DEVELOPMENT AND ENVIRONMENTAL QUALITY OF

CORAL REEF COMMUNITIES NEAR THE TANGUISSON POWER PLANT

By

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INTRODUCTION

This final report presents the results of our second year of ecological investigations into the effects of thermal effluent upon the coral reef communities at Tanguisson. Our earlier report (Neudecker 1976) presented information on the recolonization of damaged reef areas by corals and also presented preliminary information on fouling communities, but information on coral growth was not included.

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 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 devasted 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 studies presented in this report was to investigate the effects of thermal enrichment from the Tanguisson Power Plant on the structural quality of adjacent reef communities. The fouling study was designed to determine the probability of coral recruitment into denuded areas by comparing recruitment rates of organisms onto settling plates within the area of thermal effluent with rates at a control site. The growth-transplant studies assessed the impact of increased temperatures on growth rate and mortality on representative coral species. The fish surveys compared density, abundance and species diversity of the Chaetodontidae (an integral fish component of coral reefs) between those areas affected and those unaffected by the Tanguisson thermal effluent.

Recruitment Studies

Bare space is often the most important limiting resource in benthic communities (Connell 1961, Dayton 1971, Paine 1974) and a knowledge of recruitment, survival and growth is essential in understanding functional

organization of benthic marine communities (Thorson 1957, 1966; Loosanoff 1964, Grassle 1974). However, very little is known about larval dispersal, survivorship and settlement of hermatypic corals (Connell 1974, Grassle 1974). In the few investigations of these parameters, the relatively common and abundant species had high rates of recruitment and mortality (Connell 1974, Loya 1976b). Ecological studies of fouling communities which considered patterns of development and distribution have been reported by Fager (1971), Sutherland (1974), Neushul et al. (1976), Osmann (1977) and Jackson (1977). This approach is useful for understanding functional responses of these communities to a wide range of environmental parameters.

Larvae of benthic organisms are very selective in location and timing of their settlement (Thorson 1957, 1966; Birkeland et al. 1971, 1976; Harrigan 1972; Lewis 1974). Various environmental factors, chemical and physical, have been suggested as influencing the attachment and metamorphosis of sessile organisms. Long (1974) reported that light intensity and water circulation were critical and temperature and light are well known to limit coral distribution.

Coral Growth Studies

The rate at which corals grow has been investigated since Guppy (1889) estimated growth of corals around the Cocos-Keeling Islands. However, the first study to produce better than speculative results was that of Vaughan (1915) on Atlantic corals. He found considerable variation in growth rates between colonies of the same species and within individual colonies in the same environment and reported annual linear extension rates of 5-10 cm for branching Acropora. Later investigations by Mayor (1924) in Samoa, Edmondson (1929) in Hawaii, Tamura and Hada (1932) in Yap and Palau and Stephenson and Stephenson (1933) on the Great Barrier Reef all reported growth rates of the same order of magnitude with considerable inter- and intraspecific variability. The presence of this variability has been reported by nearly every researcher who has since studied coral growth.

The random variability of growth rates was confirmed with the development of a precise method for measuring calcium deposition with radioistope tracers by Goreau (1959). Using this ^{45}Ca method, random variations in short-term growth rates were clearly indicated by large standard deviations from means of replicate determinations by Goreau and Goreau (1959), Clausen (1971) and Clausen and Roth (1975a,b). These results indicate that coefficients of variation of pooled results are typically in the range of 20-30 percent, although some were higher and some were lower (Buddemeier and Kinzie 1976). Coral growth is variable on all time scales: daily, diurnally, weekly, monthly, seasonally, annually;and definite differences occur between species and possibly between growth forms of the species (Buddemeier and Kinzie 1976).

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Increased Temperature and Coral Growth

Laboratory Tolerances

Edmondson (1928) demonstrated that 11 of the 13 species of
Hawaiian hermatypic corals that were studied survived less than
24 hours at 32°, a ΔT of only +5-6°C. As with this study, most
subsequent investigations of thermal tolerances have been limited
to short-term laboratory exposures to lethal and sublethal temper-
atures (Edmondson 1946, Clausen 1971, Jones and Randall 1973,
Clausen and Roth 1975a, b; Jones et al. 1976). The results of
these experiments are conclusive: temperatures increased 4-6°C
above ambient are lethal to corals in vitro.

Besides the drawback of the short-term nature of most labo-
ratory tests, only one or two variables were tested experimen-
tally while many synergistic processes may determine the species
response in nature. Furthermore, the temperature at which feed-
ing reactions and normal metabolic processes cease are as signi-
ficant as lethal temperatures because a coral cannot survive long
in water in which it can neither move nor function (Mayer 1914).
Also, Edmondson (1929) has suggested that temperature control may
be exercised through regulation of reproductive processes. Most
of the in vitro thermal studies agree that growth is curvilinearly
related to temperature and recent laboratory investigations on the
effects of temperature on the growth rate of three Hawaiian corals
(including P. damicornis) found an optimum growth temperature of
26°C and demonstrated significant reductions in growth at temper-
atures above and below the optimum (Jokiel and Coles, pers. comm.).
This research contradicts the classical view (Mayor 1918) that
corals are more sensitive to increased temperatures because
mortality of coral after 30 days exposure was greater at the lower
lethal limit (18°C) even though the optimum growth temperature is
closer to their upper lethal limit as Mayor (1918) predicted. At
Enewetak, Pocillopora damicornis exhibited two growth optima at
27 and 31°C, suggesting genetic adaptation to different ambient
thermal regimes and in contrast to Mayor's (1918) idea that the
upper lethal limit is a fixed physiological boundry (Clausen and
Roth 1975a, Coles et al. 1976). Furthermore, measurements of
P:R ratios of tropical and subtropical corals indicate that coral
metabolism is also closely adapted to ambient temperatures (Coles
and Jokiel, pers. comm.).

Field Tolerances

Observations by Jokiel and Coles (1974) in Hawaii and Jones
et al. (1976) in Guam of damage from thermal enrichment agree with
the in vitro studies. Nearly all corals exposed to temperatures
of 4-6°C above ambient were killed. Enewetak corals survived in
situ temperatures of nearly 34°C, whereas 32°C was lethal to

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Hawaiian corals for similar exposures (Coles et al. 1976).
Neudecker (1976) has shown that recruitment of corals into areas
of thermal effluent is significantly less than at an adjacent
control site. Only two hermatypic corals were found on four
plexiglass settling plates in the effluent while nine recruits
were found on the four control plates.

While the in vitro tolerances are well known, practically
nothing is known of the growth rate of corals in and adjacent to
areas of thermal enrichment. Therefore, a major purpose of this
report is to measure the growth of coral transplants in and near
thermal effluent from the Tanguisson and Cabras Power Plants.

Differences in reported upper lethal limits have been shown
to be related to duration of exposure. Subtropical corals have
an upper lethal limit lower than their tropical conspecifics
(Clausen and Roth 1975a, Coles et al. 1976). At Enewetak, corals
survived elevated temperatures 2°C higher than their Hawaiian
conspecifics and this difference was related to the higher ambient
temperatures at Enewetak (Clausen and Roth 1975a, Coles et al.
1976). Similar results were obtained in Guam (Jones et al. 1976),
where species showed a similar higher lethal limit compared to
Hawaiian species. Jokiel and Coles (pers. comm.) found no rela-
tionship between initial size (2 to 200 g wet weight) and thermal
tolerance, although recently settled corals were more sensitive
than adults. Since Edmondson (1946) has demonstrated that
planulae are more resistant to thermal additions than adults, new
recruits are probably the most sensitive stage (Jokiel and Coles,
pers. comm.). Loya (1976 has reported high mortality rates for
new coral recruits of Stylophora pistillata (a species similar to
P. damicornis in competitive strategies).

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,
Slobodkin 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).

Since settling plates have a finite and limited space for
colonization and growth and are therefore ideal for examining
parameters affecting the distribution and succession of species
in a community, fouling studies considering recruitment of benthic
communities have often been used as measures of environmental
quality around electrical generating stations (Markowski 1959,
1960, 1961; Nauman and Cory 1969, Nugent 1970 and Wolfson 1974).
These researchers placed replicate plates within and adjacent to

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areas of thermal enrichment. This method was also used by Chesher
(1971) in his study of the effects of heated effluent on marine
communities near a large desalination in Florida.

Coral Transplant Studies

Growth and survival of transplanted corals have been used as
measures of environmental quality by several authors including Mayor
(1924), Motoda (1940), Shinn (1966), Maragos (1972) and Neudecker (1977).
This method is based on the premise that a coral living in an unfavor-
able environment will grow at a slower rate than the same species in a
favorable environment (Shinn 1966). For coral transplants testing
stress factors in which mortality does not occur, growth rate is pro-
bably the best quantitative measure, integrating a variety of physiolo-
gical effects (Birkeland et al. 1976). Ramose hermatypes are particu-
larly useful for transplant tests due to their rapid growth which is
concentrated on the branch tips. If a coral is transplanted into an
area in which it is not normally found and if adequate measurements are
made, then the growth rate could be used as an index of the coral's
adaptation to the environment (Shinn 1966) or conversely, as an index
of environmental quality.

Butterflyfish as Environmental Indicators

Clearly, the thermal enrichment from the Tanguisson Power Plant
has killed most of the corals in a zone about 20,000 m^2 (Jones et al.
1976, Neudecker 1977), but what effect has the removal of living coral
had on the rest of the reef community? The purpose of the quantitative
fish surveys was to compare the species diversity of a group of common
and abundant reef fish between effluent and control areas to obtain a
measure of the effects of thermal effluent on fish populations, perhaps
as an indirect effect through the reduction of the coral community.

Chaetodontids tend to limit their range to relatively small areas
of the reef (Bardach 1958, Randall 1961, Reese 1973, 1975, 1977) and
some are even territorial (Wickler 1963, Reese 1973, 1975, 1977).
Hiatt and Strasburg (1960) described characteristic species associa-
tions ecologically related to particular habitats and similarly
Hobson (1974) reported that different habitats at Kona, Hawaii supported
different fish communities. The diversity of coral feeding chaetodontids
has been found to be highest in areas with the greatest coral coverage
in Guam (Jones and Chase 1975) and in Hawaii (Reese 1977). Therefore,
coral feeding chaetodontids are potential indicator species for the
health of coral reefs (Reese 1977).

Many species of Indo-West Pacific chaetodontids are known to eat
coral and the list of coral specialists is increasing. Of 74 individuals
of seven species of Chaetodon examined from the Marshall Islands, five
had fed primarily on coral (Hiatt and Strasburg 1960). On the Great

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Barrier Reef, six of ten Chaetodon species examined were coral feeders (Talbot 1965). Species not eating coral are either omnivorous or herbivorus and thus within the genus Chaetodon, some species eat no coral, more feed partly on coral, and some are coral specialists. Within the Pacific Ocean the number of obligative coral feeders appears to increase with coral diversity (Reese 1977).

Because most chaetodontids stay in one area of the reef, are easily recognized in the field and many eat coral, they were selected as indicator species to compare the condition of the reef margin in areas within and adjacent to the thermal discharge from the Tanguisson Power Plant. Transect enumeration data will be compared with that of Jones et al. (1976) just before and just after the opening of the plant.

MATERIALS AND METHODS

Tanguisson 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. 144°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 (Fig. 1). 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 (Martin Arargo, pers. comm.).

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). The permanent transects established by Jones and Randall (1973) were used for these experiments (Fig. 2).

Recruitment Studies

Standing crop or biomass accumulation was considered a manifestation of net production and was measured by taking dry weights of communities of organisms on settling plates after field exposure. 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 increased temperatures.

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 cm^2 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 rate of dry weight increase of communities of fouling organisms was measured separately for upper and lower surfaces by stacking two plates. The plates were attached in a horizontal array to 0.64 x 8 cm brass bolts secured to the bottom of predator exclosures made of iron
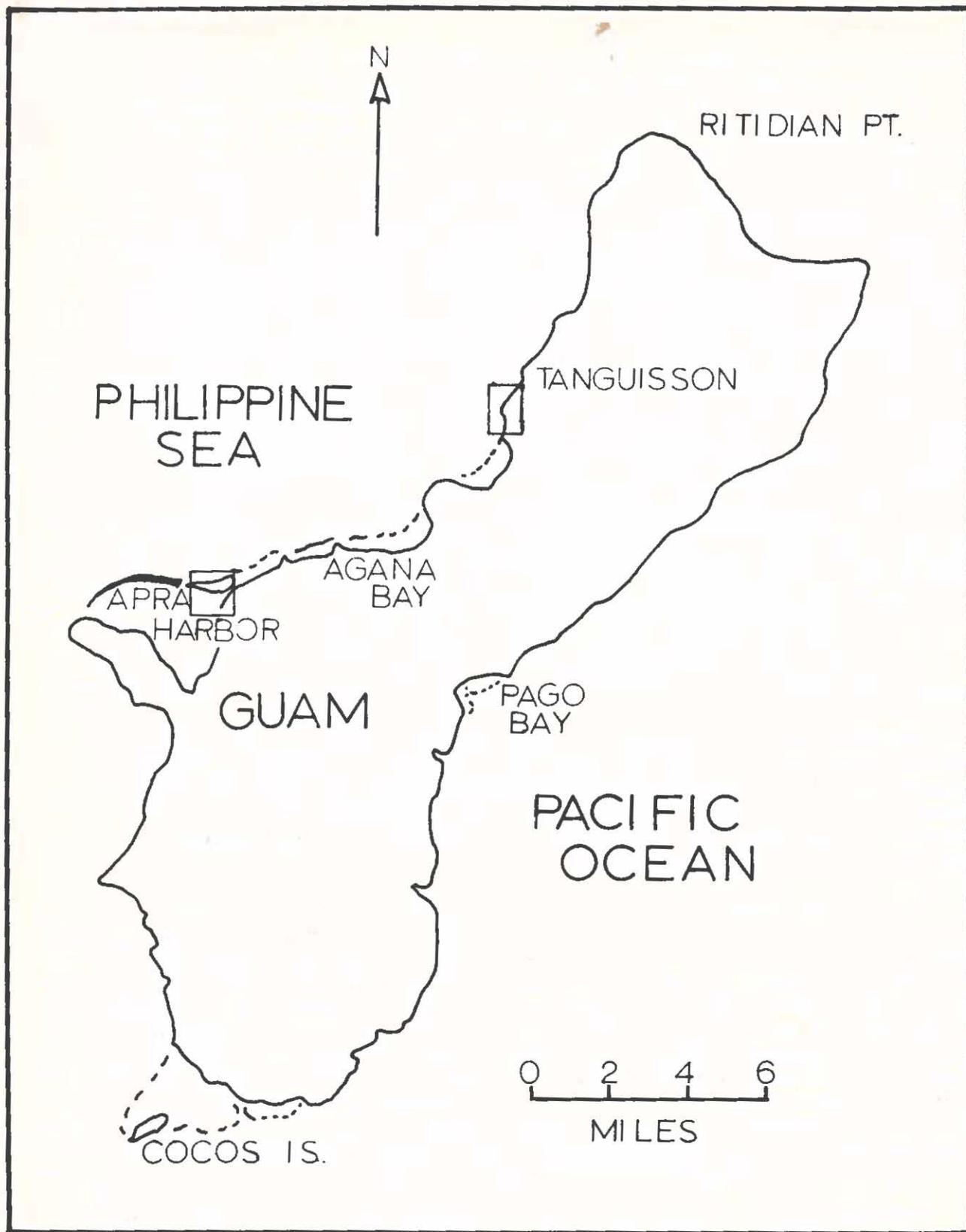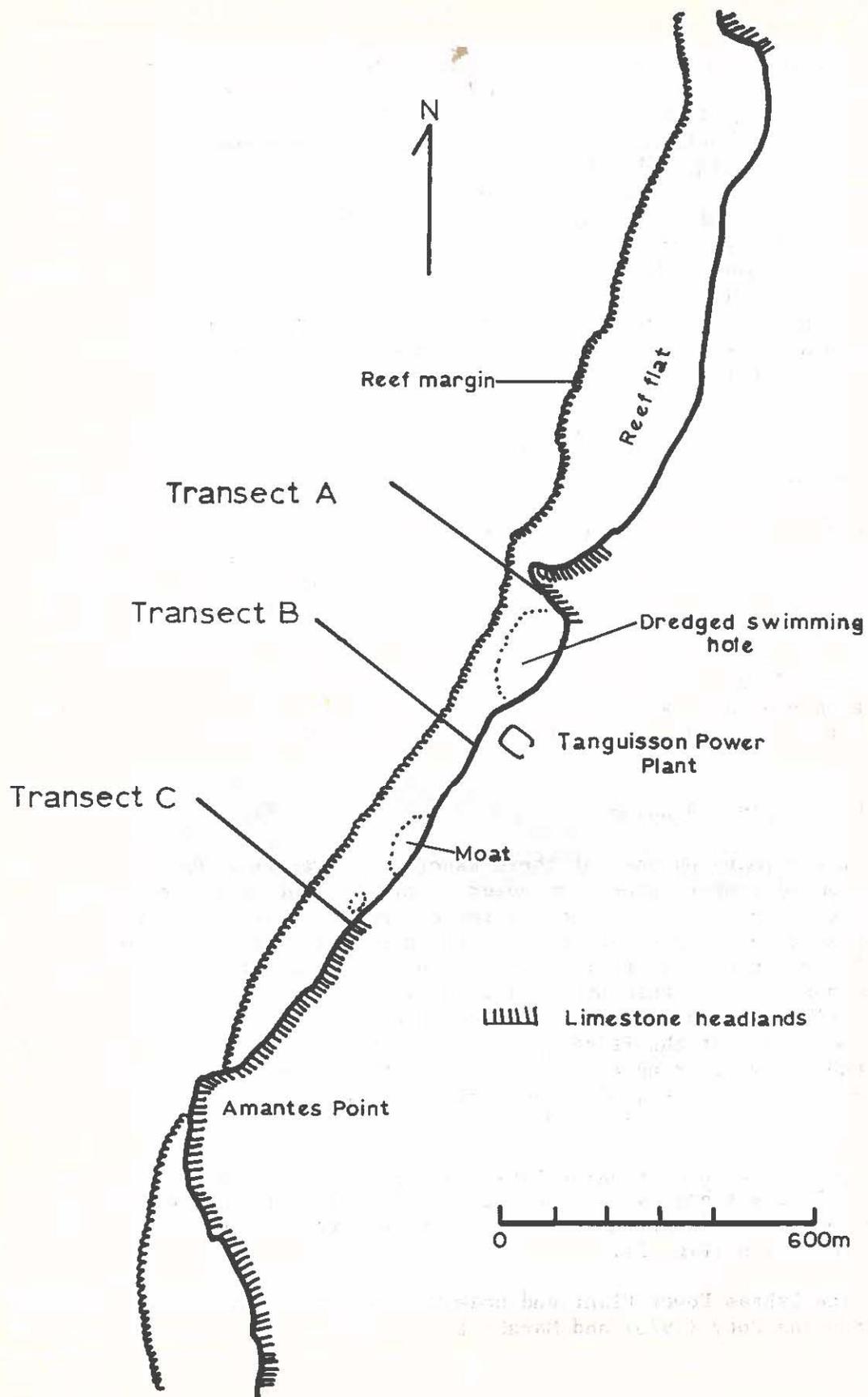
Figure 1. Map of Guam showing study sites.

Figure 2. Map of Tanguisson study site (after Jones et al. 1976)

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reinforcement rod and 1/4" 19 gauge hardware cloth (Fig. 3, 4). The cages and enclosed plates were subsequently tied to the hard reef substratum with 14 gauge plastic-coated electrical wire and 1/8" steel cable with turnbuckle tighteners. Cages were placed in -1.3 m of water on the reef margin within the effluent (B) and at control Transect A. The experiment was of nested design, with four sets of each treatment to be recovered after two and four months. Concurrently, a cage containing 12 sets of opaque surfaces (two regular plates with a 10 x 20 cm black formica plate sandwiched in between, Fig. 4) was also placed at each study site. Since the effect of increased temperature on recruitment is the focus of this study, only coral recruitment to the opaque plates is considered herein and the implications of community structure on dark surfaces will be reported elsewhere.

After the plates had remained at their reef margin locations for the desired time, they were collected and brought back to the laboratory in glass jars filled with seawater. They were then rinsed three times in fresh water to remove salts. The plates were then preserved in a ten percent formalin solution. Later, the plates were examined under 12-power magnification. The entire plate (including the sides) was carefully searched for corals and their size, location and identification were recorded. Percent coverage by each species or group was estimated by a point-sampling technique using 90 randomly positioned points (Neudecker, 1976). Subsequently, the plates were dried on a preweighed filter in an oven at 110°C for at least four days. They were then placed in a desiccator and allowed to reach ambient temperature before weighing to the nearest thousandth of a gram.

Growth-Transplant Studies

The primary purpose of these experiments was to measure the effect of increased temperatures from power plant effluent on the growth and mortality of coral transplants of three common species. The test species naturally occur in habitats that experience wide fluctuations of environmental parameters and are likely to occur in areas subject to coastal development. While this study is primarily concerned with the marine communities adjacent to the Tanguisson Power Plant, the highly wave assalted nature of the fringing reef there made transplanting and in situ thermal monitoring extremely difficult. Therefore, thermal tolerance of coral transplants was also tested in the more protected Cabras Power Plant outfall and intake.

The Tanguisson fringing reef and permanent transects have been thoroughly described by Jones et al. (1976). The transplants were placed on the reef margin in the effluent at Transect B and at a control site Transect A (Fig. 2).

The Cabras Power Plant and nearby environments have been described by Marsh and Doty (1975) and Marsh et al. (1977). The plant is located
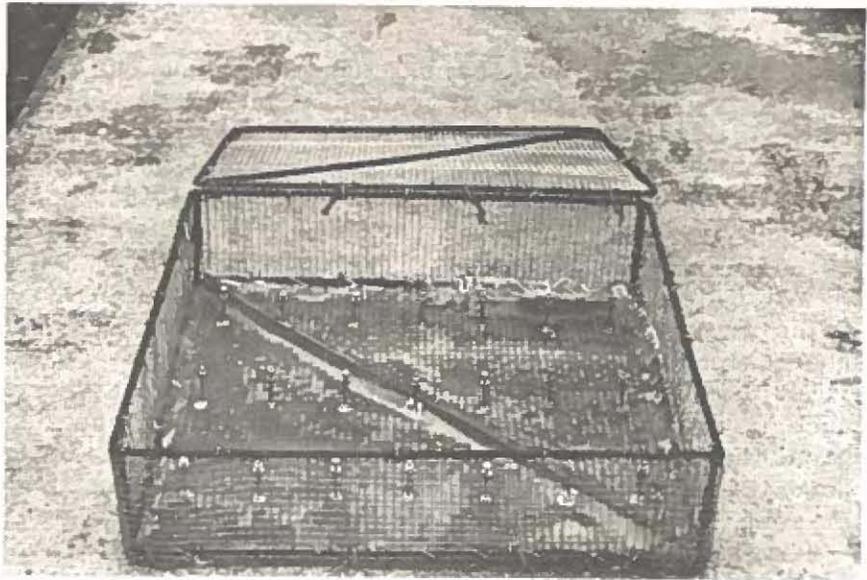
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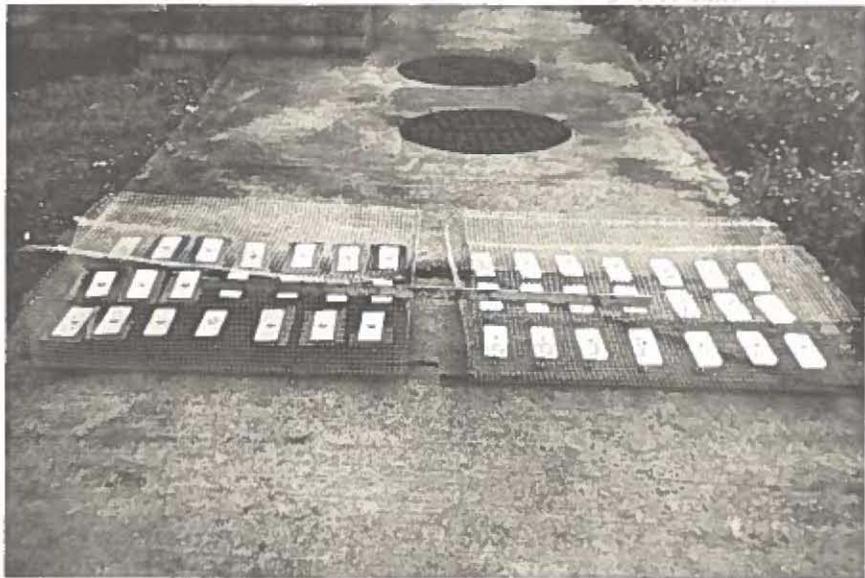Figure 3.   Settling plate cage.

Figure 4.   Settling plate cage with opaque and translucent plates.

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on Cabras Island and draws its cooling water from the ocean and Piti Bay through Tepungan Channel (Fig. 5). The heated effluent is discharged into an outfall lagoon near the upper Piti Channel. The test site was located at -3 m in the outfall channel while the control was at -3 m on a steel intake grill on the seaward side of the Cabras Island causeway. Some P. damicornis occur on this grill but the brown algal, Dictyota is far more predominant.

Colonies of Pocillopora damicornis (L.), a finely branched hemispherical coral (Figs. 6, 7), were used in tests at both study sites. P. damicornis is a eurytolerant species that recruits in abundance (Connell 1974, Harrigan 1972) and is a pioneer species in ecological succession on new or artificial substrata (Maragos 1972). Test colonies were collected from pier pilings in the Apra Harbor barrier reef lagoon where P. damicornis is by far the most predominant of the hermatypic species occurring there. Because of their attachment to a vertical substratum, the colonies had an irregular surface outline and central distal branches were the longest (Figs. 29, 31). Although P. damicornis is tolerant to a wide range of environmental parameters, its zonation on Indo-Pacific reefs is generally restricted to the reef flat, margin and lagoon environments. Probably more is known about this single species (or species complex) than any other reef-building species and the wealth of published growth data allows comparison and assessment of the experimental method.

Acropora formosa Dana was tested at the Cabras study sites and this ramose species was selected as representative of "the most important and protean genus of hermatypic corals" (Wells 1956). This is a common species and most typically occurs in protected and lagoon environments (Fig. 8). A. formosa is often fouled with a red alga, Polysiphonia sp., on branch tips and around basal branches. However, fouled colonies were not used as test organisms. The test colonies were collected from inner Apra Harbor environments where they periodically experience increased temperatures (Marsh et. al. 1977) and heavy sediment loads.

Porites andrewsi Vaughan (Fig. 9) is most often a ramose species and may form huge flat-topped masses several meters across. The branch shape is variable and may taper rapidly and crookedly, may be slender or stout, elongate or evenly divergent (Wells 1954). The test colonies were also collected from Apra Harbor and were of the lemon-lime green color variety.

For complete assessment of the effects of increased temperatures on growth and mortality of the transplants, in situ thermal monitoring is preferred, although the exposed nature of the Tanguisson study sites excluded the use of such equipment. Thermal regimes are therefore based on monthly means of daily intake and outfall maxima and minima taken by G.P.A. at the Tanguisson Plant. Maximum and minimum temperatures at the Cabras study sites were measured with Taylor Max-Min self-registering thermometers by Marsh et al. (1977). Their
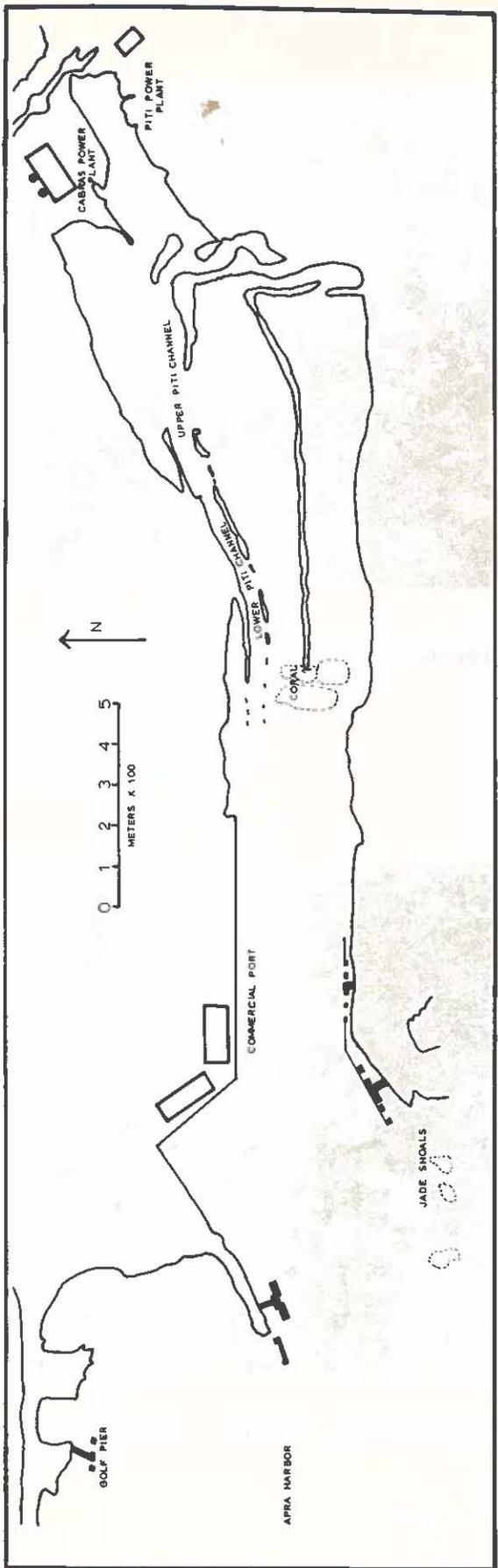
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Figure 5.　Map of Cabras Study Site (after J.E. Doty).

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Figure 6.   Pocillopora damicronis on Jade Shoals.
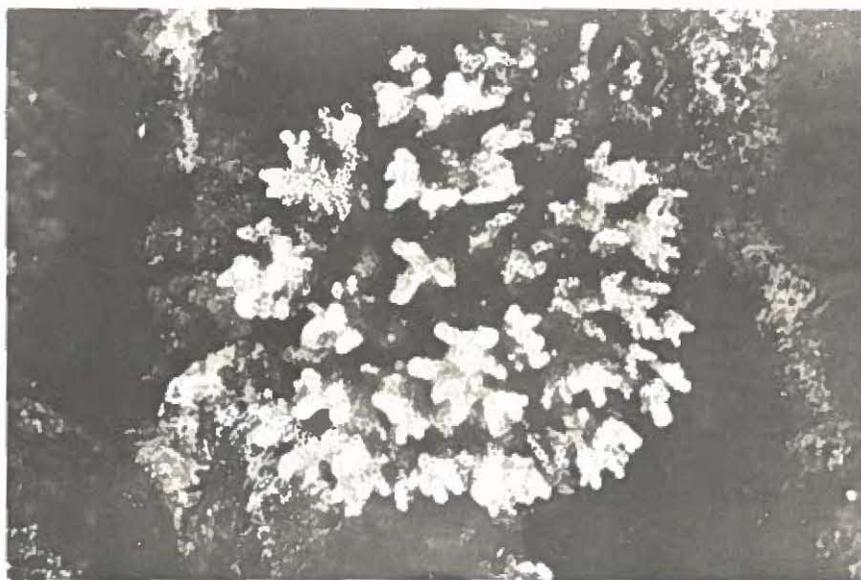

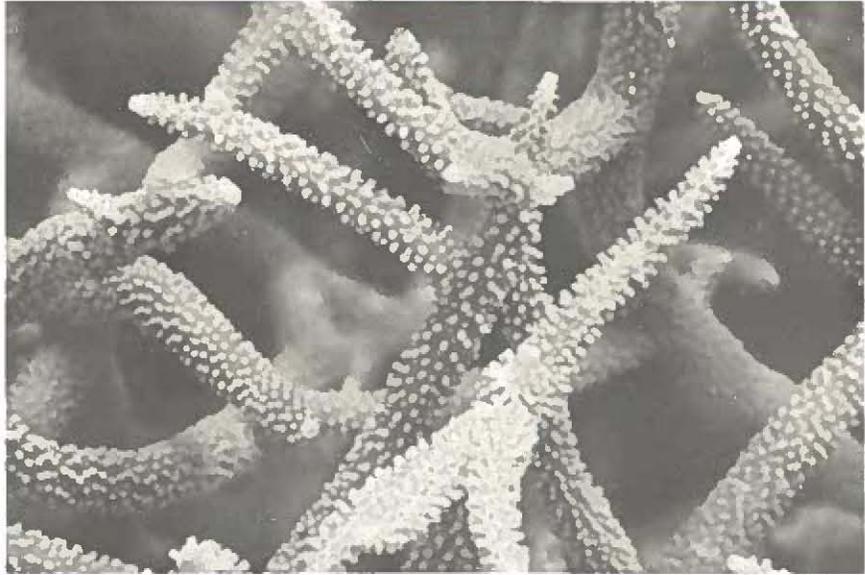Figure 7.   Pocillopora damicornis on the Cabras intake grill.

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Figure 8. _Acropora_ _formosa_ in Cocos Lagoon (R. Randall).

Figure 9. _Porites_ _andrewsi_ in Cocos Lagoon. The fish in the background is
Chaetodon _lunula_.

intake station was 50 m downstream of the control transplants while their outfall station was adjacent to the transplants. Measurements were terminated before the conclusion of the experiments but an approximate range can be derived from measurements from previous years.

Scleractinian growth rate studies were greatly simplified by Barne's (1970, 1971) method using a hydroquinone bone stain, Alizarin Red S, as an indicator of growth. As the symbiotic zooxanthellae of the coral photosynthesize and as calcium is secreted, the vital stain is assimilated and colors all deposition during the staining period pink. Therefore only parts of the colony which grow during the exposure to alizarin are stained. This stain line is then a permanent reference base from which all subsequent growth can be measured. Lamberts (1974) used this method along with the ^{45}Ca method of Goreau (1959) to measure the growth of Pocillopora damicornis, and found a very significant correlation (r = Δ.987, p < .01) between the two markers, demonstrating that the alizarin method yields an accurate measurement of calcification. The alizarin method is useful not only because of its simplicity, and applicability to field experiments, but also because there is more linear growth rate data than any other kind, permitting comparisons. The major disadvantage of the technique is the necessity to kill the coral at measurement time. Therefore successive growth can only be measured by repeated staining and concomittant manipulation before cleaning.

Most of the corals used in these experiments were stained in situ and later transplanted, although a few runs involved laboratory staining. In the field a 4-1 plastic bag containing about 0.2 g of stain was placed over the colony and secured around the basal attachment with hemp line (Fig. 10). The stain was then released, mixed and left exposed to the colony for 6 to 8 hours from midmorning to late afternoon and then the bag was removed. The plastic bags act as semipermeable membranes allowing free passage of oxygen but retain the stain. The colonies that were stained in the laboratory were treated in the same manner.

After the test colonies had been at the study site for the desired time, they were collected and placed in a concentrated solution of sodium hypochlorite for 2 to 3 days for cleaning. Any remaining tissue was then blown off with a hose and the colonies were dried to a constant weight at 90°C for at least four days. Dry weight was then measured using a triple beam balance. Growth was measured as the average vertical branch tip extension above the stain line with a Vernier caliper. Measurements were made directly on the intact colonies of Acropora formosa and Porites andrewsi and each branch was marked to prevent measuring the same branch twice. Sample sizes of up to 16 branches were measured from each colony. Due to the closely set nature of the branches of Pocillopora damicornis, the branch tips were broken off the colony and then measured.

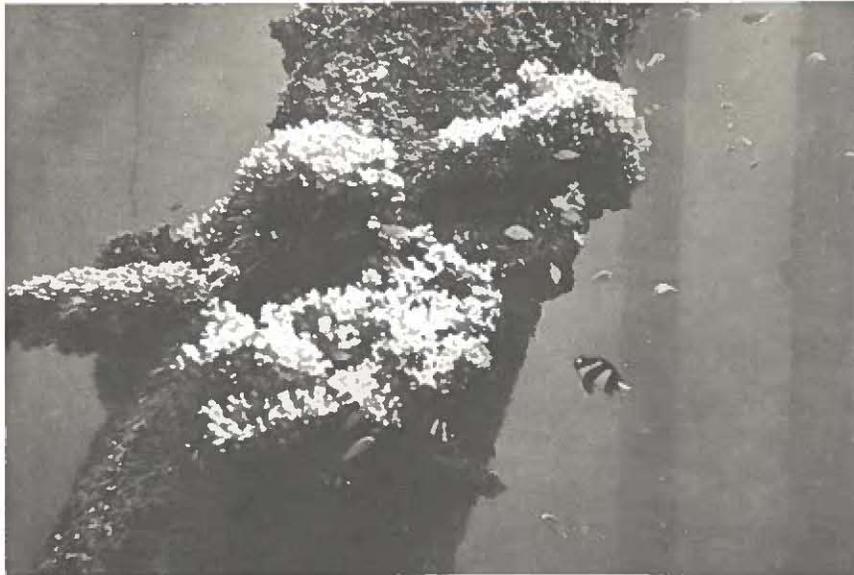16

Figure 10. _Pocillopora_ _damicornis_ on Golf Pier, Apra Harbor. Most of the colonies
of this species used in the experiments were collected here.

Figure 11. _Pocillopora_ _damicornis_ being stained on Golf Pier.

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Experiment 1 was conducted at Tanguisson for a nine week period, 26 VIII to 27 X 76. Fourteen colonies of Pocillopora damicornis were statined in situ on Golf Pier in Apra Harbor (Fig. 10) and later transplanted to -2.4 m on the reef margin at Transects A and B of Tanguisson. The colonies were tied directly to the reef substratum with 14 gauge plastic-coated copper wire.

Experiment 2 was run at the Cabras study site. For up to 11 weeks, 11 II to 28 IV 77. Twenty-six colonies of P. damicornis were collected from -1 m from Gorco Pier in Apra Harbor (Fig. 11). Acropora formosa and Porites andrewsi were collected from coral patches at the mouth of lower Piti Channel (Fig. 5). These corals are constantly subjected to high levels of sedimentation and temperatures sometimes exceed 32°C (Marsh et al. 1977). The three species were then taken to Jade Shoals (Fig. 5) and stained in -2 m of water on 10 II 77. Some of the bags broke lose and most P. damicornis and about half of the A. formosa showed signs of stress and were discarded. Therefore four P. damicornis and 12 A. formosa were transplanted only to the Cabras outfall. Twelve colonies P. andrewsi (Figs. 12, 13) were transplanted to both the intake and outfall on 11 II 77.

Experiment 3 was conducted at Tanguisson for nine weeks, 17 II to 21 IV 77. Fourteen colonies of P. damicornis were collected from Gorco Pier and stained at the laboratory 15 II 77. These colonies were transplanted to sites very near those of experiment 1 at transects A and B (-2 m).

Experiment 4 was done at the Cabras study sites for up to nine weeks, 25 II to 28 IV 77. The P. damicornis colonies were collected from Gorco Pier while the A. formosa and P. andrewsi were collected from Jade Shoals. These corals were stained on Jade Shoals 24 II 77 and transplanted the following day. Nine colonies of A. formosa were placed at the outfall and control site (Figs. 14, 15) and 11 P. damicornis were transplanted to the outfall while nine colonies were placed on the intake grill. Some of the P. andrewsi colonies were stressed during staining and subsequently only six colonies were placed in the outfall.

In addition to the controls at each study site, the growth of P. damicornis was also measured in situ at Golf Pier (Fig. 10) as well as in vitro at the laboratory. Two colonies were stained and left on Golf Pier (-1.3 m) for slightly less than ten weeks (68 days), 25 VII to 2 X 76. Four colonies were brought back to the laboratory and stained and grown in a 360 l flow-through aquarium (-0.3 m) for four weeks, 15 II to 15 III 73.

Other than the tests of thermal tolerance, the effect of reduced light intensity on the growth rate of shallow adapted P. damicornis

Figure 12.   *Porites* *andrewsi* control colonies on Cabras intake grill.   Some *Pocillopora* *damicornis* transplants can also be seen and notice the heavy growth of the brown algae *Dictyota* and *Hydroclathurus*.
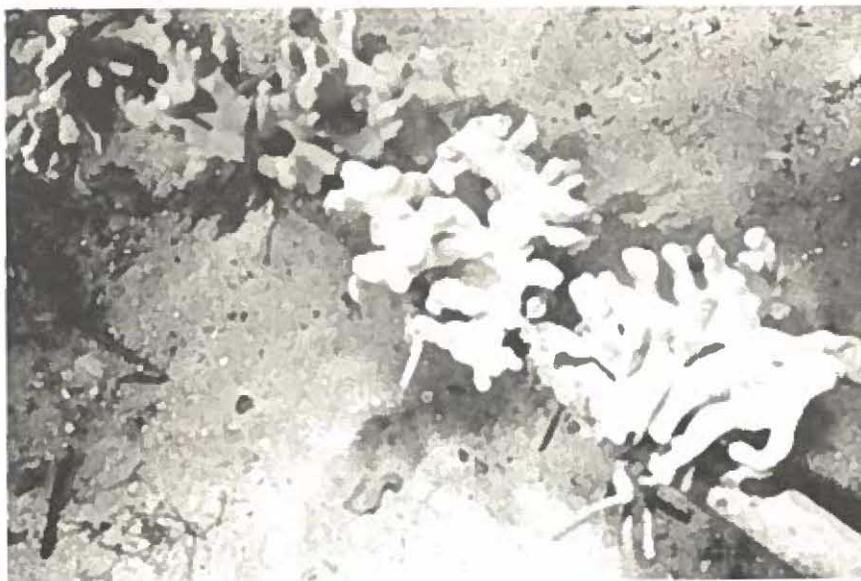
Figure 13.   *Porites* *andrewsi* colonies in the Cabras effluent.

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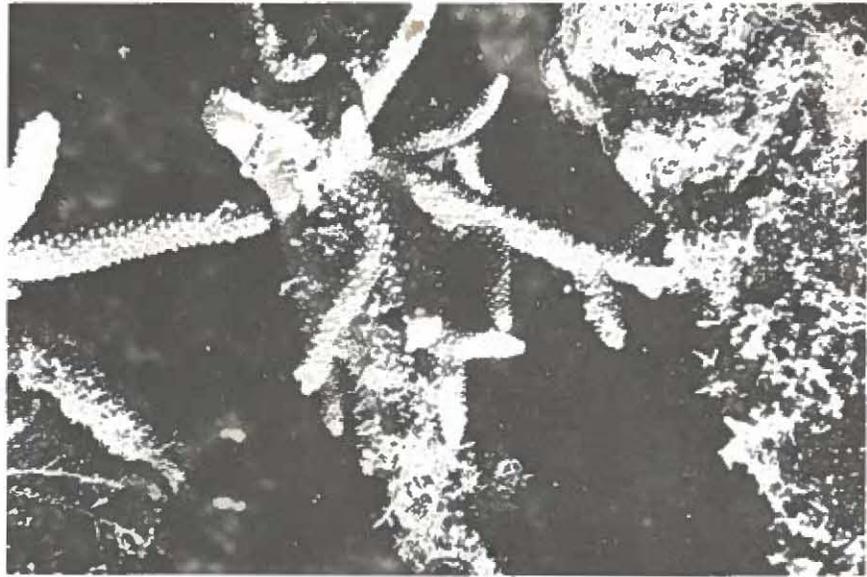
Figure 14.   _Acropora_ _formosa_ control colonies on Cabras intake grill.
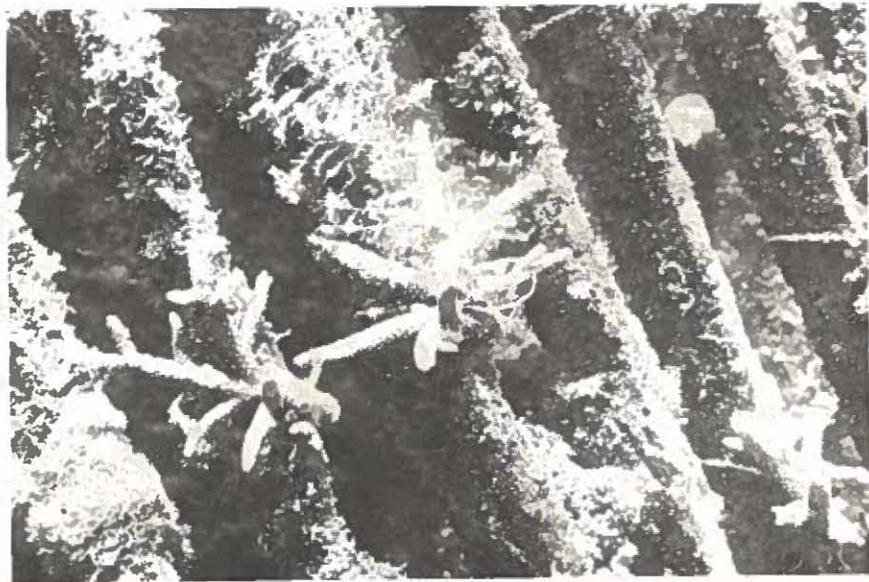
Figure 15.   _Acropora_ _formosa_ control colonies.

was also investigated. Eight colonies were stained on Golf Pier
(-1.3 m) and later transplanted to the submarine terrace (-15.2 m.
Fig. 16) and seaward slope (-30.5 m) zones along Tanguisson Transect
A. These colonies were grown in fish exclosures to prevent fish
feeding (Neudecker 1977). The growth of the transplants for a nine
week period, 1 X to 3 XII 76 were compared.

Fish Surveys

    The fringing reef margin and upper reef front normally support
a diverse fish community associated with the corals which occur there.
The purpose of the fish counts was to assess the impact of thermal
enrichment on a common representative family of coral reef fishes,
the Chaetodontidae. Visual transects were run to compare the species
diversity and population evenness of species of the genera Chaetodon,
Megaprotodon and Forcipiger.

    Fish of the study genera were counted while scuba diving along a
100-m transect tape. Fish seen within one meter to either side of
and two meters above the transect line were counted for a sample area
of 200 m^2. Individuals were classified as either paired or solitary
and obviously small individuals were considered to be juveniles.
Transects were sampled along the reef margin, parallel to shore, near
the permanent transects A, B and C. Also, a few transects were
sampled perpendicular to shore along the permanent transects.
Density and relative density for each species in each permanent
transect area were calculated.

    Species diversity was calculated by using the Shannon index
(Pielou 1975):

$$H' = -\Sigma\ p_i\ \log_2\ p_i$$

    where: p_i = the proportion of individuals of the ith species.

Shannon indices were calculated for each replicate transect and for
each permanent transect area by lumping replicates. Since diversity
is not only dependent upon the number of species present but also on
the equitable distribution of individuals among species, population
evenness (Pielou 1975) was also determined for each permanent
transect area. Population evenness (J) was calculated by the formula:

$$J = \frac{H'}{\log_2 S}$$

    where: S = the total number of species observed in the transect
            area.
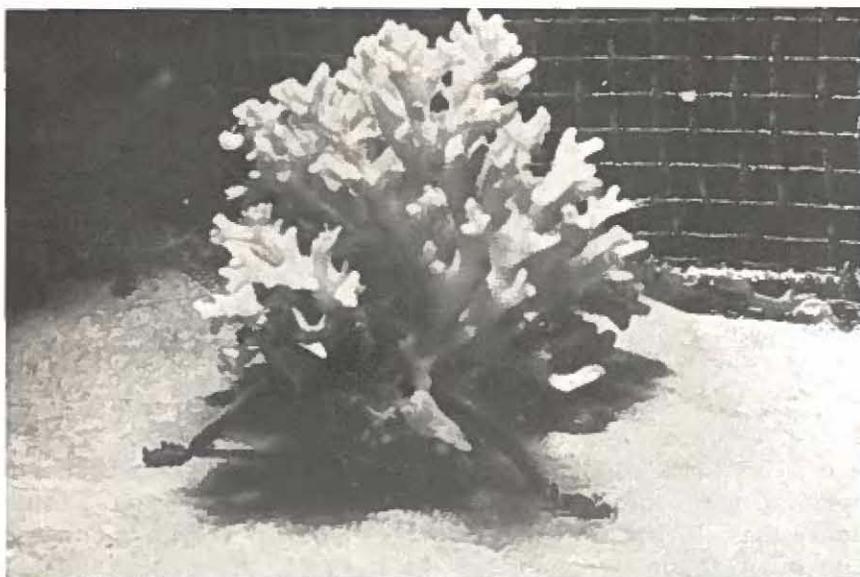
Figure 16. _Pocillopora damicornis_ in cage at -15.2 m. The forereef transplants
were caged to prevent fish feeding.
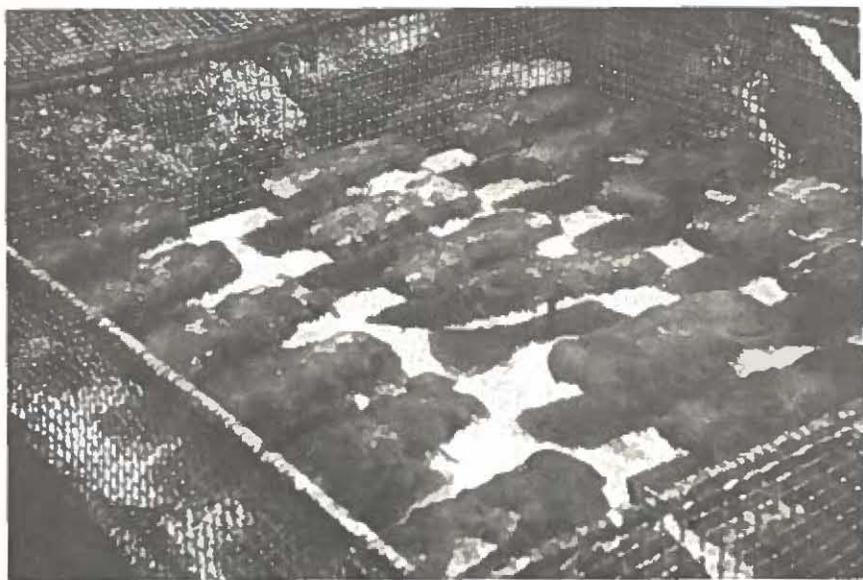
Figure 17. Settling plate cage in situ. This particular cage was at -5 m,
Transect A.

The species richness and abundance of chaetodontids on the reef margin in the effluent (Transect B) was compared to those of the two control areas pooled (A and C) by the Student's t-test (Sokal and Rohlf 1969). The Shannon diversity indices of the four 200-m^2 transects in each permanent transect area were compared by the Mann-Whitney U test (Sokal and Rohlf 1969).

A UPPER   A LOWER   B UPPER   B LOWER
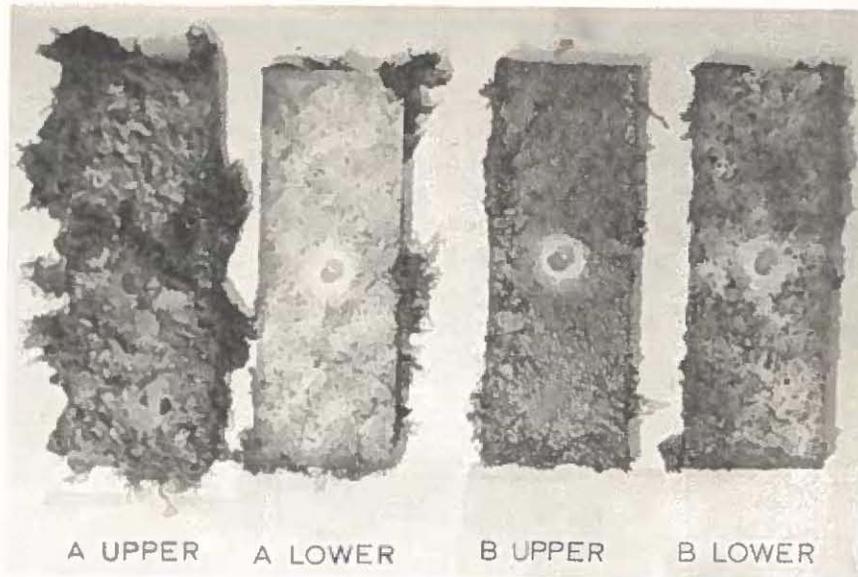
Figure 18.   Comparison of translucent plate surfaces. Differences between the effluent and control plates in biomass accumulation, surface coverage and the number of coral recruits were significant.
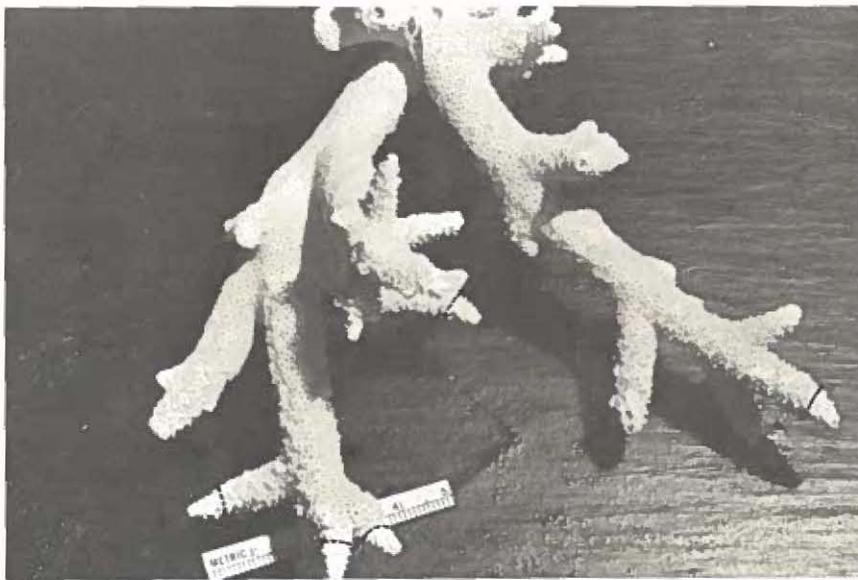
Figure 21.   Growth of an <u>Acropora</u> <u>formosa</u> colony. The alizarin stain line has been marked for easy reference.

RESULTS

Recruitment Studies

Cages of settling plates were placed at the reef margin sites
(-1.3 m) 6 VII 77 (Fig. 17). The last ten days of September brought
very heavy wave action (3.0-3.7 m) to the reef margin and two cages,
one at Transect B (opaque) and one at A (translucent), were torn loose
(along with part of the reef substratum) and later recovered in nearby
surge channels (2 IX 77). Only plates which remained bolted to the
cages were used in the analyses. The control cage was the more severely
damaged of the two. The experimental substrata thereby received environ-
mental stress typical of the reef margin and might be similar to
naturally bare and often similarly ephemeral reef substratum.

The results and analyses of the fouling study are presented in
tables 1-7. The communities on the various surfaces were visually
quite different (Fig. 18). The means of dry weight biomass accumula-
tion for plates at each station are given in Table 1. A very significant
difference (U_s = 104***) was found in the amount of standing crop pro-
duction between upper surfaces, indicating a negative effect of in-
creased temperatures. However, there was no significant difference in
biomass accumulation of lower surfaces (U_s = 66 ns). The slightly
greater production (and species diversity) of the lower effluent sur-
faces is probably because the greater biomass accumulation and more
complete surface coverage (Table 1) of the upper control plates greatly
reduces available light to the lower surface communities. As earlier
recruitment studies at these sites reported (Neudecker 1976), this may
be considered to be a case of amensalism. The increased temperatures
at B significantly reduce the upper surface production thereby allow-
ing more available light for lower surface community development.
While there was 11 percent of the upper surface still available for
colonization after 58 days in the effluent, there was less than 1 per-
cent bare space on upper surfaces at Transect A and this difference
was significant (Table 1).

The number of hermatypic coral recruits to the reef margin plates
after 58 days was very significantly greater at the control site where
nine recruits settled on 4 of 26 available surfaces while no corals
recruited to the 36 surfaces exposed to elevated temperatures (Table 2).
One of nine corals on the coral plates was overgrown by algae and dead
at time of collection. The Fisher exact probability (p = 0.03, Table
3) indicates a significant better chance of recruitment for the
control plates. The corals settled in a clumped fashion as indicated
by a coefficient of dispersion (C.D. = $\underline{S}^2/\bar{Y}$ = 2.74) much greater than
unity. Recruits also showed a definite tendency to be on vertical
surfaces of lower opaque surfaces, with 78% of the corals occurring
there.

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Table 1. Biomass accumulation of organisms on plexiglass plates after 58 days. Differences in dry weights and surface coverages are compared by the Mann–Whitney U-test. Percent of bare space available for colonization after 58 days was calculated as the number of 90 random points without coverage. Mean weight (in grams) and percent of bare space ($\overline{Y}$) plus or minus the standard deviation (S) and the sample size (n) are given. H_o: There is no significant difference in biomass accumulation on, or surface coverage of, settling plates within and nearby the thermal effluent.

Surface	Control A	vs	Effluent B
Upper	6.18 ± 0.48(8)		1.84 ± 0.45(12)
		$U_S = 104$***	reject H_o
% bare space	0.83 ± 1.1(4)		10.83 ± 4.8(4)
		$U_s = 16$**	reject H_o
Lower	0.41 ± 0.12(12)		0.77 ± 0.38(12)
		$U_s = 66$ ns	accept H_o
% bare space	16.95 ± 10.7(4)		32.5 ± 5.1(4)
		$U_s = 16$**	reject H_o

Table 2. Comparison of recruitment of hermatypic corals onto various settling plate surfaces on the reef margin (–1.3 m) at Transects A and B after 58 days. Measurements are the longest length by the longest width in millimeters. A v (vertical) indicates that the recruit settled on the side of that plate.

	CONTROL					EFFLUENT			
Station	A	A	A	A		B	B	B	B
Surface	Upper	Lower	Upper	Lower		Upper	Lower	Upper	Lower
Color	Clear	Clear	Opaque	Opaque		Clear	Clear	Opaque	Opaque
No. of plates	8	8	5	5		12	12	6	6
No. of recruits	0	1(v)	0	8(6v)		0	0	0	0
Pocilloporidae sp. 1		–		1.4 x 1.2, 1.6 x 1.4, 1.6 x 1.3, 1.2 x 1.3, 1.7 x 1.6, 1.7 x 1.6, 1.7 x 1.6, 1.6 x 1.2					
sp. 2		1.2 x 1.1		–					
Total Corals / Surfaces		9/26					0/36		

Proportion of coral recruitment to each surface

Upper	0%		
Lower	22%		
Lower vertical	78%		

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Table 3. Fisher exact probability for coral recruitment to plates at Transects A and B after 58 days.

		Plates with coral	Plates without coral	
CONTROL	A	4	22	26
EFFLUENT	B	0	36	36
		4	58	62

$$p = \frac{26! \quad 36! \quad 4! \quad 58!}{62! \quad 4! \quad 22! \quad 0! \quad 36!}$$

$$p = 0.03$$

Table 4. Comparison of coral recruitment between Transects A and B by the chi-square test with the correction for continuity. Two runs (1976-63 days and 1977-58 days) are pooled. H_o = There is no significant difference in amount of coral recruitment between settling plates in the control and effluent transects.

	A	B
1976		
Corals / Surfaces	$\frac{9}{8}$	$\frac{2}{8}$
1977		
Corals / Surfaces	$\frac{9}{26}$	$\frac{0}{36}$
	$x^2 = 12.88$***	df = 1, reject H_o

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Table 5. List of organisms occurring on translucent settling plates
indicating their location of occurrances.

	A Upper	A Lower	B Upper	B Lower
Cyanophyta				
Microcoleus lynbyaceus		x		
Schizothrix calcicola		x		x
Microcoleus matt 1			x	
Microcoleus matt 2			x	x
Microcoleus matt 3			x	
Phaeophyta				
Feldmania indica	x	x		
Ectocarpus breviarticulatus	x			
Lobophora variegata	x	x	x	
Rhodophyta				
Gelidiopsis intricata	x	x	x	x
Gelidium sp.			x	x
Rhodymenia sp.	x		x	
Hypnea sp.	x	x		
Ceramium sp.	x	x		x
Laurencia sp.	x			
Galaxura sp.	x			
Calcareous spp.		x		x
Chlorophyta				
Bryopsis sp.	x			
Bryopsis matt	x			
Chlorodesmis sp.		x		
Enteromorpha sp.	x	x	x	x
Pseudochlorodesmis sp.		x		
Annelida				
Annelid	x			
Sabellid	x			
Polychaeta				
Polychaete	x	x	x	x
Mollusca				
Micromollusk	x	x	x	x
Barnacle		x		
Foraminifera				
Baculogypsina	x		x	
Total species/surface	17	14	11	9
Total species/area	23		14	

Table 6. Diversity of fouling communities. Shannon Diversity indices (H')
and the mean ($\bar{Y}$) and s (standard deviation) of community diver-
sities of organisms on plexiglass plates after 58 days at
Transects A and B. All of the plates were translucent.

Transect	CONTROL		EFFLUENT	
Surface	A Upper	A Lower	B Upper	B Lower
H' 1.	1.4976	1.2892	1.0311	1.8212
2.	1.9024	1.7304	1.6221	2.0865
3.	1.9581	1.9772	1.6351	2.2784
4.	2.6558	2.4443	1.8553	2.9101
$\bar{Y}$	2.0035	1.8603	1.5359	2.2741
s	.4895	.4823	.3531	.4636

Table 7. Comparison of Shannon diversity indices for upper and lower
translucent surfaces at Transects A and B by the Mann-Whitney
U-test. H_O ; There is no significant difference in species
diversity of fouling communities between effluent and control
areas.

Plate Surfaces	A vs B	Conclusion
Upper	U_S = 9 ns U = 15 [.10]	(n_1 = 4, n_2 = 4) accept H_o
Lower	U_S = 8 ns U = 15 [.10]	(n_1 = 4, n_2 = 4) accept H_o

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An informative comparison of coral recruitment between the two areas can be made by pooling the 1976 (62 days) and 1977 runs (Table 4). A very significant difference exists (X^2= 12.888***) in recruitment between the two areas. It is interesting to note that equivalent numbers (9) of corals recruited to plates in the .7 m^2 cages at the coral site each run.

A list of organisms encountered in random sampling of translucent plates and their respective occurrances is presented in Table 5. Shannon diversity indices for the eight translucent surfaces at each station and the area mean diversities are given in Table 6. The upper control surfaces appear to be more diverse, although the difference was not statistically significant (U_s = 9 ns, Table 7). The species diversity of lower surfaces in the effluent was greater than that of the controls but this difference was also not significant (U_s = 8 ns) and was also related to the reduced production of upper surface communities in the thermal effluent.

Growth Studies

The mean monthly intake, outfall and increase above ambient ($\Delta T°$) temperatures from the Tanguisson Power Plant are shown in Figures 19 and 20. Since the outfall temperature was taken in the discharge lagoon, these values represent maximum temperatures the transplants could have been exposed to. During experiment 1 the monthly outfall means for August, September and October 1976 were 32.8, 33.9 and 32.2°C respectively. The outfall temperatures ranged between 30.0 and 35.5°C for a three month mean $\Delta T°$ of +5.9°C. During experiment 2 the monthly means of February, March, April and May were 34.7, 30.7, 32.2 and 35.0°C respectively, for a four-month mean outfall temperature of 33.0°C ($\bar{Y} \Delta T$ = +5.4°C)

Table 8 presents the results of all the transplant-growth experiments. The results of replicate P. damicornis transplants (Experiments 1 and 3) to the Tanguisson reef margin are quite similar. There was more growth at both sites in 1976 although the relative magnitudes are equivalent. P. damicornis grew significantly less in the effluent on both runs (t_s = 8.799***, t_s= 2.672*, Table 9). Equal sample sizes were obtained on experiment 1 and a nested analysis of variance conducted (Table 10). There was a highly significant difference in growth rates (F_s = 113.80***) due to temperature effects which accounted for 60.66 percent of the total variance. There were no significant differences in growth rates between colonies at a particular site and 38.55 percent of the total variance was between branches of single colonies and error variance.

The negative effect of thermal discharge on growth was also demonstrated at the Cabras Power Plant. Maximum-minimum thermometers

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Table 8. Growth rate of coral transplants.

Exposure Period	Number of Colonies	Size Range $\bar{X} \pm S$ (gms)	Study Site Experiment Number	Depth	mm of Growth $\bar{X} \pm S$ (n-branches) 95% Confidence Limits
Pocillopora damicornis					
26 VIII to 27 X 76 = 62 days	3	about 70 - 90	Tanguisson A Experiment 1	-2.4 m	3.8 ± 0.8 (48) L_1 = 3.78 L_2 = 3.83
26 VIII to 27 X 76 = 62 days	3	71.7 - 87.7 77.8 ± 8.6	Tanguisson B Experiment 1	-2.4 m	2.8 ± 0.8 (48) L_1 = 2.38 L_2 = 2.45
17 II to 21 IV 77 = 63 days	3	37.6 - 62.5 47.0 ± 13.6	Tanguisson A Experiment 3	-2 m	3.8 ± 0.6 (32) L_1 = 3.0 L_2 = 3.5
17 II to 21 IV 77 = 63 days	3	12.1 - 90.7 42.0 ± 43.0	Tanguisson B Experiment 3	-2 m	1.3 ± 0.6 (16) L_1 = 1.0 L_2 = 1.6
1 X to 3 XII 76 = 63 days	3	84.9 - 197.5 125.5 ± 62.6	Tanguisson	-15.2 m	6.5 ± 1.4 (48) L_1 = 6.1 L_2 = 6.9
1 X to 3 XII 76 = 63 days	3	80.0 - 337.0 22.1 ± 132.7	Tanguisson	-30.5 m	3.2 ± 0.9 (48) L_1 = 2.9 L_2 = 3.5
11 II to 13 III 77 = 30 days	4	10.0 - 39.1 19.4 ± 13.4	Cabras outfall Experiment 2	-3 m	all dead 0.75 ± 0.29 (34) L_1 = 0.65 L_2 = 0.85
25 II to 28 III 77 = 62 days	9	25.3 - 116.6 55.8 ± 31.3	Cabras intake Experiment 4	-3 m	4.9 ± 1.2 (144) L_1 = 4.7 L_2 = 5.1
25 II to 27 III 77 = 30 days	11	9.9 - 98.9 50.0 ± 27.7	Cabras outfall Experiment 4	-3 m	all dead 0.79 ± 0.18 (80) L_1 = 0.75 L_2 = 0.83

Table 8. (continued)

Exposure Period	Number of Colonies	Size Range $\overline{X} \pm S$ (gms)	Study Site Experiment Number	Depth	mm of Growth $\overline{X} \pm S$ (n-branches) 95% Confidence Limits
25 VII to 2 X 76 = 69 days	2	27.4 - 598.3 312.9 ± 403.7	Golf Pier	-1.3 m	5.9 ± 1.2 (32) L_1 = 5.5 L_2 = 6.4
15 II to 15 III 77 = 69 days	4	10.9 - 23.9 17.1 ± 6.6	Laboratory	-0.3 m	2.5 ± 0.5 (64) L_1 = 2.3 L_2 = 2.6
Porites andrewsi 11 II to 28 IV 77 = 76 days	12	30.2 - 199.0 117.2 ± 52.4	Cabras intake Experiment 2	-3 m	5.2 ± 1.1 (94) L_1 = 4.9 L_2 = 5.3
11 II 77 to death	12	23.9 - 155.0 83.0 ± 47.8	Cabras outfall Experiment 2	-3 m	6 dead 19 II 77 = 9 days 2 dead 13 III 77 = 31 days, no growth 4 < 5% alive 28 IV 77 = 77 days, no growth
25 II 77 to death	6	21.8 - 104.7 66.7 ± 36.4	Cabras outfall Experiment 4	-3 m	4 dead 17 IV 77 = 51 days, no growth 2 < 5% alive 28 IV 77 = 63 days no significant growth
Acropora formosa 25 II to 28 IV 77 = 62 days	9	9.8 - 87.6 41.6 ± 26.1	Cabras intake Experiment 4	-3 m	5.6 ± 0.18 (50) L_1 = 4.9 L_2 = 6.1 2 dead 27 III 77

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Table 8.　(continued)

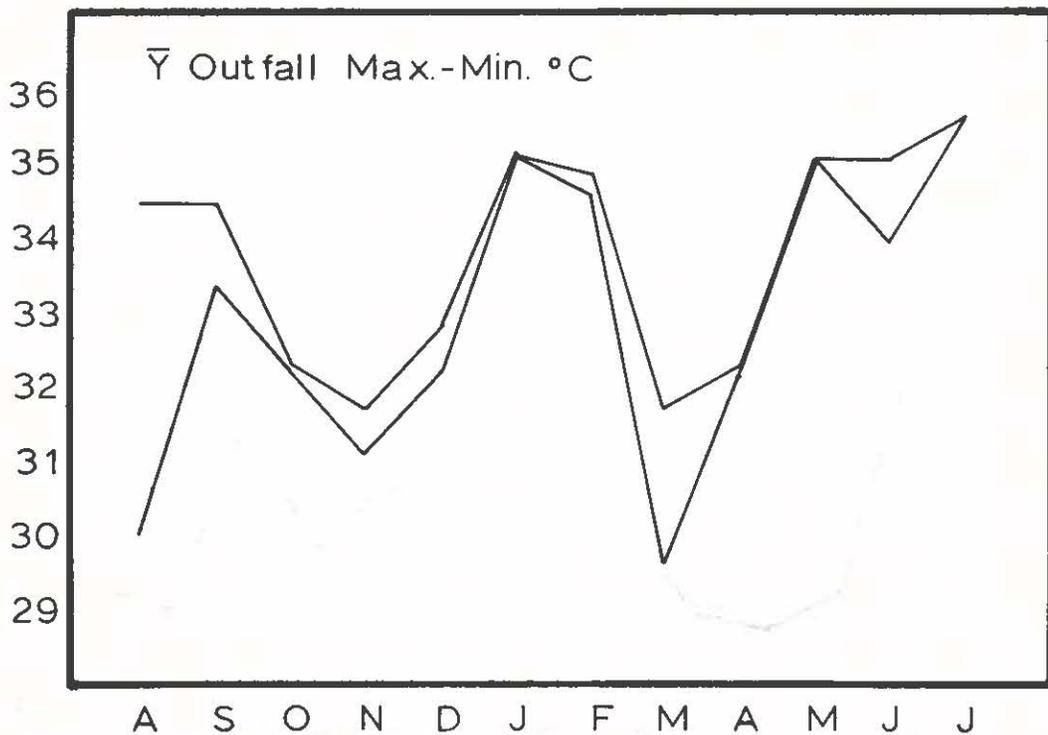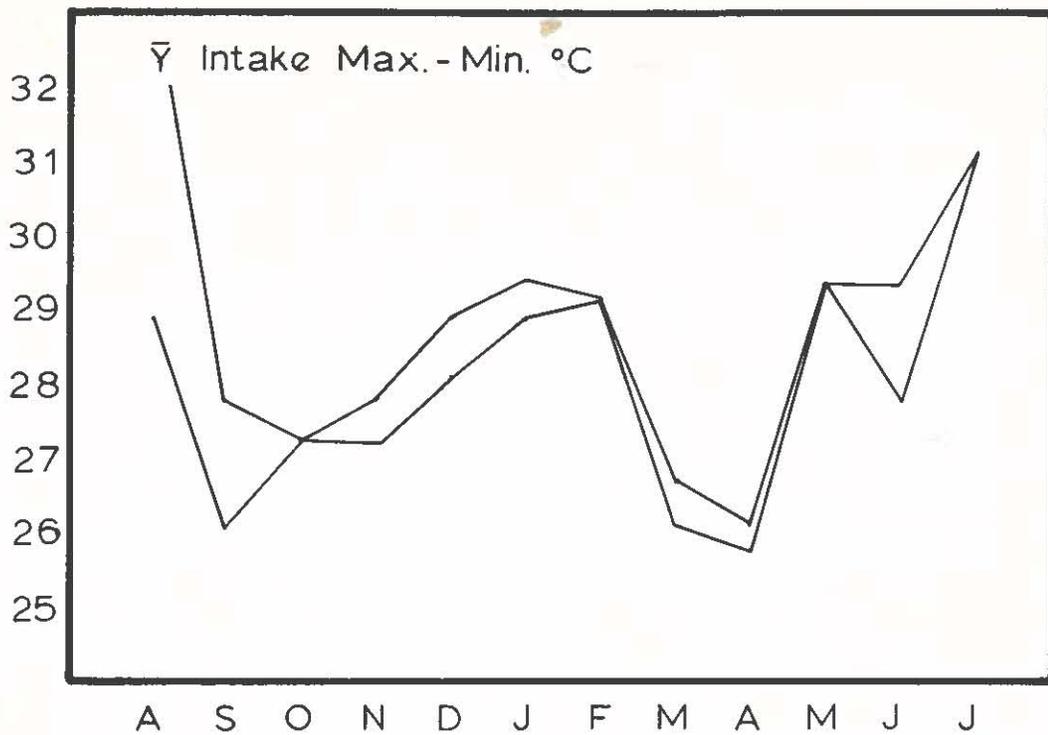| Exposure Period	Number of Colonies	Size Range $\overline{X} \pm S$ (gms)	Study Site Experiment Number	Depth	mm of Growth $\overline{X} \pm S$ (n-branches) 95% Confidence Limits
11 II 77 to 13 II 77 = 2 days	12	16.5 - 61.5 32.7 ± 14.7	Cabras outfall Experiment 2	-3 m	all dead no growth
25 II 77 to death	9	12.9 - 52.9 36.6 ± 16.4	Cabras outfall	-3 m	7 dead 27 II 77 2 dead 3 III 77 no growth

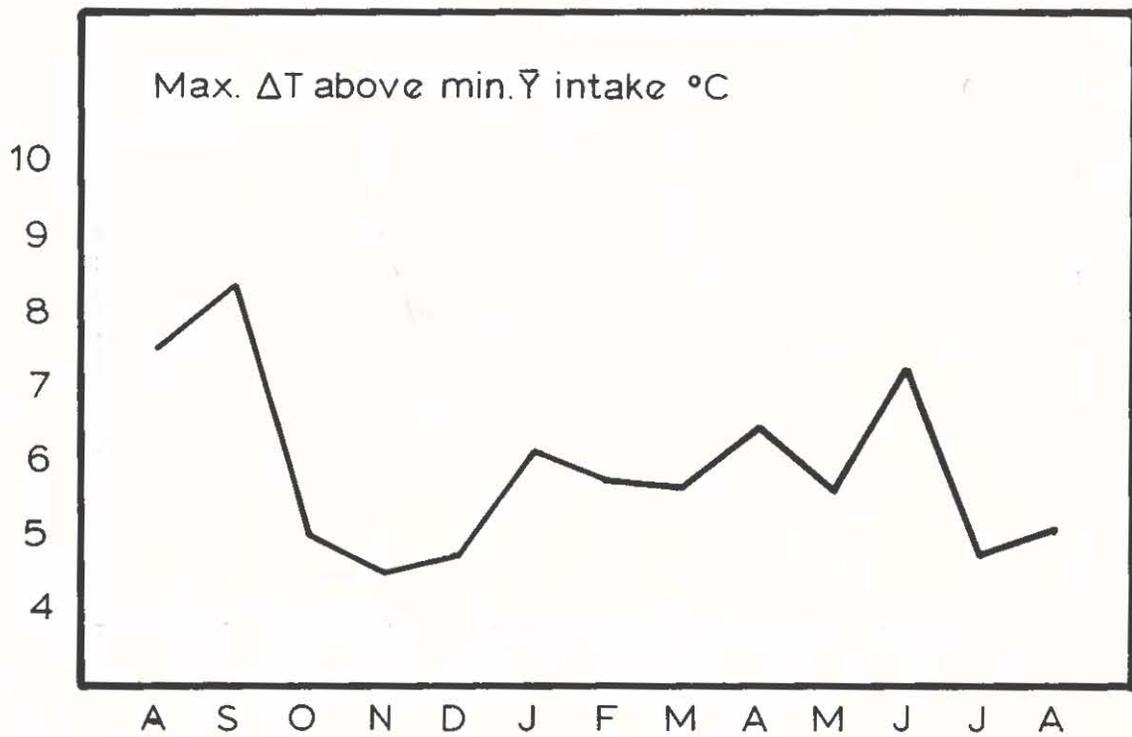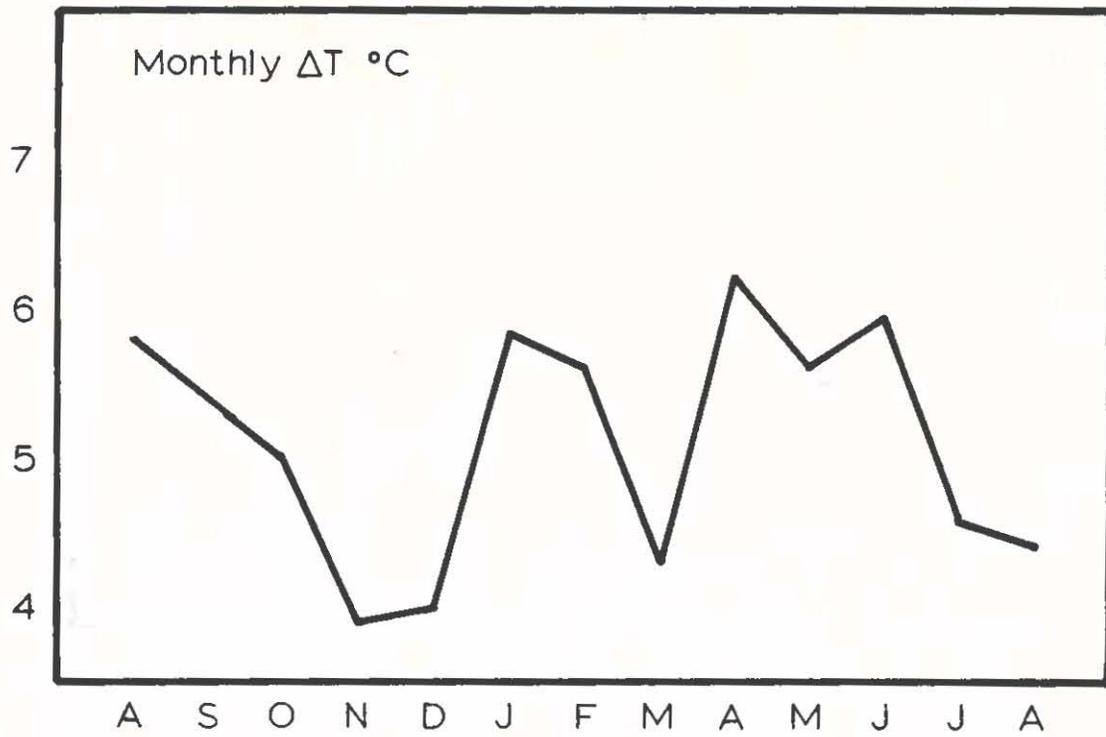Figure 19. Mean maximum and minimum intake and outfall temperatures at Tanguisson.

Figure 20.   Mean monthly ΔT° and maximum ΔT° above minimum intake temperature.

at the intake and outfall were removed mid-February. Therefore the
thermal regime can only be based on data over a one-year period (Marsh
et al. 1977). The intake temperatures were generally below 30°C while
the outfall temperatures were generally 34°C and temperatures of 36°C
were not uncommon (Marsh et al. 1977). Therefore the $\bar{Y} \Delta T^{\circ}$ was quite
similar to that of Tanguisson around +5-6 C. All twelve Acropora
formosa in the outfall in Experiment 2 were killed within two days.
Zooxanthellae and considerable amount of mucus were sloughed-off by
the colonies after only a few hours and death followed shortly. Seven
of the nine test colonies of Experiment 4 were also dead within two days,
although two colonies survived a little longer (Table 8). Two of the
control colonies were overgrown by Dictyota on the intake grill and
died after 29 days (Table 8). The other seven colonies grew well,
having a mean increase of 5.6 ± 0.2 mm in 62 days (Fig. 21). There
was obviously a very significant difference in the growth and mor-
tality ($X^2 = 17.18$***, Table 9) of A. formosa between the control and
thermal effluent areas. A. formosa was the least tolerant of the
three species tested.

Porites andrewsi was by far the most tolerant of the species tested
and a few colonies survived their entire respective test period of 63
or 77 days (Table 8, Fig. 12). However, all of the P. andrewsi colonies
exposed to the Cabras outfall (experiments 2 and 4) were still pink
upon collection, indicating that no growth occurred. In fact it is
possible that some colonies atrophied as indicated by constriction of
some branch tips (Fig. 22). However, similar branch constriction was
also observed in control colonies, possibly indicating a different
growth pattern in the well-lighted and clear water of the intake site.
Mortality and growth of all P. andrewsi transplant is shown in Figure
26, one-third (6) of the colonies exposed to elevated temperature lived
for their entire test period even though they were heavily fouled with
algae and covered with sediment, the ability of the corals to remove
sediments decreased with time as mortality increased. All 12 control
colonies grew well, $\bar{Y} = 5.2 \pm 1.1$ mm in 77 days, and some even grew
over their attachment wire (Figs. 23-25). The growth of these
colonies was primarily at the branch tips with some basal growth and
the rest colony was pink upon collection. Because none of the test
colonies grew significantly, experiments 2 and 4 were pooled and
compared against the 12 control colonies (Table 9). There was a highly
significant difference in growth and survival ($X^2 = 10.70$***) between
the two areas.

The P. damicornis colonies tested at the Cabras outfall showed a
uniform mortality with all colonies (15), of experiments 2 and 4, dead
within 31 days (Table 8, Fig. 26). Most colonies in the effluent lost their
zooxanthellae within one week but were still alive (Figs. 27, 28). Although
P. andrewsi survived longer in the hot water it did not grow, while some
growth occurred in 10 of the test colonies of P. damicornis within 31 days

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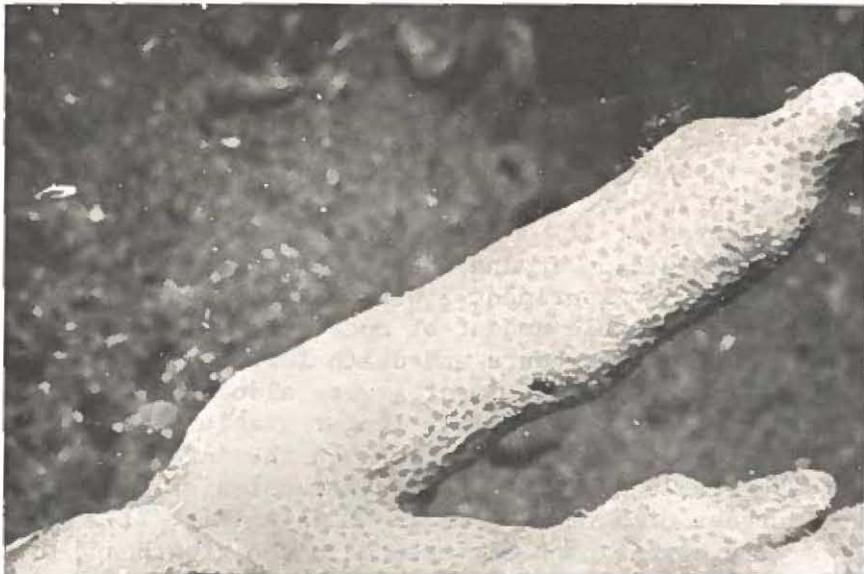
Figure 22. Constricted branch tip of <u>Porites</u> <u>andrewsi</u>. Some sediments have begun to adhere to the colony and some algal fouling in visible.

Figure 23. <u>Porites</u> <u>andrewsi</u> fouled with brown algae and bryozoans on intake grill. Surely the heavy algal growth on the intake grill had some negative effect on the growth of the controls, but only two control colonies died (both <u>Acropora</u> <u>formosa</u>).
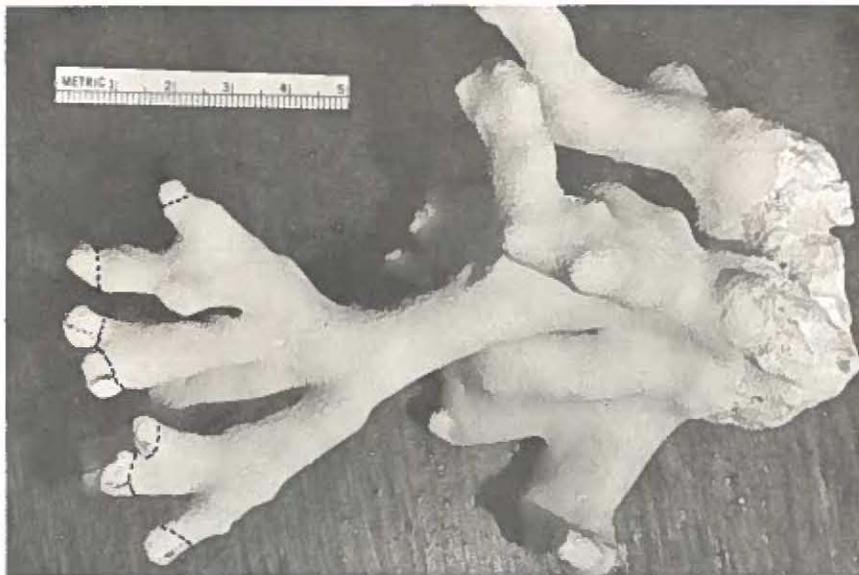
Figure 24. Growth of a _Porites_ _andrewsi_ colony. The pencil marks on the colony were put there to prevent measuring the same branch twice.

Figure 25. _Porites_ _andrewsi_ on Cabras intake which has overgrown its attachment wire.

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Pocilopora damicornis
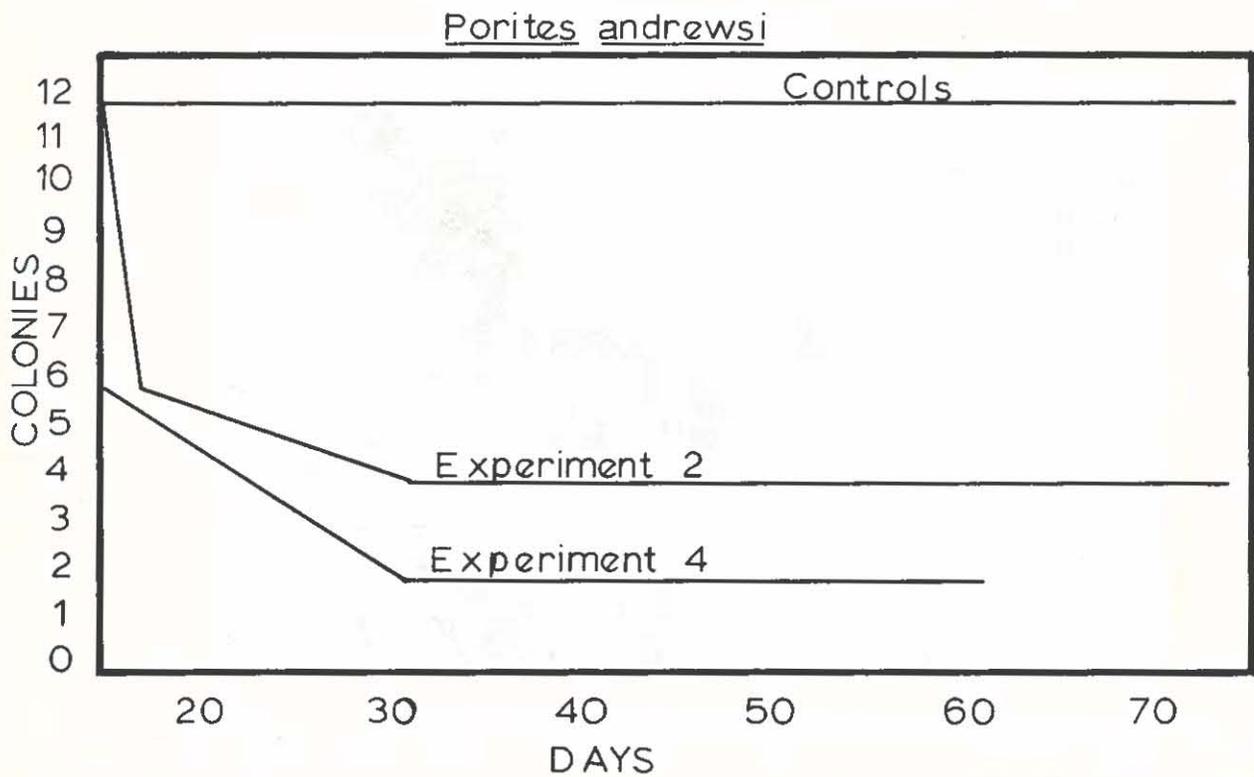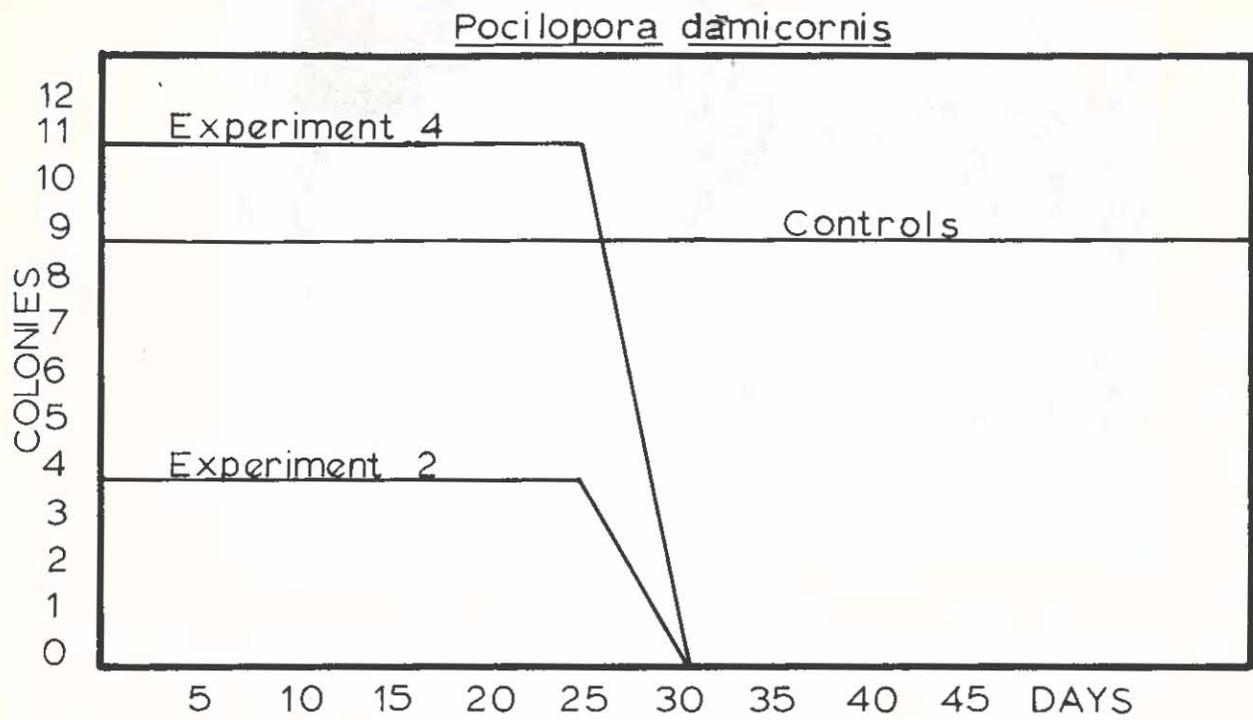
Porites andrewsi

Figure 26. Survival and mortality of _Pocillopora damicornis_ and _Porites andrewsi_ transplants.
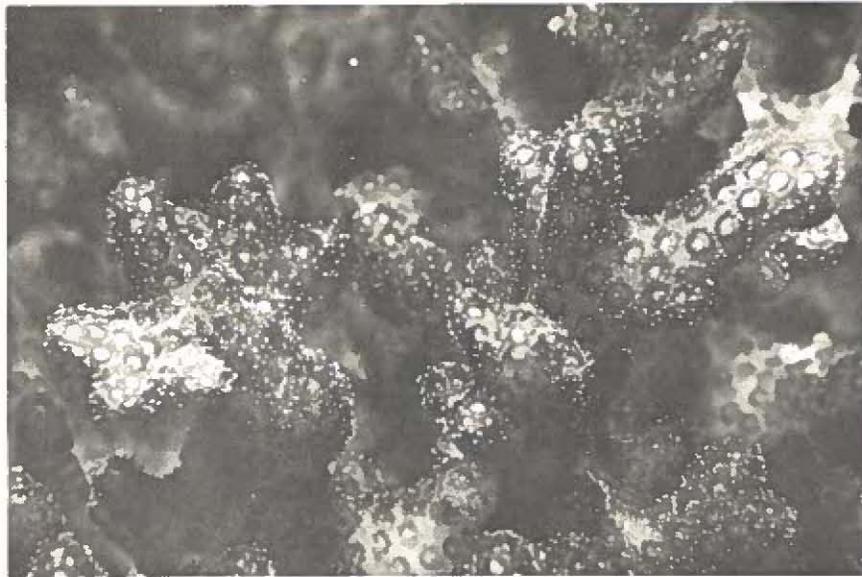
Figure 27.   _Pocillopora_ _damicornis_ with zooxanthellae at time of transplant.

Figure 28.   _Pocillopora_ _damicornis_ within two weeks of transplantation. Although
the colony was bleached it was still alive as transparent polyps can
be seen.

$(\bar{Y} = 0.75 \pm 0.3$ mm, $\bar{Y} = 0.79 \pm 0.2$ mm). There was a highly signifi-
cant difference in growth and mortality of P. damicornis between the
effluent and intake sites ($X^2 = 4.025$***, Table 9).

The growth of the forereef transplants are presented in Table 8.
There was a very significant difference in the growth rate of colonies
between -15.2 and -30.5 m ($t_S = 13.50$***, Table 9, Figs. 29-32). Inter-
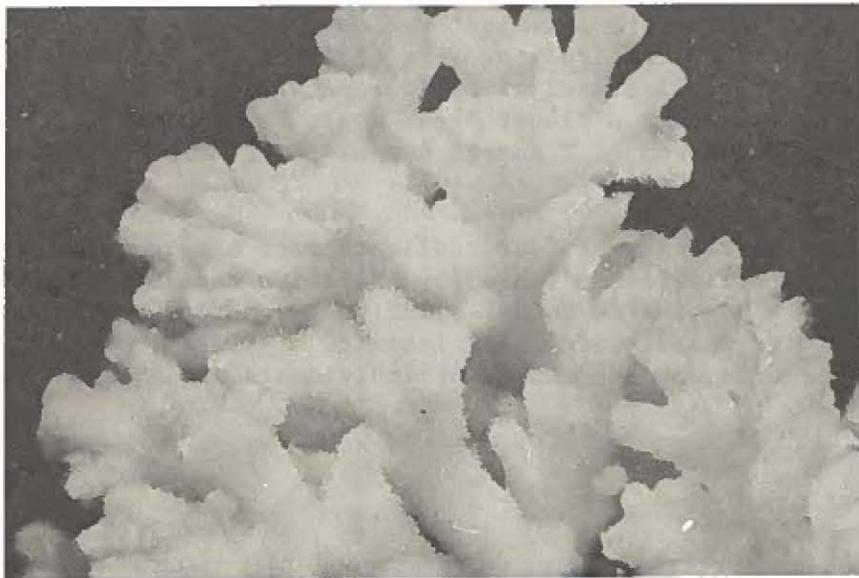estingly, the -15.2 m transplants grew significantly more than did the
colonies left in situ on Golf Pier ($t_S = 3.12$**, Table 9). In addition
to the t-tests a nested analysis of variance was made to determine the
probability that the growth of P. damicornis was the same for three
depths. It was not (Table 11) and the difference between depth accounted
for 70 percent of the total variance.

Fish Surveys

Since the coral community is essentially no different between con-
trol Transects A and C, they were pooled and any difference in
chaetodontid distribution was considered to be natural variation. Com-
parison of species diversities of the control (A + C) and the effluent
reef margin transects by the Mann-Whitney U-test, indicated a signi-
ficant difference ($U_S = 30$**) in their diversities.

Each group of four replicate reef margin surveys was pooled for
each transect area and density and relative density for each species
within an area was calculated (Table 12). Chaetodon citrinellus (Fig. 33)
was by far the most common and abundant species in all areas. Chaetodon
trifasciatus (Fig. 34), C. reticulatus (Fig. 35) and C. lunula (Fig.
36) were also common in all areas. Fifty percent (7 of 14) of the
species did not occur in the effluent area, while 79 percent of all
species encountered occurred at Transect A and 93% occurred at Transect
C.

A summary of the results of four replicate reef margin transects
within each area is presented in Table 13. Relative magnitudes are
indicated and area B has the lowest of all five parameters considered.
The number of species was significantly less ($t_S = 4.71$***, df = 10)
in the effluent area as was the number of individuals ($t_S = 6.16$***,
df = 10).

General Observations

Some corals have recruited into the denuded reef margin zone
during our two years of investigation at Tanguisson. These colonies
settled and grew satisfactorily but were recently killed by high
summer temperatures and are now heavily fouled with algae (Figs. 37,
38, 39). Randall (Jones et al. 1976) predicted that the damage zone
would expand and contract and this is what is happening. It

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Table 9. Comparison of growth rates and survival of three coral species. Growth during a nine week period was compared by the Student's t-test. Survival and mortality of the transplants was compared by the chi-square test with Yate's correction for continuity. Linear growth was assumed for the derivation of equivalent samples by multiplying the actual growth rate by the ratio of days to 63 days. ***p < .001, ** p < .01, * p < .05.

Study Site Species	Comparison	Test Statistic
Tanguisson-reef margin Pocillopora damicornis	A vs B 1976	t_s = 8.799*** df = 94
	A vs B 1977	t_s = 2.672* df = 46
and Golf Pier controls	A vs Golf (-1.3 m) 1976	t_s = 7.452*** df = 78
Tanguisson-forereef and Golf Pier	-15.2 vs -30.5 m 1976	t_s = 13.502*** df = 94
	-15.2 vs Golf (-1.3 m) 1976	t_s = 3.115** df = 60
Cabras Pocillopora damicornis	intake vs outfall Experiment 4	t_s = 4.025*** df = 22
	intake vs outfall both runs pooled	X^2 = 9.96*** df = 1
Acropora formosa	intake vs outfall both runs pooled	X^2 = 17.18*** df = 1
Porites andrewsi	intake vs outfall both runs pooled	X^2 = 10.70*** df = 1

Table 10. Nested analysis of variance to determine the probability that
           P. damicornis colonies of experiment 1 grew at the same rate
           within and nearby the thermal effluent. % S^2 means percent
           of the total variance. *** = p < .001.

Source of variance	df	MS	F_s	% S^2
increase T^o	1	0.4666	113.8049***	60.66
colonies	4	0.0041	0.6721 ns	0.79
branches	90	0.0061		38.55

Table 11. Nested analysis of variance to determine the probability
           that the growth of P. damicornis was the same in three
           zones of the Tanguisson fringing reef (reef marin, −2.4 m;
           submarine terrace, −15.2 m; and the seaward slope, −30.5 m).

Source of variance	df	MS	F_s	%S^2
depths	2	1.4788	26.7899***	69.72
colonies	6	0.0552	5.4653***	6.57
branches	135	0.0101		23.71

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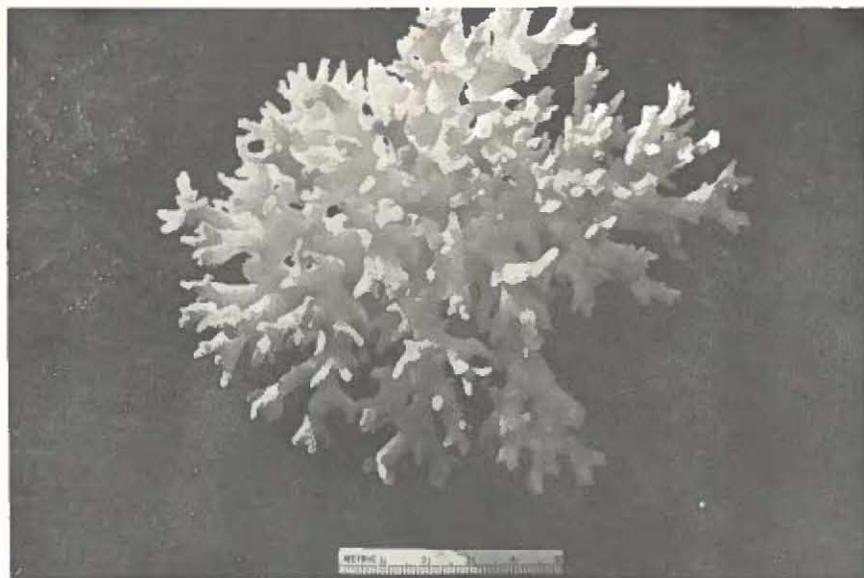
Figure 29.   _Pocillopora_ _damicornis_ colony of the -15.2 m transplant.

Figure 30.   Branch tips of a -15.2 transplant (Fig. 29).   This colony had a mean branch tip extension of 6.8 ± 0.8 mm after 62 days.
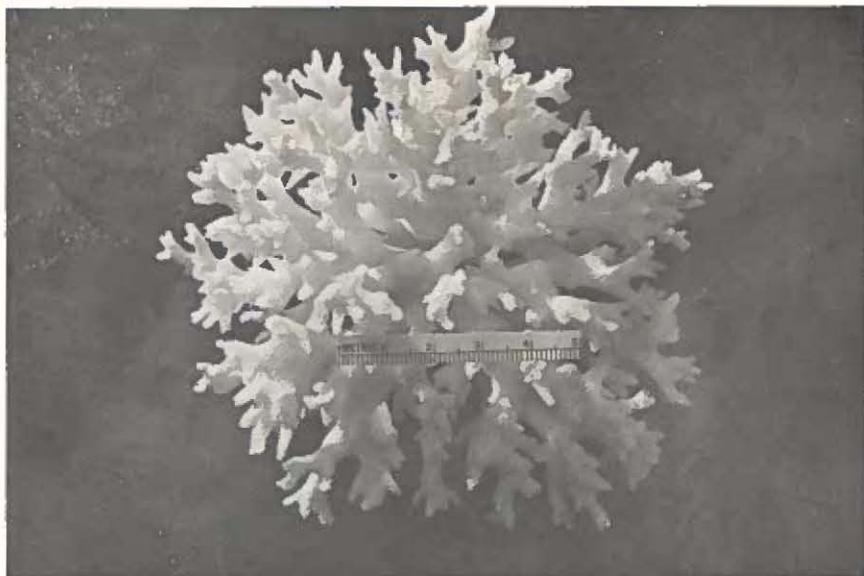
Figure 31.   <u>Pocillopora</u> <u>damicornis</u> colony of the –30.5 m transplant.

Figure 32.   Branch tips with growth of a –30.5 m transplant (Fig. 3). This particular
             colony grew the fastest of the seaward slope transplants at the rate of
             3.6 ± 1.0 mm/62 days.

Table 12. Density and relative density of chaetodontids in pooled
transect areas of 800 m^2. Density (D) = total individuals
of a species/total number of transects (4). Relative
density (RD) = (number of individuals of a species/total
number of individuals of all species) X 100.

Transect Area Species	A D	A RD	B D	B RD	C D	C RD
C. auriga	1.25	5.62	1.50	18.75	1.00	5.06
C. bennetti					0.25	1.27
C. citrinellus	7.50	33.71	3.00	37.50	4.50	22.78
C. ephippium	0.75	3.37				
C. lunula	1.50	6.74	0.75	9.38	2.25	11.39
C. melanotus					0.25	1.27
C. ornatissimus	0.75	3.37			1.75	8.86
C. quadrimaculatus	0.75	3.37			1.25	6.33
C. reticulatus	1.50	6.74	1.50	18.75	2.75	13.92
C. trifasciatus	4.50	20.23	0.50	6.25	1.25	6.33
C. ulietensis	1.50	6.74	0.50	6.25	2.00	10.13
C. unimaculatus					1.25	6.33
M. strigangulus	0.25	1.12			0.25	1.27
F. flavissimus	2.00	8.99	0.25	3.12	1.00	5.06
Σ	22.25	100.00	8.00	100.00	19.75	100.00

Table 13. Summary of chaetodontid surveys indicating relative values.

	A		B		C
Total species per area (800 m^2)	11	>	7	<	13
Total individuals per area (800 m^2)	88	>	32	<	79
Mean individuals per transect (200 m^2)	22.25	>	8.00	<	19.75
Shannon Diversity index (H') per area	3.0445	>	2.4127	<	3.3149
Evenness per area (E)	.8801	>	.4825	<	.8958

Figure 33. <u>Chaetodon</u> <u>citrinellus</u>. This species was common on all transects.
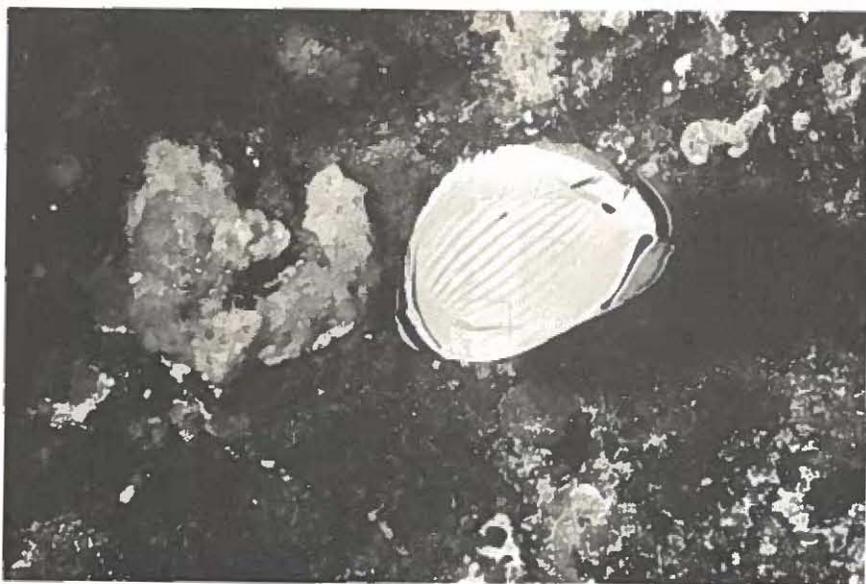
Figure 34. <u>Chaetodon</u> <u>trifasciatus</u>. This species is almost always paired and is a coral specialist.

Figure 35. <u>Chaetodon</u> <u>reticulatus</u>. This species occurred in all areas, but was less abundant at Transect B.
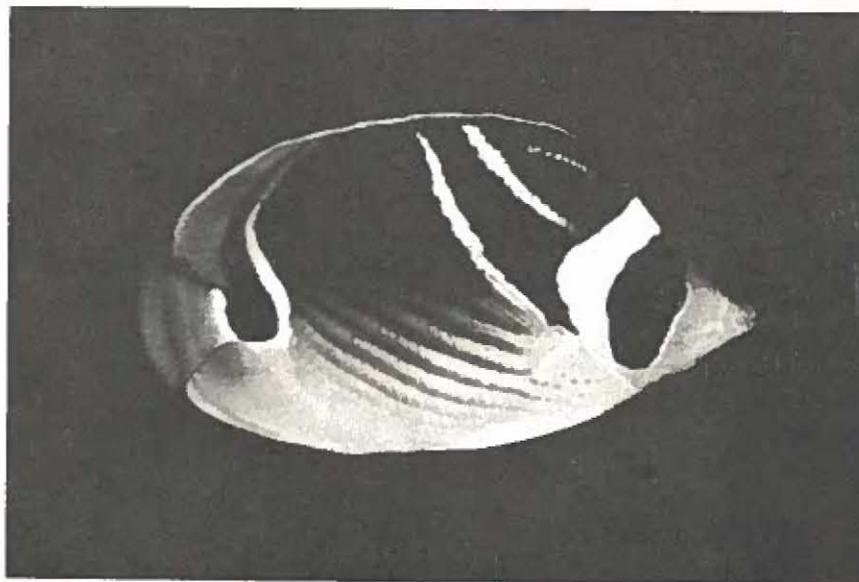
Figure 36. <u>Chaetodon</u> <u>lunula</u>. The racoon butterflyfish eats little or no coral and was also seen at Transect B.

Figure 37. Coral recruitment into the damaged reef margin zone. These colonies
were killed in August by high temperatures.

Figure 38. Dead recruit of _Pocillopora_. This colony settled and grew on the
periphery of the discharge zone. It was partially killed in August
and is now heavily fouled with algae.

appears that Galaxea fascicularis (Fig. 40) has recruited in abundance to edges of the damaged area and some corals are surviving on the lower sides of surge channels away from the stratified layer of thermal enrichment.

The Tanguisson discharge has killed all corals in a 2000 m^2 reef margin zone but is not responsible for damage in deeper forereef zones. When considering effects of man-made perturbations, it is important to keep in mind natural coral destruction as well. The devastating effect of the Acanthaster planci infestation at Tanguisson has been considered by Jones et al. (1976) and our measurements of coral recolonization of "acanthasterized" zones indicated yearly increases in aerial coral coverage (Neudecker 1976).

The high wave assalt on the Tanguisson reef margin has already been mentioned several times. During periods of heavy surf, coral rubble and boulders are tossed around on the reef margin and in surge channels, breaking off and abrading corals (Figs. 41, 42). This heavy surf also carries a large amount of wave born sediments which stress corals. Another wave related stress factor was noticed 23 IX 77 when many ramose coral species were observed to be heavily fouled by a terrestrial plant that was probably sword grass (Fig. 43). This plant was attached to colonies on the forereef down to depths of 30 m and many were still attached on 7 X 77. The back and forth surge action continually abraded the afflicted colonies and parts were killed. Richard Randall (pers. comm.) has also observed this storm related phenomenon around Guam and agrees that its effect is a significant source of adult coral mortality. If the damaged portion of the colony can not regenerate lost tissue before it is fouled by algae, it will surely die. Although coral mortality caused by a terrestrial plant has not been reported, Maragos (1972) reported that corals were smothered and killed by thick algal matts that were transported down the reef slope during heavy surf and wave conditions in Hawaii.

Besides Acanthaster, other species interactions also lead to coral damage and mortality. The effects of coral-eating fishes have been tested at Tanguisson and found to be an important factor retarding coral growth and zonation (Neudecker 1977). In addition to Acanthaster another asteroid, Culcita novaeguineae, is known to eat coral and is a significant source of coral mortality in fore reef zones at Tanguisson. Culcita is normally more abundant than Acanthaster and feeds diurnally (Goreau et al. 1972). This starfish was often found very near recently killed corals (Figs. 44, 45) and its effect on coral reef community structure is different than the crown-of-thorns. It occurs in lose aggregations (whereas Acanthaster often sworms) and it attacks small colonies (5-10 m in diameter) of Acropora and Pocillopora. The recently killed colonies are clearly visible from great distances. Goreau et al. (1972) suggested that the lack of prehensile arms prevented Culcita from attacking large or high corals.

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Figure 39. Dead recruit of <u>Acropora</u>. Algal fouling is apparent.

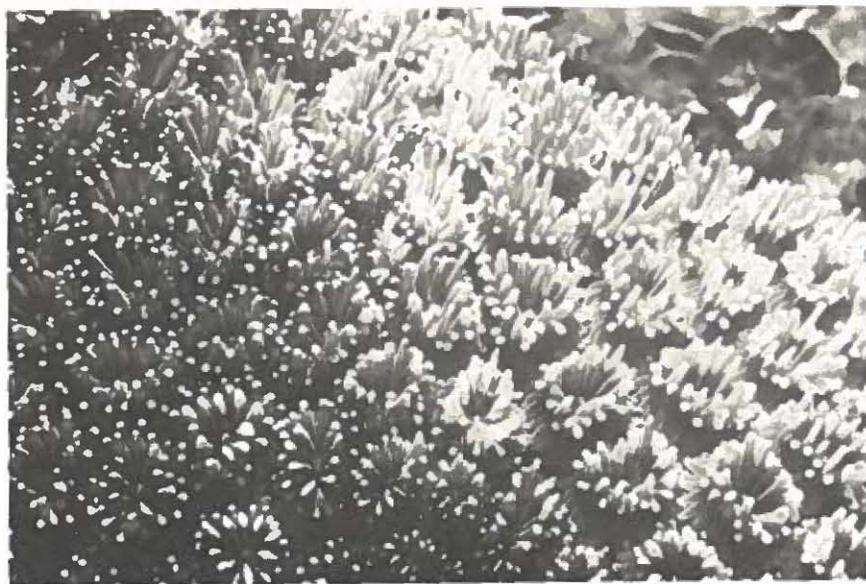Figure 40.   <u>Galaxea</u> <u>fascicularis</u> near the damage zone. This beautiful coral is
             somewhat tolerant of the increased temperature and is recruiting
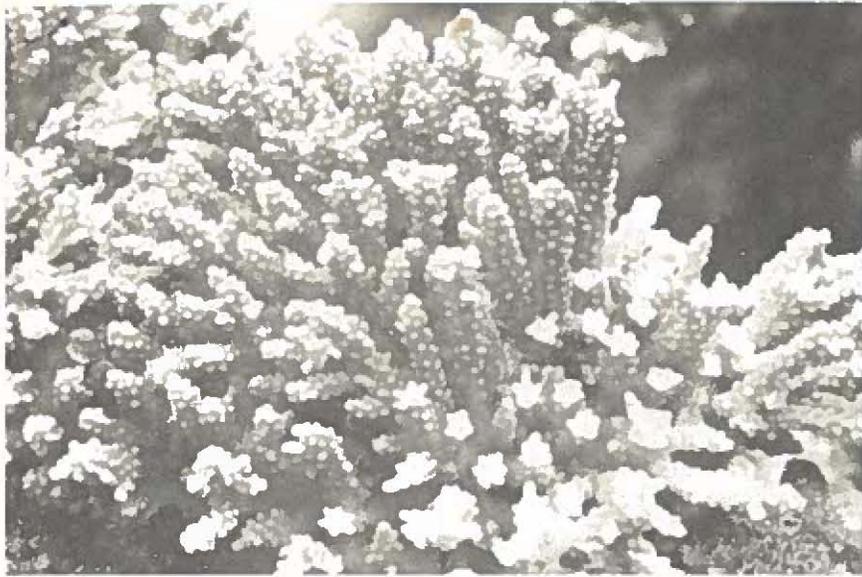   in abundance in periphreal areas.

Figure 41.   Broken colony of <u>Acropora</u>.   Heavy surf action tosses rubble and boulders around the reef margin and destroys corals.
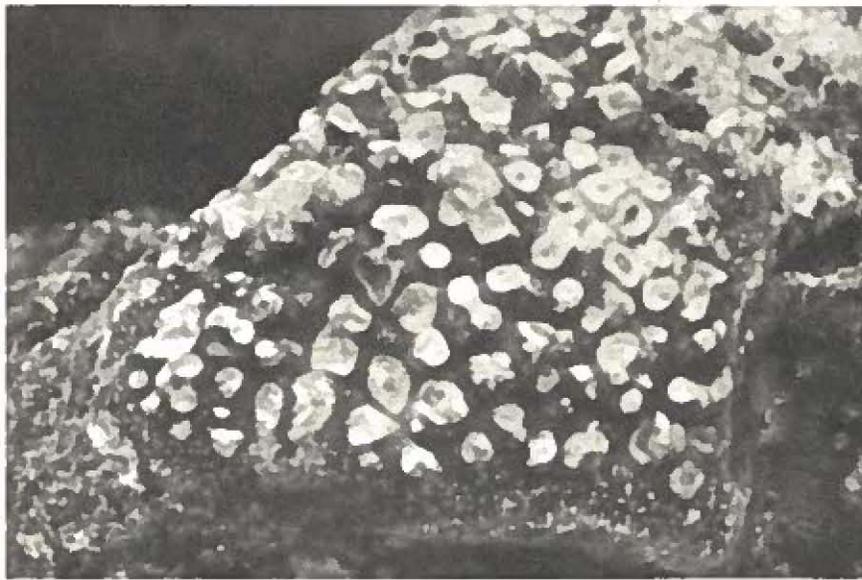
Figure 42.   Destroyed colony of <u>Acropora</u>.

A list of corals occurring at Tanguisson has already been published (Jones et al. 1976). Two new records were found during this study. In addition to that list, _Parahalomitra robusta_ (Quelch), which is also a new record for all of Guam, was found at 20 m and _Stylaster_ sp. was found on the reef margin.

A recent quantitative study of polychaete annelids at Transect C (Kohn and White 1977) found no adverse effect on that fauna due to the nearby discharge. The chaetodontid fauna is essentially the same at control Transects A and C and significantly reduced in the effluent Transect B. Previous studies have demonstrated significantly less coral coverage in the effluent zone on Transect B (Neudecker 1976). These assessments of the local fauna in three different phyla set a recognized boundary to the extent of the area of destruction. The damage zone will probably not increase in size unless the generation capacity of the plant increases.

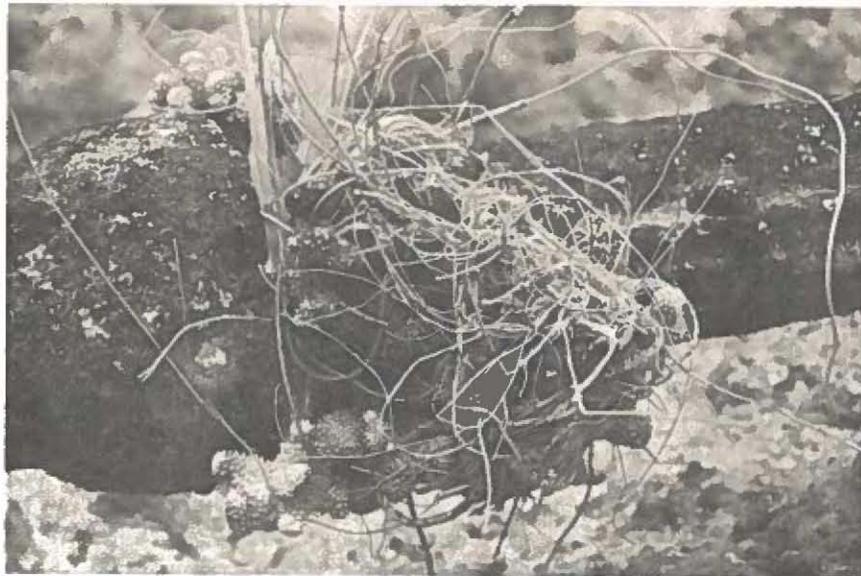Figure 43.   Terrestrial plant on coral colony at -15 m. This storm related
phenomenon causes coral damage around Guam to depths of -30 m.
The plant is probably sword grass.

Figure 44.   Culcita novaeguinae and recently eaten Pocillopora colony.
This coral eating starfish is normally more abundant than
Acanthaster planci and has an important effect on coral reef
community structure.

CONCLUSIONS

Recruitment Studies

The stability and predictability of environments are important
considerations in understanding the dynamics of communities (Pianka
1966, Sanders 1968, 1969; Slobodkin 1968; Slobodkin and Sanders 1969).
A stable (little variation in environmental parameters) and predictable
(recurring pattern) environment is expected to be more diverse than an
unstable (harsh or rigorous) and unpredictable environment. The reef
margin is both unstable and unpredictable (heavy surf and subaerial
exposure) at both sites and the added effect of increased temperatures
at B makes it significantly more rigorous than Transect A.

The fouling community at both sites is predominated by algae in
early successional stages and the trophic structure is simple. The
algae are primary producers and most surfaces have only a few individuals
of a guild of primary consumers including the polychaete and micromollusk.
This trophic simplicity is partly related to the harsh and unstable
physical nature of the reef margin as has been predicted for rocky inter-
tidal communities by Menge (1976). Competition for space, especially
on upper surfaces has the greatest effect on coral recruitment and community
structure. Few corals recruited to upper surfaces and the mortality
of those that did was high. Benthic algae inhibited coral growth and
recruitment to denuded reef substrata in Hawaii (Banner 1968, Burm and
Morris 1970). The increased temperatures at Transect B will continue
to give algae competitive advantage over corals.

Because predation from larger animals was controlled, little can
be said about its role in fouling community structure. However,
Birkeland (1977) has shown that grazing and browsing herbivorous fishes
aid coral recruitment by removing algal competitors.

Although very little is known about coral settlement, mortality
and recruitment (Connell 1974, Grassle 1974) most studies have indicated
gregarious recruitment (Harrigan 1972, Lewis 1974a, b; Loya 1976b).
Species that are known are mainly r-selected or opportunistic species
and it is not known if gregarious settlement is widespread or whether
it is just a strategy of r-selected species specifically. Most of the
recruits were of the family Pocilloporidae which contains many r-selected
species and these common corals settled in a clumped pattern. Birkeland
(1977) reported a definite tendency of planulae to settle on vertical
surfaces and this tendency was also apparent at Tanguisson. It is not
yet known wheather this represents selective settlement or if survival
is greater on vertical surfaces. More data will probably verify
selective settlement. Colonization of a substratum is directly
dependent upon the abundance of larvae and hence the most common and
abundance species (e.g., Pocillopora) have high rates of recruitment and
mortality (Connell 1974, Loya 1976b).

The limited and finite space of the settling plates is ideal
for investigating the distributional and developmental processes of the
community. But since the community structure is directly dependent on
the area of the substrata (Osman 1977, J. B. C. Jackson pers. comm.)
direct comparisons on a larger scale by simple multiplication of our
75 cm^2 samples are not valid. However, the consistent rate of coral
recruitment of nine colonies per 0.7 square meter for both runs is of the
same order of magnitude as Connell's (1974) figure of 5 colonies m^{-2}.
Connell (1974) also reported that about fifty percent of these recruits
died and my figures show about 25 percent mortality within two months
and this mortality would probably increase over time.

Growth-Transplant Studies

The negative effect on coral growth rate and survival of temper-
atures being increased over ambient temperature was demonstrated at
both Tanguisson and Cabras. Control colonies grew at normal rates at
both study sites.

The many colonies that were taken from lower Piti Channel (Fig. 5)
periodically experienced elevated temperatures and were therefore expected
to be tolerant species. While this was the case with Porites andrewsi,
Acropora formosa was very sensitive to the outfall temperatures and all
test colonies died within two days. A. formosa was also the species
most sensitive to experimental manipulation and it is not a good choice
for transplant experiments. Both Pocillopora damicornis and Porites
andrewsi exhibited no signs of trauma (such as mass mucus expulsion)
and were easy species to work with. The finely branched morphology of
P. damicornis facilitates the alizarin method and yields large sample
sizes (number of branches) from each colony.

Growth experiments with P. damicornis in Hawaii and Enewetak
(Clausen and Roth 1975a, b; Coles et al. 1976) have demonstrated that
upper lethal limits are dependent upon ambient temperature regimes and
that upper lethal limits are not fixed physiological boundries as
previously thought (Mayor 1918). These comparative growth experiments
suggest genetic adaptation to local temperatures by corals. Although
Acropora is one of the most senitive genera to increased temperatures,
it grows in shallow water environment along the Trucial Coast of the
Persian Gulf where maximum temperatures reach 40°C (Kinsman 1964).

If the thermal discharge from the Tanguisson plant persists for
many, many years, there is a possibility that some recruits will
eventually have a high fitness and survive the elevated temperatures.
But since the plant will remain in operation only a short time (less
than 30 years), successful recruitment will probably not occur. However,
the chance of recolonization of the denuded reef margin zone could be
greatly enhanced by transplanting many colonies of tolerant species,
such as P. andrewsi, and hoping that some colonies would survive and

reproduce. Even though P. andrewsi is typically a lagoon species, its tolerance of increased temperatures may allow it to survive in this area where common reef margin species with better competitive strategies would die.

Maragos (1972) reported that transplanted corals in Hawaii were able to rid themselves of sediments when not also stressed by other factors. This was also the case with test colonies of P. andrewsi in the Cabras outfall since the ability to reject sediments decreased as exposure time increased.

Colonies of P. damicornis can survive and grow well in water much deeper than they are normally found to exist. The growth rate of the deepest transplants (-30.5 m) was significantly less than that at -15.2 m and the growth at -15.2 m was significantly more than the growth in situ on Golf Pier (-1.3 m). This is in part due to photoinhibition in shallow water. The survival and growth of the deep transplants were much different than those reported by Maragos (1972), who reported that P. damicornis could not survive in low light environments or deep water. Two colonies of P. damicornis that were transplanted to -30.5 m at Tanguisson in November, 1975, are still alive and well 11 months later. Laboratory experiments in which layers of screens were used to reduce light intensity and simulate growth at depth, have suggested that P. damicornis would grow only 1.5 mm/yr at -4.1 m in Hawaii (Houck et al., 1977), whereas colonies transplanted to -30.5 m grew at 18.5 ± 5.2 mm/yr (this figure estimated by extrapolation, assuming linear growth). While the extinction coefficient of Hawaiian waters is probably greater than that of waters off Tanguisson, the Hawaiian values appear some what low. Although laboratory experiments are valuable in understanding the effects of one or two parameters on growth rate, they are not useful for estimating natural growth rates. The only way to determine how a coral really grows on the reef is to measure its growth there.

The accuracy of the alizarin method in these experiments can be tested by comparing the growth rates with those of other authors on the same species. As previously mentioned, P. damicornis is a well known species and its annual growth has been reported as 2.8 ± 1.5 cm by Mayor (1924) and 2.37 cm by Glynn and Stewart (1973). Assuming linear growth for comparison only, P. damicornis grew 3.1 ± 0.6 cm/yr on Golf Pier and 2.9 ± 0.7 cm/yr at the Cabras intake. A formosa grew at the fastest rate, 3.3 ± 0.1 cm/yr and P. andrewsi grew the slowest at a rate of 2.5 ± 0.5 cm/yr. It is interesting that the relative order of thermal tolerance was the inverse of the order of growth rate.

Corals are functional symbiotic units whose tolerances are determined not only by natural selection but also by endogenous rythms of, and synergistic responses between, plant and animal systems. Growth rate is a function of water temperature and light intensity. A total understanding of coral growth rate can only come from controlled field studies.

Fish Surveys

The species diversity, density and relative density of chaetodontids
was significantly less on the reef margin area affected by the outfall.
This indicates that removal of living corals themselves is not the only
negative effect of the increased temperature. When the corals die many
species which are closely associated with them either die also or move to
a more favorable area. Clearly, the removal of corals also means a con-
commitant reduction in the number of associated species. Chaetodontids
are useful as measures of environmental quality.

Jones et al. (1976) reported that nine of the chaetodontids
considered in this report occurred on the reef margin before the effluent
(1971), while only four species were seen after the plant became opera-
tional (1972). Three of those tolerant species (Chaetodon auriga, C.
citrinellus and C. lunula) were also seen in that area during these
studies, while C. ornatissimus was not. In addition to the species
occurring in 1972 and 1971, four additional species (C. reticulatus,
C. trifasciatus, C. ulietensis and Focipiger flavissimus) were also seen.
Many species of Chaetodon range over an area and mere presence in an
area does not mean that the fish lives there.

Figure 45.   Recently eaten Acropora colony. Culcita feeds on relatively
              small colonies (3-8 m 1-diameter) and prefers Acropora and
              Pocillopora.

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SUMMARY

Recovery of the denuded reef margin area depends mainly upon colonization by coral planulae and the subsequent growth and reproduction of surviving colonies. The recruitment studies indicate that few corals will settle in the effluent area and, even if they do, their chance of survival to reproductive maturity is quite small. The growth-transplant studies demonstrate a negative correlation between coral growth rate and increased temperatures. Field observations, that some corals have recruited into the damage zone and subsequently died, support the conclusion from the experimental studies. As long as the effluent is discharged over the reef, benthic algae will predominate and this early successional stage will persist. Corals play a central role in reef construction and maintenance and provide food and shelter for many associates, for example chaetodontid fishes. Their death means the destruction of normal coral reef community structure, drastic reduction in species diversity and subsequent predominance by benthic algae.

ACKNOWLEDGEMENTS

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