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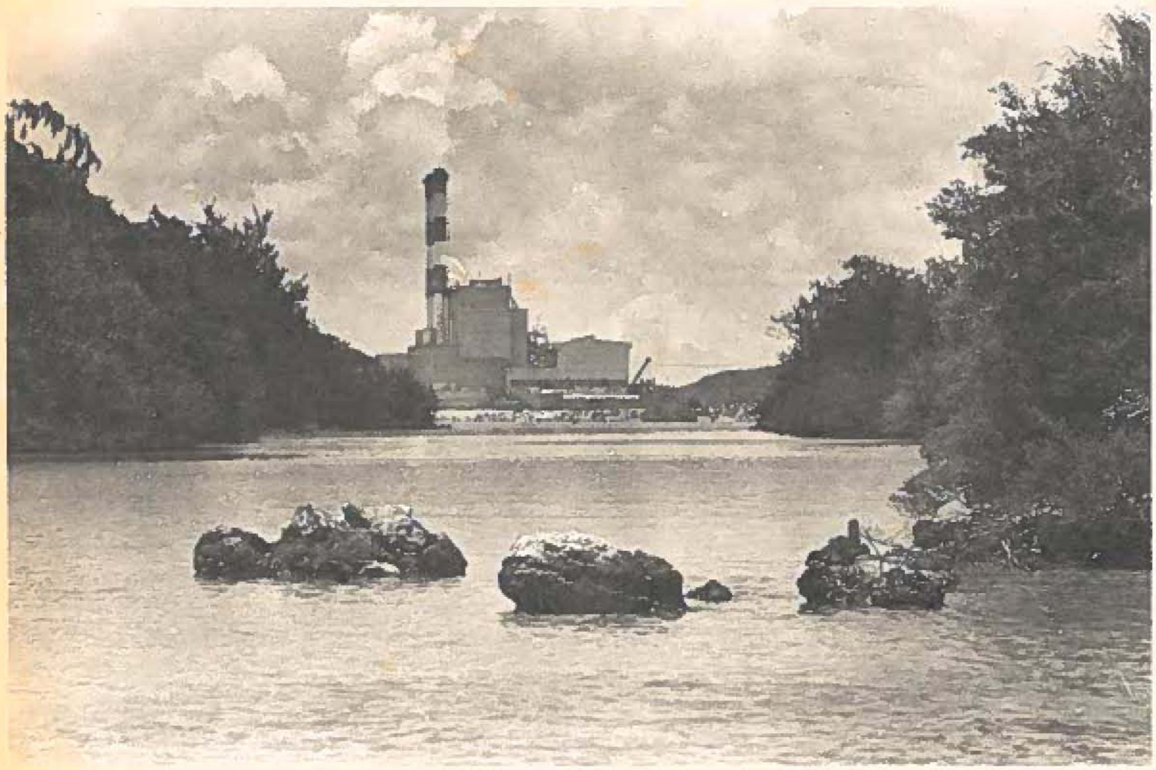
POWER PLANTS AND THE MARINE ENVIRONMENT ADDITIONAL OBSERVATIONS IN PITI BAY AND PITI CHANNEL, GUAM

JAMES A. MARSH, JR. and JAMES E. DOTY



UNIVERSITY OF GUAM MARINE LABORATORY

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POWER PLANTS AND THE MARINE ENVIRONMENT: ADDITIONAL OBSERVATIONS IN PITI BAY AND PITI CHANNEL, GUAM

by

JAMES A. MARSH, JR. and JAMES E. DOTY

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[Cover photo: View of the Cabras Power Plant taken in July 1975 from the shore of Lower Piti Channel.]

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INTRODUCTION[1]

During the past year construction has been completed on the Cabras Power Plant, Units 1 and 2, for Guam Power Authority. Unit No. 1 was completed and underwent testing in August and September 1974, and operations began shortly thereafter. Unit No. 2 began operations in March 1975. Construction of Units 3 and 4 will be initiated in the future. The new generating facilities are located on a former tidal flat which was filled during the early stages of construction and is located at the eastern end of Cabras Island, Guam (Fig. 1). The plant is located near the older Piti Power Plant operated by the U. S. Navy Public Works Center.

Environmental studies have been conducted for Guam Power Authority in the areas affected by power plant operations and new plant construction since January 1972. Three reports describing these studies have previously been submitted to Guam Power Authority (Marsh and Gordon, 1972; Marsh and Gordon, 1973; and Marsh and Gordon, 1974). In addition, a paper on community productivity of the West Piti Bay reef flat has been published in the scientific literature (Marsh, 1974). The purpose of this fourth report to Guam Power Authority is to discuss studies conducted primarily during the 1974 calendar year, although some later information is included. Studies are continuing and will run at least through December 1975. Thus, environmental data gathered before and after initial operations of the Cabras Plant are being made available.

The Piti Power Plant has a generating capacity of approximately 74 megawatts, and the two units of the Cabras Power Plant have a capacity of 66 MW each. The maximum pumping capacity of cooling waters through the Piti Power Plant condensers is approximately 4.85 cubic meters per second (64,000 gallons per minute), and that for Cabras Units 1 and 2 is 9.01 m^3 sec^{-1} (120,000 gpm). The Piti Plant was designed to raise the temperature of cooling water passing through its condensers a maximum of 5.6°C (10°F), and the design of the Cabras Plant is for a temperature rise of 5.6-8.3°C (10-15°F), according to information from the Guam Power Authority.

Both power plants receive their cooling water from a common source, Piti Canal, which cuts through the Cabras Island causeway (Fig. 17).

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[1] The views expressed by the authors are their own and do not necessarily reflect those of the Marine Laboratory, the University of Guam, or the Government of Guam.

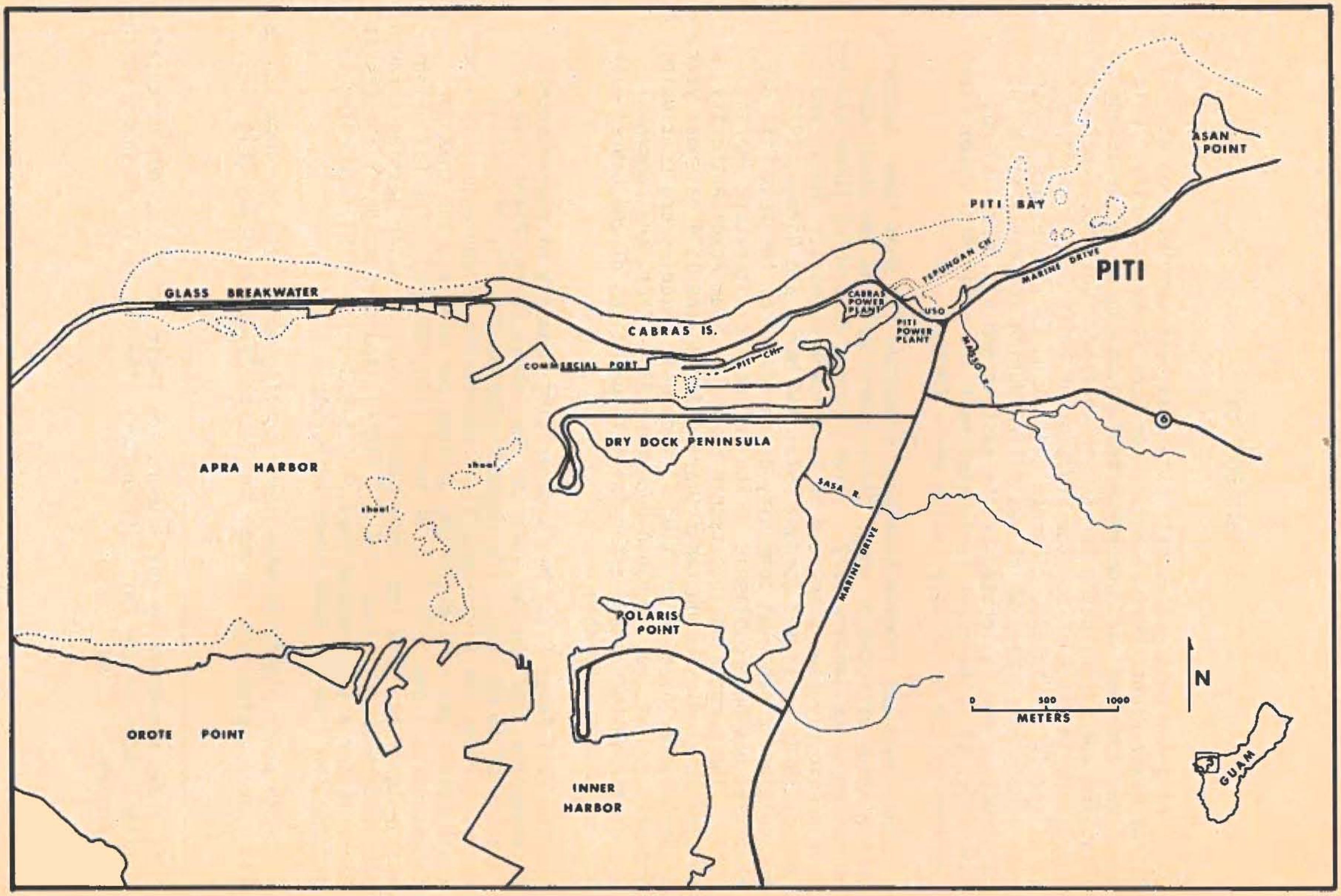

Figure 1. Geographic setting of the study area near Piti Village on the western shore of Guam.

Piti Canal in turn communicates with the waters of West Piti Bay via two passageways which cut through the causeway. The immediate connection is with Tepungan Channel, which extends in an east-west direction across the southern part of the reef flat in West Piti Bay. Tepungan Channel is a natural channel which was once continuous with Piti Channel before the causeway was constructed to connect Cabras Island with the main island of Guam. Tepungan Channel was widened and deepened between December 1972 and April 1973. At that time a new arm of the channel was dredged at its western end to provide a connecting link to the intake area of the Cabras Power Plant. Some oceanic water also enters Piti Canal directly at its mouth rather than via Tepungan Channel, although the canal has a narrow mouth which is partially blocked by boulders.

Both power plants pump their heated condenser effluent water into a common receiving area (Figs. 2, 3). This outfall lagoon is the eastern end of Piti Channel, which extends westward through an area of tidal flats for 1600 m and enters the Commercial Port area of Apra Harbor (Fig. 4). This latter area in turn communicates with outer Apra Harbor. Piti Channel is generally less than 2 m deep throughout its length. The surrounding tidal flats are often exposed subaerially during low tides and are covered by no more than a meter of water during high tides. The tidal flats are thus subject to considerable solar heating, especially during midday or afternoon low tides. Hence, the effluent area generally is subject to two major sources of heating: waste heat from the power plants and solar heating.

Previous reports are briefly summarized here. The first report (Marsh and Gordon, 1972) was submitted in June 1972. It presented the results of preliminary environmental investigations in Piti Bay and Piti Channel and attempted a before-the-fact assessment of the likely environmental effects of construction of the Cabras Plant. Particular attention was given to areas to be dredged and filled. General current patterns were described as well as general biological observations in both Piti Bay and Piti Channel. A checklist of fishes, prepared by two consulting ichthyologists, was presented. The most serious environmental problems anticipated during construction were siltation in Piti Bay, temporary blockage of water circulation through the USO swimming area, and the permanent loss of approximately 3.2 hectares of habitat in the fill area.

The second report (Marsh and Gordon, 1973) focused on temperature patterns in Piti Channel, the adjacent tidal flats, and the Commercial Port area. These observations reflected conditions before and during construction of the Cabras Plant, when only the Piti Plant was imposing a man-caused thermal stress in the area. Hence, baseline information was made available for later comparisons of temperature regimes in the area after operations of the Cabras Plant began. The report concluded that solar heating in the outfall area was just as significant as power-plant operations in governing the thermal regime.

Figure 1. Geographic setting of the study area near Piti Village on the western shore of Guam.

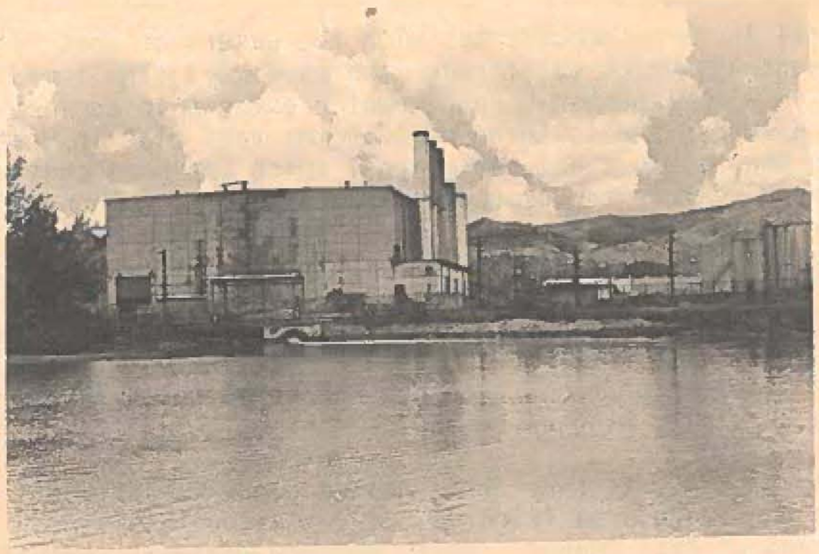

Figure 2. Piti Power Plant with its outfalls and the outfall lagoon in the foreground.

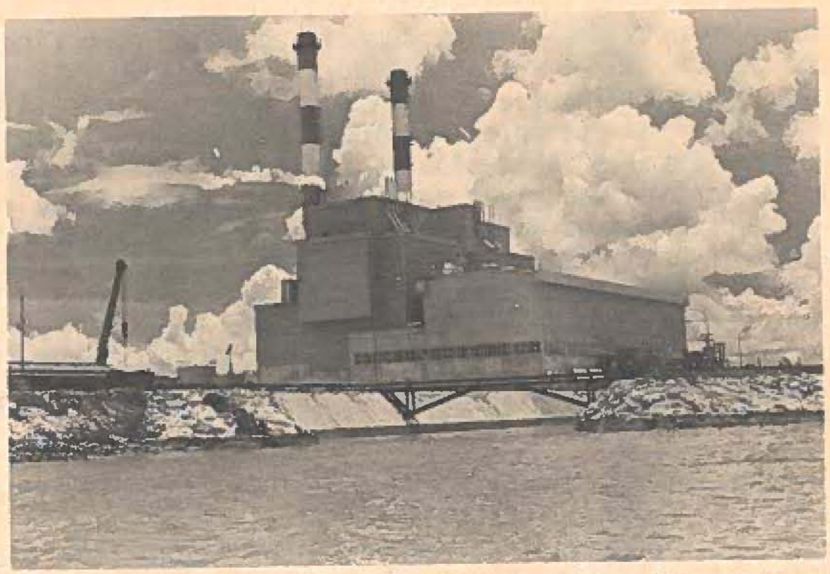

Figure 3. Cabras Power Plant with its outfall channel in foreground.

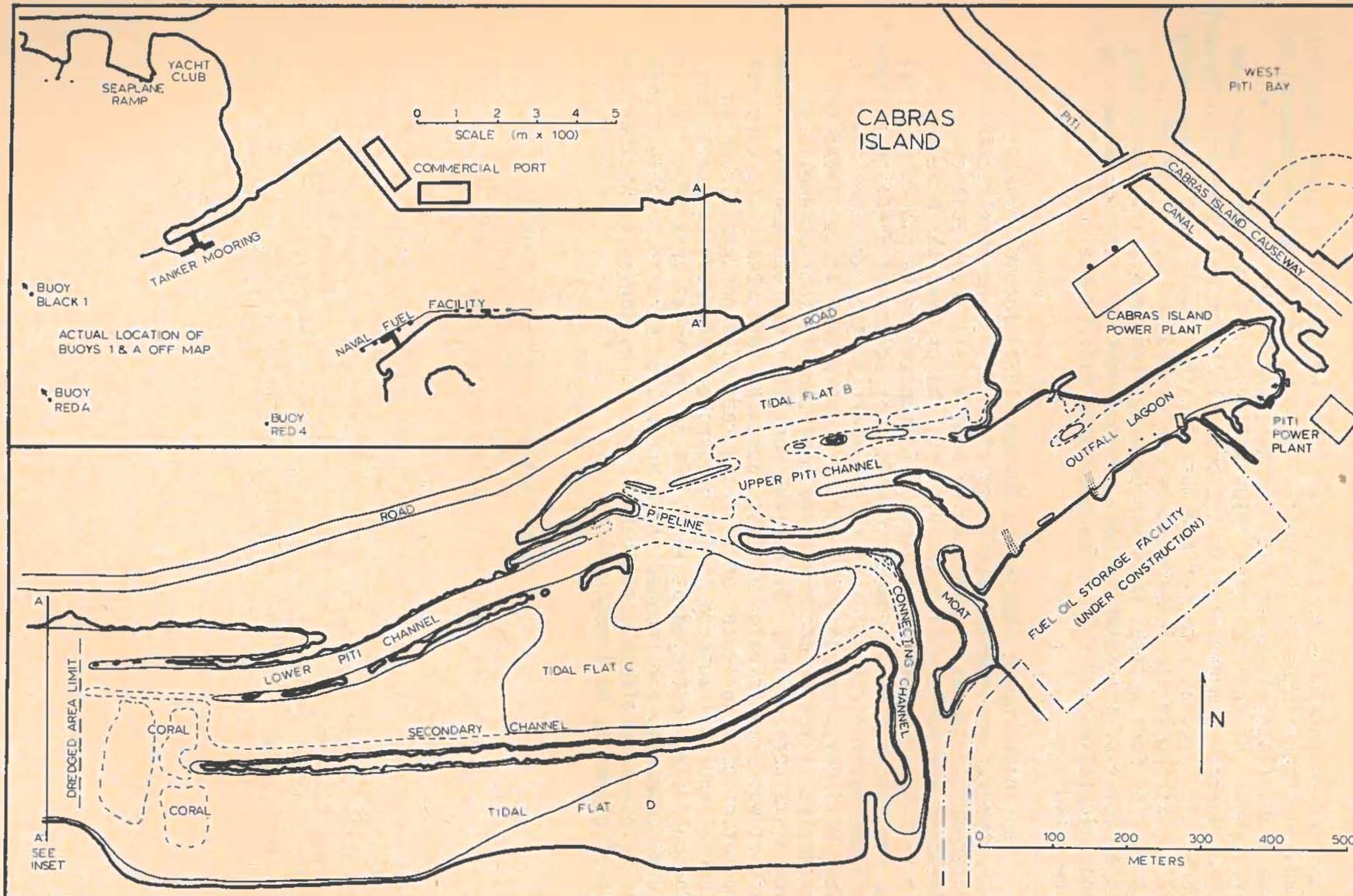

Figure 4. Major features of the area affected by the effluents of the Piti and Cabras Power Plants. Inputs of water from power plant outfalls are indicated by arrows.

Reported temperatures on the tidal flats were often as great as plant-induced temperatures in the outfall lagoon. However, temperatures on the tidal flats, in Lower Piti Channel, and in the Commercial Port area showed diurnal and tidal fluctuations and often were lower than 29°C, whereas temperatures in the outfall lagoon and Upper Piti Channel were maintained at a higher and more constant level usually exceeding 32°C. Strong vertical temperature stratification was reported in Commercial Port waters, with warmer water confined primarily to the upper meter of the water column. Measurements of current velocities and calculations of volume transports in Piti Channel were also presented.

The third report (Marsh and Gordon, 1974) focused primarily on the observed environmental effects of dredging and construction. Water turbidity was reported to be high in all areas adjacent to dredging and construction activities. The problem was more severe in Piti Bay than in Piti Channel. A temporary dike placed parallel to and just north of Tepungan Channel for access of dredging equipment blocked water circulation on the southern part of the reef flats in West Piti Bay, including the USO swimming area. It was found that extensive siltation occurred, and most benthic (bottom-dwelling) organisms were killed. By far the most serious recorded environmental effect was unanticipated and was caused by unnecessary and careless operation of a bulldozer on the Piti reef flat north of Tepungan Channel and well outside limits prescribed for dredging operations. The bulldozer destroyed at least 25% of the total area of a thriving coral community and reduced it to an area of sand and rubble. This is a long-term effect, and there is some question as to whether the coral community will regenerate.

METHODS

Information on biological communities, including their composition and zonation, comes primarily from field observations of the living organisms. Sample specimens have been collected and returned to the laboratory for preservation and detailed examination of structure to allow for positive identifications. Gill nets or seines have occasionally been used to try to catch fish for identification and size measurements. Rotenone poisoning has also been used a few times to quantitatively sample particular coral heads or other confined structures for identification and size measurements of fish. Attempts have been made to sample the infauna (animals living within the substrate) of tidal flats by passing the sediments from a defined area through a mesh sieve. Detailed observations were made along transect lines running across the Piti Bay reef flat in an approximate north-south direction and downstream from the power plant outfalls along the axis of Piti Channel. A later section of this report will describe the methodology employed for making estimates of density and the percentage of substrate area occupied by specific organisms.

Temperature observations have been continued with the use of a battery-powered telethermometer with thermistor probes which are long enough to be lowered through the water column. These have been supplemented with surface-temperature readings made with mercury thermometers. Observations have been made by wading on tidal flats or from a small boat in deeper waters.

Water currents have been plotted by monitoring patches of fluorescein dye moving with the water, as in previous years. Timing the movements of these patches over known distances allowed velocities to be calculated.

Many of the observations have been repetitive and have served to reinforce previous conclusions rather than to lead to new conclusions. This is a continuous monitoring process which allows the detection of possible environmental changes which might be associated with operations of the new Cabras Power Plant. However, an attempt is made in this report to avoid restating what was said in previous reports, and repetitive observations will be summarized for the most part.

PITI CHANNEL AND COMMERCIAL PORT

Temperature Patterns

Extensive isotherm plots were presented in an earlier report (Marsh and Gordon, 1973). The plots reflected conditions as influenced by the Piti Power Plant before construction on the Cabras Power Plant facility was begun. Additional work was done in July and August 1974, just before Cabras Unit No. 1 was scheduled to begin testing and start-up, to confirm the observations from two years previously. Representative isotherm plots are shown in Figs. 5 and 6.

Figure 5B shows an isotherm plot for a morning low tide on 16 July 1974. It may be seen that the 33° isotherm does not extend beyond the outfall lagoon and that the station immediately adjacent to the Cabras outfall was excluded from this isotherm enclosure. The 32° isotherm lay in Lower Piti Channel; and the 31° isotherm lay at the extreme western end of the Commercial Port area, with a few lower-temperature stations occurring further eastward in the Commercial Port area.

Figure 5A shows a plot for the afternoon of the same day when the tide was high. The 33° isotherm occurred further westward than in the morning and lay outside the outfall lagoon. However, the 31° isotherm and even the 30° isotherm had moved eastward into Lower Piti Channel as tidal flow brought cooler water from the outer harbor into the Commercial Port area. The entire Commercial Port area was occupied by water with a temperature lower than 30°; and the 29° isotherm, which had not appeared in the morning sampling, lay at the western end of the Commercial Port area.

Figure 6 shows temperature patterns for 23 July 1974 when the reverse of the above-described tidal stages occurred, with a morning high tide and an afternoon low tide. In the morning (Fig. 6A) there was no 33° isotherm and the 32° isotherm enclosed only small area in the outfall lagoon adjacent to the Piti Plant outfalls. The 31° isotherm lay at the extreme eastern end of the Commercial Port area, and the 30° isotherm lay approximately in the middle of that area. In the afternoon (Fig. 6B) there was a 33° isotherm enclosing a small portion of the outfall lagoon, and the 32° isotherm fell at the eastern end of Commercial Port. The 30° isotherm lay at the western end of the Commercial Port area.

The above-described figures and other data for the summer of 1974 generally reconfirm the more extensive observations described in 1973 and may be considered as representative of Piti Channel and Commercial Port before the Cabras Power Plant went into operation. The figures

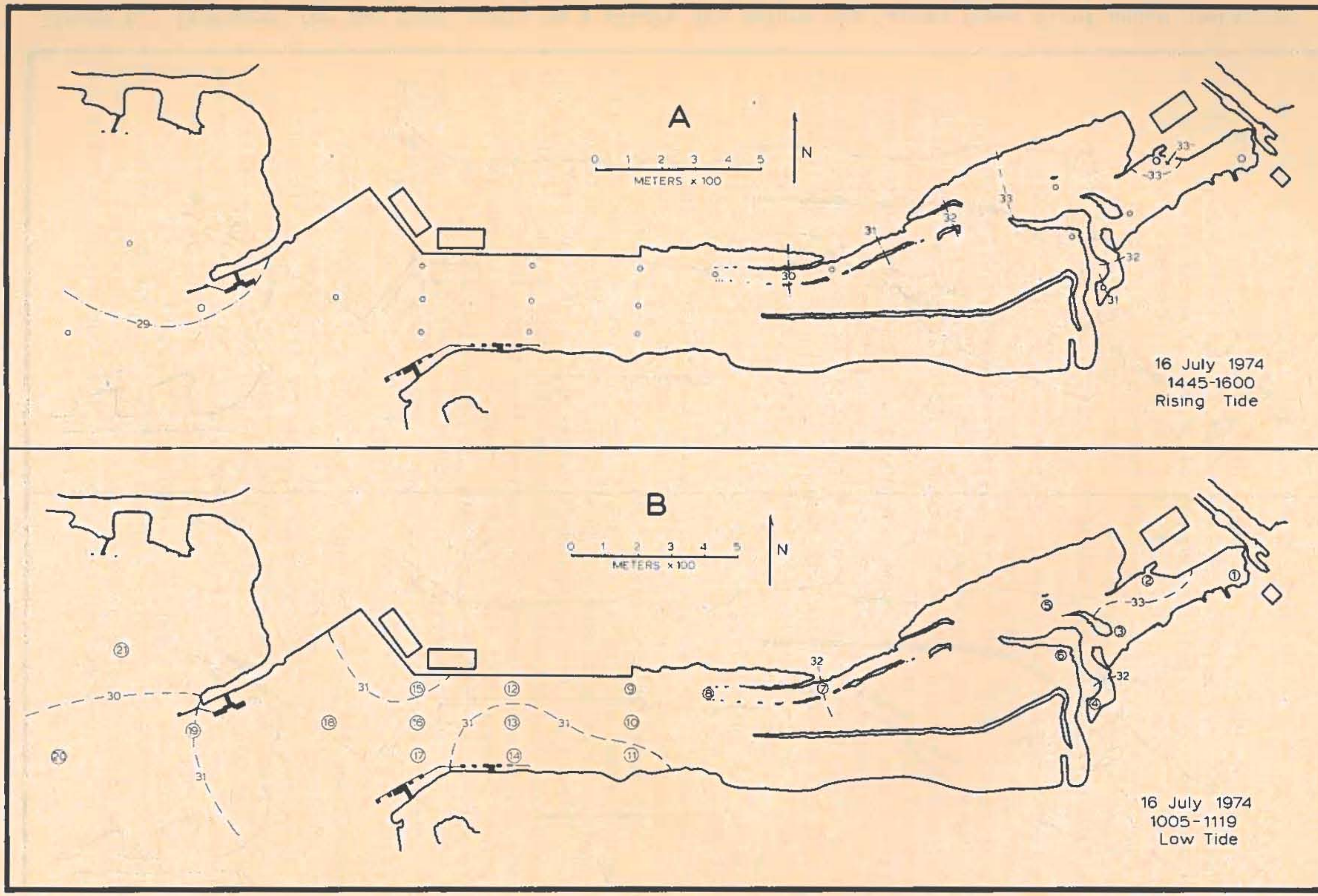

Figure 5. Isotherms for two tide levels on a single day before the Cabras Power Plant began operation. Temperatures are in degrees Centigrade. Circles indicate sampling stations.

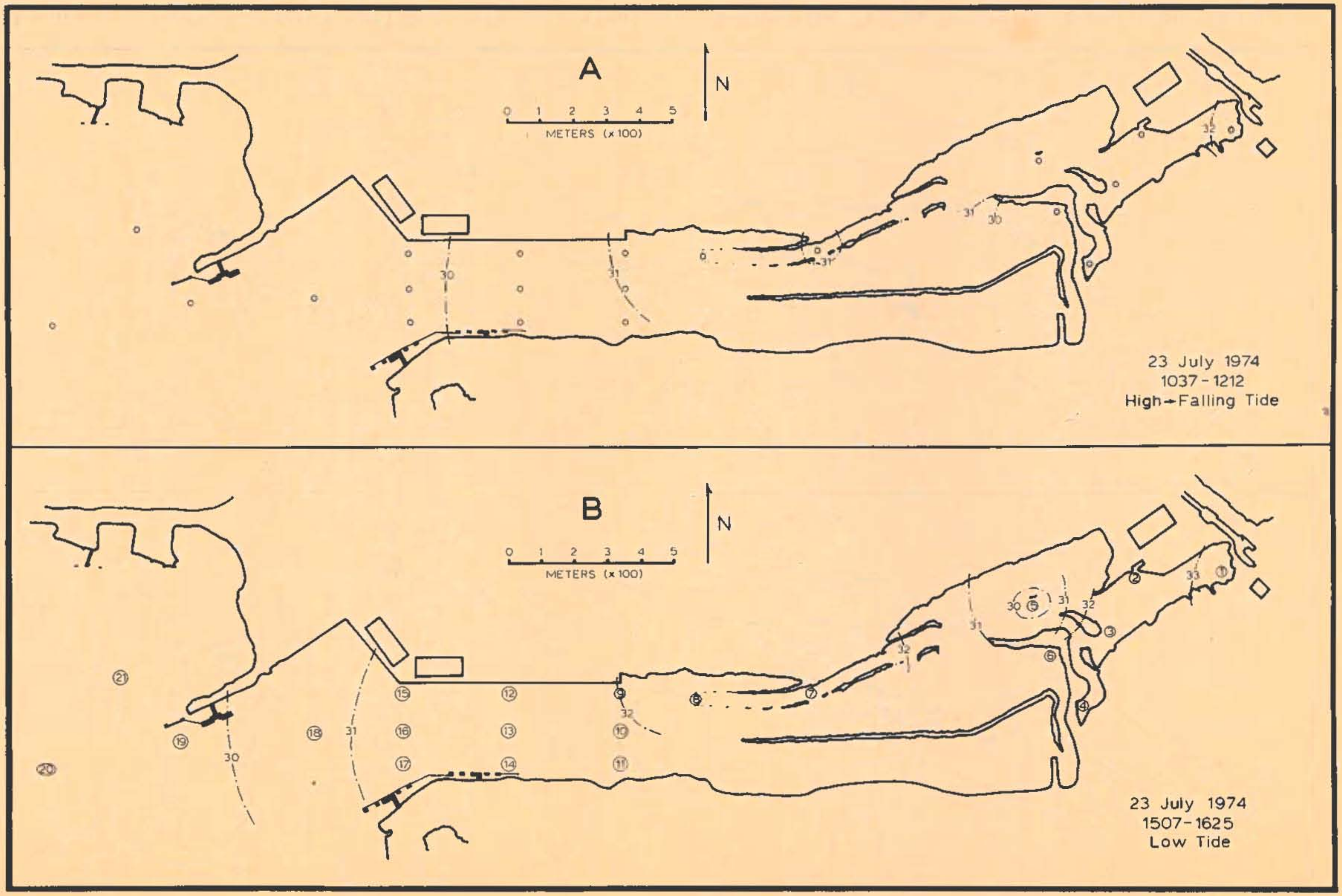

Figure 6. Isotherms for two tide levels on a single day before the Cabras Power Plant began operation. Temperatures are in degrees Centigrade. Circles indicate sampling stations.

also indicate the week-to-week variability that could occur in the area before operations of the new plant began.

There is another aspect of the 1974 temperature observations that is of considerable interest and which has not been considered previously. The 1973 report presented graphs of vertical temperature distribution in the eastern end of the Commercial Port area and pointed out that these graphs were representative of vertical temperature distributions in the deeper harbor areas generally, as opposed to the tidal flat areas. The vertical temperature distributions indicated a strong stratification, with a warmer surface layer not usually extending deeper than 1 m. This was not surprising and indicated that there was little vertical mixing, with most heat being transferred from surface waters into the atmosphere. Many of the 1974 observations confirm this pattern, but a number of them also show a different pattern which was unexpected. In some cases the higher temperatures were found at least as deep as 5 m. Representative graphs for stratified and unstratified situations are shown in Figs. 7 and 8. Figure 7 shows vertical temperature profiles for the eastern end of the Commercial Port area during high and low tides on 16 and 23 July 1974. The low-tide pattern for 16 July shows the pattern which had previously prevailed and indicates clear-cut vertical stratification. The high-tide pattern shows a relatively constant temperature for the upper 5 m, with a difference of only 0.3°C between the surface and a depth of 5 m. Temperatures at all depths are at least 0.7°C lower than during the low-tide period. Figure 7 shows a relatively constant temperature distribution with depth for the same station during both low and high tides on 23 July 1974, with low-tide temperatures at least 0.4°C higher than high-tide temperatures at all depths. High-tide temperatures show greater constancy with depth than low-tide temperatures, however. This pattern had not been observed previously, and its significance is unclear. While high-tide temperatures at the surface were about the same on 23 July as a week earlier, all deeper temperatures were higher, in some cases by as much as 1.5°C. It thus appears that the whole water column had warmed up considerably during the period of a week. That this apparent warming was not permanent was indicated by later observations when cooler temperatures prevailed at depths greater than 1 m and there was again a strong vertical stratification.

The same pattern was observed at the western end of the Commercial Port area as well (Fig. 8). On 16 July 1974 there was low-tide vertical stratification, but with warmer water extending to 3 m instead of 1 m. There was a relatively constant temperature-depth distribution at high tide, and the temperature was the same as that found in the deeper waters at low tide. On 23 July there was a constant temperature-depth distribution at both low and high tides. This was also the case on 8 August, but with temperatures almost 1°C higher at all depths than on 23 July. The apparent warming trend clearly extended throughout the Commercial Port area, since the station represented in Fig. 8 was at the extreme western end of that area. Surface temperature patterns

Figure 6. Isotherms for two tide levels on a single day before the Cabras Power Plant began operation. Temperatures are in degrees Centigrade. Circles indicate sampling stations.

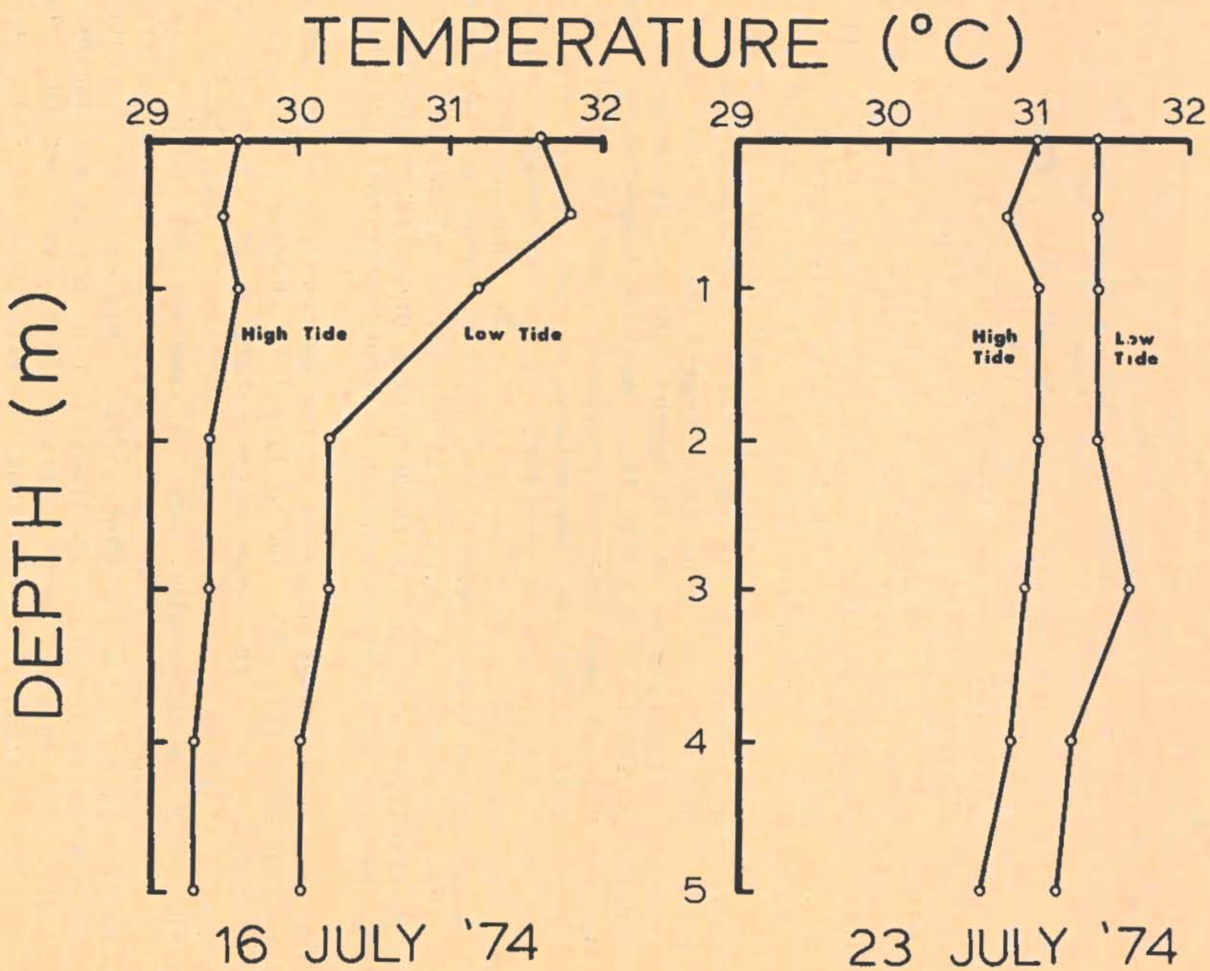

Figure 7. Temperature-depth profiles for Station 10 (see Fig. 5 or 6) located at the eastern end of the Commercial Port area.

Figure 7. Temperature-depth profiles for Station 10 (see Fig. 5 or 6) located at the eastern end of the Commercial Port area.

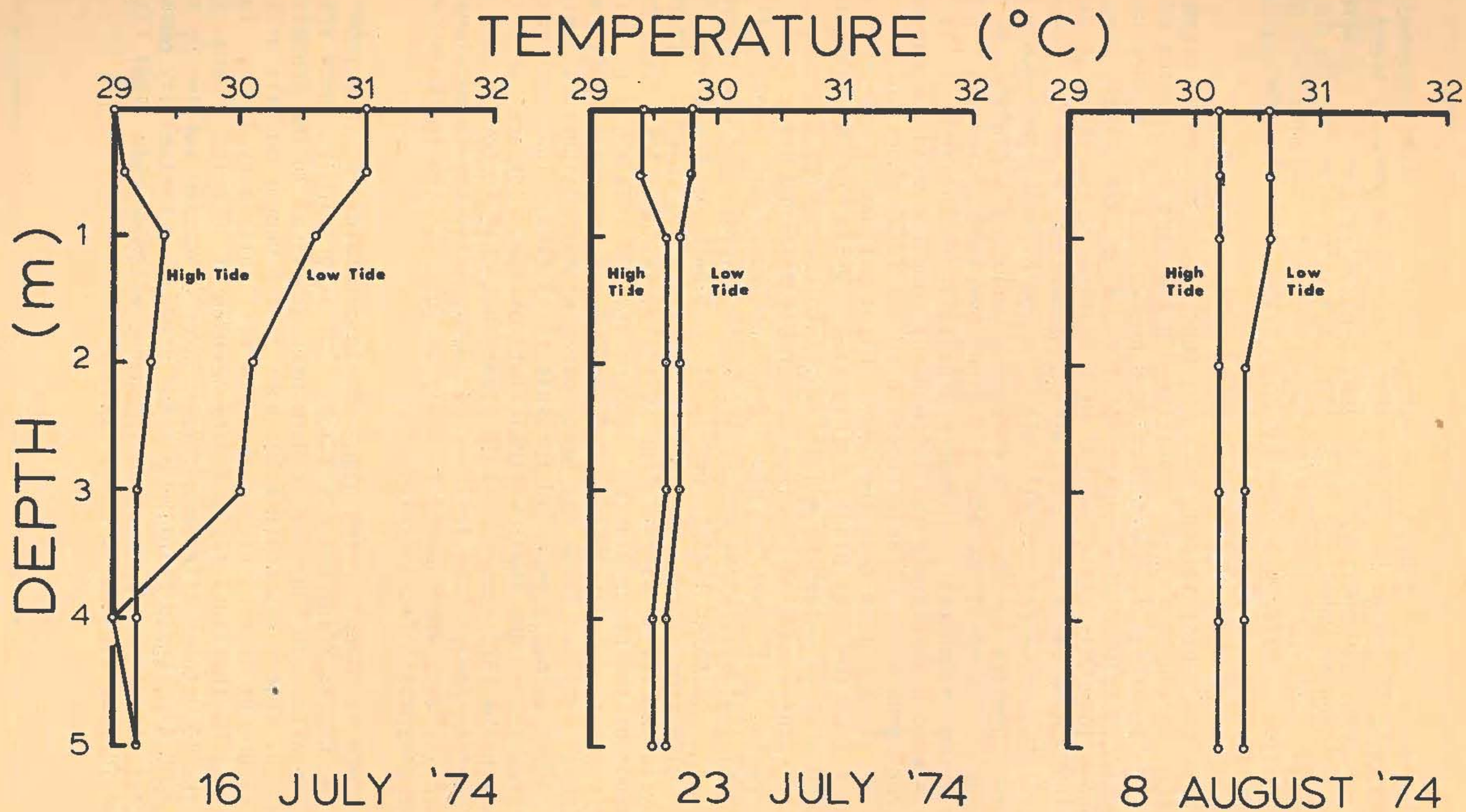

Figure 8. Temperature-depth profiles at Station 19 (see Fig. 5 or 6) located at the western end of the Commercial Port area.

(not presented here) showed that warmer-than-usual water extended even further into the outer harbor. As noted above the warming trend was not permanent, and there is no obvious explanation for it. A warming trend would be an unhealthy sign with respect to water quality in the Commercial Port area. Of most obvious concern is the fact that oxygen solubilities in water are lower at higher temperatures, leading to increased stress on biological systems.

Temperature observations were made during the period of plant testing, start-up and early operations in the last four months of 1974. Some representative isotherm plots are presented here. Figure 9A shows a low-tide, early afternoon plot for 15 October 1974. The Cabras Plant was operating during this period but not at peak capacity. It may be seen that there was a hot spot, with a temperature of 37.0°C, immediately adjacent to the Cabras outfall. This is the highest temperature ever observed anywhere in the study area and is about 2°C higher than any previously observed temperatures in the immediate vicinity or in the outfall lagoon generally. Temperatures adjacent to the Piti Plant outfall were also rather high (34.8°C, as compared with the maximum observed temperature of 35.2 reported in the 1973 report for the same station. It is clear that the Cabras Plant was having a thermal effect above that of the Piti Plant at this time. While the 34° isotherm enclosed an area extending all the way into Lower Piti Channel, additional isotherms did not enclose comparably enlarged areas. The 31° isotherm lay in the eastern end of the Commercial Port area, well within the usual limits existing before the Cabras Plant began operations. It should also be noted that temperatures on Tidal Flat B exceeded 34°C over a wide area, as was the case for most of Tidal Flat C. These high temperatures likely resulted from solar insolation rather than the influence of the power plants. Temperatures on Tidal Flat D, which is clearly not subject to thermal influence from the power plants, were as high as 33.4°C. These may be compared with the highest temperatures of 34.7°C previously reported for this tidal flat. The importance of solar heating on the shallow tidal flats of the study area was discussed in the 1973 report. It is clear that this factor is just as important as power-plant influence in determining the temperatures of the tidal flats, which would probably be just as warm in the absence of the generating facilities.

Figure 9B shows morning high-tide temperatures for 18 October 1974 when the Cabras Plant was operating. Not surprisingly, these are lower than the afternoon low-tide temperatures discussed in the preceding paragraph. There was again a hot spot at the Cabras outfall with a temperature of 35.2°C, higher than the Piti outfall by 2.4°C. Temperatures on the tidal flats in the morning of 18 October were cooler than the 15 October afternoon temperatures discussed earlier by as much as 3.6°C, again pointing out the day-to-day variability observed in previous years. Power plant influence extended onto Tidal Flat B in the form of a plume of warmer water.

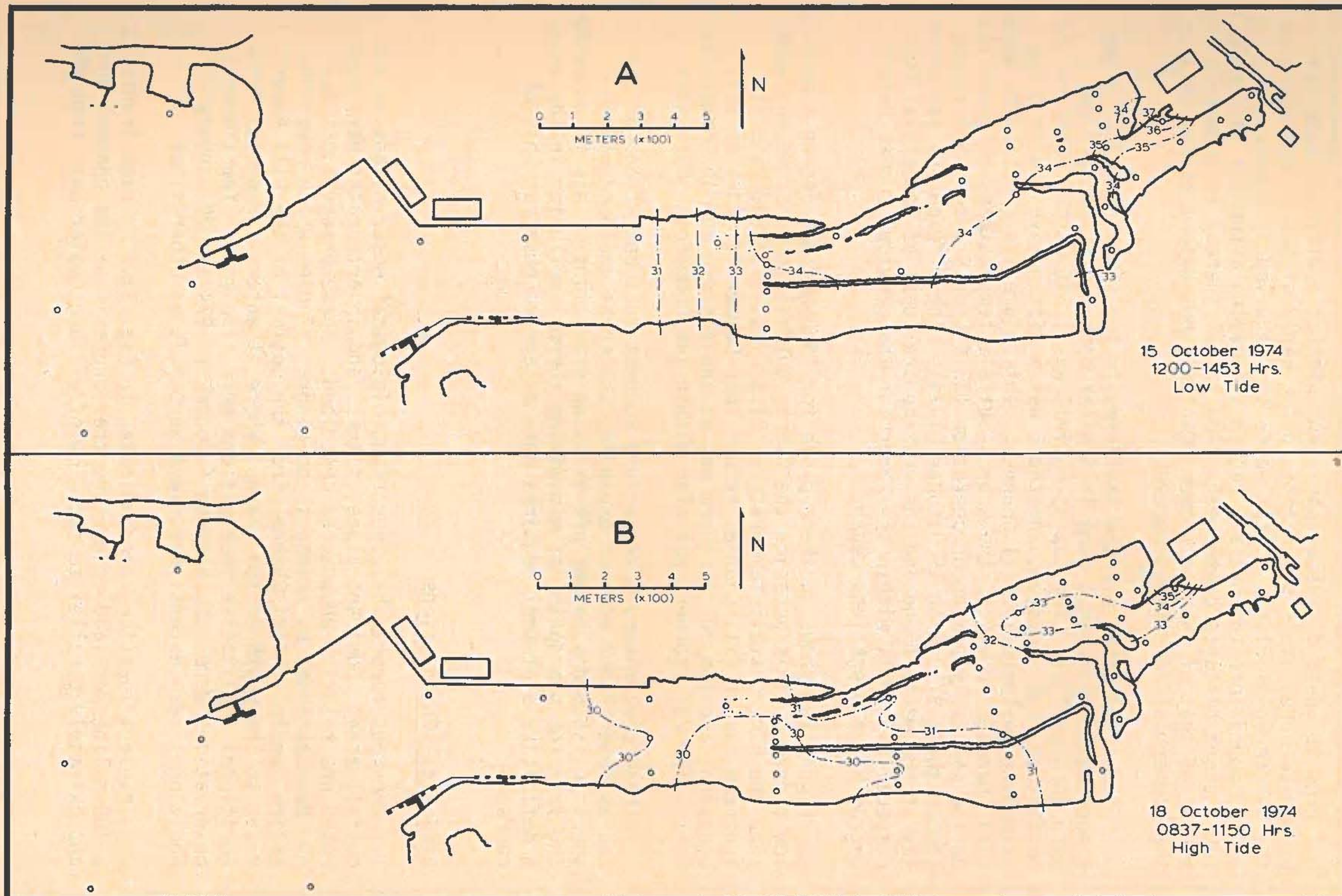

Figure 9. Isotherms at two tide levels at onset of Cabras Power Plant operations. Temperatures are in degrees Centigrade. Circles indicate sampling stations.

From the data discussed above and similar additional data not presented here, it is clear that in the early stages of operation of the Cabras Power Plant, hotter water than previously observed was being pumped into the outfall lagoon and having a thermal influence for a short distance downstream. Additional thermal influence in excess of that of the Piti Power Plant did not extend as far west as the Commercial Port area, however.

Figure 10A shows plotted isotherms in the study area just after a morning low-tide on 5 June 1975 after both Cabras Units 1 and 2 were in operation. The Cabras outfall was 1.8°C warmer than the Piti outfall on this occasion, and there was a distinctive Cabras plume extending westward in Piti Channel. This plume was confined to Upper Piti Channel. However, the Cabras outfall temperature was lower than during the early phases of operation (33.4°C on 5 June 1975 versus temperatures 37.0°C on 15 October 1974). The 31° and 30° isotherms lay at the eastern end and the west-central part of Commercial Port, respectively, well within the range for the previous summer before Cabras Plant operations began.

Figure 10B shows isotherm plots for 19 June 1975 during a morning low tide. On this occasion the Cabras outfall temperature was lower than the Piti outfall temperature (31.5°C vs. 31.7°C). The 31° isotherm was in Piti Channel rather than Commercial Port on this occasion, and the 30° isotherm was at the eastern end of Commercial Port. The 29° isotherm was also within the Commercial Port area.

These preliminary observations suggest that operations of the Cabras Power Plant are not expanding the areas enclosed within specific isotherms beyond pre-existing conditions. This is encouraging from the standpoint of minimizing thermal pollution in the area. A definitive statement requires more extensive observations, of course.

Biological Observations

Previous reports have described biological observations in the outfall area. Dominant algae, fishes, and invertebrates have been noted and relative abundances described. These observations have now been extended by transect and quadrat studies which cover the entire length of Piti Channel from the outfall of the Piti Power Plant to the mouth of the channel where it enters Commercial Port. Additional qualitative observations were also made. The transect observations were made between 6 December 1974 and 29 January 1975. Additional less extensive surveys were made at other times.

Transect locations are indicated in Fig. 11. On each transect, a 100-m line was laid down along the long axis of the channel and approximately parallel to the flow of effluent water away from the

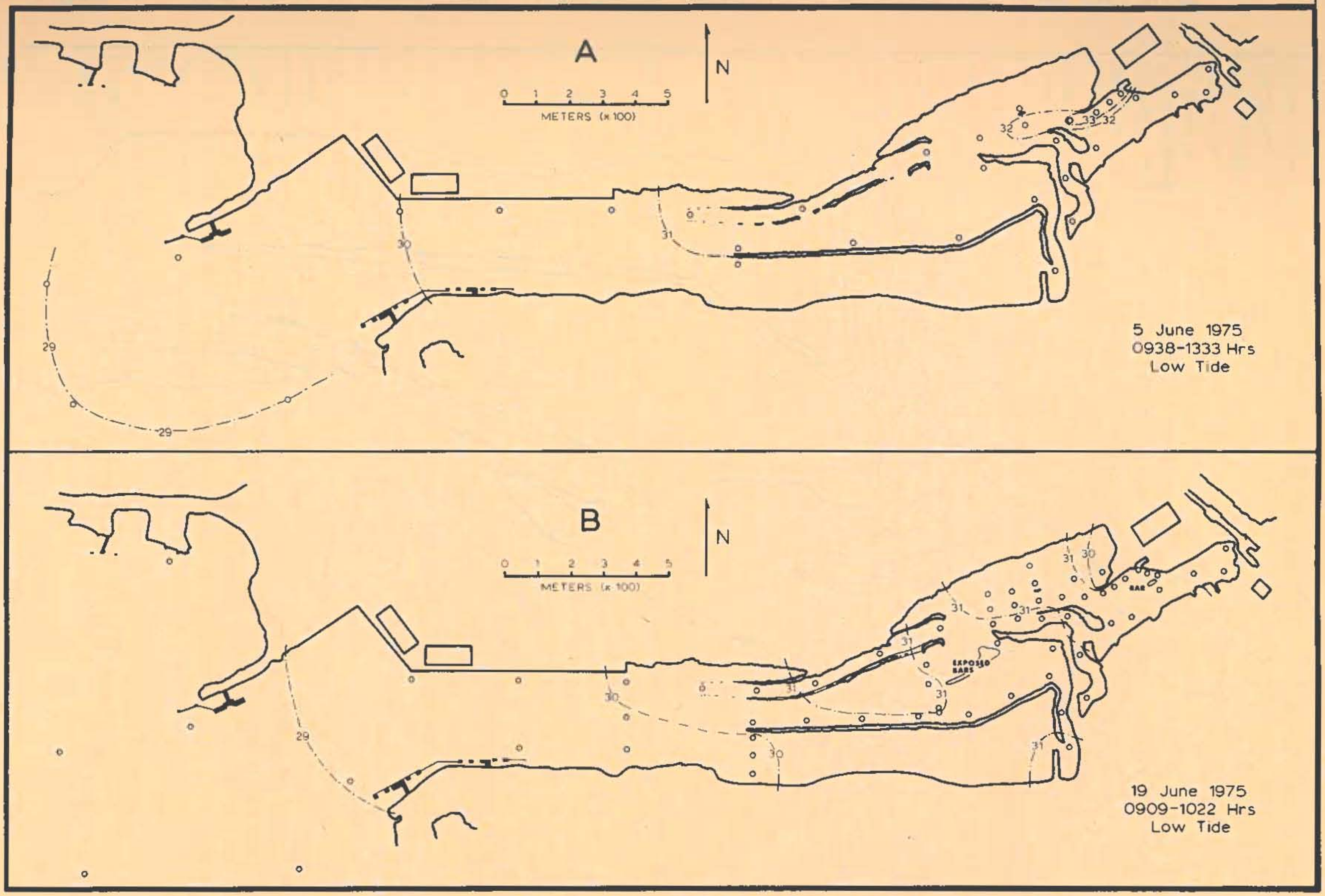

Figure 10. Isotherm pattern during normal operation of Cabras Power Plant. Temperatures are in degrees Centigrade. Circles indicate sampling stations.

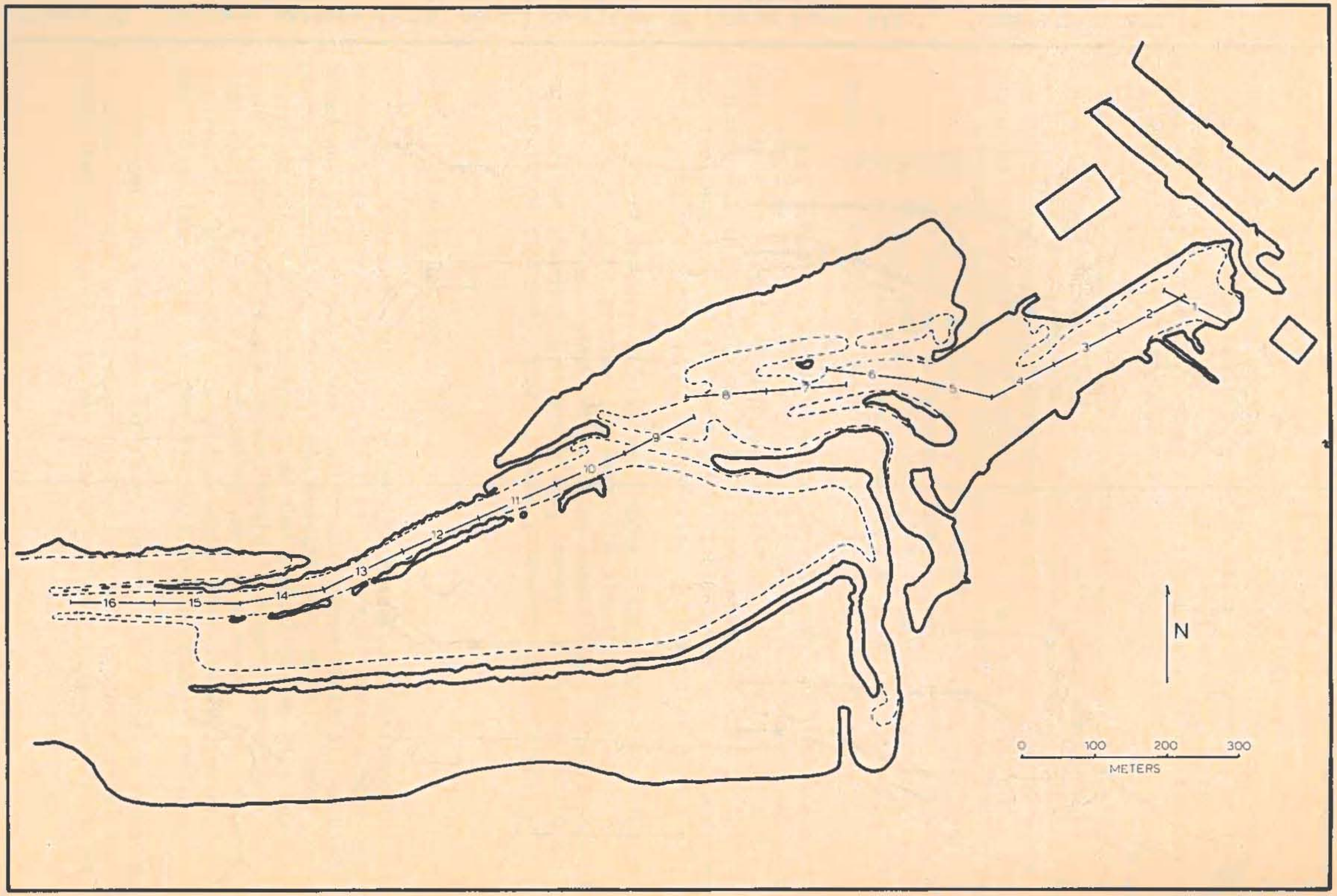

Figure 11. Location of 16 100-m transects extending down Piti Channel from the lower Piti Power Plant outfall.

power plants. Successive transects thus occupied progressively cooler portions of the temperature gradient extending westward in Piti Channel downstream of the power plants. Along the entire length of the line the nature of the substrate was noted and different types quantified by measuring the segment of the line occupied by each. Organisms which lay underneath the transect line were identified and the length of line segment occupied by each was measured. This allowed calculations of the percentage of substrate occupied by each major organism if the size of the individual or colony was large enough to occupy a significant line segment. For those organisms which were abundant but of small size, such an estimate of percentage cover would not allow them to be fairly represented. In such cases, a specified segment of the transect was noted as passing through the general region occupied by specific individuals or colonies. At the 50-m mark of each transect, a set of 5 1-m^2 quadrats was laid out and the number of individuals of each species in each quadrat was counted. In the case of organisms such as algae or corals which grow in colonies rather than as single individuals, the number of colonies was counted and a visual estimate was made of the percentage of the substrate covered by the organism. Observations and counts on the transects were supplemented by general observations in the areas on both sides of the transect line to get an idea of how "representative" the transect observations were. The transect method focused on benthic organisms and was not designed to yield information about highly mobile organisms such as fishes.

Results are presented in Fig. 12. The area immediately adjacent to the outfalls of the Piti Power Plant is characterized by two dominant algae within the first 100 m. These are the red alga *Gracilaria salicornia* (Mert.) Grev. and the brown alga *Padina tenuis* Bory which have been observed to be the dominant forms here ever since these studies began. *Gracilaria* forms large clumps which may be up to 20 cm high and 1 m across. These were estimated to cover approximately 3% of the total substrate area in the region of highly agitated water immediately adjacent to the outfalls. *Padina* (Fig. 13) was estimated to cover between 40 and 75% of the total available substrate, being denser at distances greater than 50 m from the outfall pipes than immediately adjacent to these pipes. *Padina* was sometimes found growing on *Gracilaria*. Neither of these species of algae is unique to the outfall area, both being found farther downstream in the channel and widely distributed on the tidal flats. However, their density is greater in the outfall area than in other parts of Piti Channel or the adjacent tidal flat areas. Many other organisms are common in this area but did not show up on our transect. These are listed in Table 1. We have found no organisms which are unique to the outfall area alone. Water turbulence in this region is high and the loose substrate is composed of large-grained sand and rocks, since finer material is swept away by the current.

Starting within 100 m of the Piti Power Plant outfall and continuing for the entire remaining length of Piti Channel, there are characteristic small burrows (diameter less than 2 cm) in the bottom

Figure 11. Location of 16 100-m transects extending down Piti Channel from the lower Piti Power Plant outfall.

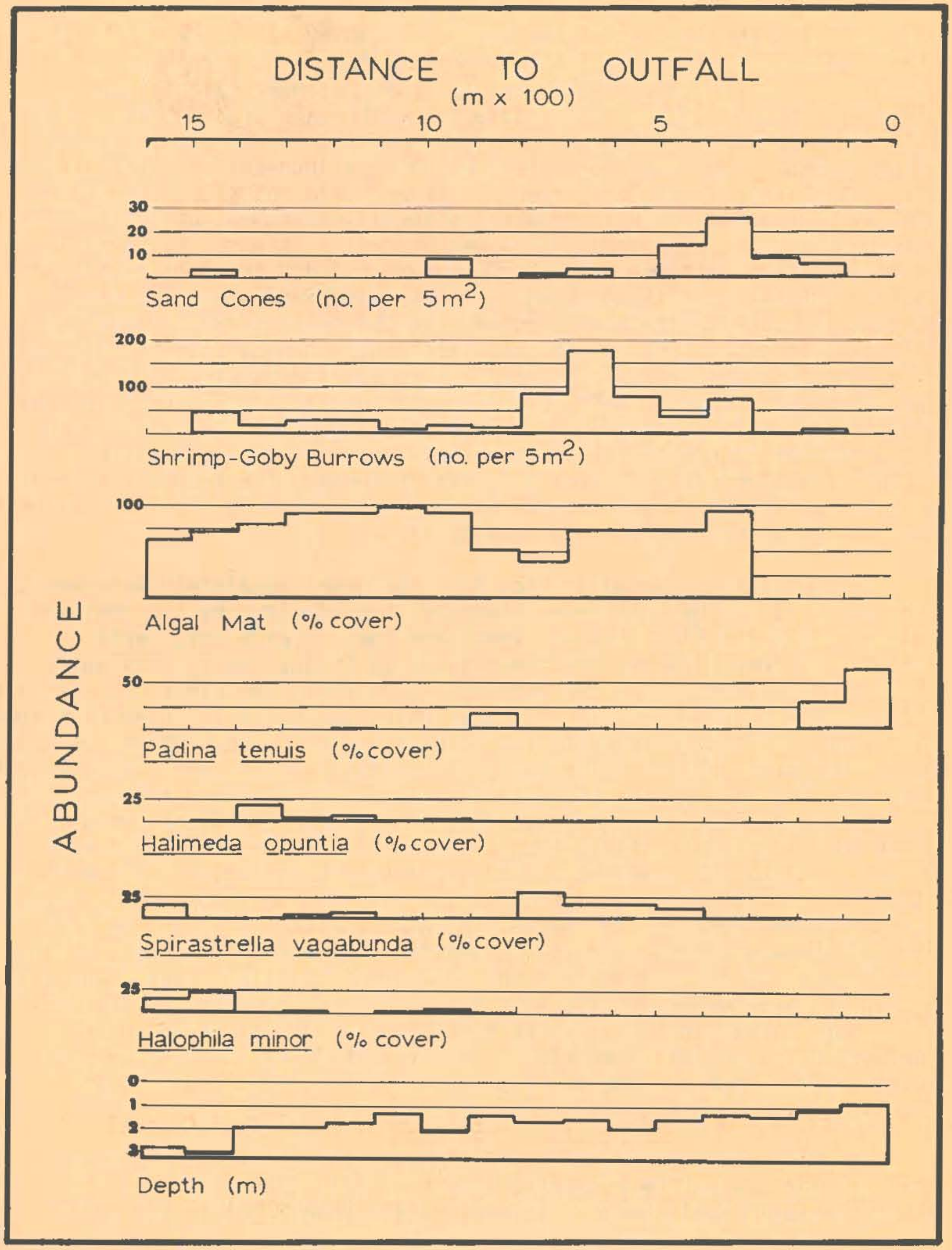

Figure 12. Abundance of major benthic features and organisms in Piti Channel.

Figure 13. Padina tenuis in Upper Piti Channel.

Figure 14. Spirastrella vagabunda in Upper Piti Channel.

occupied by shrimps and gobies, with one shrimp and one goby occupying a single hole. The shrimps are less than 5 cm long and are not edible. The gobies may be slightly larger. The shrimp-goby associations are not abundant in Transects 1-3, occurring in densities no greater than 3 m^{-2}. However, they become much denser in Tr 4-8, with the number of holes averaging 36 m^{-2} in the quadrat counts of Tr 7. Thereafter, the number of burrows declines somewhat, averaging no more than 6 m^{-2}, until the lower (western) end of Piti Channel is reached, where numbers increase somewhat up to 8 m^{-2} in Tr 15. These shrimp-goby burrows are probably as characteristic as any biological factor in Piti Channel but again are not unique to the area. We have observed the same association in other areas, such as Tepungan Channel on the intake side of the Cabras Island causeway, although we are not sure if the same species of shrimp and fish are involved.

Another characteristic of the channel for almost its whole length except the first 50 m or so immediately adjacent to the Piti Power Plant outfalls is a series of substrate cones (or mounds) throughout the area. The mounds are approximately circular and are as much as half a meter across and a quarter of a meter above the immediately surrounding substrate level. They may be much smaller than this. These cones are certainly of biological origin, but the organism which forms them has not been identified. A number of attempts to dig out individual mounds to find the organism have been unsuccessful, but similar mounds are known to be made by polychaete worms. The cones were found in greatest abundance in the quadrats at the midpoints of Tr 2-5, with the density averaging as great as 4.6 m^{-2}. In no other transects did this average exceed 1 m^{-2}, except for Tr 10, which had 8 cones in 5 m^2, or an average of 1.6 m^{-2}. The area of greatest density for the sand cones thus partially paralleled the area of greatest density for the holes occupied by the shrimp-goby association.

Another organism characteristic of practically the entire length of Piti Channel, with the exception of the first 250 m immediately downstream of the Piti Power Plant outfalls, is the brown-colored sponge Spirastrella vagabunda (Ridley). This sponge (Fig. 14) may grow individually or in colonies and has a patchy distribution, so that aggregations of many individuals or colonies are interspersed in areas of similar sandy bottom which are relatively barren. (This patchy distribution is similarly characteristic of most of the other organisms discussed here and introduces a great deal of variability into counts of organisms intersecting the transect line or occurring in the quadrats.) This organism has not been found in the area traversed by Tr 1 and 2, and only an occasional individual has been found in the area represented by Tr 3. More were found in the vicinity of Tr 4 but not directly on the transect itself. Sponge patches were quantitatively estimated to occupy 14% of the area along Tr 5, where they first became abundant. This increased to 17%, 16%, and 30% for Tr 6, 7, and 8 respectively, although on Tr 8 the sponge was concentrated in the first 70 m and did not occur in the last 30 m. This was followed by the absence of the sponge on Tr 9 and its virtual absence on Tr 10 except for an individual at the lower end of that transect. *Spirastrella* then became abundant in the last 28 m of Tr 11 and was well represented in Tr 12 and 13. It was then poorly represented on Tr 14 and 15, and Tr 16 again showed the sponge areas accounting for 16% of the substrate cover. The first area of abundance of the sponge (Tr 5-8) approximately paralleled the area of maximum abundance of the shrimp-goby association and the cone structures described above. Like the shrimp-goby association, *Spirastrella* was well represented in Lower Piti Channel.

A fourth biological characteristic of most of the transect line down Piti Channel was the presence of a low algal mat overgrowing loose sandy substrate and composed primarily of two species of red algae, *Hypnea esperi* Bory and *Champia* sp. The occurrence of this algal mat was very patchy. It was not found in the first three transects but became very prominent in Tr 4. (Here it occurred in patches occupying approximately 90% of the substrate along the transect line. Within these patches the algal mat itself covered as little as 10% of the loose substrate, with the remainder consisting mostly of bare sand.) Patches of the algal mat sometimes occupied parts of the sand cone structures, but agitation of the sand around the cones and around the shrimp-goby holes can sometimes exclude the algal mat. Dominance of the algal mat continued in Tr 5, 6, and 7, where patches occupied 70%, 70%,and 71% respectively. On Tr 8 the algal mat areas were found to be present along 55% of the transect line in the first 70 m of the transect and were not present thereafter. On Tr 9 they occurred on 56% of the total transect but were confined to the first 45 m and last 21 m. Thereafter, the algal mat exceeded 75% cover except for the last two transects. It is possible that the absence of this mat in the first three transects can be explained by the high degree of water turbulence in the upper portion of Piti Channel and especially in the region immediately adjacent to the Piti Power Plant outfall pipes.

One other prominent biological feature found along the length of Piti Channel is the presence of large clumps of the green alga *Halimeda opuntia* (L.) Lamx. and to a lesser extent of the related species *Halimeda macroloba* Decaisne. *H. opuntia* (Fig. 15) forms dense clumps which may be as much as 2 m across and as much as half a meter high. The clumps are dense enough to form a distinct micro-habitat for other organisms, which in fact are often found associated with the *Halimeda* beds. The *Halimeda* clumps can be found in the vicinity of the outfall pipes and extending downstream all the way to the west end of Piti Channel. They are smaller (less than 1 m across) and sparser in the outfall lagoon and increase in size and frequency progressively down Piti Channel, having the largest size and greatest abundance in Lower Piti Channel. Even though present in the area above this, the clumps did not appear on our transects until Tr 6. They covered very little of the substrate in Tr 6-11. Such clumps then covered 6.4%, and approximately 3% of the area along Tr 12 and 13, respectively. Bottom coverage peaked in Tr 14, with 17.5% coverage along that segment. This

Figure 15. Halimeda opuntia in Lower Piti Channel.

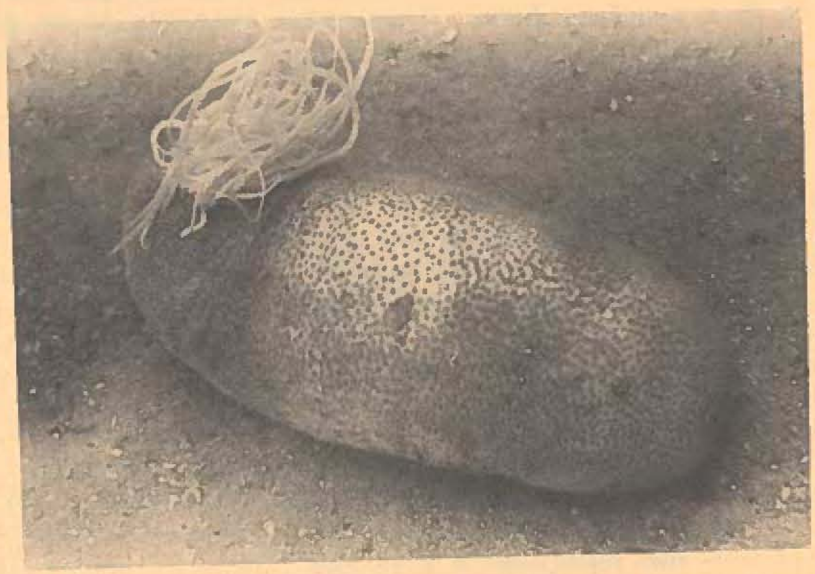

Figure 16. Bohadschia bivittata in Lower Piti Channel.

then declined to less than 2% coverage on Tr 15, with no appearance of Halimeda clumps on Tr 16 even though such clumps were present in the area. Throughout Lower Piti Channel (Tr 10-16) and to a lesser extent in Upper Piti Channel below the outfall lagoon (Tr 6-9), much of the loose bottom substrate is composed of Halimeda fragments, remains of solid calcuim carbonate concentrations deposited by the living organism. The great abundance of Halimeda fragments suggests high growth rates of that alga in the area. This characteristic is not unique to Piti Channel, since it is often found in other Guam waters and other Pacific reef areas.

In addition to quantitative differences in the abundance of Halimeda along the length of Piti Channel, with the greatest abundances coming in Lower Piti Channel, there are some obvious qualitative differences between Upper and Lower Piti Channel that suggest that these two areas are composed of two different biological regimes. One of the distinguishing features of Lower Piti Channel is the presence and abundance there of the marine grass Halophila minor (Zoll.) Hartog, which is not found in Upper Piti Channel above the pipeline (Tr 1-9). The buried or partially buried rhizomes of this plant form an extensive network in the substrate which is often revealed by the presence of upright shoots. In an area with extensive Halophila growth, the substrate is not covered by the plant as is the case with Halimeda; and a Halophila bed includes extensive patches of bare sand or algal turf. On the transects Halophila was first encountered along Tr 9 (Fig. 12), but only in the portion of that transect below the pipeline. In Tr 10 Halophila beds occupied approximately 7% of the transect line. This figure increased to 10% in the first 30 m of Tr 11, but the grass was not present on the remainder of this transect. On Tr 12 the organism did not occur at all, and it occurred only in widely scattered areas along Tr 13 and 14. The abundance increased in Tr 15, with Halophila beds occupying 23% of the entire transect. The grass beds occurred along 16% of Tr 16 but were confined to the first 31 m and last 20 m of that transect. Halophila minor thus reached its peak abundance at the extreme western end of Lower Piti Channel, with the plant having a very patchy distribution throughout Lower Piti Channel.

Another organism characteristic of Lower Piti Channel below the pipeline (except for a small colony on Tr 6) is the massive coral Porites. Scattered small colonies of this coral were seen in Tr 10, and the numbers increased progressively downstream. Colonies were especially noticeable along Tr 15 and 16, where they were as large as a meter in diameter. The transect line did not actually overlie any Porites colonies before Tr 16, where 3.9% of the line was found to be occupied by the coral. In the quadrat counts on this transect there were 17 colonies in 5 m^2, or an average of 3.4 colonies per m^2. There, colonies averaged 22.6 cm in diameter, but colonies up to 1 m in diameter could be seen in the near vicinity.

Another animal found in Piti Channel only in the region below the pipeline was the sea cucumber Bohadschia bivittata (Mitsukuri). This organism (Fig. 16) first appeared on Tr 12 between the 20- and 30-m marks. It was common throughout Tr 13 and between 60 and 95 m on Tr 14. The line-transect method was not satisfactory for estimating density; and the quadrats employed were too small for satisfactory estimates for this sea cucumber, which attains a length of at least a third of a meter in the adult form. Below Tr 14 the abundance of the animal decreased, but it was still present in the lower channel. The grain size of substrate particles may be important in determining its distribution.

Another coral besides Porites appeared in Tr 16 at the western-most end of Piti Channel. This was the branching coral Pocillopora damicornis (L.), which was not suggests present elsewhere in Piti Channel. Both the Porites and Pocillopora corals lend a certain three-dimensional structure to the habitat which in turn provides cover for a variety of fishes.

The above discussion has considered the major organisms which show distinctive distribution patterns along the length of Piti Channel. There are a number of other organisms which may be found in the area but which did not appear in large enough numbers or in enough transect segments for the detection of zonation patterns. This is true for one or more species of hermit crabs which inhabit various snail shells. Several dozen of these were found in the immediate vicinity of the transect line on Tr 1 near the outfalls and in Tr 11. Small numbers (less than half a dozen) were found in the immediate vicinity of the transect line in Tr 8, 9, 10, 12, 13, 15, and 16. These often show a markedly clumped distribution and appear to be just as common in any given part of Piti Channel as in any other part. The snail Strombus luhuanas L. was scattered about in the area represented by Tr 1 and 8 and was abundant on Tr 13, with the quadrat counts averaging 2.6 individuals per 5 m^2 for the 5 quadrats counted. Occasional clumps of the brown alga Sargassum polycystum C. Ag. can be found throughout the length of Piti Channel but seem to occur more frequently in the outfall lagoon. A number of other organisms appeared along the transect lines in only one or two segments. These include the red alga Avrainvillea sp. (Tr 10 11), the brown Dictyota bartayresii Lamx. (Tr 11, but seen widely scattered elsewhere in previous observations), unidentified grapsid crabs (Tr 13), the green alga Caulerpa racemosa (Forskal) J. Ag. (Tr 15), the cowrie shell Cypraea moneta L. (Tr 11, 12), and the cowrie Cypraea tigris L. (Tr 9). The black-spined sea urchins Diadema spp. are found in the outfall lagoon and down the length of Piti Channel wherever hard-rubble substrate is available, but these organisms form aggregations only in Lower Piti Channel. A synaptid sea cucumber was found on the transect only on the sand bar formed just upstream of the GORCO pipeline.

Some other incidental organisms may be confined only to Lower Piti Channel, although more observations are needed. The bivalve Chama sp. has been found only in Lower Piti Channel, as is true of a white-colored and a black-colored encrusting sponge and an unidentified species of oyster.

With regard to the common organisms in Piti Channel, three groups may be distinguished. The first group, composed only of the red alga Gracilaria salicornia and the brown alga Padina tenuis, represents the dominant benthic organisms in the turbulent outfall area within about 100 m of the Piti Power Plant outfalls. These species are not confined to this area, since they are common elsewhere in Piti Channel and on the surrounding tidal flats, but they have been observed to be the dominant forms in the outfall lagoon over a long period of time.

The second group of organisms is a collection of plants and animals which do not appear in the immediate vicinity of the Piti outfalls but appear and become abundant within the first 300-400 m (Fig. 12). Thereafter, they remain common or abundant throughout most or all of Piti Channel. These organisms include Halimeda, the shrimp-goby association, the sponge Spirastrella vagabunda, and the mat-forming red algae Hypnea esperi and Champia sp. The cone structures also have the distribution pattern characteristic of this second group.

The third group of organisms appears to be confined exclusively to Lower Piti Channel and to have a fairly widespread distribution there. These include the sea grass Halophila minor, the sea cucumber Bohadschia bivittata, and massive corals of the genus Porites. It is possible that this group of organisms is excluded from Upper Piti Channel by heated effluent water from the power plants and can live only in the cooler waters of Lower Piti Channel. These species are found elsewhere on tidal flats and in channels where temperatures are often as high as in Upper Piti Channel. However, Upper Piti Channel has constant temperatures and the other areas have fluctuating temperatures. The periodic occurrence of lower temperatures in the latter areas may be biologically significant. Some other factor such as nature of the substrate could also be responsible for the zonation in Piti Channel. In any case, there is a distinct qualitative difference between the biota of Upper Piti Channel and that of Lower Piti Channel.

Benthic organisms which are present in the outfall lagoon, but which did not show up in our transect counts, are listed in Table 1. Of these, the small Drupa ricina (L.) (yellow form) is noteworthy because several dozen individuals were found inside the lower outfall pipe at the Piti Plant. One juvenile of the top shell Trochus nilotocus L., a single Conus rattus Bruguiere (cone shell), and the red alga Rhodomenia were also found there. Also noteworthy, though

Table 1. Major benthic organisms noted in Outfall Lagoon (1974-1975).

ALGAE:

- *Avrainvillea obscura* J. Ag.
- *Chaetomorpha indica* Kutz.
- *Champia* sp.
- *Gracilaria salicornia* (Mert.) Grev.
- *Halimeda opuntia* (L.) Lamx.
- *Hypnea esperi* Bory
- *Padina tenuis* Bory
- *Polysiphonia* sp.
- *Rhodymenia* sp.
- *Sargassum polycystum* C. Ag.
- *Schizothrix mexicana* Gomont

SPONGE:

- *Spirastrella vagabunda* (Ridley) (rare)

ECHINODERMS:

- *Actinopyga* sp. (rare)
- *Bohadschia argus* (Jaeger)
- *Diadema setosum* (Leske)
- *Echinometra mathaei* (de Blainville)
- *Holothuria* (*Halodeima*) *atra* Jaeger
- *Holothuria* (*Mertensiothuria*) *leucospilota* Brandt

MOLLUSCS:

- *Conus rattus* Bruguiere
- *Cymatium pileare* (L.)
- *Cypraea moneta* (L.)
- *Drupa ricina* L. yellow form
- *Patella* sp.
- *Pinna* sp. (rare)
- *Planaxis sulcatus* (Born)
- *Strombus luhuana* L.
- *Trochus niloticus* L.
- *Vasum turbinellus* (L.)

CRUSTACEANS:

- *Calappa hepatica* L.
- *Calcinus latens* (Randall)
- *Clibanarius striolatus* Dana
- Additional hermit crabs
- Supra-littoral grapsid crabs
- Portunid crab
- Shrimps (several spp.)

not appearing on the transects, is the green alga *Chaetomorpha indica* Kutz., the sole macroalga found growing in the Cabras Plant effluent channel. Here it grows in large clumps which stream outward in the current, particularly on the south side of the channel where most of the hotter water seems to flow.

Additional biological observations have been made on the tidal flats. A dominant feature is the presence of large numbers of holes containing the shrimp-goby association previously described. Also widespread on the tidal flats are the cone structures found in Piti Channel. One feature on the tidal flats not seen in the channel is the widespread occurrence of beds of the sea grass *Enhalüs acoroides* (L.F.) Royle. Such sea grass beds are not unique to the study area and are often seen on other tidal flats on Guam where the substrate consists of fine silt rather than consolidated limestone or large rubble. The brown alga *Padina tenuis*, which is dominant in the outfall lagoon, is also abundant on the tidal flats of Piti and elsewhere. This alga appears to be well adapted to survive the stresses of high temperature, slight or no water motion, and turbid water. The green alga *Halimeda*, the red alga *Gracilaria*, the mat-forming red algae *Hypnea* and *Champia*, the coral *Porites*, and the brown sponge *Spirastrella* are other common species of the outfall and Piti Channel areas which are found on the tidal flats and in the Secondary Channel as well. Hence, almost any species which is common in the outfall lagoon and the remainder of Piti Channel can be found in surrounding areas unaffected by the thermal discharge. On the other hand, there are a few species common on the tidal flats which cannot be found in Piti Channel, with the sea grass *Enhalüs* being the major example. Since this plant grows on tidal flats where solar heating sometimes raises temperatures as high as for effluent water from the power plants, it is unlikely that temperature is the factor excluding the organisms from Piti Channel. There is at least one, and possibly there are two, species of rock oyster (as yet unidentified) found in other channel areas and not found in Piti Channel which may be excluded from the latter area by temperature. Overall, it appears that the nature of the substrate is more important than temperature in determining the distribution of organisms in the general outfall areas.

Debris

A large amount of construction debris has been left in the outfall lagoon adjacent to the seawall which stabilizes the southern border of the Cabras Plant fill site. Much of this consists of insulators, cable, and other materials discarded from the construction of the immediately adjacent switchyard. Some of this material might be salvaged for reuse. Additional debris has been pushed into the moat area (Fig. 4) adjacent to the construction site for new fuel tanks. Previous reports have repeatedly recommended that Guam Power Authority and its contractors not use marine waters as dumping areas for whatever junk and other materials may be left over after construction.

PITI BAY

The enlargement of Tepungan Channel (Fig. 17) was a part of the construction of the Cabras Island Plant and was carried out between November 1972 and April 1973. Biological observations began in the area before construction activities and continued during and after dredging. Observations presented here supplement those reported previously (Marsh and Gordon, 1972, 1973, 1974).

According to original plans, all operations associated with the dredging of Tepungan Channel were to be conducted only in the immediate vicinity of the channel so that damage to biological communities would be minimized. This would have limited physical destruction of habitat to the pre-existing Tepungan Channel itself and to a band immediately north of the channel which was covered by an access dike for dredging equipment. However, as discussed in Marsh and Gordon (1974), during the final stages of clean-up after dredging had been completed, a bulldozer was used to push boulders across the Piti reef flat north of Tepungan Channel far outside the area prescribed for dredging operations. The result was extensive damage to approximately 3,000 m^2 of reef flat dominated by a thriving and diverse coral community. Had operations been strictly confined to the prescribed area, damage to such adjacent coral communities would have been minimized. Before dredging, the channel and immediate vicinity were dominated by biological communities composed primarily of algae and echinoderms rather than corals. It was expected that these communities would be able to make a comeback after dredging within a reasonable time period, and the recommendations in the original report (Marsh and Gordon, 1972) were based on this assumption. That report recommended that all dredging operations be confined strictly to the vicinity of the channel specifically to minimize damage to coral communities.

The damage to the coral community was described in detail in the 1974 report. A community with significant three-dimensional habitat structure was destroyed and replaced by a flattened area covered with rubble, sand, and broken-up coral remains. Massive Porites heads and standing dead and live Acropora (staghorn coral) were crushed (Figs. 18-21). A number of other sedentary invertebrates such as sea cucumbers and sea urchins were crushed. More mobile organisms such as various species of fishes had their habitat destroyed and deserted the area. Overall, a thriving coral community was replaced by a relatively barren sand and rubble flat.

The emphasis in the past year has been on possible recolonization in three areas (Fig. 17): the enlarged Tepungan Channel, the

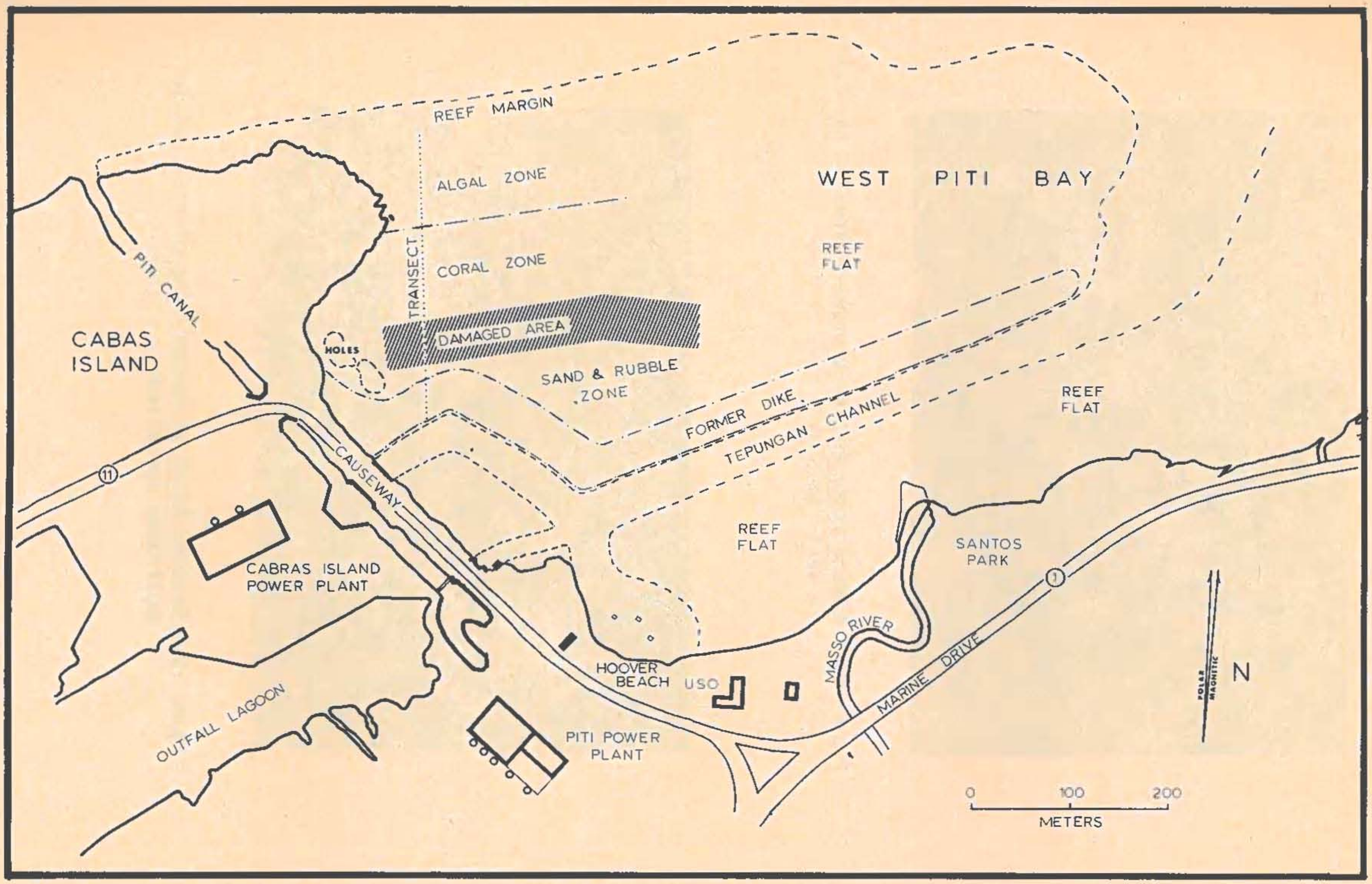

Figure 17. West Piti Bay showing the major features in the area of the Piti and Cabras Power Plants. The location of the damaged area was determined in conjunction with Guam EPA.

Figure 18. Live Acropora in an undamaged area of the reef in West Piti Bay.

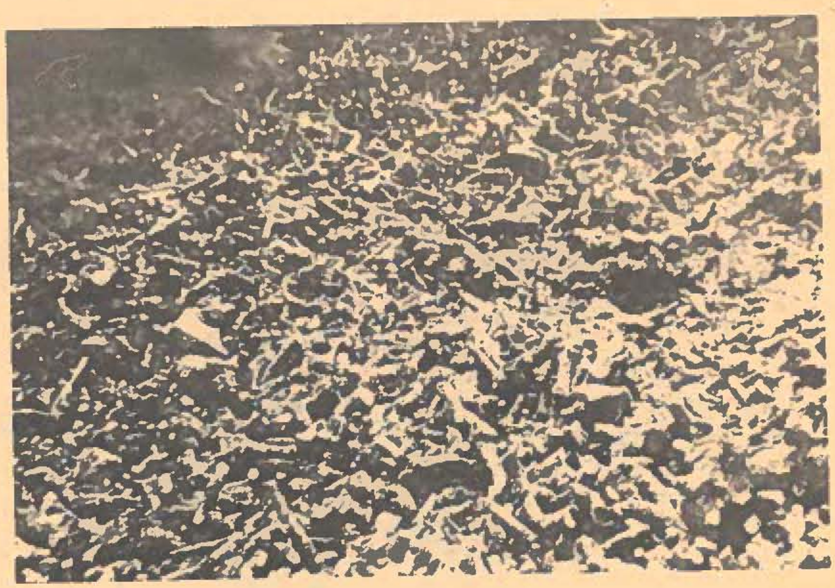

Figure 19. Crushed Acropora in the area of reef damaged by bulldozer operations.

Figure 20. Live Porites heads in an undamaged area of the reef in West Piti Bay.

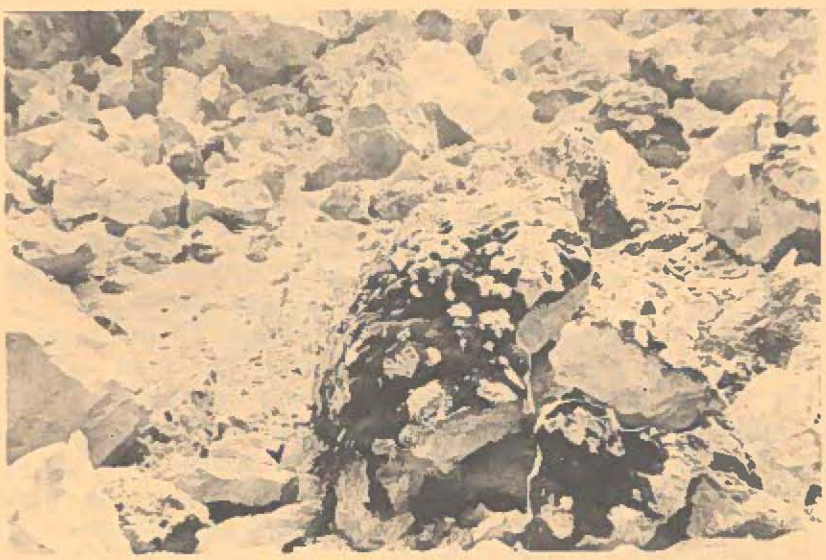

Figure 21. Crushed and split Porites heads in the area damaged by bulldozer operations.

reef-flat area formerly covered by the construction dike, and the area previously composed of a live coral community and flattened by the bulldozer. At issue is whether these areas will be colonized by new species or will experience the return of pre-existing species, as well as the relative abundance and densities of organisms.

Tepungan Channel now appears much as it did in 1974, a year after the completion of dredging operations. Colonization by new organisms has been slight, both on the sides of the channel and on the bottom. This is primarily because the substrate is composed of sand and silt, with very little hard material to provide attachment sites for organisms. Before the dredging, it had been projected (Marsh and Gordon, 1972) that construction-caused silt deposits would eventually be swept away by currents to expose a substrate of hard rubble or dead coral material. So far this does not appear to be happening. There may have been a permanent change in the area, with the algae-echinoderm community present before dredging (and also characteristic of surrounding reef flats) being replaced by some other community. The most obvious organisms presently in the area are burrowing ones, particularly the shrimp-goby association previously described for the outfall area. Some of these were present in the bottom of Tepungan Channel before the dredging, but their numbers appear to have increased since that time. Otherwise the channel sides and bottom are visually barren, except for scattered rock outcrops where occasional attached organisms such as sea urchins are found. The attractiveness of the area for snorkelers has been considerably decreased. There apparently are a number of species of fish that move into the channel at times, but it is unclear if any of these are permanent residents there. People often fish from the causeway where the old and new arms of the channel pass under the road (Fig. 17). Their catch is primarily jacks.

The second area of concern is the band of reef flat bordering the channel and lying just north of it (Fig. 17) where the temporary construction dike was in place during dredging operations. Algae and echinoderms previously living in this area were smothered by the construction dike. As noted in the last report, there was a dense growth of the green alga Enteromorpha which appeared in this zone immediately after the construction dike was removed. This disappeared rapidly. Much of this area has been occupied by few other benthic algae in the last year, although there are occasional thalli of the same algae that occupy the rest of the reef flat. The area is visually barren for the most part, in marked contrast to the rest of the reef flat. The substrate consists primarily of sand and loose rubble, with most fragments less than about 25 cm in longest dimension but with scattered larger fragments exceeding 50 cm. This type of substrate is also characteristic of a band of reef flat lying south of the channel and described as a rubble tract in the first report on the area (Marsh and Gordon, 1972). The elevation of this rubble tract south of the channel is somewhat higher than the rest of the reef flat and is more subject to subaerial exposure at low tides.

This is also true of a portion of the former dike area, and this periodic subaerial exposure probably accounts for its barrenness. The eastern end of the former dike area, paralleling the new arm of the channel, has a lower elevation and greater biological diversity.

Of the three areas of concern, the bulldozed area was the best biologically developed and the most diverse before dredging operations and has therefore been of particular interest. Two years after the damage took place, the bulldozer track is still obvious from the broken-up heads of the massive coral *Porites*. It forms a wide swath which marks a transition zone between the live coral community to the north and the sand-rubble zone, occupied mostly by an algae-echinoderm community, to the south (Fig. 17). Scattered corals also occur south of the bulldozed zone at its eastern end. While the bulldozed area is not now as barren as the portion of the reef flat formerly covered by the construction dike, it bears little resemblance to its natural state before the bulldozer damage. In place of live coral (up to a meter high) giving a three-dimensional structure to the habitat, there is a relatively flat substrate which in many places resembles the substrate in the dike zone. However, rather than being barren, the bulldozed area now generally has a high percentage of cover by benthic algae, similar to undamaged sand-rubble portions of the reef flat. The visually dominant algae are the brown *Padina tenuis* and the blue-green *Hormothamnion enteromorphoides* Bornet & Flahault. Scattered thalli of the brown *Dictyota bartayresii* are also usually present, though not in the abundance of the other two algae. (The same algae are found on the rest of the reef-flat areas as well, including the live coral areas, but not in as great abundance as in the bulldozed area.) The substrate cover represented by *Padina* is generally so great in the bulldozed zone as to give the visual impression of a "pasture." Diversity and abundance of fishes is visually less striking in this area than in the adjacent live coral areas which are representative of the damaged area in its previous state. In the spring of 1975 the bulldozed area, like other reef-flat areas in Piti Bay and elsewhere on Guam, experienced a large run of juvenile siganids (rabbitfish). This is a well known seasonal occurrence.

The remaining live coral zone (Fig. 17) is in marked contrast to the damaged area. Large heads (up to 1 m diameter) of the massive coral *Porites* constitute the dominant form. Areas of sandy bottom are interspersed between these heads. They are analogous to the trees in the forest which provide a characteristic three-dimensional habitat. It was the removal of such habitat that so markedly altered the character of the bulldozed area. In adjacent areas with somewhat higher reef-flat elevations, there is a dominance by the staghorn coral *Acropora*. At least 75% of this was killed by extremely low tides and falling sea level during the late months of 1972, but it was still standing in place and providing habitat for other organisms at the time of the dredging and bulldozer destruction. A number of species of algae, sea urchins, holothurians (see cucumbers), crustaceans (crabs and shrimps), molluscs (shelled organisms), and fishes are associated with the live coral and give the community its biological and aesthetic value. Most of these species are no longer found in the area damaged by the bulldozer, even though they were common there before the damage occurred. They are not now, nor were they before (for the most part), present in the channel and reef-flat zone temporarily covered by the construction dike. The undamaged live coral communities retain the characteristics they exhibited before the dredging, but there has been little improvement in the damaged area and it bears little resemblance to its original character.

Coral colonization is the key to the recovery of the damaged area. As pointed out by Marsh and Gordon (1974), the destruction in the bulldozed area broke up most of the large massive Porites heads and overturned the rest. Many of the broken fragments were still alive immediately after the damage occurred. A major point of interest was whether or not these broken fragments would continue to live and provide "seed organisms" or "centers of colonization" for future reef recovery. While the fate of the smallest fragments (less than about 15 cm across) could not be followed, there do not appear to be any large numbers of these fragments still alive. However, larger fragments fortunately showed good survival and for the most part are still alive. This is an encouraging sign and suggests that the damaged area does have the potential for future recovery. However, Porites is known to be a slow-growing coral, and there is no reason to shorten the previous estimate of 25 years needed for the area to reach its former state.

Another important point relates to recolonization by staghorn corals. The large areas of standing dead Acropora were noted above, as well as the fact that death was caused primarily by subaerial exposure in late 1972. Regeneration of the former Acropora thickets is now taking place in the undamaged areas but not in the damaged area. Where the staghorn corals were not crushed there were scattered live colonies at the bases of the more extensive standing dead forms, and these are serving as centers for regeneration. Since this is a rapidly growing form, we expect regeneration to proceed rapidly and the Acropora thickets to take on their former character in a few years' time. It is probable that the natural stress caused by subaerial exposure has operated in the past and that the community undergoes a kind of natural death-regeneration cycle. Unfortunately, in the area damaged by the bulldozer there were very few if any "centers of recolonization" left alive, and staghorn Acropora is not being regenerated in that area. It may be hoped that eventually that area will be invaded by larvae or live fragments that will lead to regeneration of coral thickets, with the accompanying diversity of fishes and invertebrates. It is certain that this will take place on a much slower scale than in the non bulldozed coral area, if it occurs at all.

One group of animals of particular interest is the holothurians, or sea cucumbers. This group is characteristic of reef flats on Guam and has been well represented on the Piti reef flats since the study began. Since these are sedentary organisms they are easily quantified, as opposed to the fishes which are too mobile to be readily counted. An individual sea cucumber is also readily defined, as opposed to some corals, particularly Acropora forms, where it is difficult to delineate an individual colony. Marsh and Gordon (1972) have previously characterized the non-coral portions of the Piti Reef flat as an "echinoderm-algae" community since these are the dominant organisms. One difficulty with the holothurians has been the toxonomic problem of identifying and recognizing in the field particular individual species. This problem has now been at least partially resolved with the aid of a visiting expert specialist, Dr. Frank Rowe from the Australian Museum in Sydney. A field survey was made on the Piti reef flat along a transect running perpendicularly through the various reef zones, including the bulldozed zone (Fig. 17). For each 10-m segment of the transect, all holothurians were counted and identified to species in a strip 2 m wide (1 m on either side of the transect) and 10 m long, running along the transect axis. The results are shown in Fig. 22. Several things stand out. Some species are clearly associated with particular reef zones. For example, Actinopyga mauritiana (Quoy & Gaimard) and Holothuria (Semperothuria) cinerascens (Brandt) are found only on the reef margin, (surf zone) and have high densities there. With respect to the damaged area along the transect (Fig. 17), the total holothurian density is higher (11-24 individuals per 20 m^2) than in adjacent non-damaged areas (0-8 individuals per 20 m^2). The cucumber Synapta, which was so visually obvious in the damaged area immediately after the bulldozer destruction, is no longer so visually obvious; nor is it quantitatively more abundant there. Ineed, it appears to be scattered throughout the transect area with no particular zonation. At this point, it is unclear if this can be taken as an indicator species of silty areas, as previously seemed likely. Another particularly common and obvious species, Holothuria (Halodeima) atra Jaeger, likewise appears to be scattered throughout the study area with no abundant zonation pattern.

The portion of the disturbed area which appears to bear the closest resemblance to the pre-existing conditions is the small triangular area lying between the new and old arms of the channel at the extreme western end of the reef flat (Fig. 17). This area was described previously (Marsh and Gordon, 1972) as a sand flat with little rubble or live coral. The dominant alga was the green Halimeda macroloba, with the green Udotea also being well represented. The substrate now has generally the same appearance it had before, and the term "sand flat" is an apt description. Halimeda macroloba is again the dominant alga, and Udotea is likewise common. Interestingly, Halimeda macroloba may also be found on the edges of the channel in some places, though it does not appear to be growing at depths greater than about 2 m. The sea cucumber Bohadschia bivittata is also common in the area, as was the case before dredging occurred.

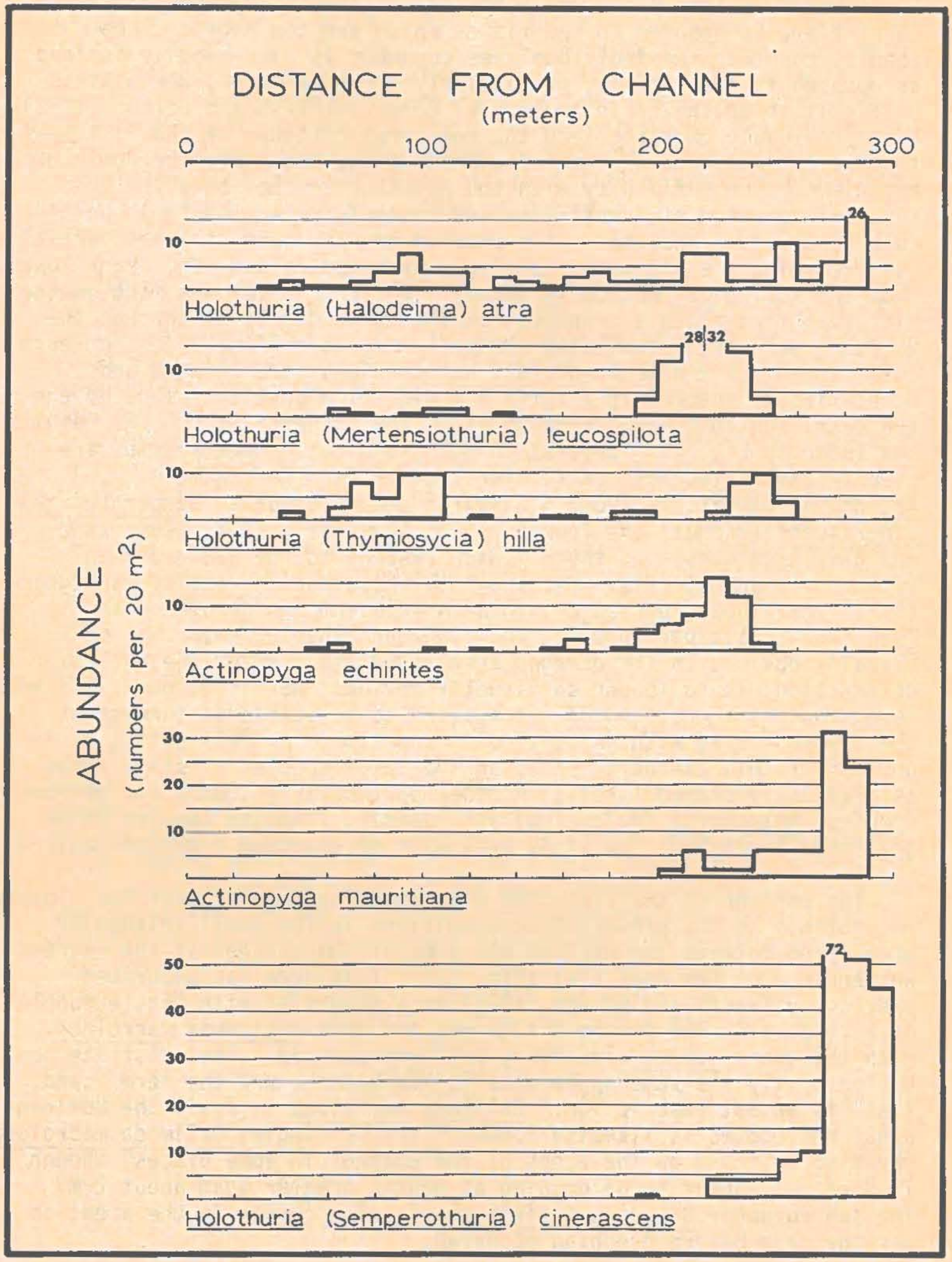

Figure 22. Abundance of major holothurian species across the reef flat in West Piti Bay.

The holes which were dug on the reef flat adjacent to the causeway (Fig. 17) were mentioned in a previous report (Marsh and Gordon, 1974). Several pieces of broken culvert and about a dozen larger boulders were discarded in these holes by the dredging contractor. This action has added some diversity to the physical habitat in the area and appears to have been more beneficial than detrimetal. Jacks and other fishes are commonly seen there, and the holes are an attraction for fishermen. Fish of the Family Mullidae (goatfishes) are also commonly seen in these sedimented holes, as in true of other large areas of sediment-covered reef flat, including the disturbed areas.

The 1974 report noted the large numbers of echinoids (sea urchins) that had settled on the Piti reef flat and other similar areas on Guam near the end of 1973. These have now reached adult size, and the species Diadema setosum (Leskel) and Echinothrix diadema (L.) appear to be much more common than during previous years of this study. It is likely that this cyclic phenomenon, with a dominant age class, is a natural feature of the populations of at least some sea urchins on Guam. [Diadema setosum is also very abundant in Piti Canal, especially that portion north of the road (Fig. 17), but we do not know if the number of adults has increased there in the last year.]

Some non-biological observations in Piti Bay also bear mention. The 1974 report presented extensive turbidity observations made during and immediately after dredging operations. Turbidity was high while dredging was going on but decreased thereafter. The latest values reported in the 1974 report, for 24 April 1973 (unfortunately mislabeled 24 April 1974), were less than 1 Jackson Turbidity Unit in Tepungan Channel and the reef flat areas north of the channel. On the reef flat south of Tepungan Channel values were higher, ranging up to 3.7 JTU. These higher values were caused by silt piles left on the reef flat adjacent to the USO swimming area after dredging of that area. The silt piles were later removed. Turbidity values for 21 March 1974 are presented in Fig. 23. Values are probably representative of conditions generally, although extensive observations have not been made since the cessation of dredging.

There is relatively minor problem in the study area which could be remedied by Guam Power Authority in a few hours. Along the shoreline of the causeway, on either side of the point where the new arm of the channel leads under the road to the Cabras Power Plant, there remains a moderate amount of construction debris (discarded rebar, twisted cables, and other material). This should be cleaned up, and similar discard of such junk should be avoided in the future.

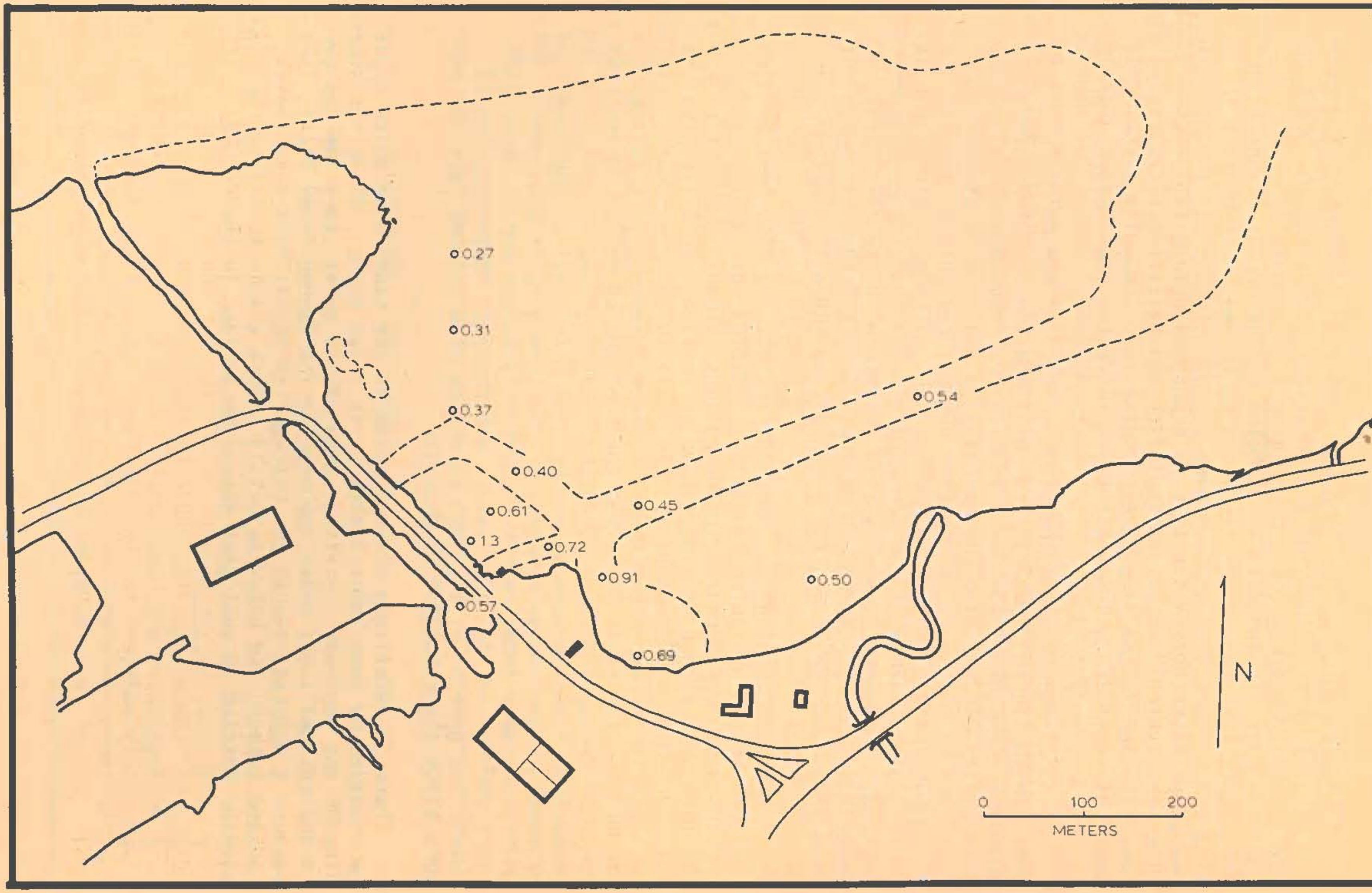

Figure 23. Surface turbidity in West Piti Bay on 21 March 1974. Data are expressed in Nephelometric Turbidity Units (equivalent to Jackson Turbidity Units).

Figure 23. Surface turbidity in West Piti Bay on 21 March 1974. Data are expressed in Nephelometric Turbidity Units (equivalent to Jackson Turbidity Units).

SUMMARY

Temperature observations in Piti Channel during testing and start-up of the Cabras Power Plant indicated the existence of a mass of hot water (up to 37.0°C) immediately adjacent to the outfall channel. Extending downstream from this was a plume of water hotter than the surrounding waters flowing from the Piti Power Plant. This plume of hotter water was not distinguishable for distances greater than a few hundred meters away from the Cabras Plant. Temperatures of effluent water from the Piti Plant at this time were well within the range previously established for the area.

Later observations were made in Piti Channel after the beginning of full-scale operations of Cabras Units 1 and 2. A hotter plume from the Cabras Plant could no longer be distinguished from cooler Piti Plant effluent waters. Isotherm plots for the area indicated no extension of given isotherms in Piti Channel or Commercial Port beyond the regions where they were found before Cabras Plant opera tions began.

In July and August 1974 there was a breakdown of the previously observed thermal stratification in the Commercial Port area. Warmer water had previously been confined approximately to the upper meter of the water column but was found to extend as deep as 5 m on some occasions in the summer of 1974. This was true even at the western end of Commercial Port. Warmer surface temperatures than usual (in excess of 30°C) were found in the harbor outside the Commercial Port area. These unusual temperature patterns were not persistent, and more usual patterns were later observed.

Studies were conducted on the occurrence and abundance of organisms along a transect running down the axis of Piti Channel from the Piti Plant outfalls to the western end of the channel. Diversity of organisms appeared to be greater in the outfall lagoon and in Lower Piti Channel, with fewer species of organisms occurring in Upper Piti Channel between these two regions. Three groups of organisms could be distinguished. The first consisted only of the algae *Gracilaria* and *Padina*, which occurred in the outfall lagoon in great abundance but were not confined to that area. The second group consisted of a shrimp-goby association, the sponge *Spirastrella*, the green alga *Halimeda*, and the mat-forming red algae *Hypnea* and *Champia*. These organisms could be found in great abundance throughout most of Upper and Lower Piti Channel but not in the outfall lagoon immediately adjacent to the Piti Power Plant effluent pipes. *Halimeda*, unlike the other organisms in this group, was more abundant in Lower Piti Channel than in Upper Piti Channel. Sand cones caused by some unknown organism also showed the abundance pattern of the second group. The third group consisted of organisms which were characteristic of Lower Piti Channel but not of Upper Piti Channel. These included the sea grass Halophila, the coral Porites, and the sea cucumber Bohadschia.

In West Piti Bay it appears that Tepungan Channel has been permanently altered to a siltier and biologically less diverse state than it showed before it was enlarged by dredging. The zone formerly occupied by the construction dike immediately north of the channel remains as a relatively barren area. It has not yet returned to its former state and to take on the characteristics of unaltered sand-rubble areas of the rest of the reef flat. The most serious and unanticipated effect of dredging, the unnecessary destruction of a portion of a coral community outside the prescribed dredging area, shows little sign of yet being corrected through natural regeneration. The presence of large numbers of live Porites fragments suggests that recovery of this area is possible, given sufficient time (probably at least 25 years).

Construction debris has been left in several areas in Piti Channel and West Piti Bay.

RECOMMENDATIONS

1. Contractors for Guam Power Authority should be directed to cease pushing construction debris into the moat area adjacent to the construction site for new fuel storage tanks. Material which has already been pushed into the waters there should be removed.

2. There should be a thorough clean-up of construction debris along the causeway shoreline in West Piti Bay.

3. There should be a thorough clean-up of construction debris discarded into the outfall lagoon adjacent to the seawall forming the southern boundary of the Cabras Plant site. In the future this area should not be used as a dumping site for such debris.

4. Present and future contractors for Guam Power Authority should be closely supervised to insure that they adhere to more rigorous standards of environmental protection than has been the case in the past.

5. Guam Power Authority should review all its operations to insure that they adhere to the revised water quality standards adopted by the Guam Environmental Protection Agency in 1975.

6. Guam Power Authority should consider placing continuously operating temperature recorders in the intake and effluent channels of the Cabras Plant to provide actual monitoring records of temperature changes. These recorders should have a sensitivity at least as fine as 0.2°C.

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