

Effects Of Thermal Effluent On the
Coral Reef Community At Tanguisson

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INTRODUCTION

Our ecological investigations on the effects of thermal effluent from the Tanguisson Power Plant began on 1 September 1975. Much of the work outlined in Guam Power Authority (GPA) job order E-7001.1-76 has proceeded on schedule. However, some experiments in progress were destroyed by Super Typhoon Pamela, 19-25 May 1976. These investigations will be started over as facilitated by a one-year extension granted by GPA.

The Marine Laboratory had previously conducted studies on the biological impact of high-temperature effluent water from Tanguisson condensers on the fringing coral reef adjacent to the thermoelectric power plant. These studies were begun in 1970 and continued through 1974. The results from these investigations were reported by Dr. R. S. Jones and Richard H. Randall in Technical Reports 7 and 28 from the University of Guam Marine Laboratory and Environmental Protection Agency Report 600/3-76-027 Jones, et al. (1976). The objectives of these earlier studies were to conduct both laboratory and field investigations on the effects of thermal stress on reef organisms. Laboratory thermal tolerance experiments on a series of coral species showed an upper lethal limit of 30 to 32°C for most species. Sublethal temperatures reduced the rates of growth of coral species. The field studies involved transects across the reef fronts, submarine terraces and seaward slopes of the fringing reef in areas exposed to, and away from, the waste heat discharge. The coral communities in these areas deeper than about 5 m had been devastated by recent infestations of *Acanthaster planci* (L.) 1968-1969. The transect studies of Jones et al. (1976) showed an increase in coral recruitment to areas away from the power plant effluent, but not in areas exposed to effluent.

The purpose of the study reported here was (1) to investigate recruitment of corals to areas within and adjacent to heated effluent from the Tanguisson Power Plant, and (2) to characterize the establishment of marine communities in general, including all macroscopic algae and animals in addition to hermatypic corals.

The research objectives for this investigation are: (1) to summarize the University of Guam Marine Laboratory Technical Reports Nos. 7 and 28 by Jones and Randall (1973) and Jones, Randall and Wilder (1976), (2) to survey recent recruitment and recolonization of hermatypic corals along the transects established by Jones and Randall (1973) (3) to monitor growth of two species of hermatypic corals along a gradient from within to outside the area of thermal enrichment and (4) to characterize the fouling communities both within and outside the heated discharge.

Temperature and Tropical Aquatic Biota

A comprehensive coverage of the broad subject of tropical marine pollution is that of Wood and Johannes (1975). There is a lot of literature available on the effects of increased temperatures on tropical and subtropical aquatic organisms (Chadwick et al., 1950; Wood, 1953; Southward, 1958; Jensen et al., 1969; Nugent, 1970). Several authors have considered effects of increased temperatures on algae (Biebl, 1962, 1972; Zieman, 1970; Schartz

and Almodovar, 1971; Thorhaug, 1971; Thorhaug et al., 1971, 1973; Hohman and Tsuda, 1973). Tropical echinoderms have also been the subject of previous investigations of thermal tolerances (Singletary, 1971; Rupp, 1973; Yamaguchi, 1974). The effects of increased temperature on fish are considered in Brett, (1956), DeSlyva (1969) and McCain et al. (1973). Information on the temperature tolerances of marine benthic organisms is of importance to both general marine ecology and to assessing the biological effects of thermal effluents (Hedgepeth and Gonor, 1969).

Most of the previous laboratory investigations of lethal temperatures were determined through short-term exposures and are of little value in predicting the effects of thermal effluents on biological communities. These temperatures have often been found by placing the organisms in a water bath and increasing the temperature at a controlled rate until 50 percent or 100 percent mortality occurs (Kinne, 1963; Jensen et al., 1969). Tolerances obtained in this manner can be misleading when applied to nature. For example, Henderson (1929) working with the common mussel *Mytilus edulis* found a lethal temperature of 40.8°C by increasing ambient temperature 1°C every five minutes. However, Wells and Gray found a much lower lethal temperature of 26.7°C in the field, Wolfson (1974; p. 2). There are other examples of organisms not being able to withstand temperatures as high in nature as they do under controlled conditions (Read, 1967; North et al., 1972). Also, it has been pointed out that the temperature at which the feeding reactions and normal metabolic processes cease are more significant than lethal temperatures (Mayer, 1914).

Another major problem with past thermal tolerance investigations is that subjecting animals to a constant temperature in the laboratory is very artificial, since temperature fluctuates constantly in nature. The brackish water amphipod, *Gammarus dubeni* exhibits normal growth and life span only when the ambient temperature fluctuates (Kinne, 1963). If thermal tolerances are to be determined in vitro perhaps one of the better methods is to use a flow-through sea water system with the thermal addition onto the varying temperature of the intake water as used by Jones et al. (1973, 1976); Yamaguchi, (1974); Rupp, (1973). A question also remains as to the stress imposed by rapid temperature fluctuations (thermal shock) (Jokiel and Coles, 1974).

Many of the chemical and physical properties of water to which aquatic organisms respond are directly related to temperature. For example, as the water temperature increases, its capacity to hold dissolved oxygen decreases. A synergistic effect occurs in that increased temperature increases metabolism and oxygen consumption. Mayer (1917) observed that the ability of a coral to resist high temperatures is conversely related to the metabolic rate (oxygen consumption). Elevated temperature generally decreases an organisms ability to tolerate other environmental stresses such as low salinity (Kinne, 1964).

Deleterious effects also come from elevated temperatures not high enough to kill the organism outright but high enough to lead to delayed mortality. Production of gametes and spawning are limited to a maximum temperature which is sublethal to the species. Thus temperature regulation of reproductive cycles restricts the geographical distribution of these

species to a temperature region considerably narrower than that of growth or survival (Barnes, 1959; Beckman and Menzies, 1960; Fritchman, 1962; Patel and Crisp 1960). Regardless of the source of increased temperatures, it is conceded that increased temperature is one of the single most important factors controlling the distribution and survival of marine organisms (Belehradek, 1931; Gunter, 1957; Hela and Laevastu, 1960).

There are several reasons why sublethal heat stress is deleterious to corals. Mayor (1918) reported that three species of Caribbean corals ceased feeding at temperatures 1.5-3.0°C below their lethal limits. Edmondson (1928, 1929) reported similar results for Hawaiian corals and also noted that reproductive rates dropped at high sublethal temperatures. Several researchers have noted that corals extrude their zooxanthellae at high sublethal temperatures (Yonge and Nicholls, 1931; Jones et al., 1973, 1976; Jokiel and Coles, 1974).

Gross photosynthesis is generally greater than respiration in hermatypic corals. As temperature increases, photosynthesis must increase faster than respiration to maintain a stable photosynthesis/respiration (P/R) ratio. Coles (1973) found that it does not. For several species of Hawaiian corals he found that P/R ratios usually decreased with temperature increases. Hohman and Tsuda (1973) obtained similar results with the reef alga Caulerpa racemosa.

Thermal Effects from Power Plants

Nugent (1970) studied the fouling community in and out of the effluent at the Turkey Point power plant on Biscayne Bay, Florida. Settlement of the ivory barnacle, Balanus eburneus was more common and earlier in the heated water during the spring, while no barnacles settled in the effluent during July and August. Growth was facilitated in the hot water in the winter and inhibited in the summer. The effluent from this station has in recent years killed virtually all plants and greatly reduced the animal populations in an area defined by the +4°C isotherm (Roessler and Ziemann 1969; Thorhaug et al., 1973; Ziemann and Wood, 1975).

Jokiel and Coles (1974) studied the effects of thermal enrichment on hermatypic corals at Kahe Point, Oahu Hawaii. Nearly all corals exposed to water 4-5°C above ambient were killed. Damage to corals was most severe in the late summer when maximum ambient water temperatures occurred. Jokiel and Coles found a positive correlation between the area of dead and damaged corals and the megawatt generation of the plant.

A related and excellent study of a Florida desalination plant by Cheshier (1971) considers effects of thermal effluent and characterizes settlement of a variety of filter feeders. Many other studies have been conducted on effects of power plant discharge and will not be considered here (Carins, 1955; Warinner and Brehmers, 1966; Adams, 1968; Clark, 1969). Studies of discharge from nuclear generating stations also provide some data useful for comparison (Preston, 1967; Salo and Leet, 1969). The scope, background and future of thermal pollution has been discussed in papers by Reid (1961), Jones (1964), Olson and Burgess (1967).

Recruitment Studies

Recruitment is one of the most important processes in understanding functional organization of benthic marine communities (Thorson, 1957, 1966; Loosanoff, 1964). An ecological approach to the study of fouling communities which considered patterns of development and distribution was followed by Fager (1971). This approach is also useful for an understanding of the functional responses of these communities to a multitude of environmental parameters.

Larvae of benthic organisms are very selective in location and timing of their settlement (Wilson, 1960; Thorson, 1957, 1966; Birkeland et al., 1971, 1976). Various environmental factors, chemical and physical, have been suggested as being influential in the attachment and metamorphosis of sedentary organisms. Long (1969) proposed that greater amounts of sunlight and increased water circulation were critical factors influencing the larvae of fouling organisms.

The scheduling of reproductive processes indicates how natural selection on the species is guided by the predictability or periodic harshness of the physical environment (Murphy, 1968; Sanders, 1969; Slobokin and Sanders 1969) or periodic fluctuations in numbers of predators or competitors (Thorson, 1960, 1966). Although more than 99 percent of the mortality for most marine organisms with pelagic larvae occurs during the planktonic stage and adults have a high probability for survival, the controlling factors regulating benthic organisms are generally found during the process of settling and metamorphosis (Birkeland et al., 1976).

An assessment of recruitment patterns of benthic communities has often been used as a measure of environmental quality in outfall areas from electrical generating stations (Markowski, 1959, 1960, 1962; Nauman and Cory, 1969; Nugent, 1970; Wolfson, 1974). These researchers placed replicates of settling plates within and adjacent to areas of thermal enrichment. A very similar method was used by Chesher (1971) to quantify the effects of heated effluents from a large desalination plant in Florida.

Recolonization of Coral Reefs

Recovery of destroyed reefs has been shown by many researchers to be a prolonged process (Maragos, 1972; Enean and Stablum, 1973; Connell, 1974; Grigg and Maragos, 1974; Loya, 1976). From observations made during Acanthaster population explosions on the Great Barrier Reef, Pearson (1974) stated that it was possible for fast growing species such as Acropora spp. to recolonize large areas in less than 10 years. However, it will take considerably longer for a more diverse assemblage to develop. Randall (1973) suggested that reef recovery from Acanthaster infestation may take several decades. Recovery of coral communities in Hawaii after inundation by lava flow takes about 20 years in exposed areas and about 50 years in more sheltered areas (Grigg and Maragos, 1974). Stoddart (1965, 1969a) reported

that reef recovery following a hurricane in British Honduras was long-delayed and the only hermatypic corals living after three years were those not killed by the storm itself.

Loya (1976) compared the recovery patterns of hermatypic coral communities on two reef flats in the northern Gulf of Eilat, Red Sea following a catastrophic low tide. One study site, the nature reserve of Eilat, Israel, is chronically polluted while the control area is pollution free. Initially (in 1969) the two coral communities did not differ significantly when the average number of species, number of colonies, living coverage and diversity were taken into account. During the low tide both communities suffered mass mortalities of corals (81 to 85 percent). A marked difference was observed in their recovery 3 years later with the control reef having 23 times the recolonization of the nature reserve. Loya (1976) suggests that recolonization will continue to be severely inhibited at the nature reserve because of the chronic oil pollution.

There are many inherent problems associated with quantitative measures of coral coverage. Difficulties are more acute at the level of the sampling unit and in field recording procedure than at the level of transect or quadrat location (Stoddart, 1969b). To measure coral coverage researcher's quadrats have varied in size from 0.8 to 930 m². Most of this work has been on accessible shallow reef flats while fore-reef slopes with greater coral growth have been neglected (Stoddart, 1969c).

Because of the diversity of growth forms and the variable reef topography, problems of field recording are acute. Many workers make sketches of coral distribution as seen in a horizontal plane, e.g. Manton (1935) and Abe (1939). Pichon (1964) discussed problems that arise when the sampling area is not horizontal. Due to the complex geometry of coral surfaces this method cannot reflect the distribution of biomass, which bears no simple relationship to area covered (Stoddart, 1969). Furthermore, measures of coral coverage cannot be used as a simple index of reef recovery because they do not account for the complexity of coral architecture or volume of total surface area of cover (Johannes, 1975).

Although simple measures of coral coverage cannot be used as an absolute index of recovery by the reef community, they can be used as a comparative index of recovery. Therefore, the measurements of percent of living hermatypic coral coverage in this report are used as an index for comparison between distinct areas of the reef; those previously affected by Acanthaster planci (reef front, submarine terrace, seaward slope); those directly affected by the thermal effluent (primarily the reef margin); and those not affected by the thermal enrichment (Fig. 3).

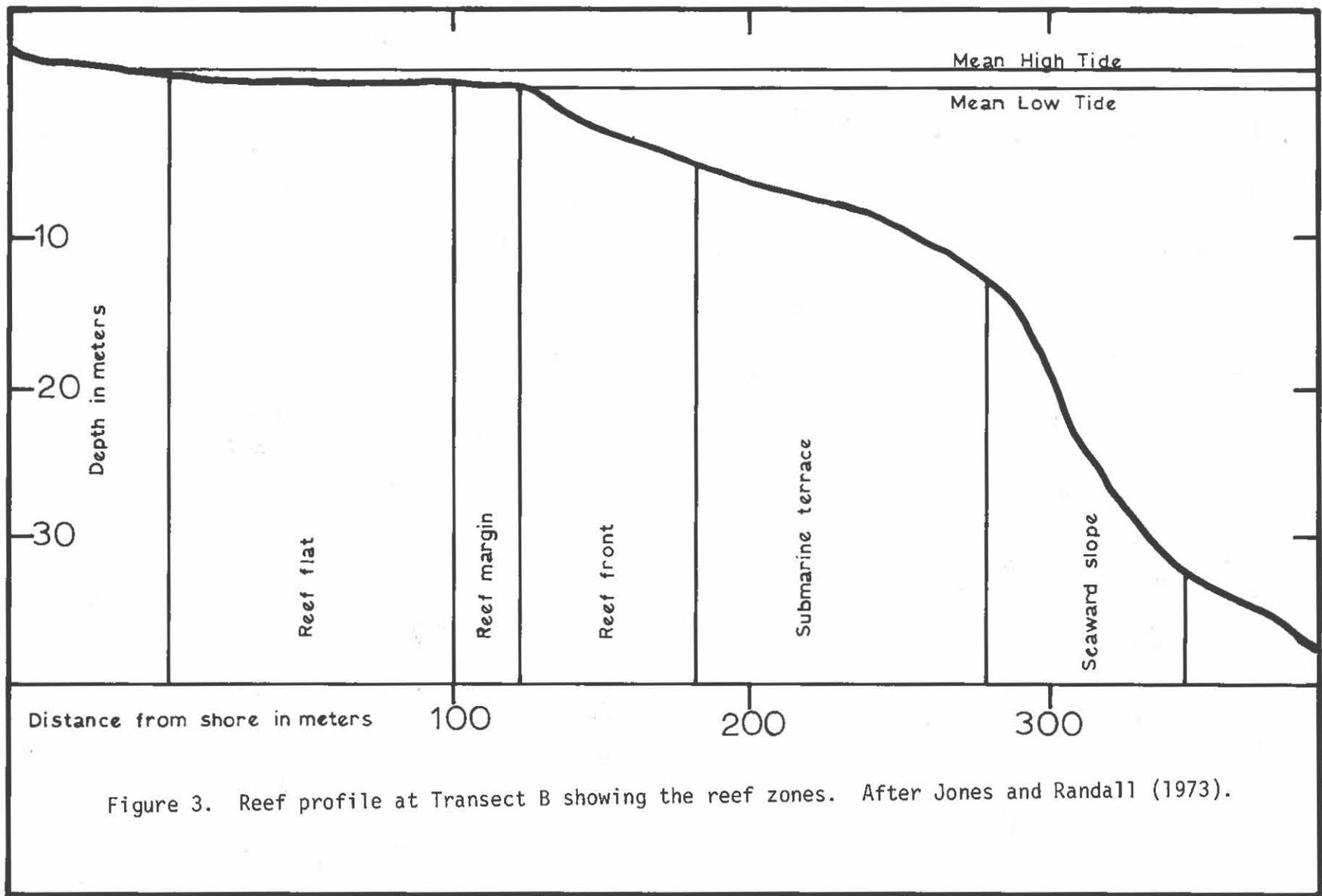


Figure 3. Reef profile at Transect B showing the reef zones. After Jones and Randall (1973).

MATERIALS AND METHODS

Study Site

Guam Power Authority's Tanguisson Power Plant, an oil-fired steam electric generating station, is located on the north-east coast of Guam (outfall lat. 13°32'50"N, long. 44°43'30"E). Cooling water for the plant's condensers is drawn from the Philippine Sea through an intake channel. This structure is 14 m wide and extends 2 m below mean low water and cuts through the reef flat and margin (Figs.1,2,6). Four circulating pumps, with capacities of about 17,000 gpm each, carry cool, ocean water to the condensers. Heated effluent is released into an outfall channel (also excavated through the reef flat) and diffuses onto the reef margin. The plant design is for generation of 26.5 megawatts per unit for Tanguisson No. 1 and No. 2. Typical generation with both units on the line is between 40 and 48 megawatts (personal communication, Martin Arargo).

A thorough description of the fringing reef and its zonation may be found in Jones et al. (1976). This description and division of the reef is based on that found in Tracey et al. (1964).

Coral Recruitment Studies

Standing crop or biomass accumulation was considered a manifestation of net production and was measured by taking dry weights of fouling communities on settling plates after field exposure (Figs, 19, 20). The number of corals settling on the plates was considered to be a direct measure of the potential success of corals in recolonizing the area damaged by the thermal effluent.

Settling plates were made of 0.6 cm thick plexiglass cut into rectangles 5 cm wide by 15 cm long. Therefore, the plates have a surface area for settling of 75 cm² per side. The plates were roughened on both surfaces by rubbing with "coarse" grade sandpaper, with 10 strokes along the length and 10 across the width (Birkeland, et al. 1976). Plexiglass was chosen for the plates in preference to natural substrata for several reasons. First, all of the plates are uniform and their topography and texture varies much less than that of natural substrata. Secondly, the surface area is constant and the plates can easily be examined intact under the Wild dissecting microscope. Finally, this standardization which eliminates many sources of variation allows study of the effect of thermal enrichment alone.

The settling plates are attached on .64 cm X 8 cm brass blots and enclosed in 1 m² cages of 1/4" 19 ga. hardware cloth (Fig. 19) which are then secured to the bottom. The cages prevent grazing by larger herbivorous fauna and allow a more accurate measure of production.

A cage with 12 plates was placed on the reef margin (Fig. 3) at a water depth of 1.2 m at Transects A and B. Four plates were recovered from each cage at two-month intervals (timed as closely as weather would permit) and brought back to the laboratory in glass jars filled with seawater. The plates were then placed in a solution of five percent formalin for at least two days for fixing.

The plates were then examined under 12-power magnification. Plates were held under a dissecting scope by placing them on nontoxic modeling clay supports

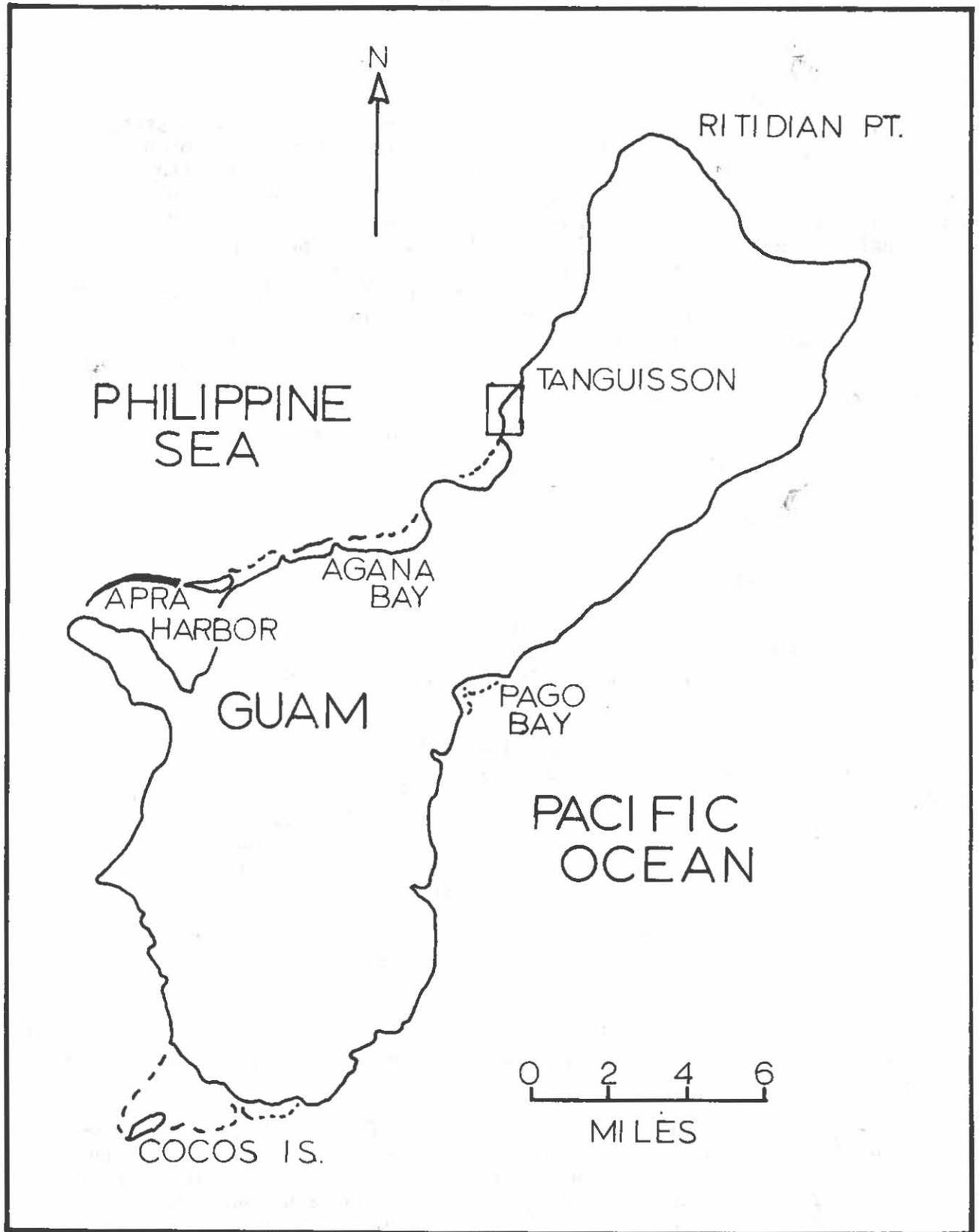


Figure 1. Map of Guam showing the Tanguisson Power Plant and the study site.

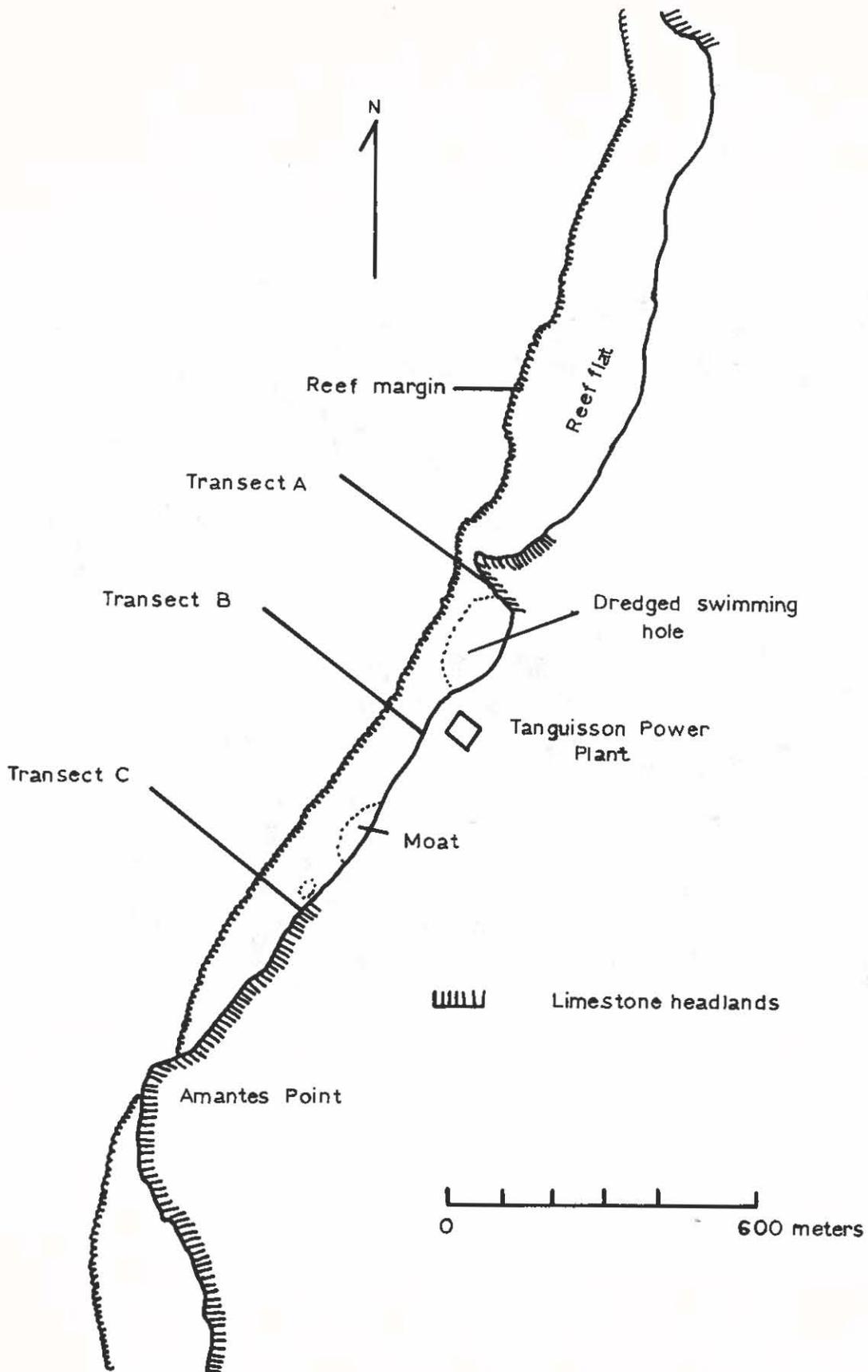


Figure 2. Study site map showing the permanent transects. After Jones and Randall (1973).



Figure 4. Aerial photograph of the Tanguisson Power Plant. (R. Randall photograph)

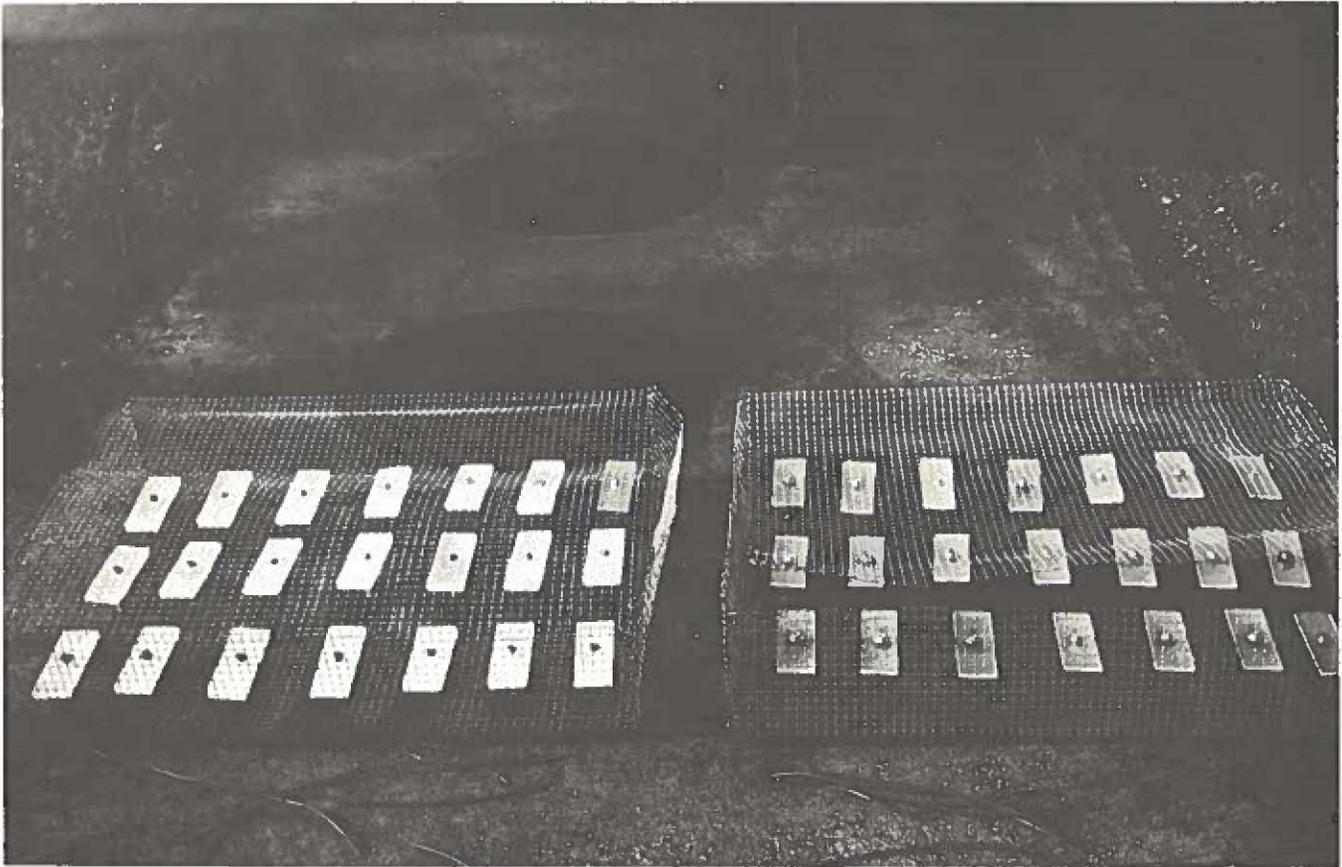


Figure 19. Photograph of settling plate cage topside. (S. Neuhecker)



Figure 20. Photograph of settling plate cage in situ, Transect A-3.0 m.
(S. Neudecker)

while immersed in seawater in a pyrex baking dish (Birkeland, et al. 1976). Surface coverage counts were made by tallying the substrata or organisms under 5 points uniformly spaced along a line in the ocular micrometer of the microscope eyepiece. The position of the line was randomly selected by turning the eyepiece. This procedure was repeated 18 times for each side of the plate, thus giving a total of 90 points on each surface. These 90 points provided a representative coverage for the entire plate. Both upper and lower surfaces were examined and the data were recorded separately. The entire plate was also thoroughly examined for any corals and a list was made of all fauna observed. Corals were identified by Mr. Richard Randall, generally according to Wells (1969), and their length and width measured using an ocular micrometer.

After the species present were recorded and the surface coverage taken, the plates were dried in an oven at 85°C for at least four days. They were then placed in a desiccator and allowed to reach ambient temperature before weighing. To prevent added weight from crystallization and accumulation of salts, the plates were soaked overnight in fresh water before drying (Birkeland, et al. 1976).

Some material fell off the plates during handling of the jars. This was filtered and the filtrate was dried in the oven and weighed. The material was then weighed and pyrolyzed at 450°C to determine the percent of organic matter. This was added to the plates' organic dry weights in the proportion of occurrence. It was also noticed that plates from Transect A had a considerable amount of sediment entrapped in the algal mat. These plates were scraped after weighing and the scrapings were pyrolyzed to determine the percent of organic matter. The total biomass was multiplied by the proportion of organic material to get a corrected measure of biomass.

Statistical tests were run to compare the amount of production and coral settlement at the two transects.

Sampling Transects

The percent of coral coverage was measured at various depths along Transects A, B and C as established by Jones and Randall 1973 (Figs. 2, 3). Transect B lies within the area of thermal influence, while A and C are not directly affected by the waste heat and thus constitute controls. A 0.25 m² grid, subdivided into twenty-five 100 cm² quadrats was placed at random 3-m intervals along depth transects of 1.2, 3 and 6.1 m. These depth transects were perpendicular to Transects A, B and C. Photographic surveys were made on the following dates: 9 X 75, 23 X 75, 5 II 76, 6 V 76, 22 VII 76 and 26 VII 76. A 35-mm transparency was taken of each grid placement (Fig. 11). Data sheets were prepared by drawing grids identical in pattern but of smaller scale to those used in the field. The transparencies (Figs. 14-17) were then projected onto these data sheets which were calibrated for the actual size. All corals falling within the grid were then traced onto the data sheets.

Exact measurement of the coral coverage was made by using a Keuffel and Esser compensating polar planimeter. Two planimeter measurements were made for each coral colony and the average of the two was considered to be the area of coverage.



Figure 14. Photograph showing the method used to measure the percent of living hermatypic coral coverage. Photo taken at Transect A. (S. Neudecker)

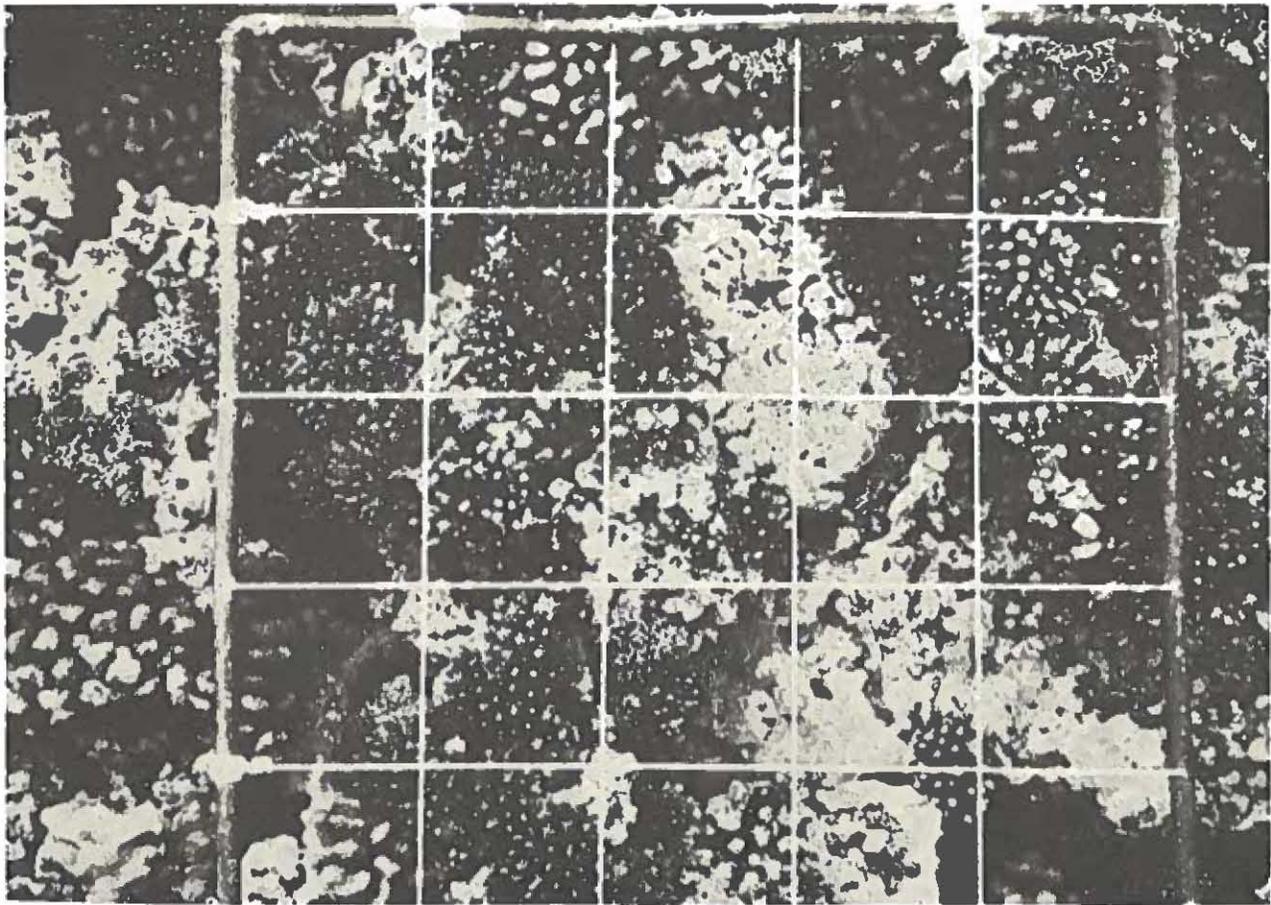


Figure 15. Photograph of quadrat A15-1.2 m. (C. Birkeland)

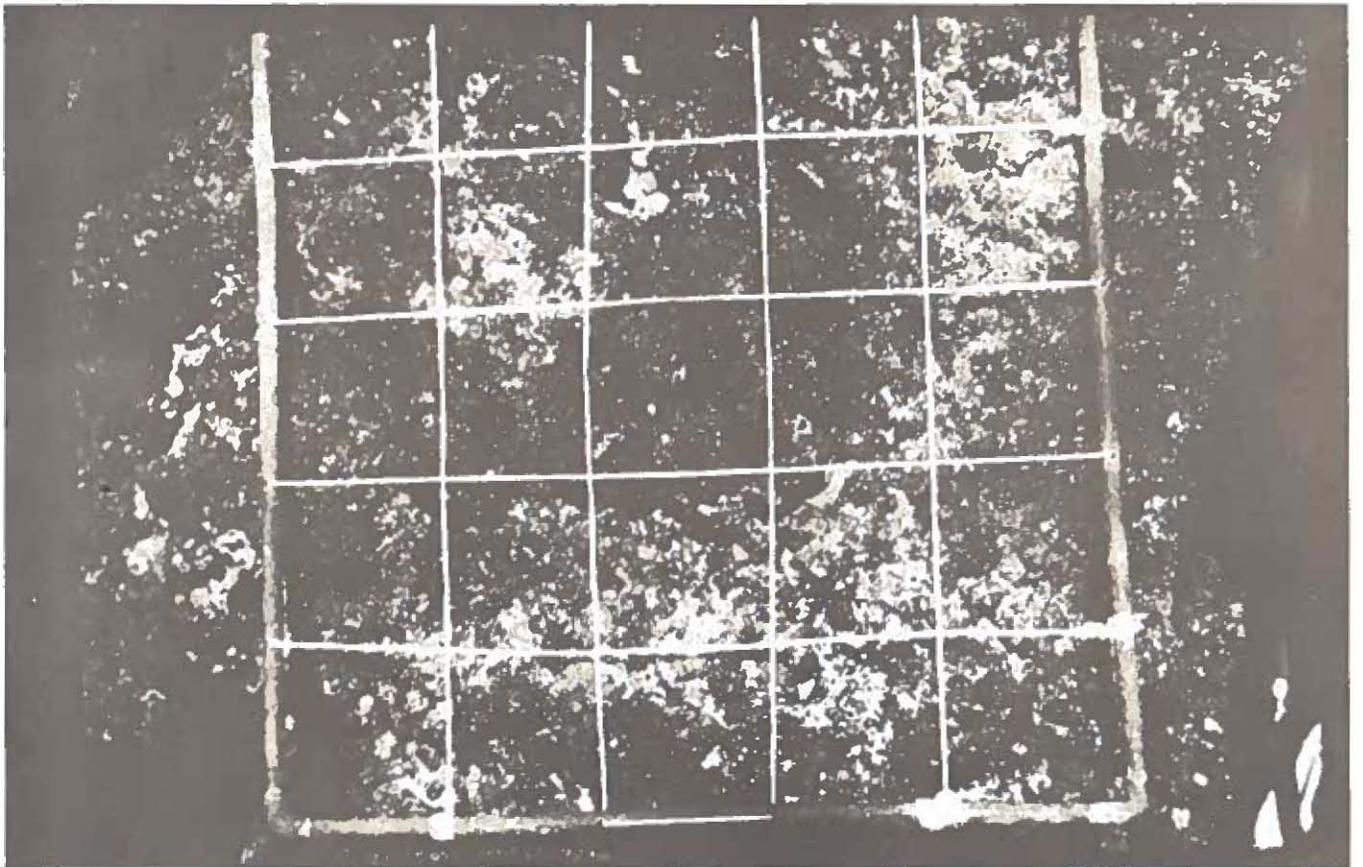


Figure 16. Photograph of quadrats B10-1.2 m. (S. Neudecker)

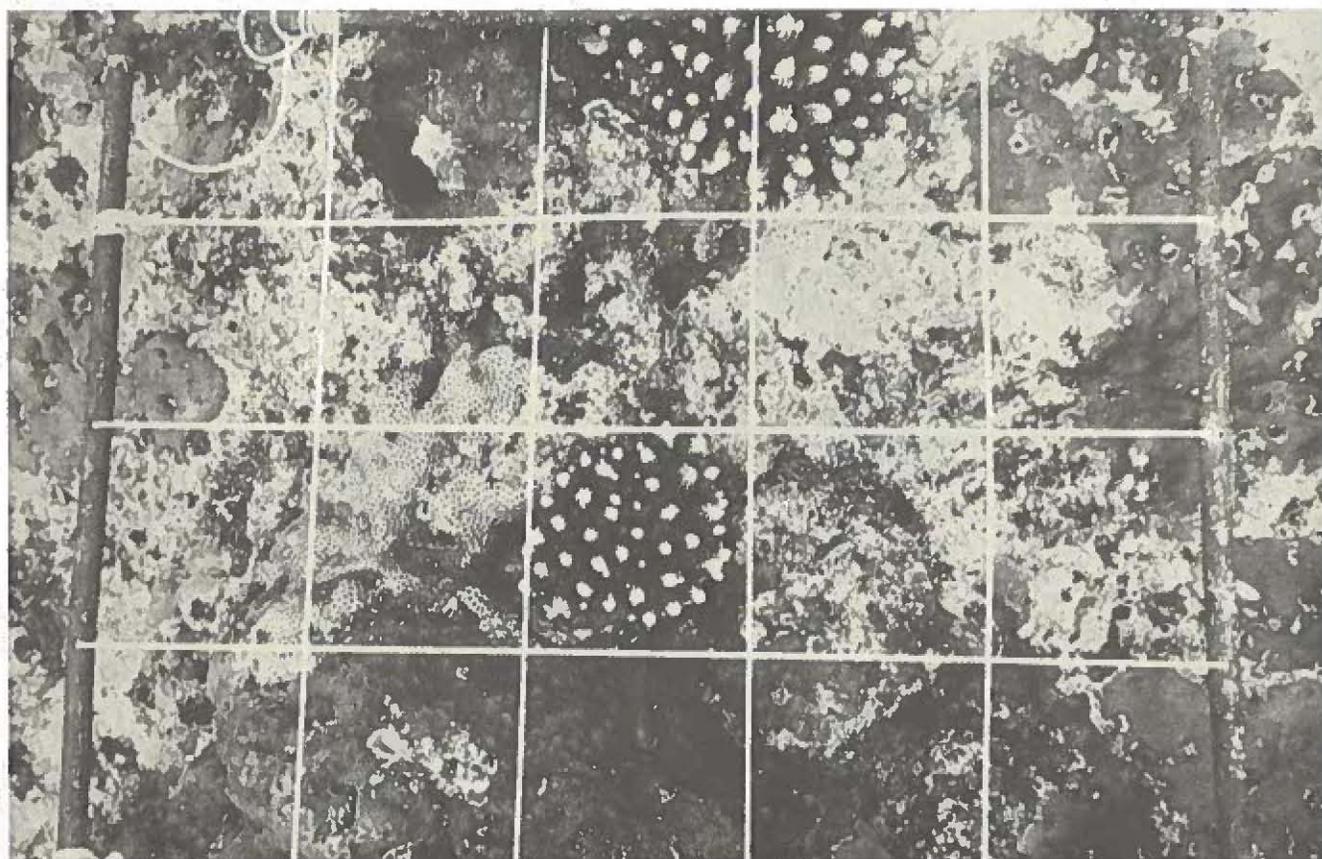


Figure 17. Photograph of quadrat A14-3.0 m. (C. Birkeland)

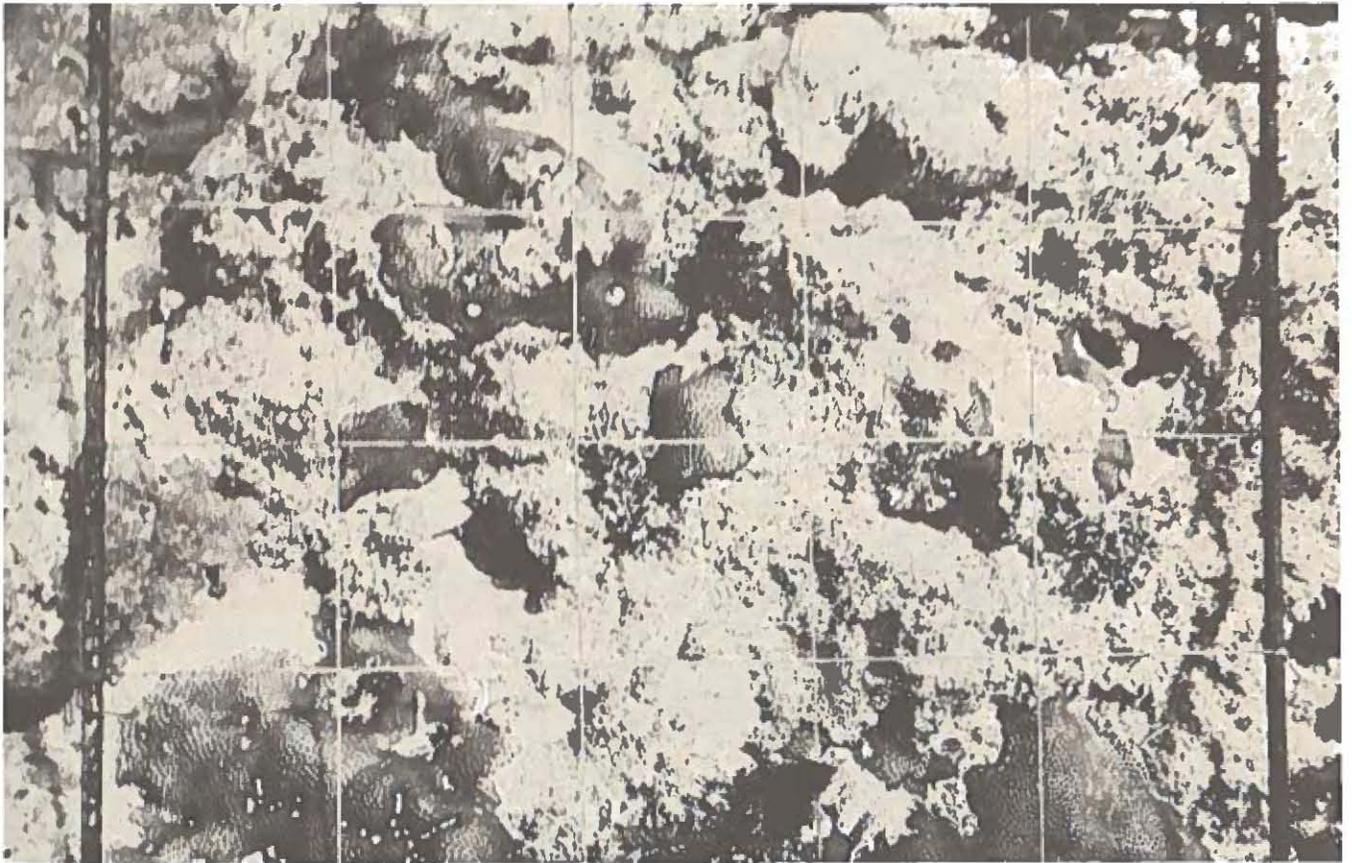


Figure 18. Photograph of quadrat B11-3.0 m. (C. Birkeland)

A problem was encountered with the planimeter readings in that each grid took about 75 minutes to measure. A less time-consuming method was sought and found. Each of the 25 quadrats was further divided into quarters by a series of intersecting lines. The original quadrat lines and the new lines gave 9 points of intersection for each row horizontally and 9 points for each column vertically, yielding a total of 81 points. Coverage was then calculated by counting the number of data points which fell in an area of coral coverage and taking the ratio of these to the total of 81.

Both methods were applied to 20 grids and compared statistically to see if there were differences in the two methods.

Table 2 shows the results of a comparison of two techniques for measuring the percent of living hermatypic coral cover. The results of both the t -test for paired comparisons and the sign test indicate that there is no significant difference between results of the two techniques so "number of points covered", as described in the methods section, was therefore chosen as the procedure for analysis of the remaining data. This method is easier to use and requires much less time than the polar planimeter measurements.

After all the data had been recorded and traced, statistical analyses were run to characterize the data (see Tables 1, 2, 3). Because the coverage was computed as a percentage and the variables were continuous, the Mann-Whitney u -test was used. Statistical tests were done according to Sokal and Rohlf (1969).

Coral Growth Studies

On 11 III 76, 1-m² panels of 1/4" 19 ga. hardware cloth were placed in 1.2 m of water at Transects A and B. These panels were to serve as platforms for attaching corals for growth comparisons.

Alizarin Red S, a hydroquinone bone stain, was used to mark the coral skeleton and provide an indicator of growth. As the symbiotic zooxanthellae of the coral, exposed to stain, photosynthesize and as calcium is secreted the stain is assimilated. The incorporation of the dye during calcification colors the terminal calices red (where most of the growth occurs, Goreau, 1961, Edmondson, 1929) and with continued growth after staining, a reference line will remain as an indicator of the growth since exposure to the stain.

Several colonies of *Pocillopora meandrina* Dana, 1846, *P. verrucosa* (Ellis and Solander, 1786), *Acropora surculosa* (Dana, 1846) (Fig. 23) were collected live, brought back to the laboratory in plastic buckets, and placed in a 360-L flow-through aquarium. On 17 III 76 these corals were stained with alizarin dye. About .2 g of stain was placed in 4 L plastic bags which were placed in the aquaria with a coral in each. The bags were sealed with a rubber band to keep the stain from escaping. The nature of the plastic bags is such that stain cannot pass through, while oxygen can. The corals were thus exposed to the stain solution for 7-8 hours during maximum insolation. The corals were to have been returned to the field the following day but inclement weather prevented this. Typhoon Pamela (May 20-21) killed these corals and tore away the test panels. Because the running seawater system of the Marine Laboratory was also destroyed in that storm, an alternate

Table 1. Statistics for the percent of living hermatypic coral coverage at the Tanguisson transects. $\bar{Y} \pm S$ (sample size).

Zone (depth)	A	B	C
Reef margin (1.22 m)	32.6 \pm 14.2 (27)	0.52 \pm 1.45 (24)	35.1 \pm 18.4 (20)
Reef front (3.05 m)	30.3 \pm 18.3 (20)	30.0 \pm 8.5 (19)	40.3 \pm 13.2 (20)
Reef front (6.10 m)	15.0 \pm 20.4 (11)	11.8 \pm 8.4 (19)	41.6 \pm 14.7 (20)

Table 2. Comparison of two methods for measuring the percent of living hermatypic coral coverage by the t -test for paired comparisons and the sign test.

	% coverage by polar planimeter	% coverage by points covered	$D=Y_1-Y_2$
1.	45.47	50.62	+5.13
2.	42.40	44.44	+2.04
3.	10.45	12.35	+1.90
4.	23.24	30.86	+7.62
5.	29.60	33.33	+3.73
6.	15.61	19.75	+4.14
7.	32.50	27.16	-5.34
8.	68.29	69.14	+ .85
9.	37.70	43.21	+5.51
10.	47.94	40.74	-7.20
11.	24.54	27.16	+2.62
12.	7.91	6.17	-1.74
13.	14.11	12.35	-1.76
14.	13.13	14.85	+1.68
15.	25.40	24.69	- .71
16.	41.93	48.15	+6.27
17.	3.99	4.94	+ .95
18.	30.84	41.98	+11.14
19.	31.89	29.63	-2.26
20.	38.91	40.74	+1.83
ΣX	585.87	622.22	36.35
\bar{Y}	29.2935	31.1110	1.8175
S	15.9784	16.5912	4.3349
			ΣD^2 423.1067

t -test for paired comparisons

$$t_s = \frac{\bar{D} - (\mu_1 - \mu_2)}{S_{\bar{D}}}, \text{ where } \bar{D} \text{ is the mean difference between the paired comparisons}$$

$$t_s = 1.9795 \text{ ns with 19 d.f.}$$

Sign test

$$n \leq 25 \quad p = \sum_{i=0}^r \binom{n}{r_i} p^{r_i} q^{n-r_i}, \text{ where } n = \text{number of pairs not equal, } p \text{ and } q = .5, \text{ and } r = \text{number of fewer signs in } n$$

$$p = .0577 \text{ ns}$$

Table 3. Comparison of the percent of living hermatypic coral coverage at Tanguisson by the Mann-Whitney U test.

Null Hypothesis (H_0): There is no difference in the percent of living coral coverage between sampling transects.

Zone (Depth)	A vs B $n = 27$	B vs C $n = 24$	C vs A $n = 20$
Reef margin (1.22 m)	$\bar{Y}\%$ cover = 32.65 $t_S = 6.36$ $p < .001$ with 37 d.f. reject H_0	$\bar{Y}\%$ cover = 0.52 $t_S = 5.8$ $p < .001$ with 42 d.f. reject H_0	$\bar{Y}\%$ cover = 35.13 $t_S = 0.13$ ns fail to reject H_0
Reef front (3.05 m)	$n = 20$ $\bar{Y}\%$ cover = 30.31 $t_S = 0.15$ ns fail to reject H_0	$n = 19$ $\bar{Y}\%$ cover = 29.97 $t_S = 2.82$ $p < .01$ with 37 d.f. reject H_0	$n = 20$ $\bar{Y}\%$ cover = 40.30 $t_S = 1.84$ ns fail to reject H_0
Reef front (6.10 m)	$n = 11$ $\bar{Y}\%$ cover = 15.04 $t_S = 1.03$ ns fail to reject H_0	$n = 19$ $\bar{Y}\%$ cover = 11.83 $t_S = 4.78$ $p < .001$ with 37 d.f. reject H_0	$n = 20$ $\bar{Y}\%$ cover = 41.58 $t_S = 3.44$ $p < .01$ with 29 d.f. reject H_0

$$t_S = \frac{(u_S - \frac{n_2 n_1}{2})}{\frac{(n_1 n_1) [(n_1 + n_2)^3 - (n_1 + n_2)] - \sum_{j=1}^m T_j}{[(n_1 + n_2) (n_1 + n_2 - 1)] 12}}$$

where u_S = The Mann-Whitney statistic

$$\sum_{j=1}^m T_j = (t_j - 1) t_j (t_j + 1)$$

t_j = number of tied observations

Reject H_0 : Conclude that the percent of living hermatypic coral coverage differs significantly between Transects A and B.

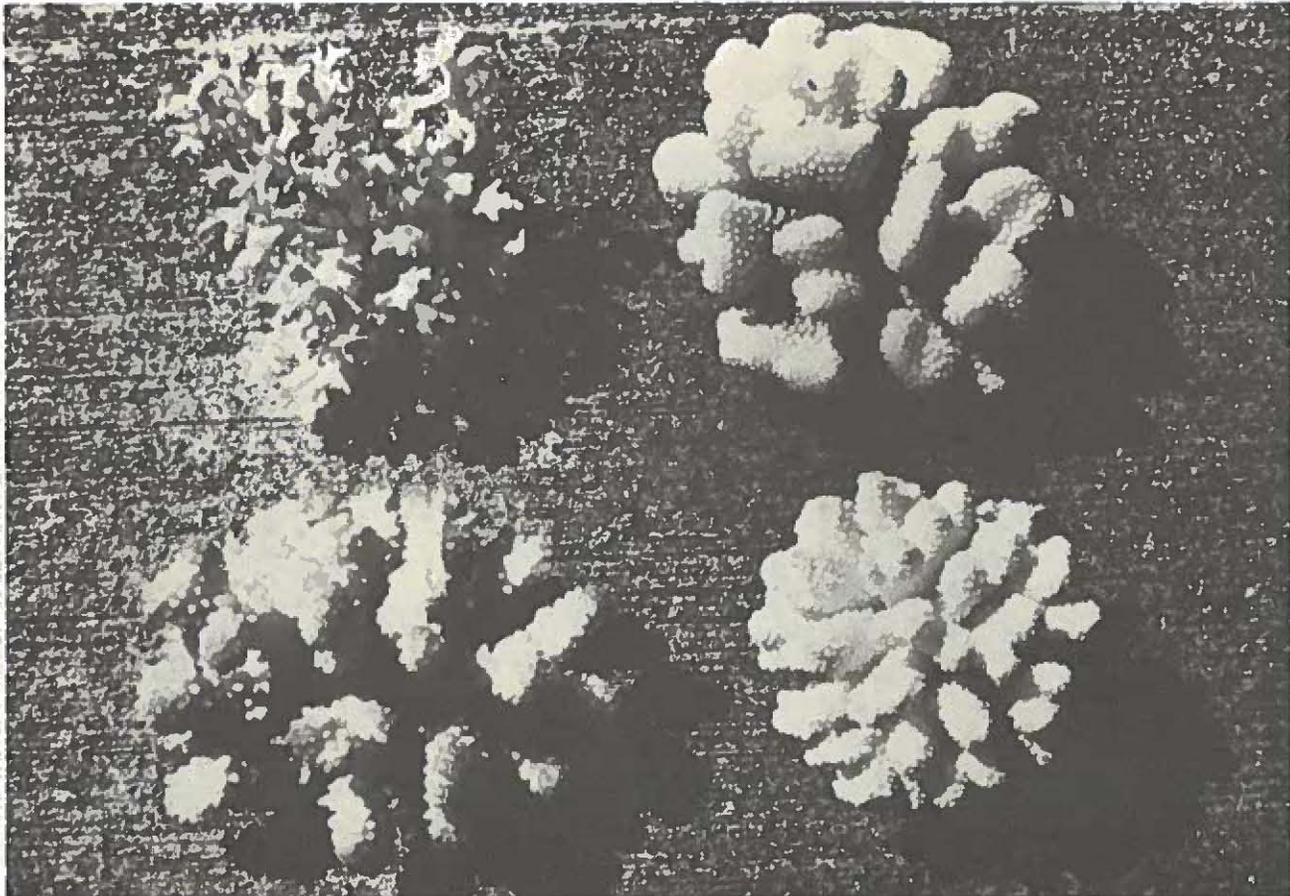


Figure 23. Photograph of corals used in the growth studies. Upper Right - Pocillopora meandrina. Upper Left - Pocillopora damicornis. Lower Right - Acropora surculosa. Lower Left - Pocillopora verrucosa. (S. Neudecker).



Figure 22. Photograph showing a coral colony being stained on Golf Pier.
(S. Neudecker)

staining method was explored. On 25 VII 76, 15 colonies of Pocillopora damicornis (L.) 1758 (Fig. 22) were stained in their natural habitat (1.2 m deep) on Golf pier of the Mobil Oil Company near the seaplane ramp in Apra Harbor (Fig. 21). The method described above was used with the exception that the corals were left attached to their substrata (in situ) and the plastic bags were tied around their basal attachments with 1/8" hemp line. On 18 VIII 76 these corals were removed, placed in plastic buckets of seawater and moved to Tanguisson by boat. They were then placed in 1.2 m of water at Transects A and B by tying them directly onto the reef with #12 electrical wire (plastic covered).

Branch samples will be taken from the colonies in two months and hopefully again after four months. The individual branches will be filed down to expose the stain line and a direct measurement of growth will be taken.

Several additional heads of P. damicornis were stained 18 IX 76. These colonies will also be taken to Tanguisson for replicate studies. Since none of the colonies have been in situ long enough, no quantitative measurements have been made. The results of these experiments will be reported in the yearly report for the 1976-1977 contract.

Permanent Transects

The three permanent Transects A, B, and C, as established by Jones et al. (1973) were used to continue the study of recovery of hermatypic corals after damage to the reef front, submarine terrace and seaward slope zones (Fig. 3) by Acanthaster planci 1968-1969.

At each station along the transects, a 1-m² grid was placed in the same location as used by Jones et al (1973). Within the 1-m² grid, four .25-m² quadrats were photographed. Two 1-m² grids were taken at each station of 50, 60, 70, 80, 90, and 100 ft.

These data were analysed according to the method described in the sampling transects section. At the time of writing only Transect A had been completed and the results comparing these measures of coral coverage to those of Jones et al (1976) will be presented in the next annual Tanguisson report.



Figure 21. Photograph of Pocillopora damicornis on Golf Pier. (S. Neudecker)

RESULTS AND CONCLUSIONS

Sampling Transects

The data for the sampling transects are summarized in Table 3. The results of the Mann-Whitney U -test indicate that there is a significant difference between reef margin (1.22 m deep, Fig. 3) transects at A and B as well as B and C ($P < .05$ in both cases). No significant difference was found between the two control Transects A and C. These data suggest that Transect B at 1.22 m is directly influenced by the thermal effluent from the Tanguisson Plant. As indicated by the \bar{Y} mean percent of living hermatypic coral coverage at Transect B (0.52 percent) the damage to the coral community has been extensive. This region is now dominated by algae. The only corals observed in this area were encrusting forms which were often growing in holes or indentations, which placed them farther away from the effluent.

The differences between transects at the two other depths measured are not as clear as those of the shallow transect. At the reef front (3.05 m deep, Fig. 3) there was a significant difference between B and C ($P < .01$) while no significant difference was found between A and B. This was also the case at the reef front (6.05 m deep) with B and C ($P < .001$) while A and B were not significantly different. This is probably due to the fact that Transect C had the most surface coverage at all depths (cf. Table 3).

There are inherent problems with this sampling method and it is worthwhile to mention them. First, it is nearly impossible to identify the species and quite often even the genera. Secondly, the amount of relief under the sampling grid varies and it is hard to get a measure of coverage except in one plane.

For a comparison of the changes in the amount of living hermatypic coral coverage after the damage by Acanthaster planci and the operation of the Tanguisson Power Plant, data were compared with those of Jones et al. (1976) (Table 11, Figs. 9, 10 and 11). Part of the difference in the measures of the coral coverage is due to the difference between methods use to quantify the coral coverage, especially on the reef margin because the 1976 measures were taken on the upper limit of the reef margin.

Studies of recolonization of hermatypic corals are valuable in assessing the recruitment rates for the reef. However, our measures of the percent of coral coverage cannot be used as a simple index of the recovery of the coral community. Coral diversity on a recovering coral reef may rapidly equal or even exceed that of the original community. This is due to the fact that many small colonies may develop on the unoccupied substratum (Goreau et al., 1969; Grigg and Maragos, 1974). Such opportunistic species may rapidly cover large areas of the bottom, resulting in high measures of coral coverage. However, the growth form may not be the same as before (e.g. arborescent) and as such would not provide the same number of niches as the pervious coral. Therefore, full recolonization of the coral community by the myriad of associated fauna (e.g. fish and invertebrates) may be delayed for years. These associates require a greater volume, surface area and complexity of coral architecture than young colonies provide (Wood and Johannes, 1975, p. 46).

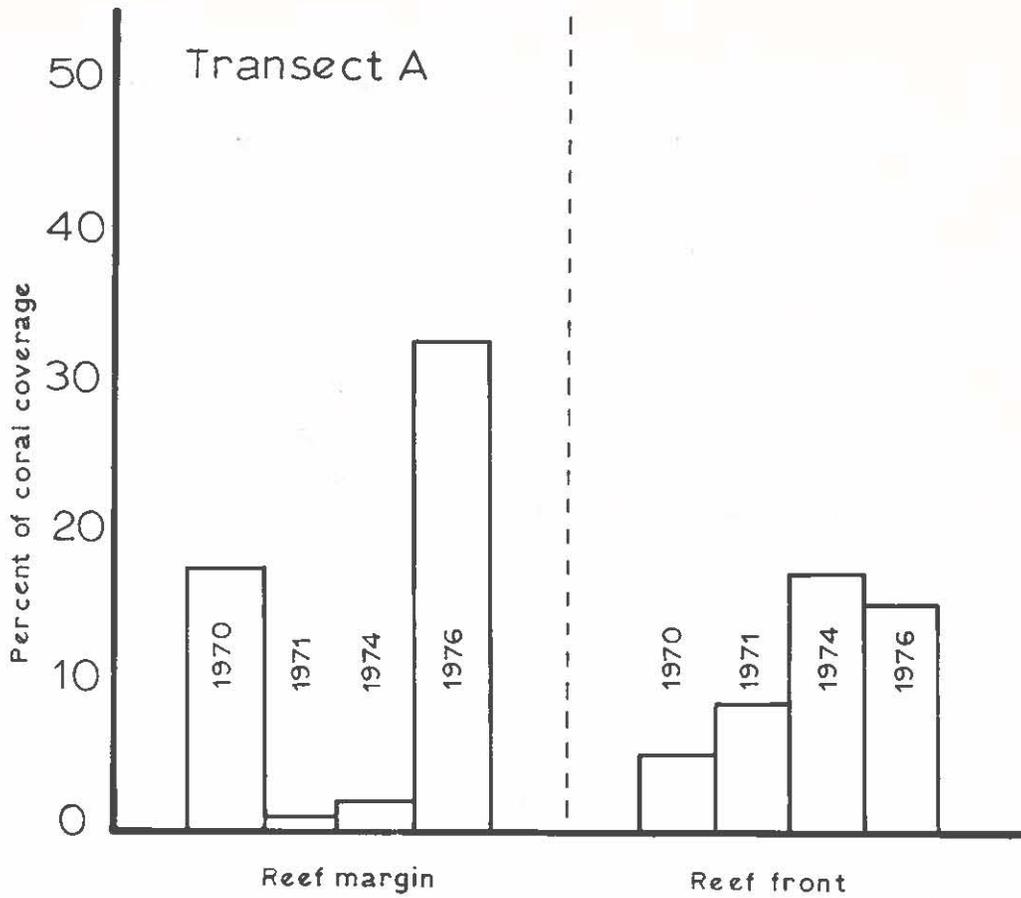


Figure 9. Comparison of the living hermatypic coral coverage along the reef margin and reef front at Transect A, from 1970 to 1976.

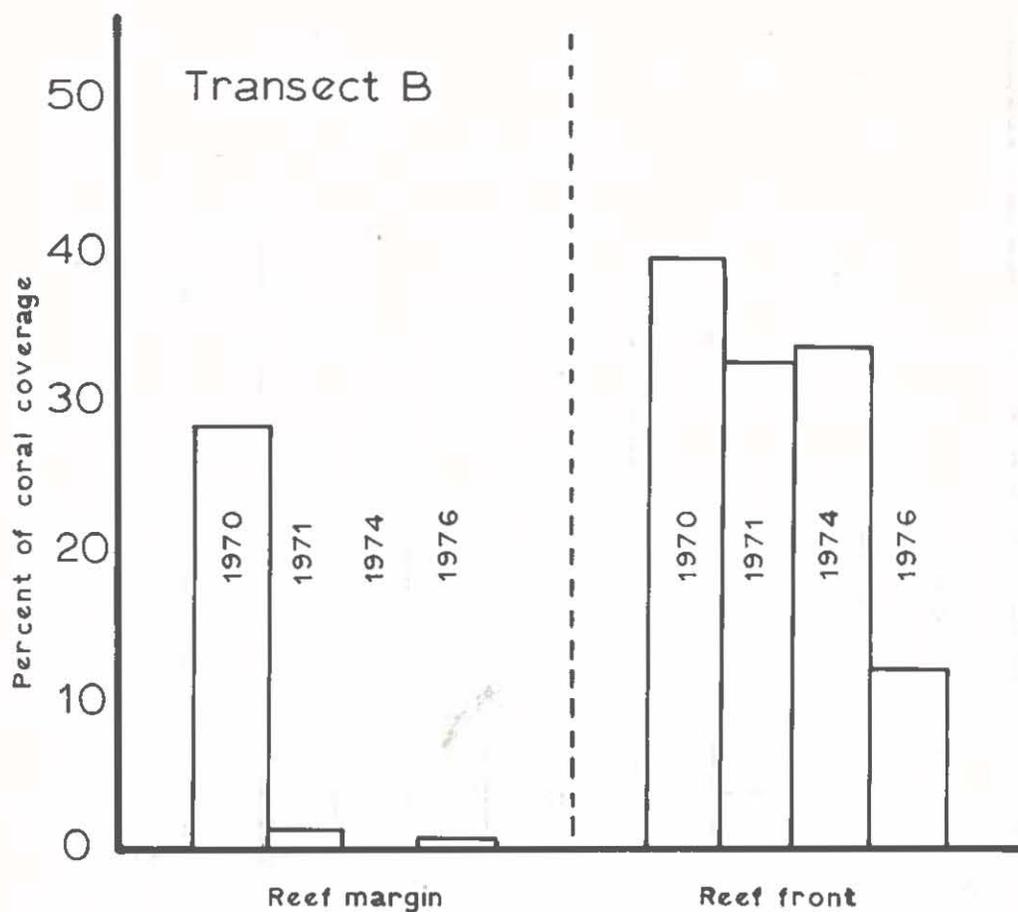


Figure 10. Comparison of the living hermatypic coral coverage along the reef margin and reef front at Transect B, from 1970 to 1976.

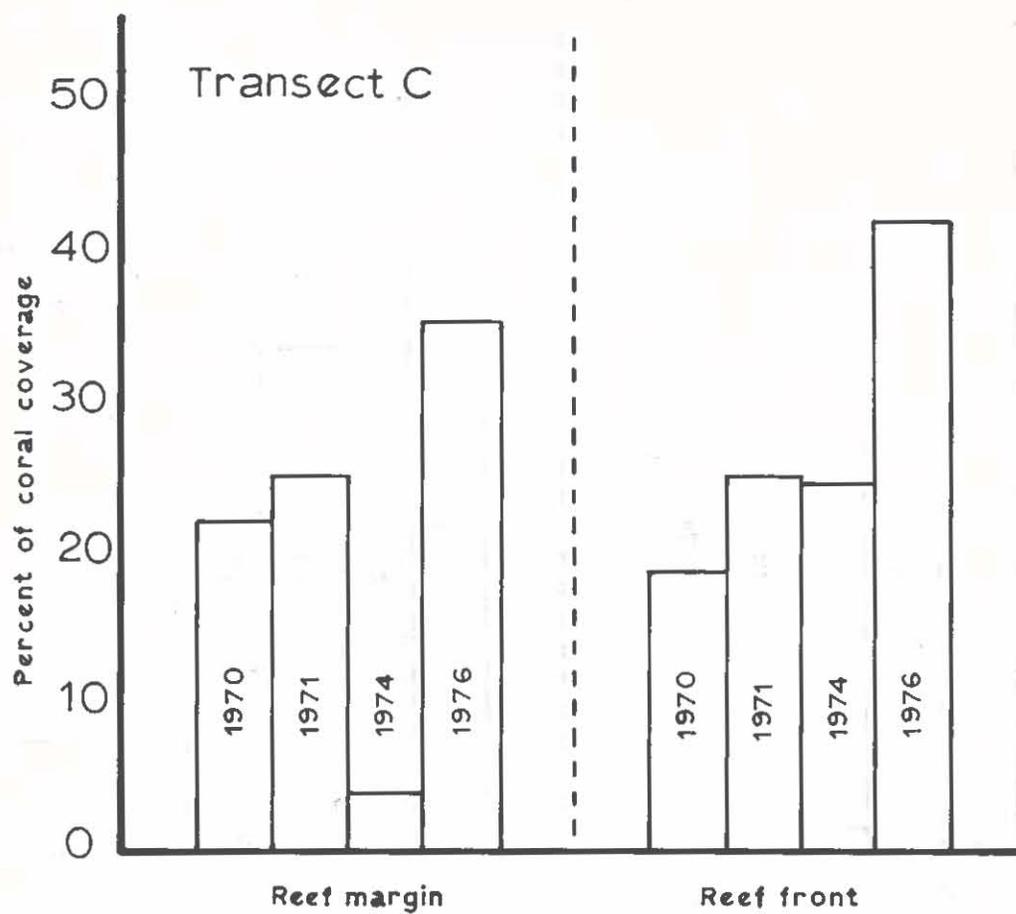


Figure 11. Comparison of the living hermatypic coral coverage along the reef margin and reef front at Transect C, from 1970 to 1976.

Table 11. Changes in the percent of living hermatypic coral coverage by reef zones along transects from 1970 to 1976. 1970-1974 from Jones et al. (1976)

	Transect A				Transect B				Transect C			
	1970	1971	1974	1976	1970	1971	1974	1976	1970	1971	1974	1976
Reef Margin	17.5%	0.1%	0.2%	32.6%	28.0%	1.5%	0.0%	0.5%	22.2%	25.0%	3.9%	35.1%
Reef Front	5.1%	8.7%	17.0%	15.0%	39.0%	32.2%	33.1%	11.8%	18.8%	24.8%	24.4%	41.6%

Recruitment Studies

The results of the settling plate experiment may be found in tables 4-11. The number of hermatypic corals settling after 70 days at Transect A was significantly greater than at Transect B, as indicated by the Chi-Square test ($P < .05$, see Table 4). This demonstrates that the thermal effluent is detrimental to settlement of coral planulae. Even though two planulae did settle on the plates exposed to the waste heat, they probably would not have survived long. It is also interesting to note that all planulae which settled at Transect A may not have matured. This is because a couple of small corals were observed to have dense algal growths surrounding and touching them. It is doubtful that these recently metamorphosed corals would have out-competed the algae for space.

The amount of production in terms of standing crop or biomass accumulation was shown to be significantly greater at Transect A by the Mann-Whitney *u*-test ($P < .05$). This indicates that thermal enrichment has a negative effect on communities of organisms on settling plates. This is the opposite of what has been reported from temperate areas. Markowski (1959, 1960, 1962), as well as Nauman and Cory (1969), found more biomass on plates exposed to thermal effluents. This is probably because tropical organisms live at temperatures closer to their upper lethal limit (Mayer, 1914).

The dried weights alone (Table 5) of fouling communities on plexiglass plates reflect the difference of standing crop between the two stations that was apparent to the naked eye at time of collection. Because of the amount of sediment that was entrapped in the algal mat on the A plates, ash-free dry weights were taken to get a better representation of biological production. However, 85 to 95 percent of the sediment was composed of foraminifera (Russ Clayshulte, personal communication). Although, these forms were living animals, nearly all of their weight is calcium carbonate which does not burn at 450°C. Therefore, the corrected ash-free weights are a very conservative measure of standing crop.

The number of species and species groups found on the plates is much greater at Transect A (Tables 7, 8). The species diversity, as measured by the Shannon-Wiener index (Tables 9-11), was significantly greater on upper surfaces at Transect A, as indicated by the Mann-Whitney *u*-test ($P < .05$). Although the species diversity was greater on the lower surface at Transect A, the difference was not significant between lower surfaces of plates on the two transects. It was generally observed that when there was a heavy growth on the upper surface (Transect A plates) the standing crop or species diversity was less on the bottom surface than it was on plates with roughly equivalent standing crops on both surfaces (Transect B). This could be a case of amensalism, a situation in which the environment of one species is adversely effected by the presence of the other species, while the habitat of the other species is not affected. Perhaps the accumulation on top reduces the amount of light available to the under surface and thus inhibits its growth while the top surface remains unaffected.

A similar conclusion may be drawn from the effects of a heavy oil spill following the breakup of the ship "Tampico Maru" (North, et al. 1965). The

Table 4. Comparison of the settling of hermatypic coral planulae after 70 days on the reef margin at Transects A and B. Measurements are in millimeters.

Plate	Top Surface	Bottom Surface	Side
A1	Pocilloporidae 2.5 X 2.2	-	-
A2	<u>Montipora</u> sp. 3.8 X 4.2, 1.8 X 1.7, 1 X 1.3	<u>Montipora</u> sp. 2.5 X 2.3	Pocilloporidae 2.3 X 1.8
A3	<u>Montipora</u> sp. 2.5 X 2.2	<u>Montipora</u> sp. 2.3 X 2.2	-
A4	-	<u>Montipora</u> sp. .9 X 1.4	-
B1	Pocilloporidae 2.3 X 2.3	-	-
B2	-	-	-
B3	<u>Montipora</u> sp. 1.8 X 2.2	-	-
B4	-	-	-

$$\chi^2 = \sum_{i=1}^n \frac{(O_i - E_i - \frac{1}{2})^2}{E_i}$$

where O_i = observed frequency

E_i = expected frequency

$$\chi^2 = 4.55 \quad p < .05 \text{ with 1 d.f.}$$

Reject H_0 = Conclude that settling of hermatypic corals differs significantly between Transects A and B.

Table 5. Raw data for biomass accumulation of organisms settling on plexiglass plates for 70 days at Transects A and B. Plates are 75 cm² in area on each side, for a total of 150 cm² per plate.

Plate	Plate Weight	Paper	Plate & Paper & Biomass	Paper & Residue	Dry Weight of Filtrate	Sediment & Biomass	Crucible	Crucible & Biomass	Burnt	% Organic	Biomass	Biomass + Filtrate
A												
A1	48.6308	0.9230	53.8708	1.0230		4.4170	1.8983	2.4276	2.2002	42.96	1.8975	2.2416
A2	53.0178	0.9581	57.7678	1.0923	1.1121	3.9261	1.8324	2.7664	2.4498	53.90	1.3308	1.5721
A3	53.9258	1.0683	59.7945	1.1754		5.9753	1.7728	2.5920	2.3645	27.77	1.6595	1.9604
A4	51.8498	0.9557	55.7063	1.0264		2.9715	1.8604	2.5558	2.2645	41.89	1.2448	1.4706
B												
B1	49.7334	1.0046	51.8171	1.118							1.1863	1.2447
B2	51.8530	1.0526	53.8398	1.1761	.2245						1.0573	1.1093
B3	52.1514	0.9643	54.4309	1.0630							1.4139	1.4835
B4	48.6808	0.8950	50.4220	0.9469							0.9031	0.9476

Table 6. Comparison of biomass accumulation of organisms on plexiglass plates on the reef margin at Transects A and B after 70 days (9 VI 76 to 18 VIII 76).

	A	B
Biomass Accumulation	n = 4	n = 4
	$\bar{Y} = 1.8112$	$\bar{Y} = 1.1963$
	S = .3562	S = .2268

$$F_S = \frac{S_1^2}{S_2^2}, \text{ where } S^2 \text{ is the variance}$$

$$F_S = 2.47 \text{ ns}$$

Fail to reject H_0 : Conclude that there is no significant difference in the variance for biomass accumulation at Transects A and B.

$$t_S = \frac{(u_S - \frac{(n_1 + n_2)(n_1 + n_2 + 1)}{2})}{\sqrt{\frac{(n_1 + n_2)[(n_1 + n_2)^3 - (n_1 + n_2) - \sum_{i=1}^m T_i]}{[(n_1 + n_2)(n_1 + n_2 - 1)] (12)}}$$

where u_S = The Mann-Whitney statistic

$$\sum_{i=1}^m T_i = (t_i - 1) t_i (t_i + 1)$$

t_i = number of tied observations

$$t_S = 2.91 \quad p < .05 \text{ with 3 d.f.}$$

Reject H_0 : Conclude that the amount of production in terms of biomass accumulation, after 70 days, differs significantly between Transects A and B.

Table 7.. List of species and species groups found on plexiglass plates after 70 days at Transects A and B. 0 = not found at that transect. + = found on plates.

<u>Species or Species Group</u>	<u>Transect A</u>	<u>Transect B</u>
Chlorophyta	+	+
Phaeophyta	+	0
Rodophyta		
<u>Jania</u> sp.	+	+
gelatinous	0	+
branching	+	0
calcareous	+	+
coralline	+	+
unidentified sp. 1	+	+
sp. 2	+	+
Sabellid	+	0
Serpulid	+	0
errant polychete	+	0
ascidian	+	0
scleractinian coral	+	+
Foraminiferins		
<u>Baculogypsina sphaerulata</u> (Parker & Jones)	+	+
<u>Amphisorus hemprichii</u> Ehrenberg	+	+
<u>Amphistegina madagascariensis</u> d'Orbigny	+	+
<u>Triloculina</u> cf. <u>T. oblonga</u> (Montagu)	+	+
<u>Triloculina</u> cf. <u>T. bicarinata</u> d'Orbigny	+	+
<u>Triloculina marshallana</u> Todd	+	+
<u>Triloculina</u> sp. A	+	+
<u>Triloculina</u> sp. B	+	+
<u>Quinqueloculina</u> sp. A	+	+
<u>Quinqueloculina</u> sp. B	+	+
<u>Quinqueloculina</u> sp. C	+	+
<u>Quinqueloculina</u> sp. D	0	+
<u>Robulus</u> sp.	0	+
<u>Elphidium advenum</u> (Cushman)	+	+
<u>Discorbis</u> sp.	+	+
<u>Orbulina</u> sp. A	+	+
<u>Orbulina</u> sp. B	0	+
<u>Globorotalia</u> sp.	+	+
<u>Texturlia</u> sp.	0	+
<u>Miliolinella</u> sp.	+	+
<u>Spiroloculina</u> sp.	+	0
<u>Archias angulata</u> (Fichtel & Moll)	0	0
Globigerinacea		
<u>Miliolidae</u> spp.	+	+

Table 8. Species diversity data for communities of organisms settling on the top surface of plexiglass plates at Transects A and B, after 70 days. Comparison is by the Shannon-Wiener index, $H^1 = -\sum p_i \log_2 p_i$. Where p_i is the proportion of individuals of the i^{th} species.

	A1	A2	A3	A4	Σ	B1	B2	B3	B4	Σ
Chlorophyta	20	27	22	30	99	17		14	14	45
Phaeophyta			3							3
Rhodophyta sp.	13	6	4	7	30		3			
gelatinous branching		1			1					
calcareous		23			23			8	1	9
coraline		3	1	1	5	24	29	12	31	96
<u>Jania</u> sp.	40		40	32	112			3		3
sabellid										
serpulid			3		3					
errant polychete										
Foraminifera										
<u>Baculogypsina</u> sp.	5	7	3	4	19	9	4	10		23
<u>Amphisorus</u> sp.		2		1	3	1				1
<u>Amphistegina</u> sp.										
<u>Triloculina</u> sp.	2	3	1		6		2			2
Sp. 1										
ascidian										
scleractinian coral			2		2					
substrata	13	30	20	22	85	41	54	42	44	178
	93	109	99	97	391	92	92	89	90	364
H^1	2.24	2.49	2.37	2.25		1.87	1.94	2.15	1.44	
all of A top surfaces						all of B top surfaces				
	$H^1 = 2.63$				>	$H^1 = 2.07$				

Table 9. Species diversity data for communities of organisms settling on the bottom surface of plexiglass plates at Transects A and B, after 70 days. Comparison is by the Shannon-Wiener index, $H^1 = -\sum p_i \log_2 p_i$, where p_i is the proportion of individuals of the i^{th} species.

	A1	A2	A3	A4	Σ	B1	B2	B3	B4	Σ	
Chlorophyta	16	34	11	11	72		2	15		17	
Phaeophyta											
Rhodophyta											
gelatinous								15		15	
branching											
calcareous	9	4	1	5	19	4	5	11	1	21	
coralline	9	16	15		40	56	29		45	130	
<u>Jania</u> sp.											
sabellid		1			1						
serpulid				2	2						
errant polychete											
Foraminifera											
<u>Baculogypsina</u> sp.	1				1						
<u>Amphisorus</u> sp.											
<u>Amphistegina</u> sp.		2			2						
<u>Trioculina</u> sp.		2		1	3						
Sp. 1											
ascidian	6	5	4		15						
scleractinian coral		1		1	2						
substrata	48	27	61	63	199	30	54	49	44	177	
	89	90	92	84	355	90	90	90	90	360	
H^1	1.93	1.19	1.45	1.29		1.15	1.32	1.71	1.08		
For all of A bottom surfaces						For all of B bottom surface					
	$H^1 = 1.92$					>	$H^1 = 1.67$				

Table 10. Comparison of the Shannon-Wiener indexes for top and bottom surfaces of plexiglass plates at Transects A and B by the Mann-Whitney u -test. u_S is the greater of the two quantities C and $(n_1 n_2 - C)$, where $C = n_1 n_2 + n_2 \frac{(n_2 + 1)}{2} - \sum R^2$ and R rank of datum. H_0 : There is no significant difference in the species diversity between communities of organisms on surfaces of plexiglass plates at Transects A and B after 70 days.

Plate Surface	A vs B	
Top surface	$u_S = 16$	$p < .05$ ($n_1 = 4, n_2 = 4$) reject H_0
Bottom surface	$u_S = 13$	$p < .2$ ($n_1 = 4, n_2 = 4$) fail to reject H_0

expansion of kelp was assumed to be caused by the negative effect of the oil on kelp's main predator, a herbivorous echinoid. The conclusion is not that the oil helped the algae but rather its negative effect on algal's predators was the critical factor. Therefore, the population of urchins was affected by the oil while the kelp was not. However, a confounding factor exists in that under certain conditions oil has been shown to enhance algal growth (Birkeland et al., 1976).

In this case amensalism could be an explanation of why there is not a significant difference between the species diversity of lower surfaces of Transects A and B. While the hot water seems to inhibit all growth at Transect B, it may give an advantage to the lower surface communities by keeping the upper surface growth minimal. If a perfect, translucent anti-fouling agent existed and was applied to the upper surface of the plates, the growth and species diversity would probably be clearly greater on the bottom surface of the Transect A plates. More data are needed to adequately demonstrate that growth and species diversity on the lower surfaces of plexi-glass plates is significantly less in the area of thermal effluent.

Growth Studies

As stated in the Methods and Materials, the growth experiment was recently destroyed by Typhoon Pamela and has been started over again. This was also the case with the settling plate cages. It is becoming increasingly obvious how difficult it is to get data from an area that receives so much surf action. These experiments will be tried again and hopefully some data will be aquired.

Thermal Regimes

The data collected by the staff of the Tanguisson Plant are summarized in Figs. 5, 6, 7. They are presented as representative data for the daily intake and outfall temperatures. Because no records were kept on the minimum intake temperatures, the ΔT above the monthly mean was calculated. As stated in the Figure 7, this is a conservative estimate of the average monthly ΔT .

These data do not facilitate many conclusions about the biological activities of the benthic biota, e.g., reproduction, growth and distribution (Hedgepeth and Gonor, 1969). Constant recording of temperatures is needed for these types of conclusions. As Bullock (1957) has noted, we cannot assume that the monthly average, daily average, or any measure short of the complete curve of temperature against time, is biologically appropriate, since we do not know how the organism weighs equal departures from the average for different lengths of time. Maximum-minimum thermometers are often used but there is no way of knowing how long the maximum temperature lasted.

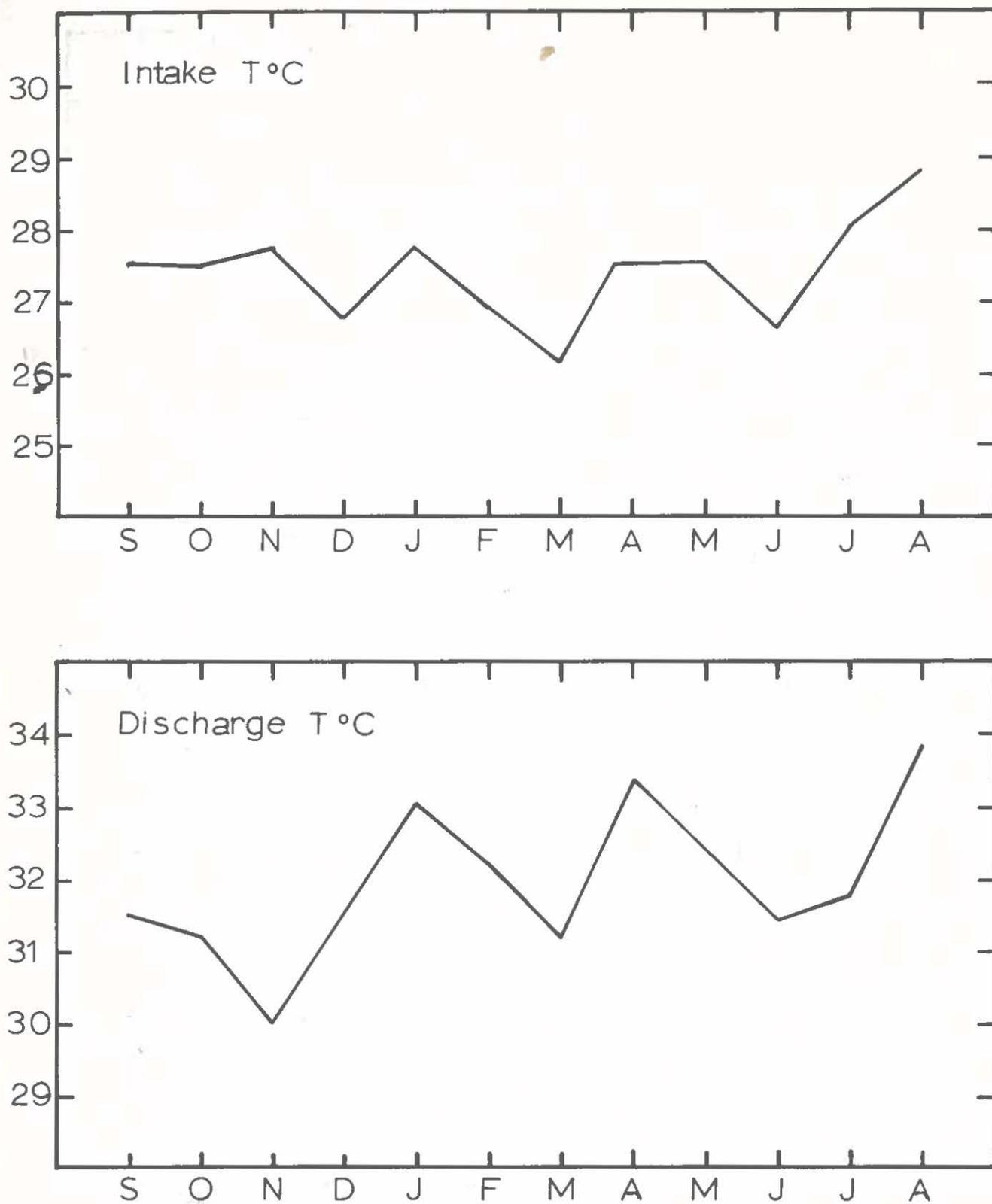


Figure 5. Monthly intake and discharge temperatures of the Tanguisson Power Plant.

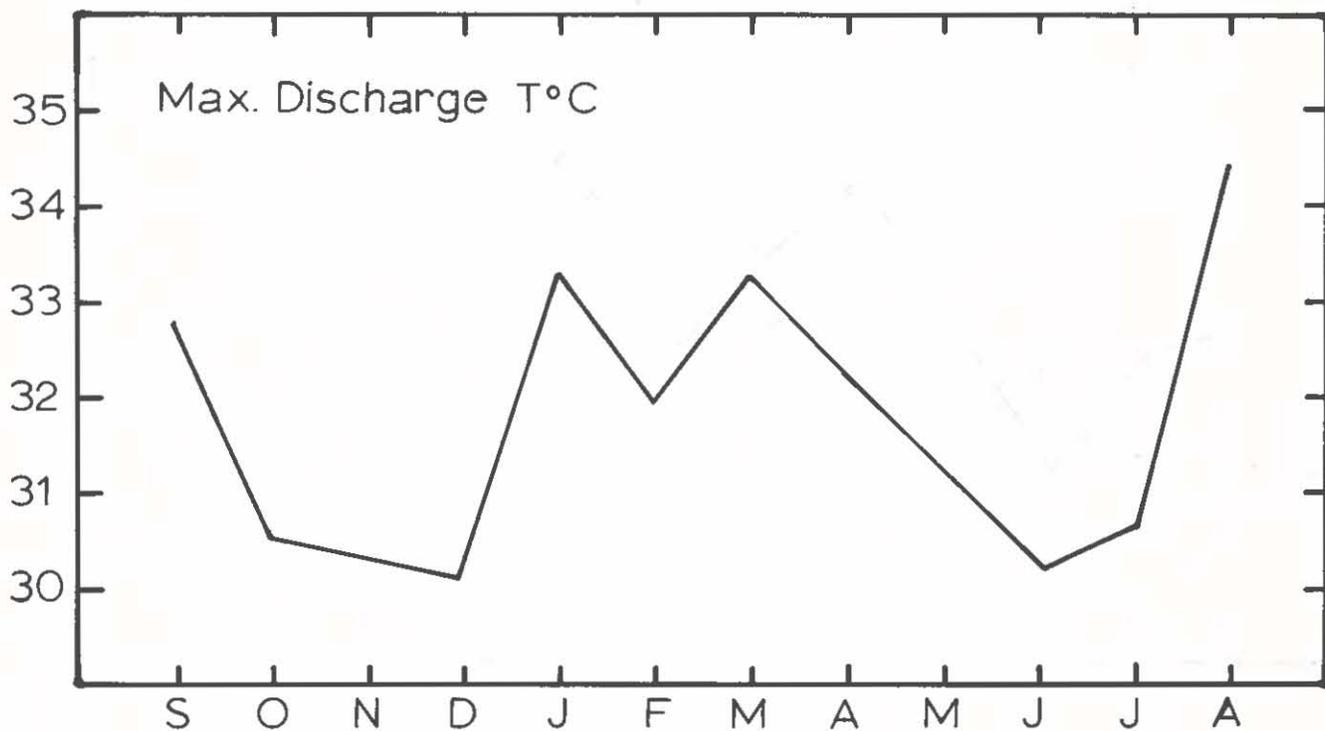
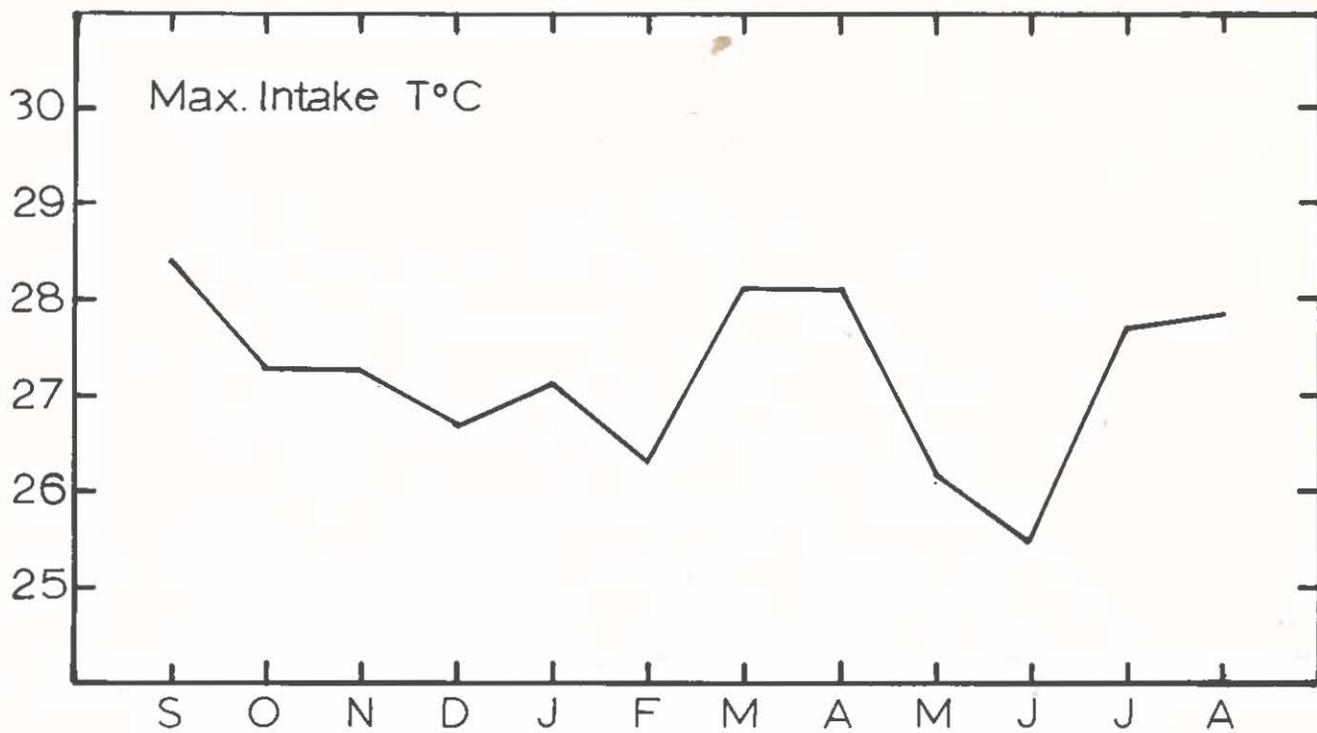


Figure 6. Maximum intake and discharge temperatures of the Tanguisson Power Plant.

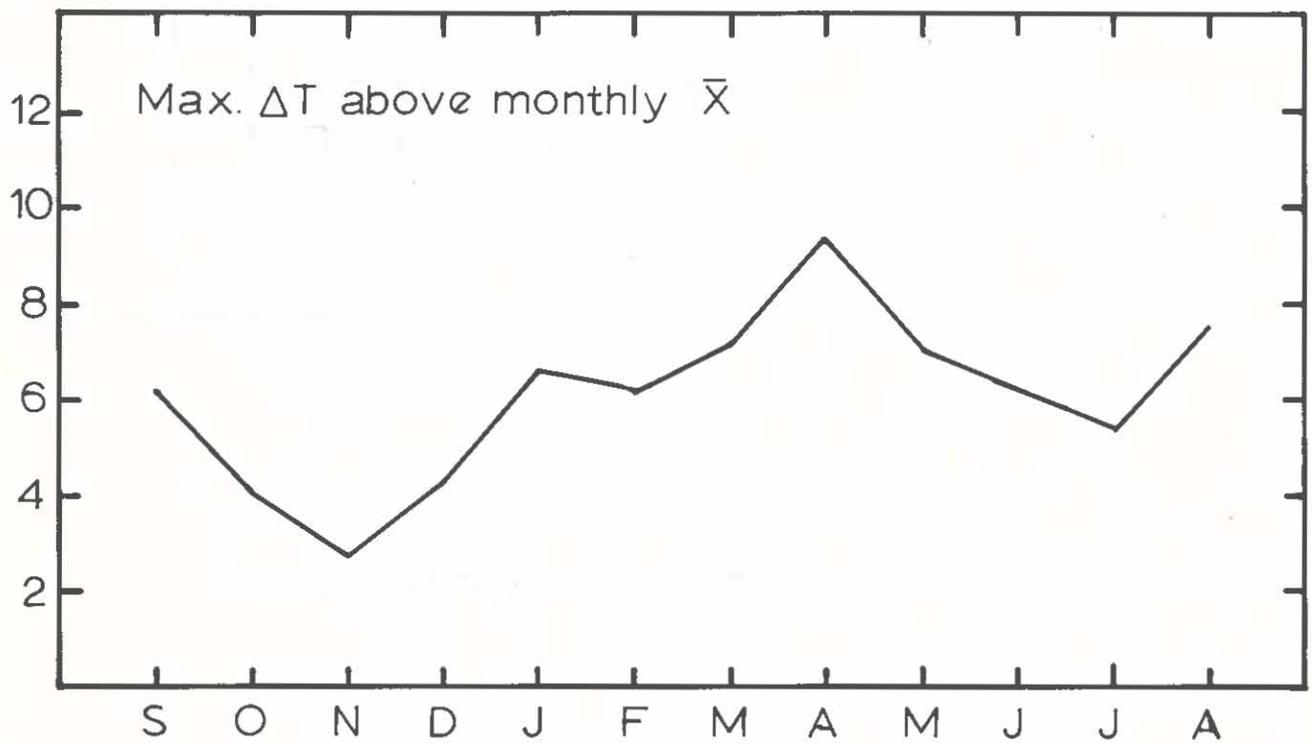
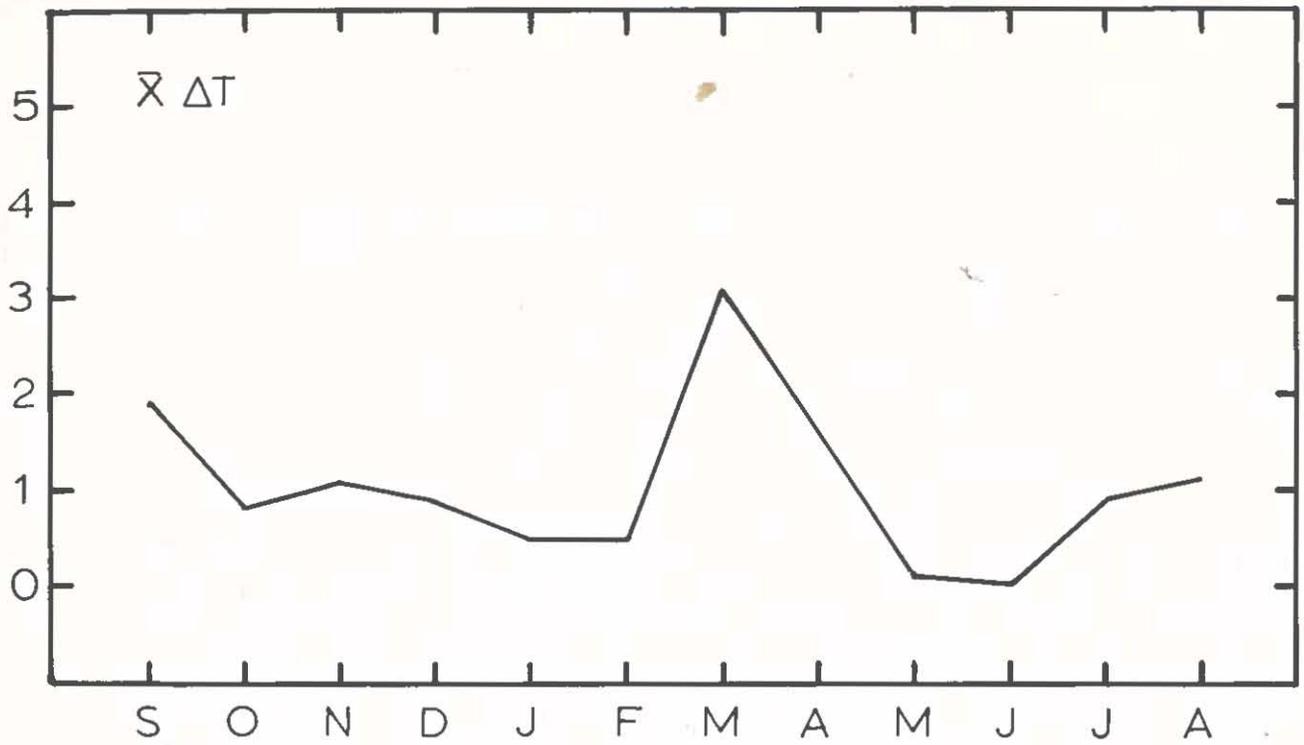


Figure 7. Mean monthly ΔT 's and conservative maximum monthly ΔT .

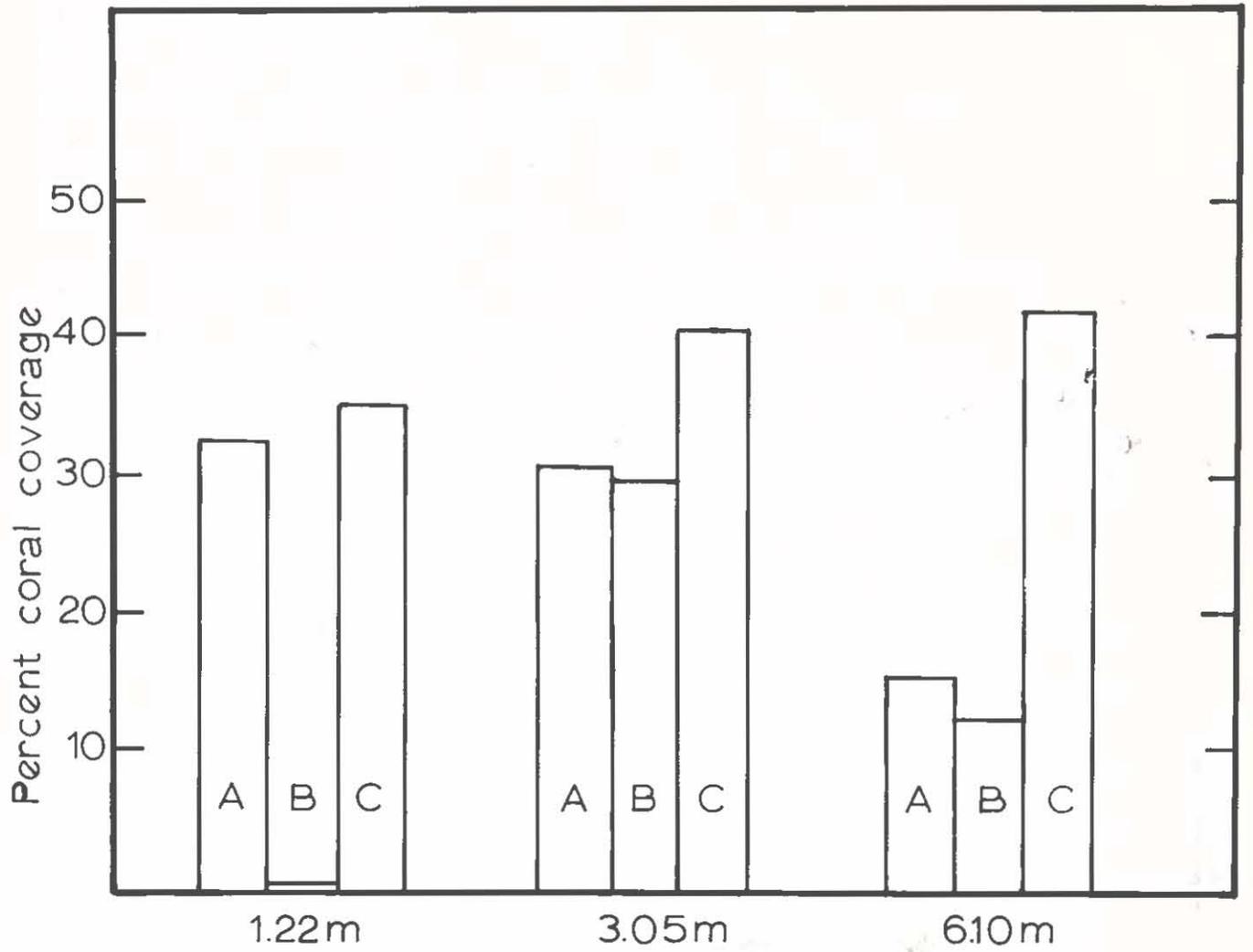


Figure 8. Percent of living hermatypic coral coverage in zones along Transects A, B and C.

General Conclusions

We have no reason to believe that the area of coral kill is expanding. This zone of about 20,000 m² extends 600 m along the reef margin and the area is essentially the same as reported by Jones et al. (1976) (Figs. 12, 13). Even though corals that received sublethal stress for long periods of time may have died since the completion of the Jones et al. (1976) study, the area of damage has not grown. The zone of coral destruction is directly proportional to the generating capacity of the plant (Jokiel and Coles, 1974). Unless the generating capacity increases above the present 54 megawatts or toxic chemicals are discharged, this region will not increase by a significant amount.

We agree with Jones et al. (1976) that there is no doubt that the thermal effluent from the Tanguisson Power Plant is responsible for the death of hermatypic corals along the reef margin. Furthermore, our studies indicate that hermatypic corals will not be able to recolonize the area affected by the waste heat. However, recruitment and recolonization are showing annual increases in the zones previously damaged by Acanthaster planci (Figs. 8, 9, 10 and 11).

There is no evidence that any endangered species are being affected by the effluent. This is because the area of the coral kill was no different in species composition than the control Transects A and C where the corals still live.

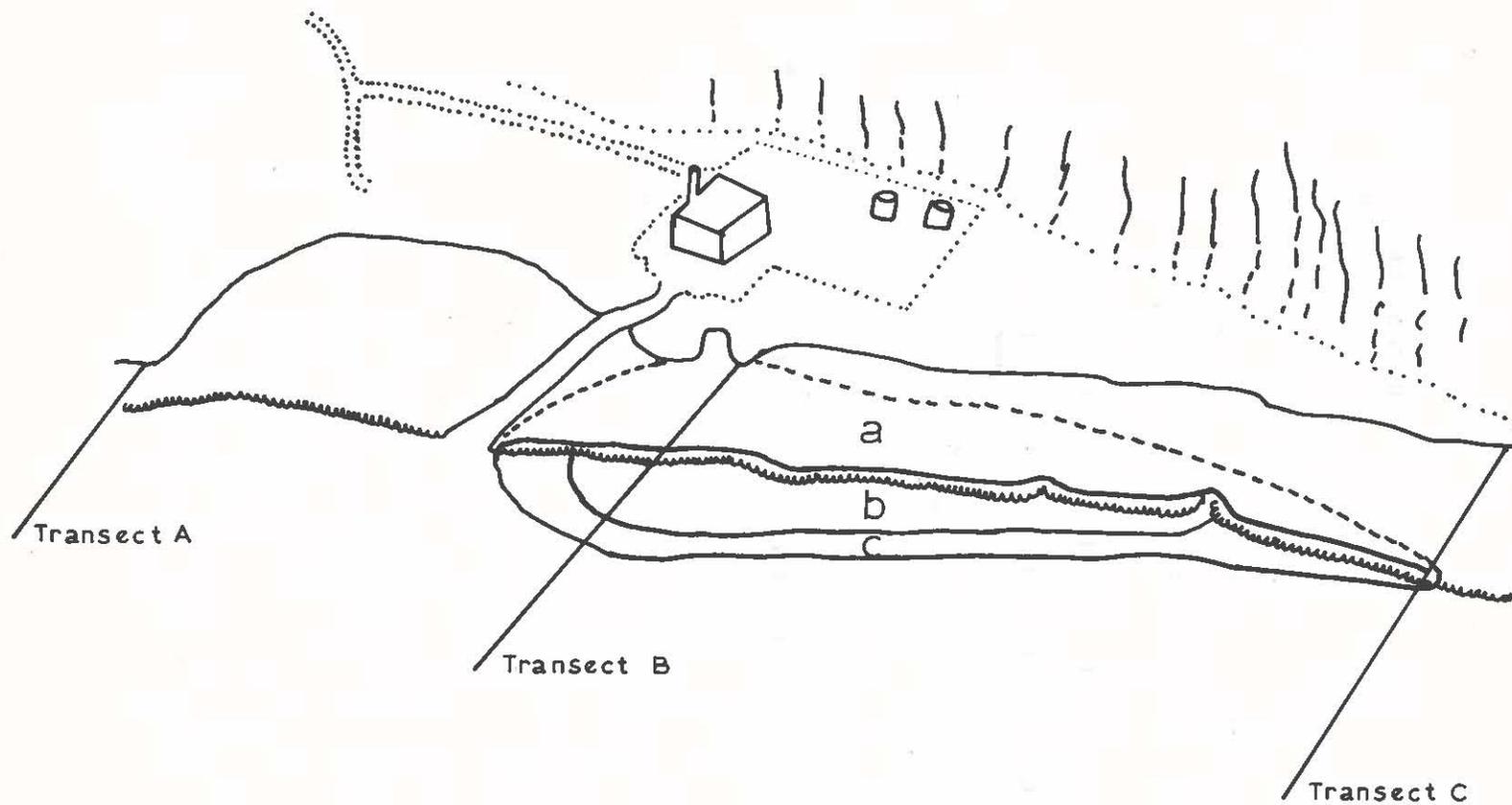


Figure 12. Limits of the coral kill, October 1974 as reported by Jones et al. (1976). a = thermal influence on the reef flat where few corals ever existed. b = the "core zone" of the coral kill. c = the peripheral zone where the corals killed were usually limited to those on the upper surfaces of buttresses and channels.

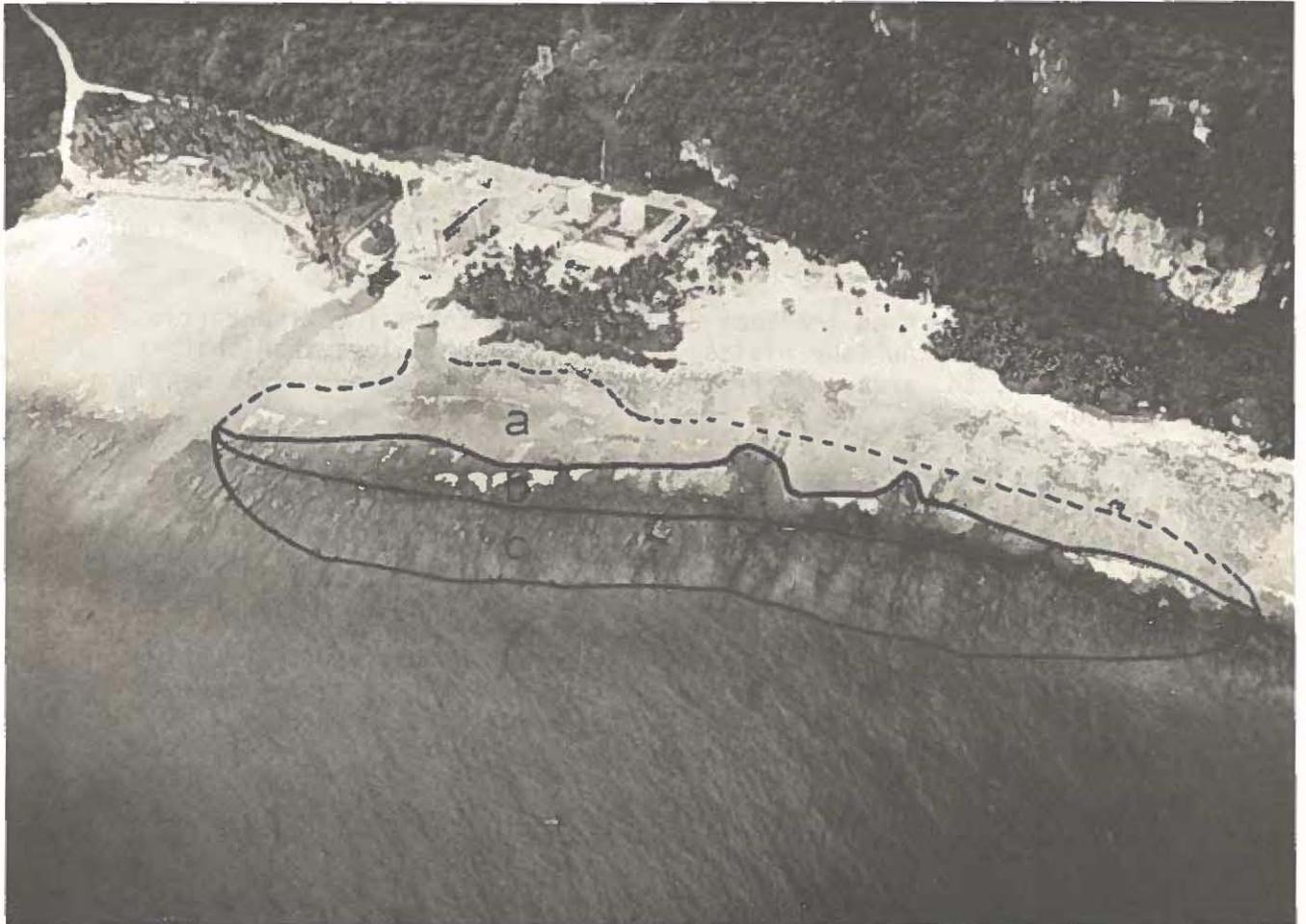


Figure 13. Aerial photograph showing the coral damage, September 1976.
(R. Randall)

SUMMARY

1. There is significantly less coverage of the substratum by hermatypic corals along the reef margin at 1.2 m in the area of thermal effluent on Transect B (0.5 percent living coral) than in areas outside the influence of thermal effluent on Transects A (33 percent living coral) and C (35 percent living coral). This indicates that the thermal effluent has a negative effect on the coral community.
2. The amount of coral coverage on the reef front at depths of 3 and 6 m does not differ significantly between Transects A and B. This indicates that the influence of thermal effluent is concentrated along the reef margin at Transect B.
3. Coral recruitment on Transect B, the area of thermal effluent (two corals settling on four plates), is significantly less than that at Transect A, the area away from thermal effluent (seven corals settling on four plates).
4. The amount of production in terms of biomass accumulation on plexiglass plates is significantly less on the reef margin at Transect B, the area of thermal effluent (average biomass accumulation 1.8 g) than at Transect A, away from thermal effluent (average biomass accumulation 1.2 g).
5. The number of species, the number of species groups and the species diversity of organisms found on plexiglass plates is significantly less at Transect B, in the region of thermal effluent, than at Transect A, in the area away from thermal effluent.
6. There is no doubt that the thermal effluent is responsible for the death of hermatypic corals along the reef margin.
7. The area of hermatypic coral destruction, by the waste heat is not growing significantly.
8. There is no evidence that any endangered species are being affected by the waste heat because Transect B was initially no different than Transects A or C.
9. It is extremely difficult to acquire data on communities of organisms inhabiting reef margins which periodically receive heavy surf action.

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