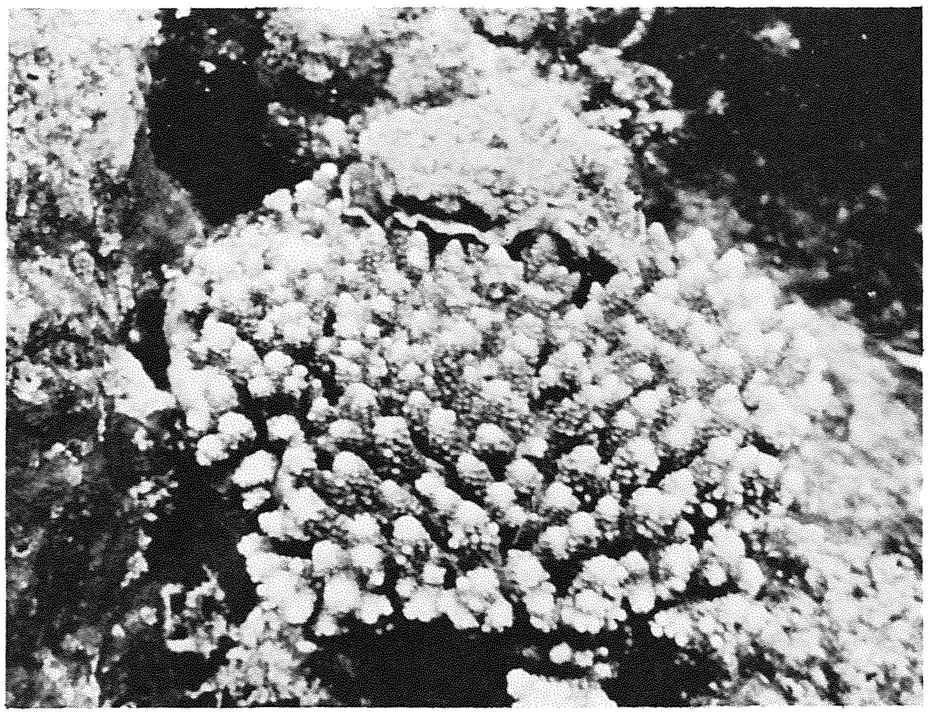

UNIVERSITY OF GUAM MARINE LABORATORY

Technical Report No. 60

November 1979

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Abstract

Six-hundred forty-three coral colonies or separate branches were transplanted to the reef margin at Tanguisson: 326 in the thermal effluent area and 317 in a nearby control area free of the effects of thermal effluent. After periods of heavy wave action, such as Tropical Storm Tip, only 138 (21.5%) of the corals remained attached. Eighty-seven coral colonies were transplanted to a protected harbor area where 55% of the corals remained attached after 1 yr. Seed populations of Pavona frondifera were successfully started at Western Shoals and at three sites in Cocos Lagoon. The P. frondifera was transplanted to other sites because it was feared that the only population on Guam (the population near Commercial Port) was in danger of extinction because of proposed dredging operations for port expansion. Our transplant methods were successful in establishing small populations in low-energy environments. Our studies showed that to establish large populations or to reestablish a large area of reef in a high-energy environment is economically unfeasible. Transplantation is a potentially effective method of saving populations from extinction or for reestablishing coral communities in sheltered areas, but it is not a practical method for reestablishing coral communities on reef margins of the exposed coast.

Corals became permanently reattached when transplanted to the surfaces of relatively fast-growing coral colonies because the underlying colonies became attached to the transplanted colonies by overgrowth of the bases of transplanted colonies. Transplanted colonies did not reattach themselves by growth at their basal ends during our study, although a separated Acropora branch reattached by growth from its broken basal end. The stocks for coral populations can be transplanted to healthy coral communities, but not to areas affected by thermal effluents, because living resident coral colonies are the most effective mechanism for permanent reattachment.

Nearly all corals transplanted to the thermal effluent area at Tanguisson died (3% survival) and those remaining alive were in poor health. There was 95% survival in the control area (free of effects of thermal effluent); the survivors all appeared in good health and some colonies became permanently reattached to resident colonies. Even the coral species determined to be the most tolerant of high temperatures in laboratory experiments were killed by the thermal effluent, but survived in the control area.

The growth rates of Pocillopora damicornis colonies differed significantly, but there was no significant regression of colony growth rate on colony size.

Abundant natural recruitment of corals by settling planulae occurred during the dry season in the peripheral zone of the thermal effluent area, but these recruiting colonies were killed during the wet season. The total area of thermal effluent effects has remained about the same over the previous 8 years, but the margin of the area fluctuates back and forth. The question that remains to be answered is whether the reef frame in the

thermal effluent area is undergoing internal erosion by boring organisms and solution, and thereby weakened to the extent that physical disintegration by wave action would become more severe than in nearby control areas.

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INTRODUCTION

With increasing frequency, economic coastal development for transportation or power facilities comes into conflict with preserving natural habitats for recreational purposes, for promoting tourism, for rare or endangered floral and faunal species and for many aspects of maintaining a balanced and healthy ecosystem. Any solution to this conflict must involve some compromise because we need transportation and power facilities but we must also be responsible for assuring that a supply of natural resources and a properly balanced ecosystem exist for future generations. The alternatives are not in terms of keeping one at the expense of the other. Both are essential. So we must work out a modification of the overall plan to allow for both aspects of the problem to be taken into account.

A point of concern with the Tanguisson Power Plant that had been raised by the Guam Environmental Protection Agency was the negative effects of the thermal effluent on the shallow coral reef communities. There were at least two sorts of arrangements that might have potentially allowed for both the activities of the power plant and the existence of a coral reef community. One was to pipe the thermal effluent offshore into deeper water for release in order to relieve the thermal stress on reef margin organisms and to provide a quicker and more efficient mixing of the thermal effluent. A second procedure that might have been thought to have had the potential of allowing for the presence of the power plant was to transplant species of reef-building corals with relatively high thermal tolerances. This would not reestablish the original coral reef, but it might have established a substitute coral reef with a reasonable alternative for a set of species. This potential solution to a conflict seemed plausible, but it had not been tested for areas affected by thermal effluents.

The concept of using transplantation as a mechanism for management of our marine resources is not new (Marx 1967:55, Kelly et al. 1971, Thorhaug 1974). The restocking of damaged reefs with corals has been suggested by several authors (Shinn 1972, Hubbard 1974, Maragos 1974, Johannes 1975, Neudecker 1977) as a means of repairing man-made damage. The establishment of reefs is sometimes prevented by problems for coral recruitment rather than adult survival (Birkeland 1977, Randall and Birkeland 1978), so if adult coral colonies are transplanted, the reef may recover where it otherwise could not have recovered. The field studies by Maragos (1974) demonstrated the effectiveness of coral transplantation as a method of preserving and creating coral reefs in areas where natural recovery or establishment is likely to fail.

Maragos (1974) has used coral transplantation as a method of enhancing recovery of coral reefs that have been damaged by sedimentation and sewage. Randall and Birkeland have used coral transplantation to preserve an endangered species on Guam in 1977; the results are presented in this report. In 1979, we transplanted corals into areas subjected to thermal effluent near the Tanguisson Power Plant thermal effluent in an attempt to reestablish a reef community where it used to exist. In this report, we present the findings of this research.

The primary goal of this project was to determine whether a coral reef community could indeed be reestablished in the thermal effluent area. Three methods of coral transplantation were used and the methods were compared in terms of their relative reliabilities for successful transplant results and in terms of their relative cost (man-hours, equipment, boat-time). The results were then analyzed in terms of the comparative cost-benefit ratio of the three methods. To effectively transplant corals, we should transplant them at an age or size at which they have the greatest growth potential. To determine the size of colonies with the greatest growth potential, we measured the growth of coral colonies or branches of different initial sizes. The results are presented in this report.

METHODS AND MATERIALS

Corals were collected for transplantation and placed directly in buckets of seawater. The buckets were immediately transported by boat from the collection sites to the transplantation sites or transported by truck to the Marine Laboratory and held in an outdoor, continuous flow seawater system, shaded by plastic screening from direct sunlight.

A total of nineteen species of hermetypic or reef-building corals were chosen for transplantation. Selections were based on the thermal tolerances of coral species found in laboratory studies by Jones et al. (1976) and on the general morphology of the colonies. The branching and mounding growth forms were selected which could be most easily tied to the reef. Coral species were also chosen on the basis of fast growth rate and ability to cement themselves to the substratum when whole or fragmented.

Three methods of coral transplantation were used. The first method was to remove entire coral colonies or branches from the reef substratum and tie them with plastic-coated electrical wire at the experimental and control sites. The wire was wrapped around heads and through branches in such a way as to minimize abrasion to coral tissue. Corals were tied to the reef through holes, around knobs, and on shelves of the substratum.

The second method was to scatter shards (or pieces) of corals. Corals were transported to the transplant locations, broken into pieces with hammers and chisels, and scattered by hand at each area.

The third method was to transplant coral nubbins of different ages and size classes to determine survival, recruitment, growth rates, and whether planulae of the same species could be induced to settle from the plantation to the area. For this experiment, corals were transported to the laboratory where they were broken into nubbins and mounted on terra cotta bricks with underwater epoxy putty (cf. Birkeland

1976). The nubbins were stained with Alizarin red S, a medical bone stain, to monitor growth and survival. The stain was prepared in a closed aquarium with circulating sea water. Mounted nubbins were exposed to the stain for eight hours, returned to normal seawater, and transported to the field location the following day.

STUDY SITES

Transplantation experiments were set up near the power plant at Tanguisson, in Apra Harbor, and in the lagoon between Guam and Cocos Island (Fig. 1). Corals to be transplanted were collected from Tumon Bay (Fig. 1), from a reef flat just north of the Tanguisson Power Plant (Fig. 2) and from several locations in Apra Harbor (Fig. 3), including Sasa Bay, the Gulf Pier, inside the Glass Breakwater, and near the entrance of Piti Channel from Commercial Port.

Three locations were established as study sites for transplantation, one experimental and two control. Two sites were near the Tanguisson Power Plant. The experimental area was in a surge channel directly seaward of the power plant discharge (on Transect B as described by Jones et al.(1976). The experimental area was divided into four zones of increasing distances from the heat effluent. The first zone on the reef flat was immediately adjacent to the thermal outfall and received the most extreme and continuous elevations in ambient temperatures. The next three zones, called the "inner mixing zone", the "outer mixing zone" and the "peripheral zone", respectively (Fig. 4), were each divided into three depths, 0.3 m, 1 m, and 3 m in reference to lower low water tide level.

The inner mixing zone on the reef margin continually receives heated water at all depths (Fig. 4). This zone is additionally stressed by heavy pressure from wave action breaking on the reef. In the outer mixing zone, the water is usually stratified. the upper layer warmer than the lower 2 layers of ambient sea temperature. This zone will be stratified except during times of storm and heavy seas. The peripheral zone has a thin layer of warm water on the surface which is mixed with the lower normal temperature water only during extreme sea conditions. Corals were tied to three depths on the walls of the channel and on reef rock pillars projecting up from the middle of the channel.

The second site at Tanguisson, a control, is located just north of the effluent along Transect A established by Jones et al. (1976). Corals were tied on the north face of the reef contour. Zones and depths of coral transplants were comparable to those in the experimental area.

A second control area was established in Apra Harbor, at Western Shoals, on the reef platform at a depth of 1 m and on the reef slope at 8 m, and along the inside of the Glass Breakwater in 3 m of water.

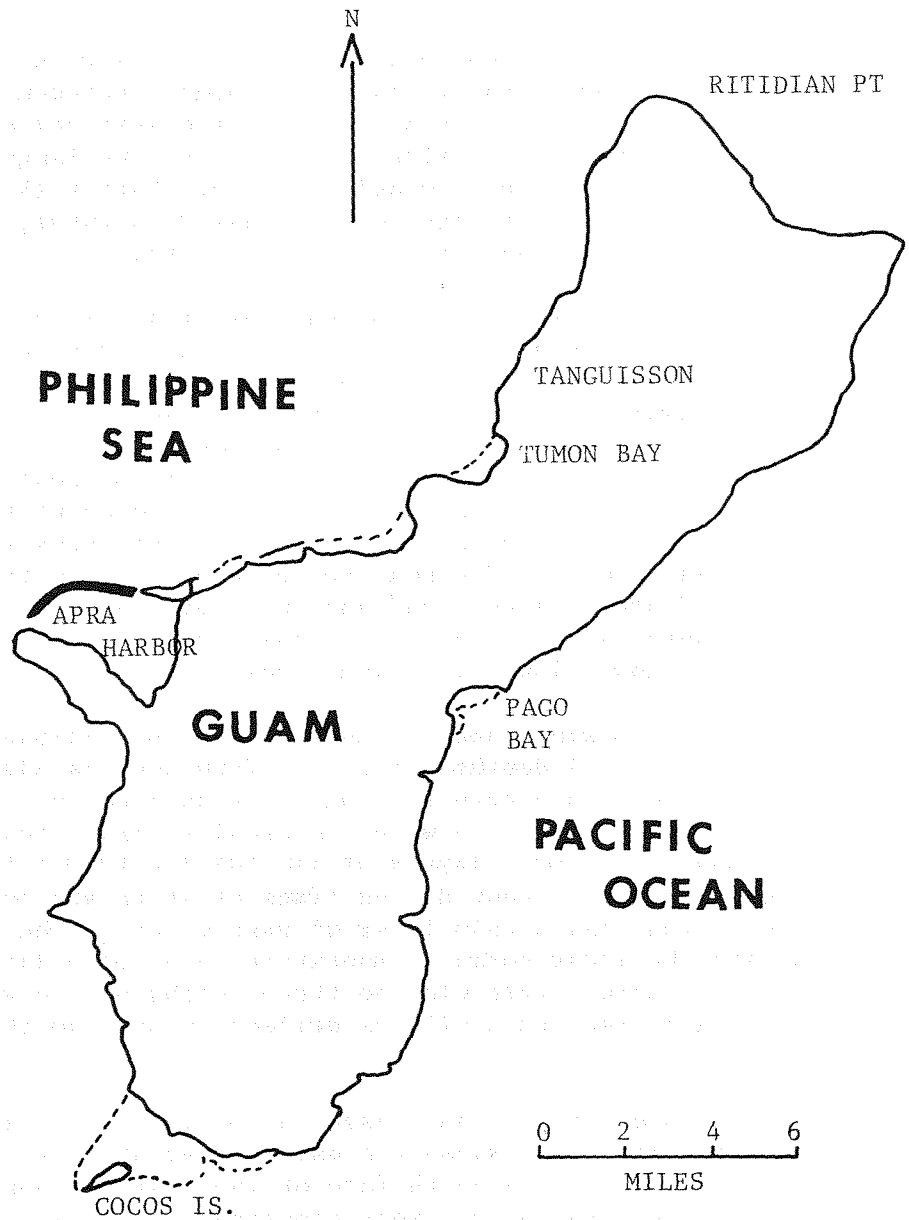

Fig. 1. Location map of Guam showing study areas.

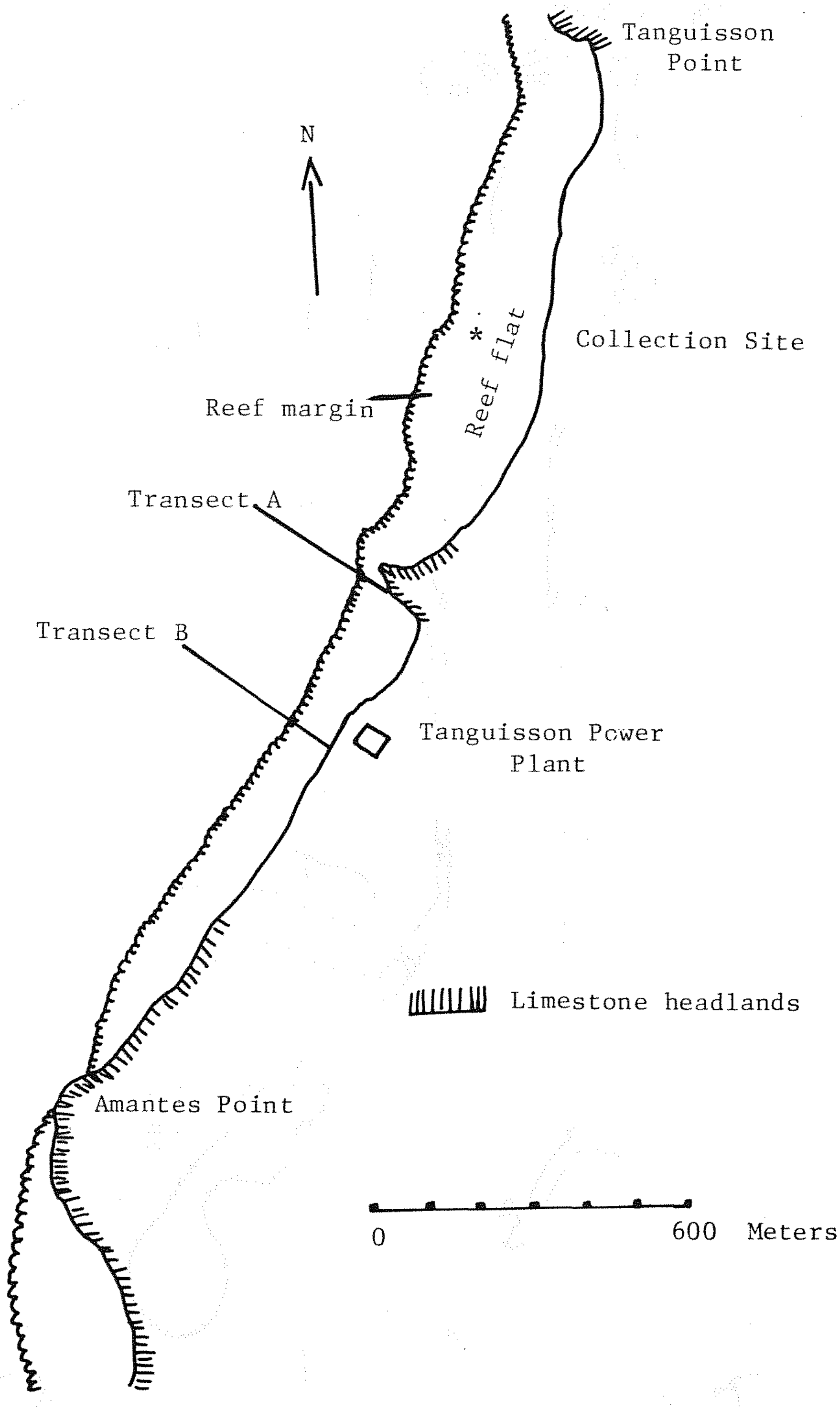

Fig. 2. Detailed map of the Tanguisson Point study area showing transect locations.

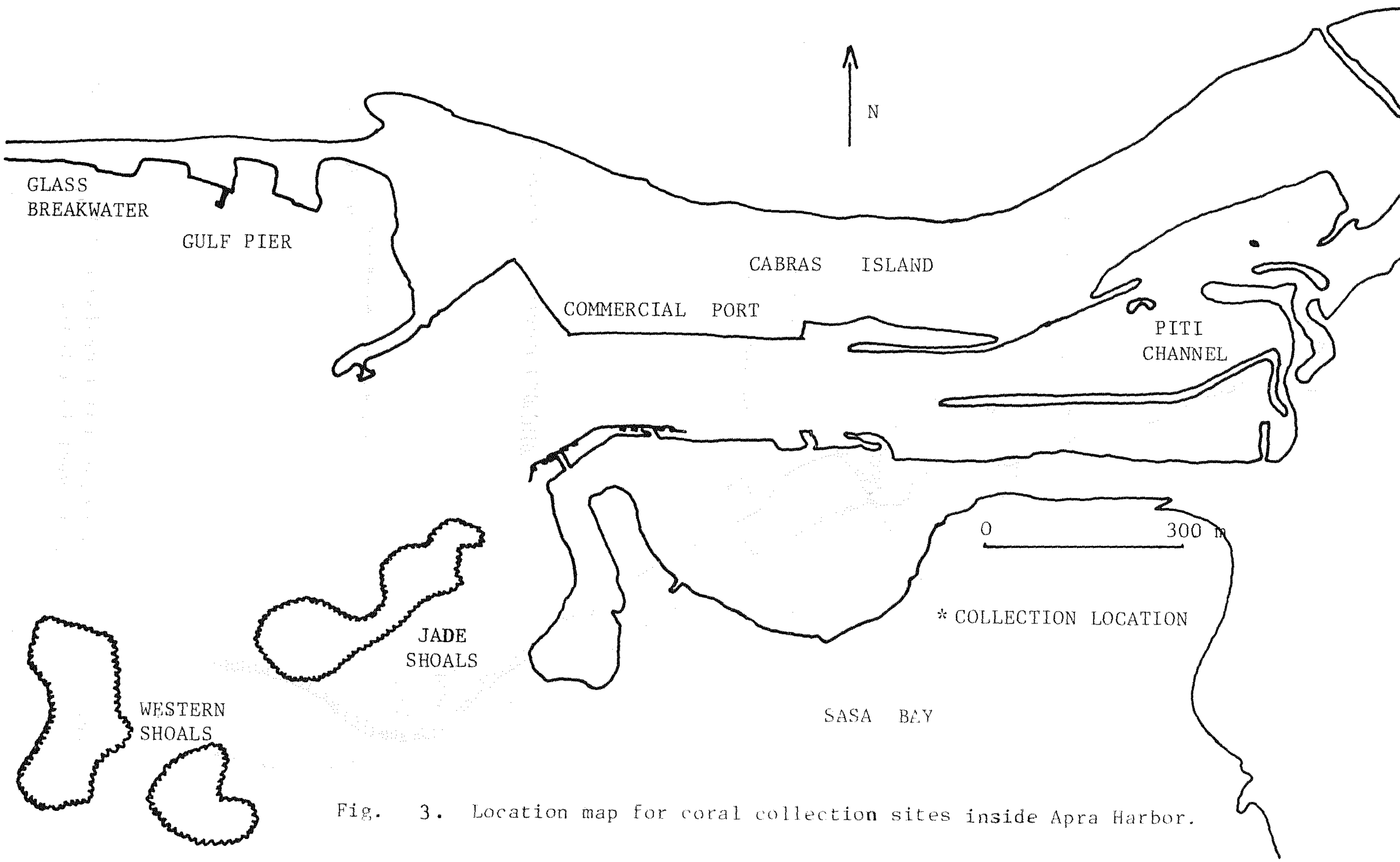

Fig. 3. Location map for coral collection sites inside Apra Harbor.

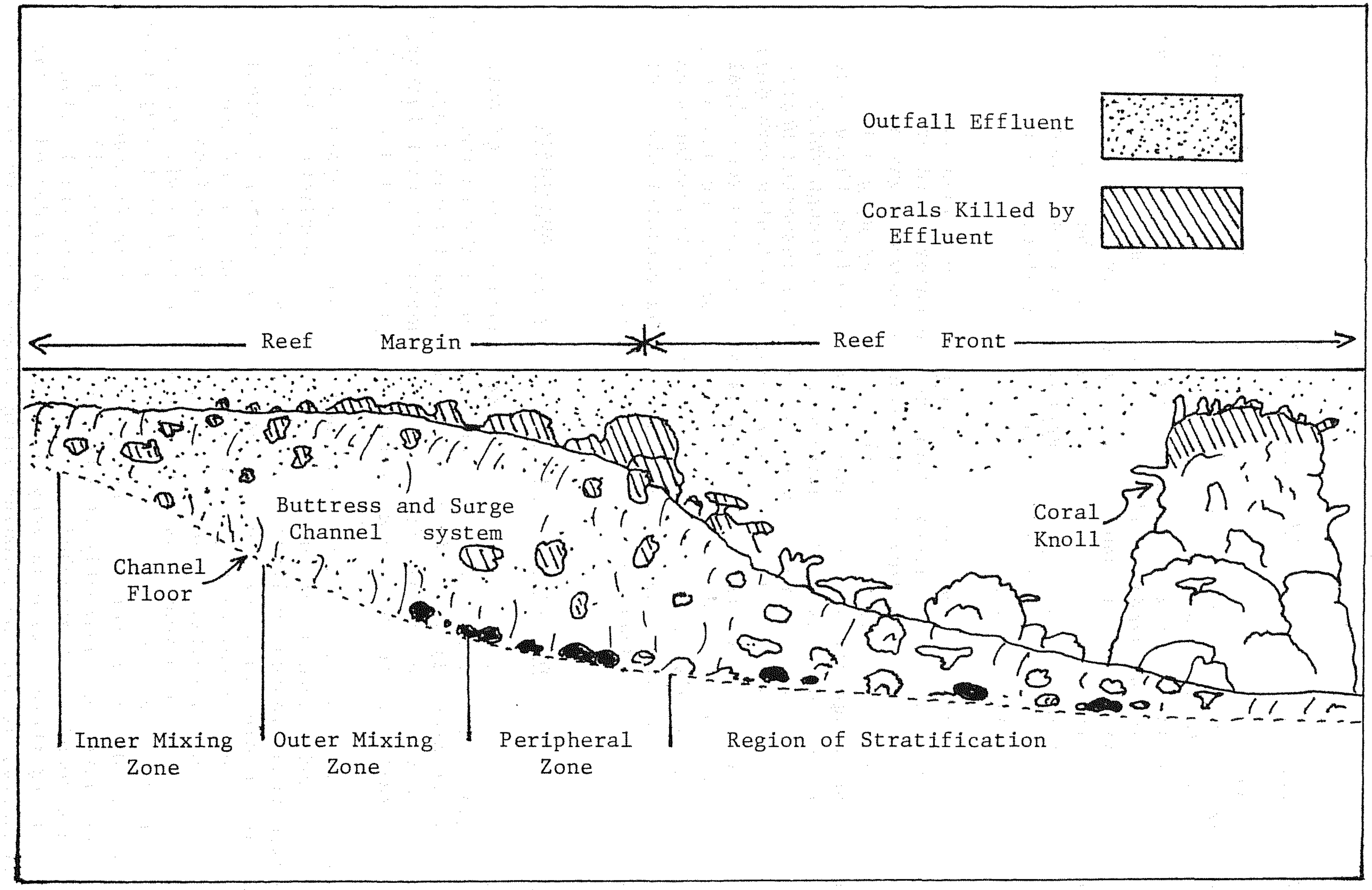

Fig. 4. Vertical profile through the reef margin and reef front zones.

RESULTS AND DISCUSSION

Transplants on the reef-flat platform at Tanguisson

Although much of the reef flat at Tanguisson (Transect B) becomes exposed during low spring tides and corals were absent before the power plant became operational, there were a few shallow holes, troughs, and depressions on the outer third of the platform that previously supported a few colonies of corals (Randall 1973). Because of high effluent temperatures and the historical paucity of corals, only one set of corals were transplanted onto the reef-flat platform. The species selected for transplanting was *Acropora aspera*, which is a common to abundant species found in the reef-flat moat a short distance north of Transect B at Tanguisson Point.

On 25 January 1978, 25 specimens of *A. aspera* were transplanted from the reef-flat moat at Tanguisson Point to the outer-third of the reef platform at Transect B. Many of the colonies showed signs of stress by producing large quantities of mucus while they were being tied down. Even though the signs of stress were immediate, there were two nearly colorless colonies in the outermost shallow trough which still had a few patches of living polyps present when inspected nearly a month later on 22 February 1979. The remaining 23 colonies were dead, but apparently they died at different times as part of them were algal coated while others were a bleached white color whose surface had not yet been colonized by algae. A final inspection of the transplants on 15 March 1979 revealed that the two partially living colonies observed on 22 February were also dead and coated with algae.

Transplants on the reef margin and reef front zones at Tanguisson

A total of 643 coral colonies or separate branches were tied onto the reef margin at Tanguisson (Tables 1 and 2): 326 in the thermal effluent area (Transect B) and 317 in the control area (Transect A). The control area was free of the effects of the thermal effluent factor, but for other factors, the two areas appeared to be very similar.

Nearly all corals that remained attached on Transect A appeared in good health and stayed alive until the end of the experiment. Most of the corals transplanted on Transect B rapidly lost their zooxanthellae and died in a few weeks. The heavy surf during Tropical Storm Tip and other periods of high wave action removed many of the colonies from both transects. However, enough colonies remained attached to demonstrate beyond reasonable doubt that corals will not be able to become reestablished into a thermal effluent area by transplantation (Table 3). Of the 21 corals found still attached in Transect A, 20 were still alive and apparently in good health (95% survival). Of the 117 corals found still attached in Transect B, 3 were still alive (3% survival) and these 3 were in very poor health (as evidenced by the loss of zooxanthellae and the colonies being largely overgrown with algae). The difference in survival that could be attributed to the thermal effluent was very very significant ($X^2_{[1]} = 103.5^{***}$).

Table 1. A list of coral species transplanted on the reef margin and reef front zones of the thermal effluent area (along Transect B) along with the date of the transplant and the number of colonies or separate branches tied to the substratum.

SPECIES	No. Tied: Inner Mixing Zone	No. Tied: Outer Mixing Zone	No. Tied: Peripheral Zone	Date of Transplant (1979)
Psammocora digitata	6	6	6	2 July
Psammocora sp. (ramose 1)	6	6		13 September
Psammocora sp. (ramose 1)			6	7 September
Stylophora mordax	5	5	5	1 June
Pocillopora eydouxi	6	6	6	8 June
Acropora irregularis	5	5	5	31 May
Acropora smithi	5	5	5	1 June
Acropora surculosa	5	5	5	25 May
Montipora sp. (faveolate purple)	6	6	6	2 July
Pavona clavus	6	6	6	25 June
Pavona (Polyastra) obtusata	6	6		13 September
Pavona obtusata			6	7 September
Pavona praetorta	6	7	7	23 May
Pavona (Polyastra) venosa	6	6		13 September
Pavona venosa			2	7 September
Porites andrewsi	6	6	6	4 June
Porites andrewsi	15			24 May
Porites lutea	6	6	6	4 June
Porites (Synaraea) iwayamaensis	6	6	6	2 July
Favia stelligera	6	6	6	8 June
Favia pallida	6	6	6	2 July
Lobophyllia hemprichii	6	6	7	25 June
TOTAL	119	105	102	

Table 2. A list of coral species transplanted on the reef margin and reef front zones of the control area (along Transect A) along with the date of the transplant and the number of colonies or separate branches tied to the substratum.

SPECIES	No. Tied: Inner Mixing Zone	No. Tied: Outer Mixing Zone	No. Tied: Peripheral Zone	Date of Transplant (1979)
Psammocora digitata	6	6	6	2 July
Psammocora sp. (ramose 1)	6	6	6	7 September
Stylophora mordax	5	5	5	1 June
Pocillopora eydouxi	6	6	6	8 June
Acropora irregularis	5	5	5	31 May
Acropora smithi	5	5	5	1 June
Acropora surculosa	5	5	5	25 May
Montipora sp. (faveolate purple)	6	6	6	2 July
Pavona clavus	6	6	6	25 June
Pavona (Polyastra) obtusata	6	6	6	7 September
Pavona praetorta	6	6	8	23 May
Pavona (Polyastra) venosa	6	6	6	7 September
Porites andrewsi	6	1	4	4 June
Porites andrewsi	5		5	29 May
Porites lutea	6	6	6	4 June
Porites (Synaraea) iwayamaensis	6	6	6	2 July
Favia stelligera	6	6	6	8 June
Favia pallida	6	6	6	2 July
Lobophyllia hemprichii	6	6	6	25 June
TOTAL	109	99	109	

Table 3. A comparison of survival of coral transplants in the thermal effluent area with those in the control area free of the effects of thermal effluent.

	alive	dead
Thermal effluent area	3	114
Control area	20	1

$$X^2_{adj\ [1]} = \frac{\left(\left|3 \cdot 1 - 114 \cdot 20\right| - \frac{138}{2}\right)^2 138}{117 \cdot 21 \cdot 23 \cdot 115} = 103.5^{***}$$

The surviving corals on Transect A were Psammocora sp. (3), Pocillopora eydouxi (2), Acropora irregularis (2), Acropora smithi (1), Montipora sp. (2), Porites andrewsi (3), Porites lutea (3), Pavona (P.) venosa (1), Pavona (P.) obtusata (1), Favia stelligera (1), and Lobophyllia hemprichii (1). The survivors represented a wide array of coral families.

The coral species that we hoped would be relatively successfully transplanted into the thermal effluent area because of their tolerances of relatively high temperatures were not particularly successful. In fact, Porites andrewsi was a coral to be found tolerant of higher temperatures in laboratory experiments (Jones et al. 1976). When we transplanted colonies of P. andrewsi from Sasa Bay, the colonies "bleached out" or lost their zooxanthellae. This may be partly because Sasa Bay was characterized by turbid water and the corals were not conditioned to the levels of light that were available in the clear waters of the reef margin on the open coast. To test this, we also transplanted P. andrewsi from the Apra Harbor side of the Glass Breakwater where the waters were clearer than Sasa Bay. The P. andrewsi transplanted from the Glass Breakwater did not lose their zooxanthallae on Transect A, but those on Transect B soon died, apparently from the effects of thermal effluent.

Interestingly, Pavona praetorta, a deep-water species thought to be relatively sensitive to elevated temperatures, remained alive longer in the thermal effluent area than any other transplanted species. A few colonies survived for up to 140 days, Pavona praetorta is a fragile foliaceous species that was not expected to survive well in high-energy reef zones and the last remaining living transplants in the thermal effluent area were removed by Tropical Storm Tip.

The three corals that survived in the thermal effluent area (Transect B) were all of species that are commonly found on reef flats: Psammocora sp., Pavona (P.) venosa and Porites lutea. However, although they were still alive, they appeared very unhealthy in the thermal effluent area and might soon be dead. Also, they are naturally found in nearby reef flat areas. Therefore, if they could survive in the thermal effluent, they would probably move in naturally. The purpose of the transplants was to see if species not found nearby could reestablish a reef if they were introduced manually. We have found that this would not work.

We hoped that species not usually found on the open coast and tolerant of relatively high temperatures were actually excluded from the open coast in part by biological interactions such as competition with other coral species. If these other species were eliminated by thermal effluents, then the species usually restricted to sheltered bays could survive on the open coast areas in which the usual species were eliminated because they were freed from interspecific competition. This was found not to be the case. Porites andrewsi did survive as a transplant on Transect A among the corals usually present on the reef margin and P. andrewsi did not survive the thermal effluent in the area in which it was freed of interspecific competition.

We should point out that the method of coral transplantation by tying down colonies or parts of colonies with plastic-covered wire was a success on Transect A. In two instances, purple Montipora colonies tied to the tops of Acropora surculosa colonies became permanently attached to the A. surculosa colonies. The wires holding them were pulled loose, but the colonies will stay indefinitely. Another instance of a colony cementing itself was an Acropora irregularis that was tied to a vertical wall along Transect A and which grew onto and attached itself broadly to the substratum in three places. The plastic-covered wires that tied the corals to the substratum were, in several instances, overgrown and buried in the coral skeleton.

Although the transplantation of corals works, we found it not to be economically feasible in high-energy environments. Of the 643 transplants tied down at Tanguisson on the high-energy open coast, only 138 (21.5%) remained attached after periods of heavy wave action such as Tropical Storm Tip. (Some dead colonies were counted as remaining attached if they were removed by hand for the purpose of providing a place to attach additional colonies.)

After Tropical Storm Tip, we noticed that there was a striking amount of damage to the resident corals. Branches were recently broken off and the white bare skeleton showed conspicuously. The greatest amount of damage was in the peripheral zones of our transects and the least was in the inner mixing zones of our transects. This indication of stronger wave action in the peripheral zone might explain the increase in proportion of missing corals and "empty wires" (wires remaining, but the previously tied corals missing) from the inner mixing zones to the peripheral zones. The ratio of corals still attached to empty wires was 2.18 in the inner mixing zone, 0.42 in the outer mixing zone and 0.17 in the peripheral zone. Strong wave action and turbulence are the major forces that prevent coral transplantation from being an economically feasible method for use on reef margin and reef front zones of the exposed coast.

Transplanting was also attempted by scattering bucket-loads of shards, chips and branches in large numbers around the study area. Fast-growing species and those that dominate early successional stages of reef communities are generally able to cement themselves to the substratum by growth and establish new colonies when fragmented and strewn across the bottom (Shinn 1972, Johannes 1975). We scattered 7 bucket-loads (ca. 240 dm^3) of finger-sized to fist-sized shards of Porites andrewsi near the inner mixing zone area of both Transects A and B. All of the shards were gone after two months. Apparently none became established.

Branches of Pocillopora damicornis and Porites andrewsi were attached to terra cotta bricks and the bricks were tied to the substratum just near the peripheral zone study sites. The purpose of securing branches of different coral species to different terra cotta bricks was to determine if coral larvae selectively settle into areas in which their own species have been transplanted. Heavy wave action carried away all 20 of the bricks, 10 from each of the transect areas.

Transplants on Western Shoals

A total of 87 colonies of *Porites andrewsi* were transplanted from Sasa Bay to Western Shoals in Apra Harbor. Thirty-three of the colonies were transplanted on 25 November 1978 to an area at about 3 m depth and 50 m northwest of the cement bulkhead on Western Shoals. The other 54 colonies were transplanted from Sasa Bay to another area at about 3 m depth on Western Shoals about 120 m northwest of the cement bulkhead on 27 January 1979. All the colonies were tied to the substratum with plastic-covered wire.

The success of the transplants was surveyed on 15 November 1979. Forty-eight (55%) of the colonies were still in place. Of those still in place, 41 (89%) were still alive. The proportion of colonies that remained tied in place was significantly larger than the porportion found tied in place on the open coast (Table 4). This was almost certainly because the wave action was greater on the open coast than in Apra Harbor. The 85% survival on Western Shoals was not significantly different from the 95% survival in the Tanguisson Control Area (Table 5).

The mortality of corals in Western Shoals appeared to result from overgrowth by algae. Western Shoals was characterized by thick and extensive beds of *Padina*, *Halimeda*, *Dictyota*, and filamentous red algae. All seven of the dead *Porites andrewsi* coral transplants lay buried within extensive and thick mats of filamentous red algae.

Only one of the transplanted colonies of *Porites andrewsi* became permanently attached. It was transplanted over a colony of *Psammocora contigua* which grew over the base of the transplanted *Porites andrewsi*. All other living transplanted colonies were still tied to the substratum but would have been loose if not for the wires holding them to the substratum. Although branch tips and nubbins were found to grow from their bases and reattach to the substrata in previous experiments with coral nubbins, entire colonies did not grow from their bases and reattach when transplanted. Colonies grew only at their branch tips. They did not produce more skeleton or grow from their bases.

Seven bucket-loads of *P. andrewsi* shards (finger to fist-sized) were scattered over the transplant area at Western Shoals but we could not find any of the shards reattached or growing.

Nubbins of *Pocillopora damicornis* were attached to six terra cotta bricks with an underwater epoxy putty. Two of the bricks were placed at each of 4.5, 9, and 18 m depths, respectively. New *P. damicornis* colonies started from planulae settling on the vertical surfaces of three of the terra cotta bricks. The two bricks at 4.5 m depth had 6 and 2 new colonies and one of the bricks at 9 m depth had 2 new colonies.

Table 4. A comparison of the proportions of corals that remained attached on the open coast site at Tanguisson with those that remained attached on Western Shoals in Apra Harbor.

	Attached	Gone
Tanguisson	138	505
Western Shoals	48	39

$$X^2_{[1]} = \frac{(138 \cdot 39 - 505 \cdot 48)^2\ 770}{643 \cdot 87 \cdot 186 \cdot 544} = 45.9^{**}$$

Table 5. A comparison of the proportions of transplanted corals that lived and died at the Tanguisson Control Area with those that lived and died on Western Shoals.

	Alive	Dead
Tanguisson Control Area	20	1
Western Shoals	41	7

$$X^2_{adj\ [1]} = \frac{\left(\left|20 \cdot 7 - 41 \cdot 1\right| - \frac{69}{2}\right)^2 69}{61 \cdot 8 \cdot 21 \cdot 48} = .584 \text{ ns}$$

Natural coral recruitment in the thermal effluent area

During the course of the study, we noticed considerable natural coral recruitment taking place within the peripheral zone of the reef area affected by power plant effluent. In this peripheral zone, 30 recently recruited corals were found on the flattened upper surface of a single reef front knob that measured approximately 2 meters long and 1.5 meters wide. Species observed on the upper knob surface included: *Acropora irregularis*, *A. monticulosa*, *A. nasuta*, *A. squarrosa*, *A. surculosa*, *A. variabilis*, *A. wardi*, *Acropora* sp., *Goniastrea retiformis*, *Pocillopora setchelli*, and *Pocillopora* sp. *Acropora* recruits clearly dominated the knob surface, with *A. surculosa* occurring most frequently. Most of the recruits were in the 0-5 cm diameter size class with a few ranging up to 10 cm. A reconnaissance swim along the entire peripheral region of the thermal effluent area revealed that the recruitment pattern was characteristic of the area.

This recruitment appeared to take place during the dry-season months when ambient water temperatures were lower; or possibly it was related to planulation periods of specific corals during that time. Growth of the newly settled corals continued until August when we noted that many of the young corals had died and many were undergoing stress, as evident in the paling of their tissues. Possibly the higher ambient seawater temperatures coupled with reduced water agitation and midday low spring tides that occur during the wet-season months were stressing and killing these corals. If the slight annual difference in seawater temperature was killing those newly settled corals, it then indicates that at least recruitment and growth of some corals can take place very near their upper thermal tolerance. It was also interesting to note that most of the new recruitments in the outer part of the reef affected by the thermal effluent were *Acropora* species, a genus thought by many to have a relatively low upper thermal tolerance.

These observations on the natural coral community indicates that the area affected by thermal effluent from the power plant is remaining about the same size. During the dry season, the corals invade the thermal effluent area and during the wet season, the invaders are killed back. The total area of thermal effluent averages about the same, but the margin fluctuates.

Pavona frondifera transplants in Cocos Lagoon and Apra Harbor

One of the major problems encountered in transplanting corals to the shallow reef zones at Tanguisson was stabilizing the colonies in high energy environments. For transplant to be successful and attach to the reef framework in such regions, they must be rigidly tied so that no movement occurs from currents and breaking waves and surf. To test transplant success in lower energy environments, a limited number of *Pavona frondifera* colonies from Piti Channel were transplanted to three different locations in Cocos Lagoon and to a shallow platform at Western Shoals in Apra Harbor (Figs. 1 and 2). *Pavona frondifera* was primarily selected for transplanting because the species has only been found in the outer part of Piti Channel where it has been periodically subjected to a severe but unknown environmental stress that threatens the entire community there. These transplants would thus represent an effort to save a species from local extinction. Another reason for selecting P. frondifera was to see if natural mechanical fragmentation of the colonies by occasional rough seas is an important mode of asexual reproduction for this species. Knowledge of species which successfully reproduce in this manner is important in coral transplantation effectiveness because it represents a method with low unit effort and cost. Natural fragmentation not only increases the number of individuals quickly, but because of the relatively large size of the fragments in comparison with small recruits formed by planula settlement, they may be quite successful in competing for space and colonizing unstable sandy substrata.

On 8 September 1977, 14 colonies of P. frondifera were transplanted from Piti Channel to the upper patch reef platform on Western Shoals. The transplants were collected from low mounds 2 to 3 m deep and included both sections and entire coralla ranging from 10 to 28 cm in diameter. At the time of collection, the P. frondifera colonies were somewhat stressed, as indicated by pigment loss, and ranged from a near-normal brown to very pale tan colore. The transplants were placed loosely on reef rock pavement or reef rock with a thin veneer of scattered coral rubble, in water 6 to 7 m deep. On 22 September 1977, the transplanted colonies were inspected and, except for one colony, they had regained much of their normal brown pigmentation. The P. frondifera colonies were again inspected on 25 January 1979, and all 14 of the original transplants were found in a healthy state and growing. Some colonies had become attached to the substratum and fragmentation was evident, as many living loose shards were found scattered about.

On 15 February 1979, 35 colonies of P. frondifera were transplanted from Piti Channel to three locations in Cocos Lagoon. The colonies ranged from 10 to 25 cm in diameter and were placed loose on the bottom in about a meter of water. Of the 35 colonies transplanted, seven were placed at the west end of the lagoon on a rubble and sand substratum, 14 were placed about 250 meters north of Babe Island at the east end of the lagoon on a rubble and sand substratum, and 14 were placed at the northern end of the lagoon on a predominantly sand substratum with patches of bare reef rock. In a relative scale of exposure to waves and currents at the three lagoon sites, it was lowest at the eastern end because of protection from Babe Island and highest at the western and northern ends of the lagoon. The colonies were all in a healthy condition with normal color pigmentation when transplanted. Some loose fragments and very small sections of colonies were also placed on the bottom at each of the three transplant sites.

On 15 May 1979, the 35 transplanted colonies at Cocos Lagoon were inspected and their condition was assessed. The original placement pattern of the corals was somewhat altered, with a few colonies overturned, but most were found within a meter of their original position. Colonies placed on sandy and bare reef rock substrata showed evidence of more movement than those on substrata composed mostly of coarse rubble. Survival appeared to be related to the stability of the substrata and degree of exposure to waves and currents. There was no significant difference in colony survival between the western and northern parts of the lagoon where the exposure to waves and currents were somewhat similar, but a significant difference was found between the eastern site where protection was afforded by Babe Island and the other two more exposed lagoon sites (Table 6). The number of fragments produced by the transplants also appeared to be related to substratum composition and degree of exposure to waves and currents. There was no significant difference ($X^2_{[1]}$ = .7975 ns, Table 7) in the numbers of fragments produced by the transplants at the western and northern ends of Cocos Lagoon, but there was a very significant difference ($X^2_{[1]}$ = 48.055***, Table 7) between the east end and the other two sites. Once a fragment was produced by a colony, it appeared to have an equal chance of survival, as there was no significant difference between the proportions of live and dead fragments in the western and northern ends of the lagoon ($X^2_{[1]}$ = 2.71 ns, Table 7). Only one fragment was found at the protected eastern lagoon site.

Growth rate in relation to colony size of *Pocillopora damicornis*

Eight colonies of *Pocillopora damicornis* were stained with Alizarin red S medical bone stain in the outdoor aquaria at the Marine Laboratory, then transplanted to Western Shoals in Apra Harbor at a depth of 7.7 m. A number of branch tips from each colony were measured for growth increments. The results are presented in Table 8. There was a significant difference between the growth rates of the colonies ($F_{s[7,306]}$ = 31.8***), but there was no significant regression of growth rate on colony size ($F_{s[1,6]}$ = 1.80). The smallest colony was 100 cm^3 and the largest was 400 cm^3 (measured by the volume of water displaced). A significant regression of growth rate on colony size might be obtained if a greater range of colony sizes is tested. Fifty-five percent of the variance was a result of differences in branch tips within the colonies. Forty-five percent of the variance was because of differences between the mean growth rates of the colonies.

Cost-benefit assessment

The costs of the three coral transplant methods used in this project are tallied in Table 9 in terms of both effort (hours) and equipment expense (dollars). The cost of labor in terms of money varies, so we left this in terms of hours so that the costs of future projects of this sort could be easily estimated by multiplying the hours required by the current pay rates. Similarly, the cost of boat and vehicle use varies both with the type of boat and vehicle used and with the current fuel costs; therefore, the reader can calculate the current travel costs from the table in which the required usage was tallied in terms of hours.

Three or four personnel were involved in each hour of field work, two or three persons tying the coral colonies to the substratum and one

Table 6. A comparison of extent of survival of coral transplants at three different locations in Cocos Lagoon. Living tissue for each colony was calculated to the nearest 5 percent by using a line-intercept method across the longest dimension of the colony.

Percentage of Living Tissue	West Lagoon (7 colonies) A	East Lagoon (14 colonies) B	North Lagoon (14 colonies) C
100	1	9	1
95	2	1	2
90	2	1	4
85		2	1
80	1	1	
60			1
45			2
40			1
30			1
0	1		1

Mann-Whitney U test

West vs East = 92***

West vs North = 34.5 ns

East vs North = 161***

Table 7. A comparison of fragment production of *Pavona frondifera* and the survival of the fragments at three different locations in Cocos Lagoon.

	Live Fragments	Dead Fragments
West Lagoon (7 colonies)	20	9
East Lagoon (14 colonies)	1	0
North Lagoon (14 colonies)	41	6

able 8. Growth of 8 colonies of Pocillopora damicornis transplanted to Western Shoals, 7.7 m depth. The growth took place between 11 May and 26 September 1979 (138 days). All measurments in cm.

Mean Growth Increment	Standard Deviation	Number of Branches Measured for Growth Increments	Dimensions of the Colony (width x width x heigh
0.83	0.314	50	18 x 13 x 11
1.42	0.310	50	17 x 14 x 9
0.95	0.502	50	15 x 12 x 11
0.90	0.232	50	14.5 x 10.5 x 8
1.06	0.367	40	10.5 x 11 x 9
0.54	0.164	50	14 x 9 x 7
0.39	0.105	7	11 x 10.5 x 7
0.79	0.228	17	7 x 9 x 6

Table 9. Comparative assessment of costs involved with three transplant methods.

Method	Location	No. Trips	HOURS Labor	Road Travel	Boat Travel	Total Hours	Equipment Expense*
Tying of entire colonies or branches with plastic-coated wire	Tanguisson	13	24	13	11	48	Plastic-coated wire $0.06 per foot = $300.00 Pliers $9.00 each = $27.00 Scuba air fills $1.50 per fill = $45.00
	Western Shoals	2	2.8	3	.8	6.6	Total = $372.00
Coral nubbins on bricks							Plastic-covered wire $0.06 per foot = $3.60 Pliers (same as above)
	Apra Harbor**	8	3	12	2	17	Terra cotta bricks $0.45 each = $18.00
	Tanguisson	1	1	1	.7	2.7	Underwater epoxy putty, $15.00 per kit = $30.00
	Western Shoals	2	3	3	.3	6.3	Scuba air fills $1.50 per fill = $27.00
	Glass Breakwater	2	3	3	.3	6.3	Total = $78.60
Scattering of shards							Plastic buckets $3.00 each = $30.00
	Tanguisson	2	1.5	4	1.5	7	
	Western Shoals	1	1	2	.7	3.7	Total = $30.00
TOTAL		31	39.3	41	16.8	97.6	$480.60

*Other equipment expenses involved were boat and truck fuel costs. These vary so much that it is best if the reader just adds these expenses himself by multiplying the current rates times the hours of travel. The truck averaged about 35 m.p.h.

**The Apra Harbor trip was for collection of coral heads from which the nubbins were stained and fixed to bricks in the laboratory.

boat operator. The laboratory work of attaching coral nubbins to bricks was done by one person. The total number of man-hours should be calculated from Table 9 by multiplying the total labor and travel times by a factor of 3.

The successes of the methods were inversely ranked to their costs in terms of both time and money. The two less expensive methods were so totally unsuccessful that a quantitative analysis of a cost-benefit ratio would serve no purpose. Furthermore, the method of tying of entire colonies to the substratum with plastic-coated wire was successful only if the substratum was a relatively fast-growing living coral. The success of a coral transplantation relies entirely on the nature of the substratum (living coral) and the exposure of the habitat to wave action (with greater success in protected areas). There are no alternative methods of varying cost.

RECOMMENDATIONS

Coral transplantation appears to be a successful method of manipulating the location of coral colonies among healthy coral communities and therefore might well serve as a mechanism for securing the survival of endangered populations. However, coral transplantation does not appear to be a dependable method for establishing coral communities in areas in which other corals are not living and therefore transplantation is not an effective method of establishing corals in a thermal effluent area.

Corals cannot be transplanted successfully into thermal effluent regions for two reasons. First, even species from other natural reef habitats with higher temperature tolerances were not able to survive in thermal effluent regions although individuals of the same species survived quite well when transplanted into healthy reef communities. Second, colonies of most species do not readily attach themselves at their bases, but when transplanted onto a healthy colony of a relatively rapidly-growing species, the transplanted colony is soon secured to the substratum indirectly by growth and attachment by the underlying coral colony. Since there are no healthy corals in thermal effluent regions, the transplanted coral colonies lack an effective mechanism for attachment.

The costs of transplantation to reestablish a reef community over a large area is exceedingly expensive, especially in areas of heavy wave action. Furthermore, reestablishing a reef in an area with no living corals has very low probability of success while transplanting corals onto the surface of other living corals has a high probability of success. The transplantation of colonies to establish endangered species in a number of locations has a good chance of success if they are transplanted onto the surface of relatively fast-growing living colonies in healthy reef communities. When a species is found only in an area that is destined to be dredged or severely polluted, colonies could be transplanted to numerous other locations which appear to be appropriate, so that the species does not have "all its eggs in one basket.

The cost-benefit ratio of establishing endangered species in numerous locations is nearly impossible to analyze because the benefits of maintaining a rich and varied gene pool cannot be converted into a monetary scale. However, multimillion dollar projects have been halted in defense of endangered species, so at least the indirect monetary benefits are real.

Since reestablishment of a coral community by transplantation in reef areas impacted by the power plant effluent was not successful, the remaining question concerns the integrity of the reef framework in the affected area. A comparison of reef physiography at Transect B before the power plant became operational in December 1971 (Jones et al., 1976) and during this study, after eight years of operation, shows that little change has occurred. Corals killed by the thermal effluent are generally in place with their surfaces covered mostly by fleshy algae, and at least superficially there is no evidence of increased physical erosion or degradation of the original reef framework. It must be kept in mind that these observations of the reef frame integrity are only qualitative and superficial. The reef frame may be undergoing significant internal eroision by biogenic action of boring organisms and solution and may in time be weakened to a degree where physical disintegration by wave action would become evident. To test this hypothesis, the internal structure of the reef frame at Transect B should be compared with that from a nearby reef where there is no impact from power plant effluent. Such a comparable reef can be found immediately north of Transect A.

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