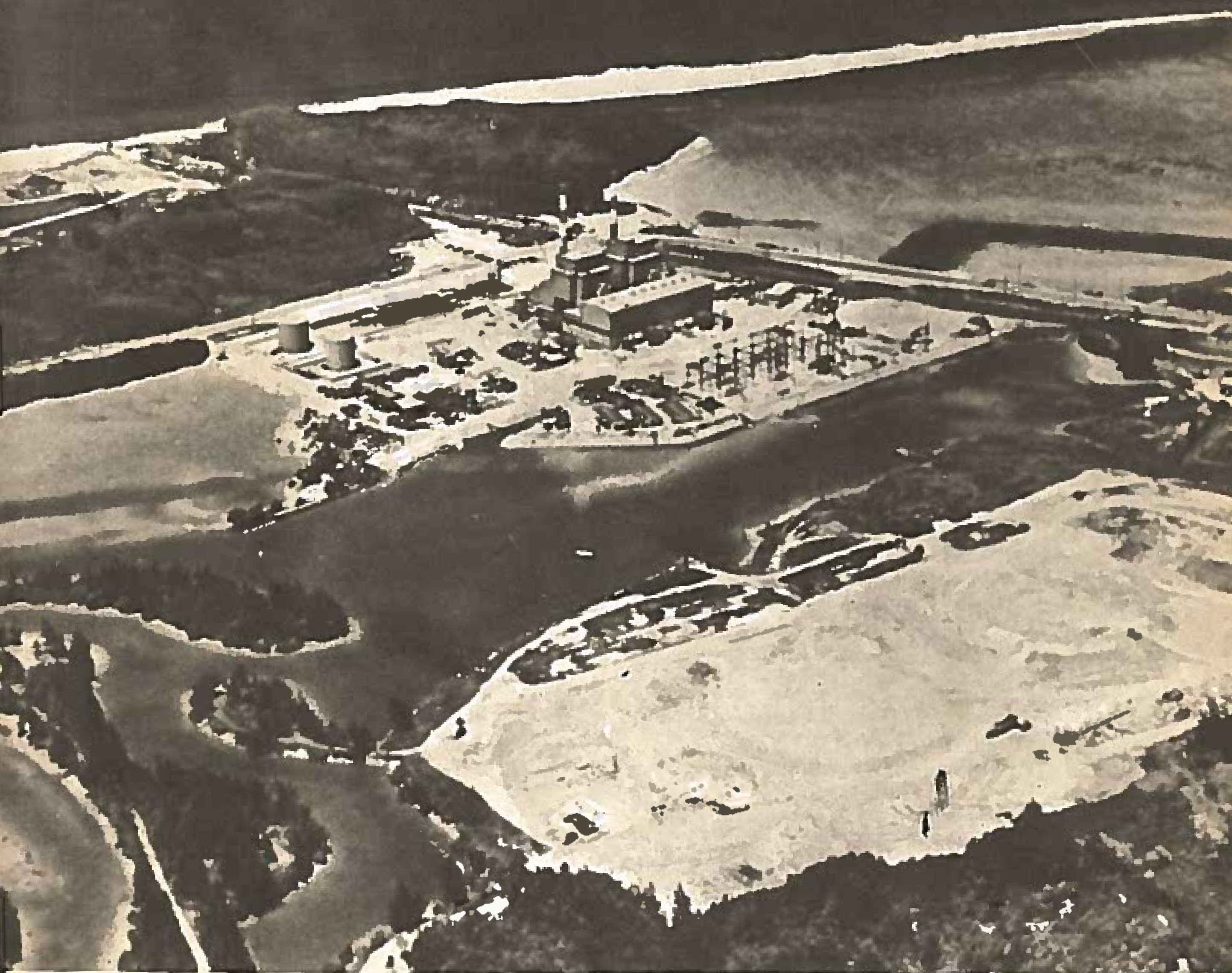
THE INFLUENCE OF POWER PLANT OPERATIONS ON THE MARINE ENVIRONMENT IN PITI CHANNEL, GUAM: 1975-1976 OBSERVATIONS

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



UNIVERSITY OF GUAM MARINE LABORATORY

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Attached is your complimentary copy of our report entitled "The Influence of Power Plant Operations on the Marine Environment in Piti Channel, Guam: 1975-1976 Observations." This is the fifth in a continuing series of reports concerning the impact of power plant construction and operation on shallow marine environments in the Piti area. I hope that you find the report useful and informative.

James A. Marsh, Jr.
JAMES A. MARSH, JR.
Director

THE INFLUENCE OF POWER PLANT OPERATIONS ON THE MARINE ENVIRONMENT IN PITI CHANNEL, GUAM:1975-76 OBSERVATIONS

By

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Submitted to

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THE MARINE LABORATORY

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[Cover Photo: Aerial photograph of the Cabras Power Plant, Outfall Lagoon and surrounding area taken in April 1975 by Island Aviation.]

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INTRODUCTION

This report presents the results of environmental studies conducted in Piti Channel, Guam, and nearby areas in 1975 and 1976. The focus is on the time period from July 1975 through March 1976, although some reference is made to additional observations outside this period. The observations reported here are part of a continuous study which began in January 1972. These studies have resulted in four previous reports submitted to Guam Power Authority (Marsh and Gordon, 1972; Marsh and Gordon, 1973; Marsh and Gordon, 1974; and Marsh and Doty, 1975).

The focus of the studies is on the environmental effects of Guam Power Authority activities in Piti Bay and Piti Channel. The original concern was with thermal and biological conditions prevailing prior to construction of the Cabras Power Plant. This necessarily considered West Piti Bay (Figure 1), since Tepungan Channel, located in the inner reef flat of that bay, was dredged and enlarged during the early phase of construction. Piti Channel and the surrounding tidal flats were also included in early studies, both because they would be affected by construction and because they were subject to thermal influence of the pre-existing Piti Power Plant (Fig. 2) and would be affected by operations of the Cabras Power Plant (Fig. 3) once it had been constructed. As construction proceeded, our studies focused on the observed impact in Piti Bay and Piti Channel and then shifted to assessments of biological recovery once such activities were concluded. At the same time there were continuing studies of thermal conditions prevailing in Piti Channel prior to operations of the new generating plant. More recently, the focus has shifted to thermal conditions as they are actually affected by full-scale operations of the new facility.

Construction of the Cabras Power Plant began in December 1972 with the initiation of dredging in Tepungan Channel. The dredged material was used to fill in a tidal flat to provide a site for the new facility. Dredging was completed in April 1973. In the meantime plant construction had begun, and this continued through 1973 and 1974. Cabras Unit No. 1 underwent testing in August and September 1974 and went on line in October 1974. Construction of Cabras Unit No. 2 was proceeding simultaneously, and that unit went on line in May 1975.

Each of the two Cabras units has a generating capacity of 66 megawatts, and the total capacity of the five units of the older Piti Plant is approximately 74 MW (information supplied by Guam Power Authority). Production of this plant has been curtailed since the Cabras Units went into operation. Sea water is used to cool the

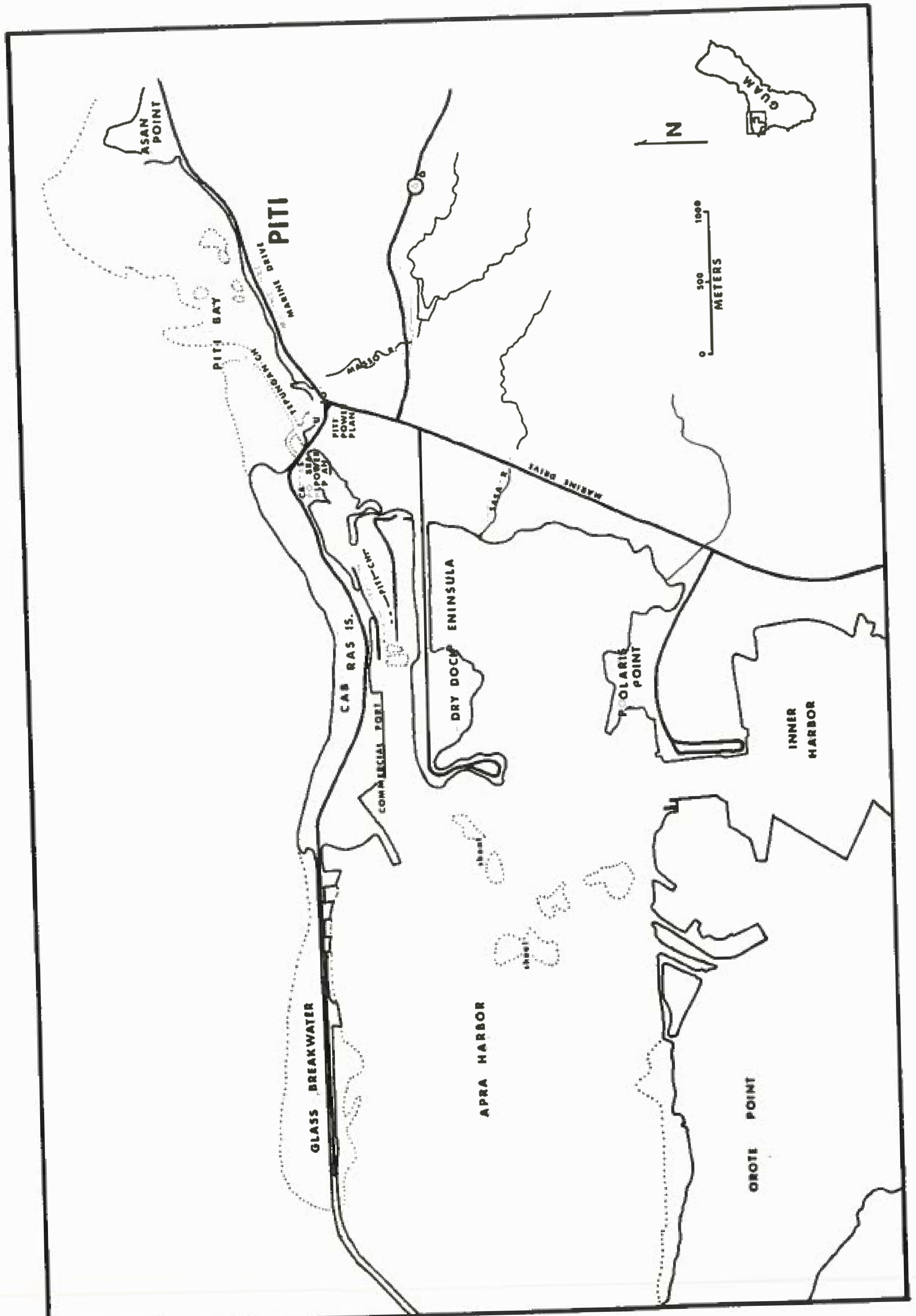


Figure 1. Geographic setting of the study area near Piti Village on the western shore of Guam.

condensers in both plants. The maximum pumping capacity of cooling waters through the condensers of the Cabras Plant is approximately 9.01 cubic meters per second (120,000 gallons per minute) for both units combined. The plant was designed to have a temperature rise of 5.6-8.3° Centigrade (10-15° Fahrenheit) for cooling waters passing through the condensers. Maximum pumping capacity of cooling water through all Piti Plant condensers is approximately 4.85 m^3 sec^{-1} (64,000 gpm), with a designed maximum temperature rise of 5.6°C (10°F).

The common source of cooling water for both power plants is Piti Canal, a man-made canal which cuts through the Cabras Island Causeway in a northwest-southeast direction (Fig. 4). Water enters this canal through its mouth, which is partially blocked by large boulders, and via two passages through the causeway. These passages connect with two arms of Tepungan Channel, the north arm created by the 1972-73 dredging and the older (and shallower) south arm which apparently represents a natural channel that existed before the construction of the causeway some 30 years ago. Water enters Tepungan Channel by flowing southward from the surf zone across the reef flat or by inflow from the deeper portion of Piti Bay (Fig. 1).

Both power plants pump their heated condenser effluent water into an outfall lagoon that represents the eastern end of Piti Channel and forms a cul-de-sac. The waters then flow westward in this channel for approximately 1600 m and enter Apra Harbor at the Government of Guam's Commercial Port area. Some areas of the outfall lagoon and channel have been dredged in the past, and prevailing depths are mostly 2-3 m. The channel is adjacent to a series of tidal flats which are often exposed subaerially at low tides and covered by approximately a meter of water at high tides. The tidal flats are subject to considerable solar heating, especially during midday or afternoon low tides.

The first report of environmental studies in the area (Marsh and Gordon, 1972) was submitted in June 1972 and provided baseline information required for a Corps of Engineers dredging and filling permit. It described general current patterns in the area and presented general biological observations. An appendix gave a check-list of fishes on both the intake and outfall sides. The report anticipated that the most serious environmental problems likely to be caused by construction activities were siltation in West Piti Bay, temporary blockage of water circulation in the USO swimming area, and the permanent loss of approximately 3.2 hectares of marine habitat in the fill area.

The second report (Marsh and Gordon, 1973) was concerned primarily with thermal patterns in Piti Channel, the adjacent tidal flats, and the Commercial Port area. The conditions described were those before and during construction of the Cabras Plant, when the only man-caused thermal stress in the outfall region was from the Piti Plant.

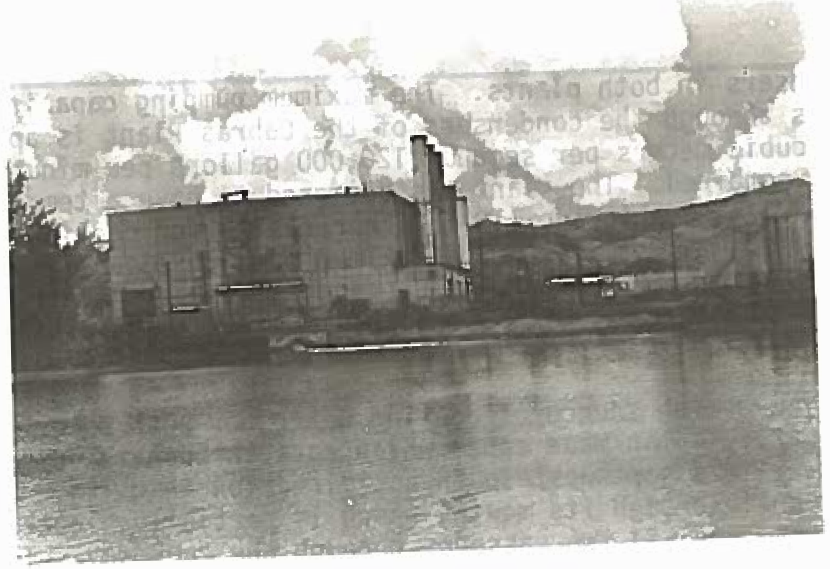


Figure 2. Piti Power Plant with its outfalls and the outfall lagoon in the foreground.

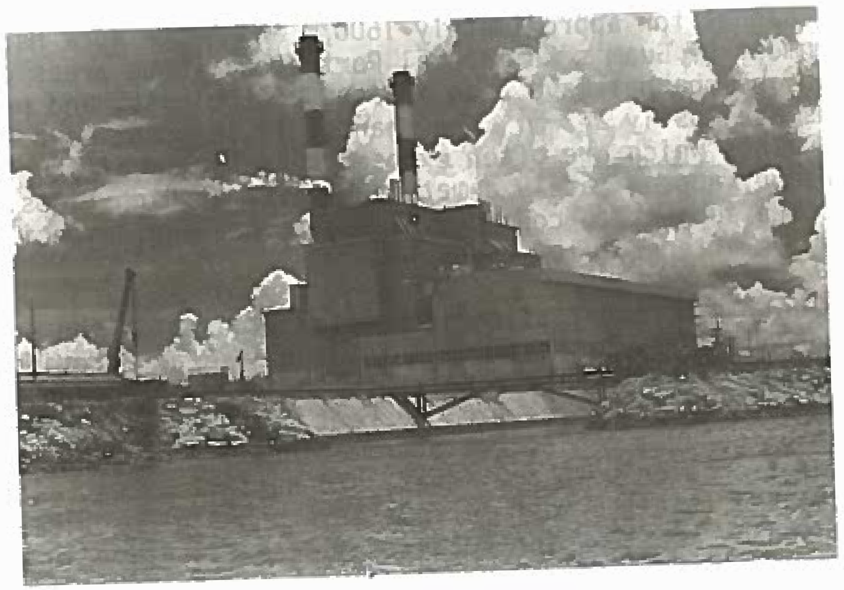


Figure 3. Cabras Power Plant with its outfall channel in foreground.

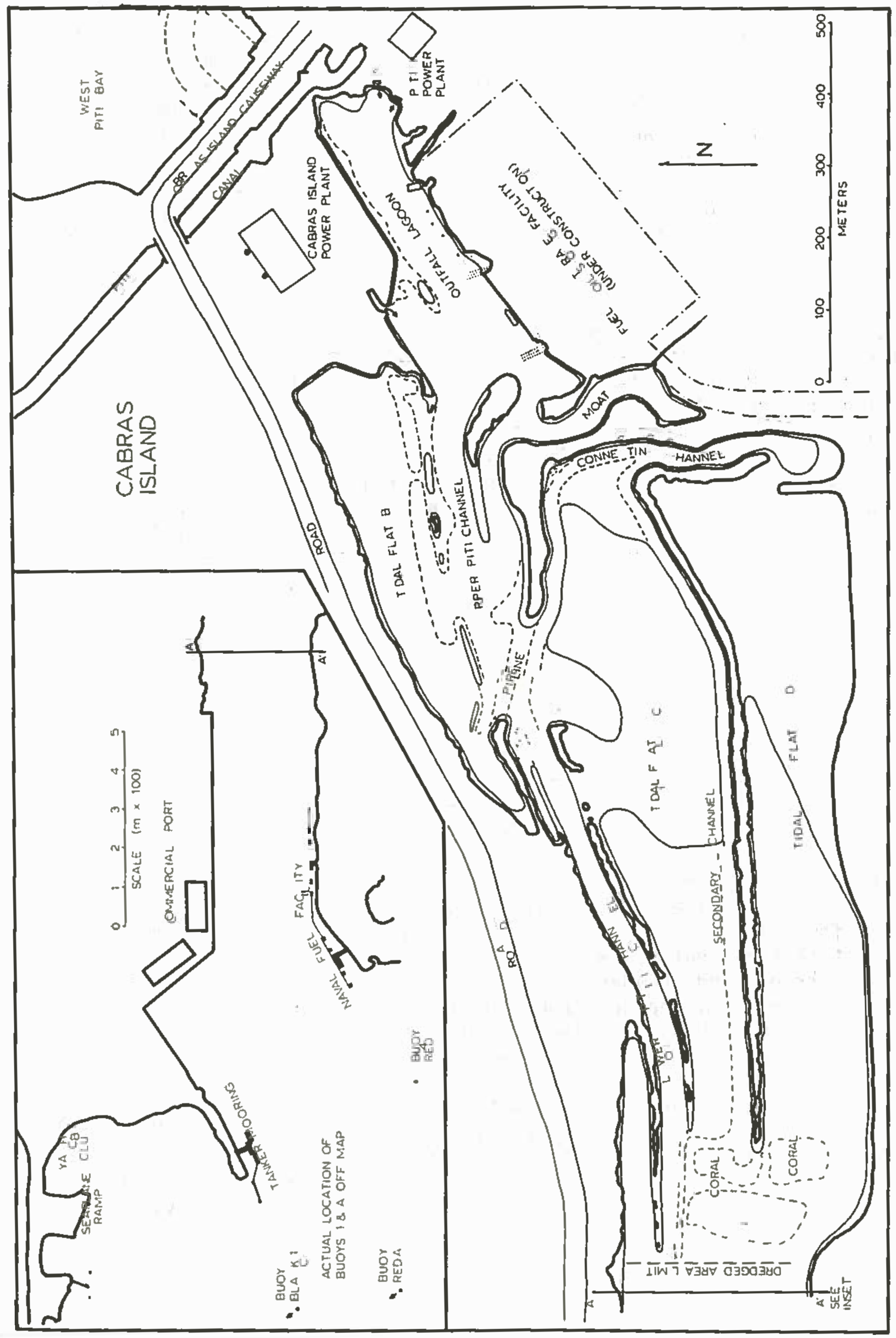


Figure 4. Major features of the area affected by the effluents of the Piti and Cabras Power Plants. Inputs of water from power plant outfalls are indicated by arrows.

Attention also focused on the significance of solar heating in the area, a factor which was found to have a strong influence on thermal patterns. It was reported that temperatures on the tidal flats could get as high (up to 35°C) as temperatures in the outfall lagoon caused by the thermal load from the power plant. However, natural diurnal and tidal fluctuations were reported to result in periodically lower temperatures in the Commercial Port area, Lower Piti Channel, and the tidal flats than in Upper Piti Channel and the outfall lagoon, where temperatures were maintained at a higher and more constant level usually exceeding 32°C.

The third report considered primarily the observed environmental effects of dredging and construction. The most severe effects included the large increase (often exceeding an order of magnitude and less commonly exceeding two orders of magnitude) in water turbidities; extensive bottom siltation, with the smothering of biological communities; and the blockage of water circulation in the southern part of West Piti Bay, including the USO swimming area. These effects were largely unavoidable if there was to be any construction. However, there was an additional major environmental impact that could have been avoided, namely the destruction of about 25% of a live coral community lying seaward (north) of the necessary limits prescribed for dredging operations on the reef flats of West Piti Bay. This was a long-lasting effect that may or may not be corrected through natural biological regeneration over the course of years.

In the fourth report (Marsh and Doty, 1975) we described temperature observations in Piti Channel during testing and start-up of the Cabras Power Plant and noted a plume of hot water (up to 37°C) adjacent to the outfall channel. This was distinctly higher than effluent from the Piti Power Plant or immediately surrounding waters in the outfall lagoon. Later observations indicated that this "hot spot" had become somewhat cooler. Preliminary isotherm plots during initial Cabras Plant operations suggested no expansion of areas enclosed by particular isotherms at that time. A breakdown of the previously observed thermal stratification in the Commercial Port area was found in July and August 1974, but later observations indicated that this new pattern was not persistent. We reported studies of 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 Lower Piti Channel, with fewer species occurring in Upper Piti Channel between these two regions. We distinguished between the distribution patterns of three groups of organisms along the transect. We also reported that in West Piti Bay, Tepungan Channel appeared to have been permanently altered to a siltier and biologically less diverse state (at least for benthic communities) than it showed before dredging operations. Finally, we observed little sign of natural biological regeneration yet occurring in the area of West Piti Bay where the coral community had been destroyed.

METHODS

Temperature measurements have been made with several different kinds of thermometers and thermistor probes. A mercury bucket thermometer was used to get measurements of water temperatures at the surface Mercury maximum/minimum thermometers were left in place at various sites in the study area for long periods of time and read and reset periodically. A YSI battery-powered telethermometer with thermistor probes having long leads was sometimes used to get surface temperatures and temperatures at various depths and was operated from a small boat. A YSI scanning telethermometer with 12 channels was connected to a single-channel recorder and left in place near the mouth of the Cabras Plant outfall channel, with long thermistor leads extending to various points within about 20 m (75 ft.) of the instrument. The instrument was powered with normal line voltage through a drop cord provided by Guam Power Authority.

Visual biological observations were made in the field at various sites throughout the study area. Occasional specimens were collected and preserved for laboratory verification of identifications. Detailed observations were made along a transect line laid out downstream from the Piti Plant outfalls along the axis of Piti Channel. Specific methods used for making estimates of density and abundance will be d[illegible] atter section of this report.

Certain chemical analyses were also made. The technique for measuring dissolved oxygen followed the azide modification of the standard Winkler technique (APHA, 1971). Analyses of heavy metals in the sediments were carried out by the U. S. Navy's Fena Laboratory, utilizing an atomic absorption spectrophotometer. We thank Mr. Ralph Lytle, head of that laboratory, for his cooperation in this regard. The field sampling was done on 22 October 1975 by scooping approximately a kilogram of surface-layer (0-10 cm) sediments into glass jars or polyethylene bags.

TEMPERATURES

General Isotherm Plots

Some general isotherm plots are presented in Figs. 5-7. The two in Fig. 5 are representative of a larger number of isotherm plots which we have obtained with the Cabras Power Plant in operation and reduced loading for the Piti Power Plant.

Figure 5A shows a plot for the morning of 8 January 1976 just before high tide. At that time the Cabras outflow temperature was higher than the Piti outflow temperature (32.6° vs. 30.0°C), and the Cabras plume was distinguishable from the upstream Piti water in the outfall lagoon. However, the 32° isotherm enclosed only a small area adjacent to the Cabras outfall. The 31° isotherm included Piti Channel as far downstream as the GORCO pipeline and also included the middle portion of Reef Flat B; the 30° isotherm lay close to this and included a small part of Lower Piti Channel. The 29° isotherm lay well within Lower Piti Channel, and the entire Commercial Port area had surface waters of less than 29°.

Figure 5B shows a plot for the early afternoon of the following day, on a falling tide. The Cabras outfall temperature, at 32.7°, was warmer than the two Piti outfall pipes, which had temperatures of 29.9° and 30.6°. Again, the Cabras plume was warmer than the upstream Piti-influenced water in the outfall lagoon. The 32° isotherm extended onto Tidal Flats B and C and as far as the GORCO pipeline in Piti Channel. The 31° isotherm lay in Lower Piti Channel and also extended across the western end of Tidal Flat C. The 30° isotherm was near the eastern limit of the Commercial Port dredged area, and the 29° isotherm enclosed approximately half of the Commercial Port area. Both of the isotherm plots of Fig. 5 are representative of many results we have gotten since the Cabras Plant went into operation, although it should be noted that the figure is for winter months rather than summer months and for times when the Cabras outfall was well below its maximum temperature. The surface areas enclosed by particular isotherms are no more extensive than similar such enclosed areas before the Cabras Plant began operations. For instance, the 32° isotherm appears to extend downstream of the GORCO pipeline now no more frequently than it did previously.

Figure 6 shows two isotherm plots which represent the coolest prevailing conditions we have observed throughout the study area: these are "best case" plots with respect to the problem of thermal pollution caused by the Cabras Power Plant. Fig. 6A, for 9 April 1976, represents an early afternoon high tide under rainy and overcast conditions which had persisted all day. There had been shutdowns of both the Piti and Cabras Plants at approximately 0300 hours that

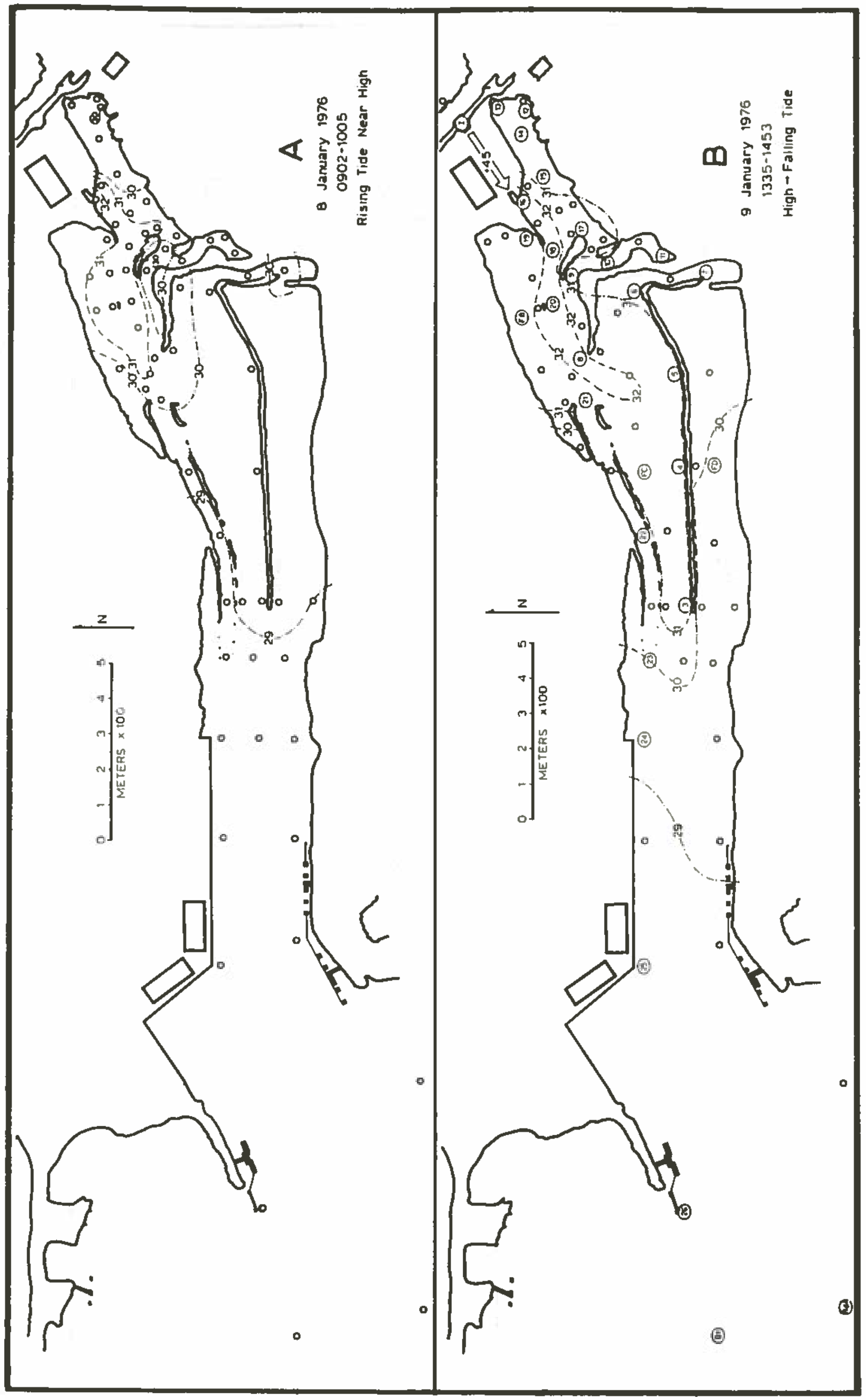


Figure 5. Typical surface temperature patterns in the Piti Channel area. A. 0902-1005 on 8 January 1976. B. 1335-1453 on 9 January 1976. Circled numbers in Figure 3B indicate stations referred to in Table 1.

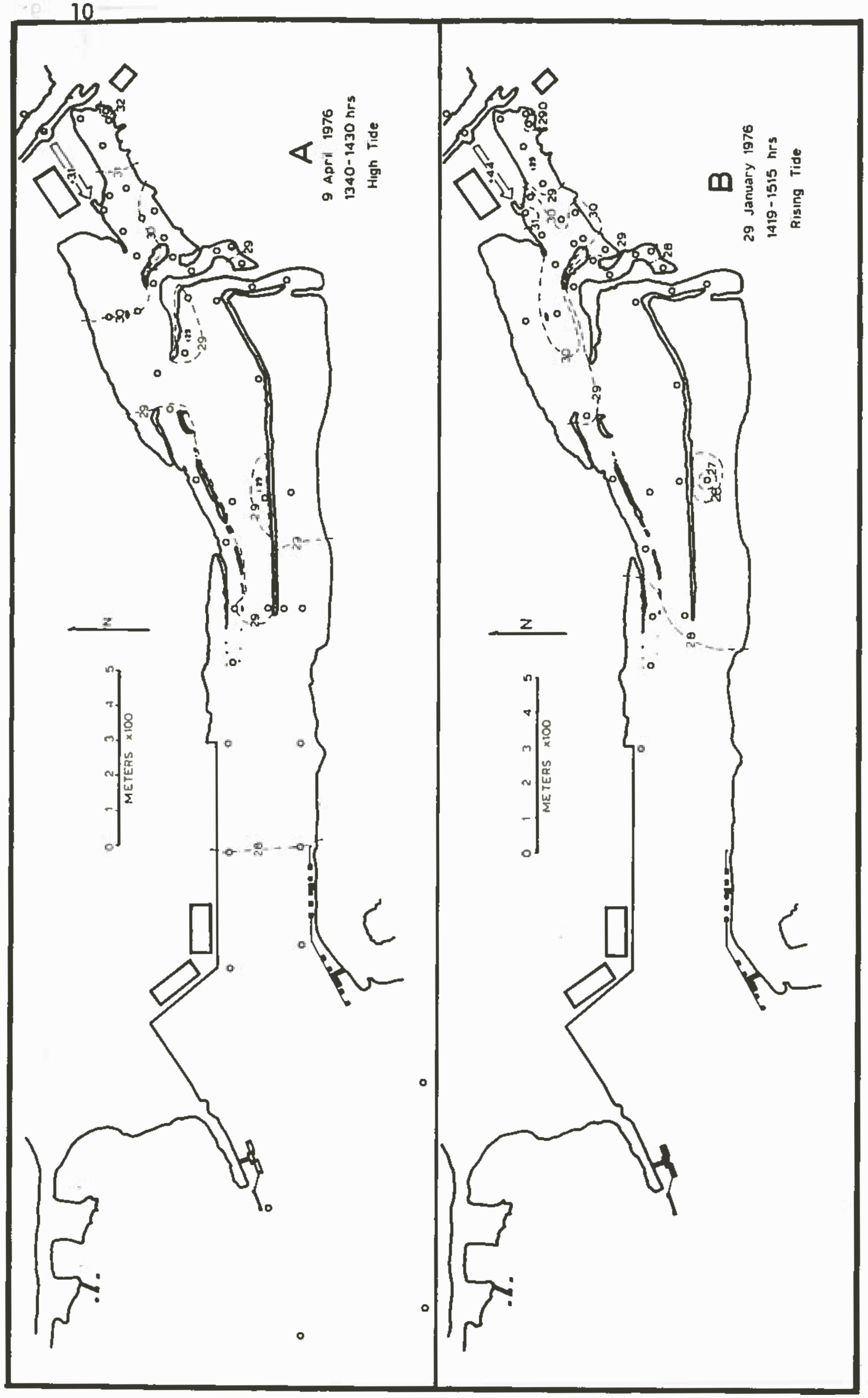


Figure 6. Coolest surface temperature patterns observed in the Piti Channel area. A. 1340-1430 on 9 April 1976. B. 1419-1515 on 29 January 1976.

morning. The Piti Plant had gone back into operation at about 0730 hours and Cabras Unit No. 1 at shortly after 1000 hours. In contrast to the usual situation in preceding months, the Cabras outfall, at 30.8°C, was cooler than the two Piti outfall pipes, at 31.1° and 32.2° respectively. The 31° isotherm included the area adjacent to the Piti Plant but did not extend as far downstream as the Cabras outfall. The 30° isotherm lay in Upper Piti Channel and the 29° isotherm in Lower Piti Channel. The 28° isotherm lay about in the middle of the Commercial Port area, with cooler water thus occupying a part of the area. Water on Tidal Flats C and D was cooler than 30° throughout and cooler than 29° in some spots.

Somewhat similar conditions prevailed in the afternoon of 29 January 1976 (Fig. 6B), when there had also been heavy rains and squalls all day. At this time the Cabras outfall was warmer than the Piti outfall area, however, with the eastern part of the outfall lagoon being the cooler portion. The 28° isotherm also lay in Lower Piti Channel rather than in the Commercial Port area. Tidal Flats C and D were slightly cooler than depicted in Fig. 6A. The "best cases" shown in Fig. 6 represent the coolest conditions ever found throughout the entire study area, except for once in March 1972 (Marsh and Gordon, 1973).

A "worst case" isotherm plot is shown in Fig. 7A, which represents falling-tide conditions for a mid-afternoon in August 1975. In this case the Cabras outfall temperature was 34.6°C (4.6°C higher than its intake temperature), and the 34° isotherm enclosed a large area extending into Lower Piti Channel. Again, the upper part of the outfall lagoon affected by the Piti Plant was cooler. All of Lower Piti Channel was included within the 33° isotherm, which lay in the eastern end of the Commercial Port area. Both the 31° and 30° isotherms lay at the western end of the Commercial Port area, which thus had a steep temperature gradient.

These "worst case" patterns and several others similar to them occurred mostly in August and September 1975, thus coinciding with the highest intake temperatures for the Cabras Plant (see the discussion of maximum/minimum temperature observations later in this report) and apparently coinciding with maximum plant loading as well. These appear to be the only conditions when the 33° isotherm extends into Lower Piti Channel or the Commercial Port area. These "worst cases" are similar to conditions observed in October 1974, during testing and start-up operations for the Cabras Plant, and also in August 1972 (see Marsh and Gordon, 1973) when only the Piti Plant was operating. Note that the "worst case" conditions reported here include the Commercial Port area as well as Piti Channel.

Figure 7B presents an isotherm plot that includes observations in the shallow mangrove and tidal flat area south of Dry Dock Peninsula (Fig. 1), which forms the southern limit of the usual study area. This mangrove area has not previously been included in our

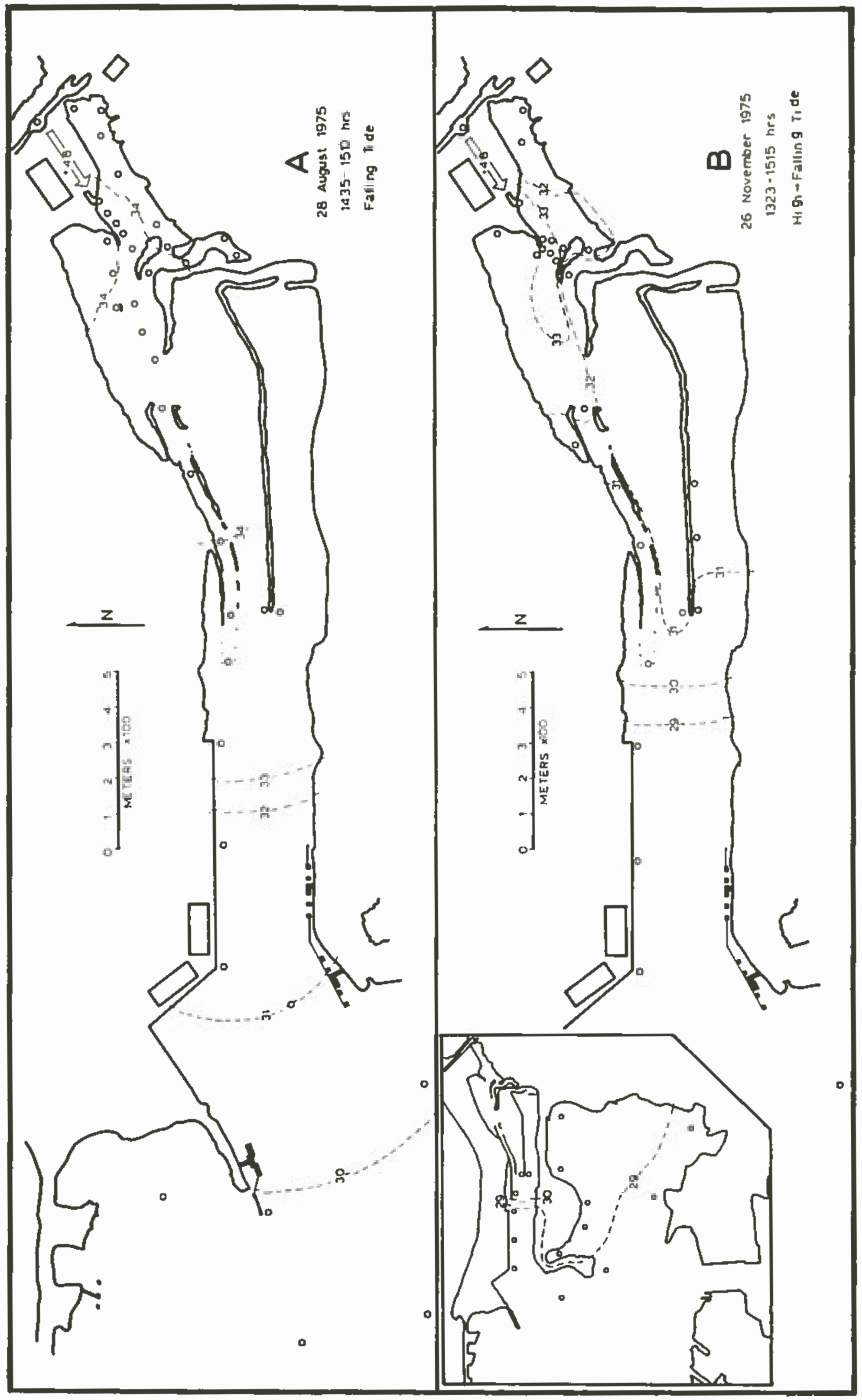


Figure 7. "Worst case" temperature pattern (Figure 7A) and surface temperatures in Piti Channel (Figure 7B) in comparison to an area outside power plant influence (Figure 7B inset). A. 1435-1510 on 28 August 1975. B. 1323-1515 on 26 November 1975.

observations but is in some ways similar to the tidal flats of the study area. It is a semiclosed area 1-2 m deep which has no water circulation other than that induced by tidal exchange and it is not subject to any possible thermal effects from the power plants. On the afternoon of 26 November 1975, temperatures in this area were cooler than those on the tidal flats of the usual study area by as much as 2.0-2.5°C (Fig. 7B). South of Dry Dock Peninsula, warmer temperatures occurred on the tidal flats and mangrove areas and cooler temperatures in the adjacent deeper waters. Elsewhere in the usual study area, conditions were similar to those often observed on other occasions. The portion of the outfall lagoon influenced by the Piti Plant was 1.5-2.0° cooler than the portion under Cabras Plant influence. The 33° isotherm lay in Upper Piti Channel, and the 32° isotherm lay near the GORCO pipeline. A steep temperature gradient existed in the eastern end of the Commercial Port area, with the 30° and 29° isotherms lying close together in that region.

The isotherm plots discussed above are sufficient to give an idea of the temperature range and usually encountered conditions in the study area since the Cabras Plant began full operations. Additional observations are presented in Table 1, which shows temperatures at selected stations (located in Fig. 5) at different sampling times.

From the information in Table 1 it may be noted that the temperature increase through the Cabras Plant ranged from 3.1° to 6.0° at the times when field observations were made, with the values mostly showing a through-the-plant increase of 3-4°C. However, we know from other data in this report, especially that derived from the maximum/minimum thermometers, that the increase is sometimes greater and the outfall temperatures higher than shown in Table 1. The table also shows that the Piti Plant outfall had generally lower temperatures after October 1975 than before that, and this was reflected in other stations in the upper part of the outfall lagoon as well. Piti outfall temperatures were generally higher than Cabras outfall temperatures until August 1975 and lower after that. Table 1 also shows generally lower temperatures at all stations during the first part of 1976 than during the last part of 1975. Not surprisingly, there is a general downstream (westward) decrease in temperatures below the Cabras Plant at all sampling times.

Diurnal Isotherm Plots

Most of our isotherm plots have been for the daytime hours. In order to get an idea of how these might change with the time of day, we made a series of observations designed to cover a diurnal and tidal cycle on 22-23 June 1975, beginning with noontime low-tide observations on 22 June. The predicted tides were as follows: 1252, -0.4 ft.; 2015, 2.4; 0106, 1.6, and 0610, 2.4. Measurements of surface temperatures at a large number of stations throughout the channels and tidal flats were made four times at successive high and low tides. Results are presented as isotherm plots in Figs. 8 and 9.

Table 1. Temperatures at various stations for various dates, times of day, tides, and weather conditions since the Cabras Power Plant began full operations. Tides: H, high; F, falling; L, low; R, rising. Weather: S, sunny; O, overcasts; R, rainy. See Fig. 3 for station locations.

	DATE 1975							
	22 Jun.	22 Jun.	23 Jun.	23 Jun.	27 Aug.	28 Aug.	28 Aug.	18 Sept.
Time	1227-1355	1927-2050	0050-0206	0550-0634	1608-1717	1438-1510	1706-1730	1142-1245
Tide	L	H	L	H	L	F	L	L
Weather								
Station								
I	-	-	-	-	30.0	30.0	30.0	-
3	32.5	31.3	-	30.6	33.7	-	34.4	32.2
4	32.8	31.6	31.3	30.8	33.9	-	-	-
5	33.0	31.6	31.3	30.8	33.8	-	-	32.4
6	33.0	32.0	31.3	30.8	33.5	-	-	32.2
7	34.7	32.4	31.3	30.8	33.3	-	-	31.8
8	32.8	32.2	31.4	30.9	33.0	-	-	32.6
9	32.7	32.7	31.6	31.1	32.8	34.5	33.3	31.4
10	32.1	32.7	31.8	30.9	32.4	34.0	-	31.4
11	32.3	31.6	31.3	31.5	31.2	33.9	-	30.1
12	33.9	32.6	31.5	31.4	33.7	33.7	-	33.5
13	33.7	32.6	31.6	31.2	33.6	33.6	-	32.4
14	33.7	32.8	31.7	31.2	33.7	33.5	-	33.0
15	33.5	32.9	31.7	31.2	33.5	33.5	-	32.7
16	33.1	31.5	31.3	31.2	33.8	34.6	34.5	34.1
17	32.9	32.9	31.7	31.1	-	34.6	-	33.9
18	33.1	32.9	31.7	31.2	33.0	34.6	34.4	33.7
19	32.2	32.5	31.5	30.5	-	33.7	-	29.8
20	33.0	32.7	31.5	31.1	33.0	34.3	34.2	33.4
21	33.0	32.5	31.2	30.9	33.3	34.4	34.0	32.2
22	33.0	31.2	31.1	30.7	33.2	34.0	34.0	32.3
23	32.7	30.3	30.9	30.2	33.2	33.7	-	32.0
24	30.8	29.5	30.1	29.3	33.0	33.2	-	31.2
25	-	28.6	30.1	28.7	31.8	31.4	-	30.6
26	29.6	28.6	28.9	28.7	29.6	29.9	-	29.6
RdA	29.4	28.6	28.5	28.6	29.2	29.9	-	29.0
B1	29.1	-	-	29.6	29.2	29.7	-	29.3
FB	-	-	-	-	-	-	-	-
FC	-	-	-	-	-	-	-	-
FD	-	-	-	-	-	-	-	-

Table 1. (continued)

	1975								
	18 Sept.	18 Sept.	19 Sept.	22 Sept.	1 Oct.	26 Nov.	12 Dec.	19 Dec.	19 Dec.
Time	1245-1258	1300-1344	1635-1720	1609-1617	0950-1024	1323-1515	1328-1430	1000-1036	1330-1424
Tide	L	L	R	L-R	L	H	H	H	L
Weather									
Station									
I	-	-	30.9	-	-	29.0	29.0	-	28.5
3	-	32.2	-	-	-	31.5	32.2	29.6	31.3
4	-	32.7	-	-	-	-	32.6	29.7	31.6
5	-	32.6	-	-	-	-	32.7	29.6	31.2
6	-	32.5	-	-	-	-	32.3	29.1	30.6
7	-	-	-	-	-	-	32.0	-	30.6
8	-	-	-	-	-	-	32.4	30.5	31.5
9	-	-	-	-	32.0	31.0	-	31.1	31.5
10	-	-	-	-	31.8	-	-	-	-
11	-	-	-	-	30.9	-	-	-	-
12	33.6	-	-	-	32.2	31.8	30.2	28.7	29.7
13	33.4	-	-	-	31.8	-	30.8	29.4	29.4
14	33.5	-	-	-	32.1	31.8	30.8	29.5	29.4
15	33.3	-	-	-	32.1	-	30.7	30.6	31.3
16	34.2	35.0	37.0	35.0	33.9	33.8	33.8	33.5	32.9
17	34.2	34.7	-	-	-	-	33.7	-	-
18	33.8	34.3	36.0	34.8	33.3	33.2	33.3	31.7	-
19	-	-	34.2	-	-	-	31.4	-	-
20	33.5	33.9	-	34.6	33.1	-	32.8	30.4	31.7
21	33.0	33.1	-	34.0	32.8	32.2	32.5	30.2	31.3
22	-	32.5	-	33.8	32.4	30.5	31.3	28.6	31.0
23	-	32.1	-	33.5	32.2	30.6	31.3	28.1	30.4
24	-	31.0	-	-	-	28.7	29.1	28.1	28.4
25	-	31.2	-	-	-	28.3	28.7	28.1	28.3
26	-	30.0	-	-	-	-	28.6	28.0	-
RdA	-	-	-	-	-	-	-	28.1	-
B1	-	29.6	-	-	-	-	-	28.3	-
FB	-	-	-	-	-	-	32.6	-	32.2
FC	-	-	-	-	-	31.5	32.4	-	31.5
FD	-	-	-	-	-	30.0	32.3	-	29.5

Table 1. (continued)

	1975			1976				
	26 Dec.	2 Jan.	5 Jan.	8 Jan.	9 Jan.	16 Jan.	23 Jan.	29 Jan.
Time	1000-1124	1427-1553	1348-1416	0902-1005	1335-1453	0911-1040	1307-1410	1419-1515
Tide	R	L	F	R	F	F	F	R
Weather								R
Station								
I	28.5	28.3	28.3	-	28.3	-	28.0	27.1
3	29.7	31.5	31.9	29.6	31.3	29.4	30.9	28.6
4	29.6	31.6	32.2	29.5	31.5	29.9	30.8	29.0
5	29.9	31.4	31.8	29.5	31.3	29.7	30.6	28.8
6	29.8	31.5	31.3	29.9	30.6	28.6	29.5	28.5
7	30.5	31.0	31.1	30.1	30.7	29.1	29.9	28.6
8	-	-	-	30.7	-	29.9	30.8	-
9	-	31.1	31.6	29.8	30.2	31.0	30.8	28.4
10	-	-	-	30.1	30.3	29.8	30.2	28.2
11	-	-	-	30.2	30.1	29.4	29.8	27.9
12	30.0	31.6	-	30.0	30.6	29.6	29.7	29.1
13	29.6	31.4	-	29.8	30.2	29.5	29.5	28.6
14	29.6	31.4	-	29.8	30.6	29.6	29.6	28.8
15	29.7	31.5	-	29.9	30.6	30.7	29.7	28.9
16	33.0	33.0	33.8	32.6	32.7	32.6	32.6	31.5
17	-	-	-	-	32.5	32.3	32.3	30.7
18	32.0	32.2	33.5	31.8	32.5	31.9	31.4	30.7
19	-	-	-	30.3	31.3	29.7	30.3	-
20	31.7	32.2	-	31.6	32.0	31.0	31.0	30.4
21	30.4	32.1	32.5	30.4	31.7	30.7	30.9	29.1
22	29.4	31.2	31.8	28.8	30.7	30.2	29.4	28.2
23	28.2	29.4	31.0	28.2	30.0	29.1	29.4	27.4
24	28.3	29.5	-	28.6	29.8	28.1	28.2	27.3
25	28.2	29.6	-	28.5	28.6	27.7	27.9	-
26	-	28.8	-	28.4	28.3	27.7	27.9	-
RdA	-	28.6	-	28.2	28.2	-	-	-
Bl	-	28.6	-	28.2	28.3	27.7	-	-
FB	31.4	32.4	32.8	31.3	31.8	31.2	30.9	29.9
FC	30.5	31.8	32.4	-	31.5	30.5	30.9	28.7
FD	29.1	30.4	30.8	-	29.8	28.6	30.6	26.9

Table 1. (continued)

30 Jan.	13 Feb.	26 Feb.	2 April	9 April
1408-1523	1427-1524	1400-1420	1436-1524	1340-1430
L	R	R	L	H
				O
-	28.0	27.5	28.7	27.7
-	29.4	-	-	29.1
-	29.8	-	-	28.3
-	29.7	-	-	29.5
-	29.2	-	-	29.2
-	29.4	-	-	29.5
-	29.7	-	-	28.8
27.9	29.1	30.0	30.7	29.4
28.8	28.6	-	30.6	28.4
27.9	28.2	-	30.1	28.5
29.1	28.4	29.8	29.3	31.1
28.8	28.4	29.9	29.2	31.6
28.9	28.2	30.0	29.3	31.3
29.1	28.6	30.0	29.3	30.3
31.7	31.5	30.8	32.6	30.8
31.4	31.1	-	32.0	30.5
-	30.7	30.6	31.7	30.4
-	-	-	-	-
-	30.3	30.3	31.4	30.0
-	29.3	30.2	31.1	28.9
-	29.2	29.7	31.1	28.9
-	27.5	28.0	30.9	28.2
-	-	28.0	30.4	28.3
-	-	27.5	28.6	27.9
-	-	28.0	28.0	27.9
-	-	-	27.9	27.6
-	-	-	27.8	27.8
-	-	-	29.0	30.0
-	-	-	32.0	29.0
-	-	-	31.2	29.4

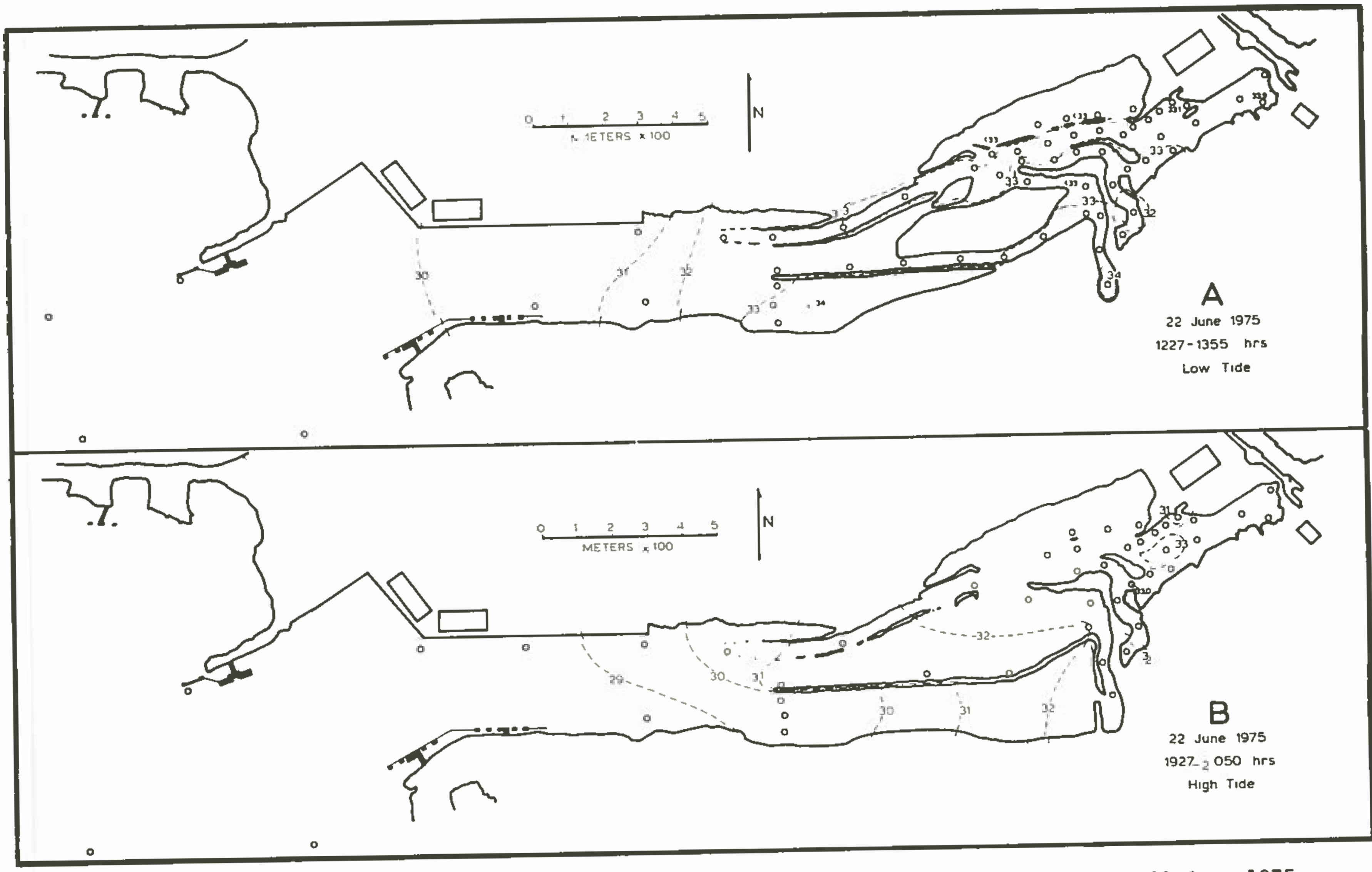


Figure 8. Surface temperatures in the Piti Channel area during low and high tides on 22 June 1975. A. During a low tide predicted to be -0.4 ft. at 1251. B. During the following high tide predicted to be +2.4 ft. at 2015.

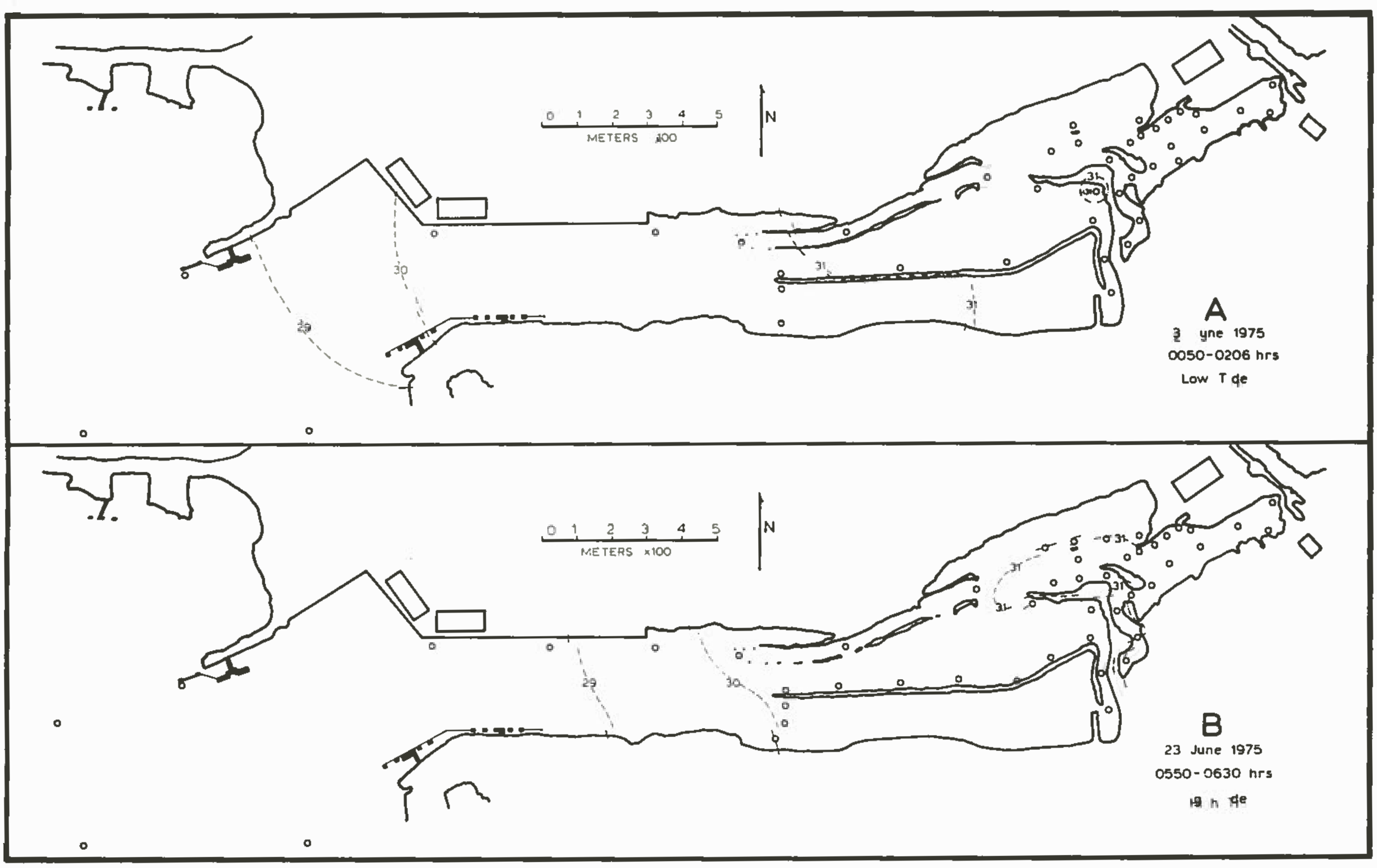


Figure 9. Surface temperatures in the Piti Channel area during low and high tides on 23 June 1976. A. During a low tide predicted to be +1.6 ft. at 0106. B. During the following high tide predicted to be +2.4 ft. at 0651.

At the time of the noon low spring tide on 22 June (Fig. 8A), much of the area of Tidal Flats C and D was exposed to the air and had no standing water. Temperature at the Piti Plant outfall (33.9°C) was 0.8° higher than the Cabras Plant outfall. The 33° isotherm enclosed much of the outfall lagoon and extended downstream in Piti Channel, enclosing more than half of Lower Piti Channel. Portions of the connecting channel and secondary channel also contained water exceeding 33°, and the cul-de-sac extension of the connecting channel had water in excess 34°. This high temperature water had drained off the exposed tidal flats during the falling tide. The 32° isotherm at this time lay at the lower (western) end of Lower Pite Channel, with the 31° isotherm just west of it in the eastern end of the Commercial Port area. The 30° isotherm lay approximately in the middle of the Commercial Port area.

By the time of the high tide just after dusk (Fig. 8B), there was 33° water at only two stations, with the rest of the outfall lagoon having water mostly with a temperature of 32.8-32.9°C. Water at the Cabras outfall was 31.5° lower than water at the Piti outfall by 1.1°. The 32° isotherm lay approximately one-third of the way down Lower Piti Channel, and the 31° isotherm lay about two-thirds of the way down Lower Piti Channel. Both the 30° and 29° isotherms lay in the eastern end of the Commercial Port area, and most of the Commercial Port area had water lower than 29°C.

By the time of the midnight low-tide sampling (Fig. 9A), there was no water anywhere with temperatures in excess of 32°, and the outfall lagoon was filled with water between 31° and 32°. Temperatures at the Piti and Cabras outfalls were similar. The 31° isotherm lay in Lower Piti Channel in the same approximate position as in the previous high-tide sampling. The 30° and 29° isotherms lay in the western end of the Commercial Port area and thus enclosed more extensive areas than at the previous high tide.

At the dawn high-tide sampling (Fig. 9B) the outfall lagoon was filled with water having a temperature between 31° and 32°C, and the Cabras and Piti outfalls had similar temperatures. The 31°isotherm had moved eastward into Upper Piti Channel, enclosing its smallest total area of the entire cycle. The 30° and 29° isotherms lay in the eastern end of the Commercial Port area, in the same approximate locations as in the dusk high-tide sampling ten hours earlier.

Isotherm plots during this diurnal cycle indicate that most parts of the outfall lagoon and Piti Channel were subjected to diurnal variations of approximately 2°C. This also the case for the limited number of stations on the tidal flats, part of the connecting channel and in the western end of the secondary channel. Diurnal fluctuations in the eastern end of the secondary channel and in the cul-de-sac of the connecting channel were greater, being 3° to 4°. These diurnal variations are not as great as day-to-day variations suggested by the data from the maximum/minimum thermometers (discussed below). It was not surprising to find high-temperature water draining off Tidal Flat D at the noontime low spring tide; indeed, the sampling time was deliberately chosen to examine this situation. Clearly, on this occasion there was higher-tmeperature water draining off the tidal flat than was being put out by the power plants. However, the effluent from the Cabras Plant was at least a degree lower on this occasion than we have usually found in our daytime observations. Moreover, we usually find Cabras outfall temperatures to be higher than Piti outfall temperatures, in contrast to the situation discussed here.

Maximum/Minimum Temperatures

Maximum/minimum thermometers were secured at various sites (Fig. 10) in the study area and left in place for several months. These were read and reset at periodic intervals, with readings being made to the nearest 0.5 degree. Three of these thermometers were qraduated in Fahreheit units, but the readings from these were converted to the nearest 0.5 degree Centigrade. Results from all sites are shown in Table 2.

The instrument at the Cabras Plant cooling-water intake site was secured to the grillwork in front of the pumps at a depth of approximately 3 m. Later in the study period the instrument was moved to the side of the intake area at a new depth of approximately 1 m below MLLW. Minimum temperatures recorded by this thermometer ranged from 28.0 to 28.5°C (with the exception of 1 reading of 30.0°) during August and September 1975 and from 26.0 to 27.0°C (with the exception of 1 reading of 28.0°) from November 1975 through March 1976. The maximum recorded temperatures were 30.0-31.0°C in August and September and 28.5-29.5° (with 1 exception of 30.0°) from November through March. The average mean temperature for November through March was 27.9° (5=0.5°). Mean temperatures were calculated as the average of the maximum and minimum temperatures for each reading period.

An instrument placed in the outfall channel for the Cabras Plant generally recorded minimum temperatures of 31.0-32.0°C from August through October 1975 and maximum temperatures of 34.0-37.0°C. This instrument was later moved to another site after the YSI recording telethermometer was installed at the outfall site.

A maximum/minimum thermometer was also maintained in shallow water near Station 18 at the downstream end of the seawall that extends westward from the Cabras outfall along the northern side of the outfall lagoon (see Fig. 4). Minimum temperatures at this location ranged from 29.0 to 29.5°C (with one exception) from November 1975 to January 1976 and from 27.0 to 28.0°C from January to April 1976. Maximum temperatures were 33.0-34.5 during the former interval and 32.0-33.0 during the latter interval, with one exception in each case.

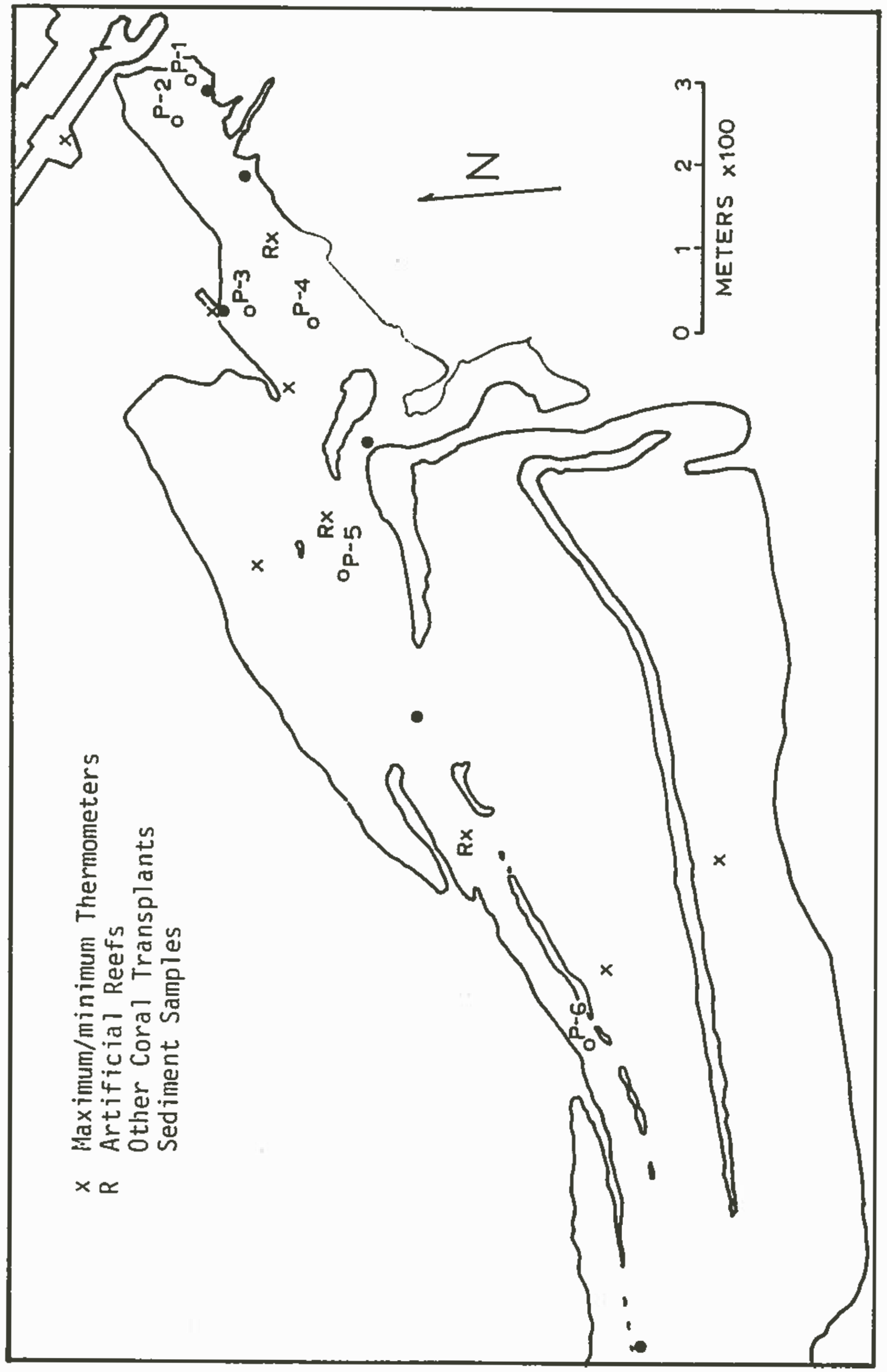


Figure 10. Location of sampling stations.

A thermometer maintained on Tidal Flat B (see Fig. 10 for specific location) recorded minimum temperatures of 29.0-30.0° from September to January and 28.0-29.0° from January to April, except for one lower reading of 25.5° in February. The maximum temperatures ranged from 33.0 to 34.5° during the earlier period and 32.0 to 32.5° (with 1 exception) in the latter period. The recorded temperatures for Tidal Flat B closely paralleled those for Sta. 18.

There is a suggestion of slight seasonality in maximum and minimum temperatures in the data from the thermometers at the cooling-water intake, Sta. 18, and Reef Flat B. Such seasonal changes approximate 1.0 to 1.5°C. The pattern is not well established in our data, however. Possible seasonal changes have a smaller range than diurnal or day-to-day changes.

A thermometer on Tidal Flat C (Fig. 10) showed minimum temperatures generally of 27.0-28.0°C from September 1975 through April 1976. There were occasional minimum temperatures outside this range, the most notable example being a period of lower temperatures in the range 22.5-25.5° in February and March 1976. Maximum temperatures at this site ranged from 33.0 to 34.5° from November to March and 31.5 to 32.5° from January to April, again suggesting possible seasonality. Minimum temperatures were more variable than maximum temperatures on Reef Flat C.

On Tidal Flat D (Fig. 10) minimum temperatures generally ranged from 22.5 to 24.0°C from November 1975 to April 1976, but the total range was from 21.0 to 29.0°. As on Reef Flat C, the lowest temperature occurred in the middle of February. Maximum temperatures ranged from 30.0 to 32.5° throughout the period of record, with the exception of one lower temperature of 29.5°. Maximum temperatures were thus much less variable than minimum temperatures. In the past we have found higher temperatures, ranging up to 34.7° on Tidal Flat D. There is no indication of seasonality in the maximum/minimum temperature records on this tidal flat.

An inspection of Table 2 reveals that, for given time intervals, minimum temperatures on Tidal Flat B are higher than those on Tidal Flat C, which in turn are higher than those on Tidal Flat D. There are only a few exceptions to this, and in these cases the temperature differences are small. Maximum temperatures also have a tendency to be higher on Flat B than Flat C, and higher on Flat C than on Flat D. However, this rank order is not as strongly developed as for minimum temperatures, and the differences between tidal flats are not as great in the case of maximum temperatures. Tidal Flat B is clearly subject to thermal influence from the power plants, and this may sometimes be true for Tidal Flat C. Tidal Flat D is probably subject to solar heating only, although it conceivably could receive some effluent water from the power plants after that water has entered the Commercial Port area and spread out, then flowing back onto the tidal flat on a rising tide.

Table 2 clearly shows a period of lowered minimum temperatures in February and March 1976 for all tidal flats. This was not accompanied by lowered maximum temperatures. Again, the lowered minimum temperatures reflected a descending rank order from Tidal Flats B to C to D. The lowered minimum temperatures on all flats may reflect subaerial exposure during nighttime low spring tides or lowered water temperatures due to heavy rainfall.

Figs. 11-13 show another way of looking at the maximum-minimum data. In these figures, each reading is plotted using maximum and minimum values as x and y coordinates respectively. Along with these x and y axis, a second pair of axis is depicted. Points with equal ranges (i.e., maximum minus minimum) fall along a line with a slope of +1. Points with equal temperatures (i.e., the average between maximum and minimum) fall along a line with a slope of -1. Hence each cluster of points representing the temperature regime of a given location can be compared in four ways: minimum, maximum and mean temperatures and temperature range.

Fig. 11 shows the temperatures at Station 18 are consistantly higher than in Piti Canal (intake). The average temperature at Station 18 during the period from December 1975 to April 1976 was 30.5 (S.D. = 0.9) and 27.9 (S.D. = 0.5) in Piti Canal. Furthermore, Station 18 experienced a greater temperature range (4.5°C, S.D. = 0.9) than Piti Canal (2.6°C, S.D. = 0.6).

Fig. 12 clearly shows a separation of the temperature regimes of Tidal Flat D from those of Tidal Flats B and C with Flat D having generally lower maximum and minimum temperatures. The figure also shows some separation between Flats B and C with lower minimum temperatures for Flat C but not lower maximum temperatures. The figure again shows greater differences in minimum temperatures than in maximum temperatures between the different tidal flats. It shows greater constancy of maximum temperatures than of minimum temperatures on Flat D, but this is not markedly the case for Flats B and C. Finally, Fig. 12 shows a greater range between maximum and minimum temperatures for Flat D than for Flats B and C. The average temperature from December 1975 to April 1976 was 30.8°C (S.D. = 0.8) on Flat B, 30.0°C (S.D. = 1.1) on Flat C and 27.8°C (S.D. = 1.1) on Flat D.

From the foregoing discussion and from previous years' results, it is clear that the major thermal influence of the power plants on the tidal flats is not in raising short-term temperature levels higher than would sometimes occur because of solar heating, but rather in imposing maximum temperatures a greater proportion of the time and especially in raising minimum temperatures above the natural level most of the time. The effect of the power plants is to impose a greater temperature constancy on Tidal Flat B and possibly on Tidal Flat C, with this more constant level being in the upper part of the natural temperature range.

Table 2. Minimum/maximum temperatures (°C) at selected sites in the study area from August 1975 to April 1976. Underlined values represent the temperature at the time of previous resetting of the thermometer. Temperatures at the stations on Tidal Flats B, C, and D were measured in °F and converted to the nearest 0.5°C.

Observation Interval	Cabras Intake	Cabras Outfall	Sta. 18	Tidal Flat B	Tidal Flat C	Tidal Flat D	Sta. 15	Sta. 20	Sta. 2
					Station				
16-18 Aug. 75	28.0/31.5	31.0/34.0							
18-27 Aug.		29.0/35.0							
27-28 Aug.	28.0/30.5	32.0/35/0							
28 Aug. - 5 Sept.	28.5-30.5	31.0/36.0							
5-10 Sept.	28.5/31.0	30.5/34.0							
10-11 Sept.	28.5/30.0	31^- /34^-							
11-15 Sept.	28.5/30.5	32^+ /36.0							
15-19 Sept.	30.0/32.0	31.0/37.0							
19-22 Sept.		33.5/37.0							
22 Sept.-17 Oct.		31.0/37.0							
19 Sept.-26 Nov.	27.0/32.5								
26 Nov. - 6 Dec.			30.5/34.5	29.0/33.5	27.5/33.5	28.0/29.5			
6-10 Dec.	26.5/29.5		29.0/33.5	29.5/34.0	27.0/33.5	23.5/31.5			
10-12 Dec.	26.5/29.5		29.5/33.0	30.5/34.0	30.5/33.0	29.0/31.0			
12-19 Dec.	27.0/29.0		29.0/33.5	29.0/33.5	27.5/33.0	24.5/31.5			
19-26 Dec.	26.5/29.0		29.0/32.0	28.0/33.0	27.0/32.0	23.0/30.5			

Table 2. (continued)

Observation Interval	Cabras Intake	Cabras Outfall	Sta. 18	Tidal Flat B	Tidal Flat C	Tidal Flat D	Sta. 15	Sta. 20	Sta. 21
26 Dec 75- 2 Jan 76	27.0/31.0		29.0/34.5	29.0/34.5	27.0/34.5	23.5/32.5			
2-5 Jan.	27.0/30.0		29.0/34.5	29.0/34.5	27.0/34.5	22.5/32.5			
5-9 Jan.	27.0/29.0		29.5/33.0	30.0/33.5	28.0/33.0	25.0/30.0			
9-16 Jan.				29.5/33.5	31.5/32.5	24.0/30.0			
9-23 Jan.	26.5/29.0		29.0/32.0						
16-23 Jan.				29.0/33.0	28.0/32.0	23.0/30.5			
23-29 Jan.	27.0/28.5		28.0/32.5	28.0/32.5	26.5/31.5	22.5/30.0			
30 Jan- 5 Feb.							28.0/29.5		
29 Jan- 5 Feb.	26.5/28.5		28.0/32.5	29.0/32.5	27.0/32.5	24.5/30.0			
5-13 Feb.	27.0/29.0		28.0/32.0	28.0/32.0	27.0/31.5	24.0/30.0	28.0/29.0	28.0/32.0	28.0/31.5
13-24 Feb.	26.0/29.0		27.0/32.0	25.5/32.5	22.5/32.0	21.0/31.0	27.0/30.5	28.0/32.5	26.0/32.0
24-27 Feb.	26.0/28.5		28.0/31.0	28.0/31.0	25.5/31.5	23.0/30.5	28.5/31.0	28.5/31.0	27.5/30.0
27 Feb- 5 Mar.	26^+/29.0		27.0/32.0	28.0/32.5	25.5/32.0	23.5/31.0	27.0/31.0	27.0/32.0	28.0/32.0
5-12 Mar.	26.0/28.5		27.0/32.0	29.0/32.0	28.5/32.0	24.5/30.5	27.0/30.0	28.0/31.0	28.0/31.0
12-17 Mar.	26.0/28.5		27.5/32.5	28.0/32.0	27.5/32.0	25.5/32.5	28^-/29.5	28.0/31.5	27.5/31.5

Table 2. (continued)

Observation Interval	Cabras Intake	Cabras Outfall	Sta. 18	Tidal Flat B	Tidal Flat C	Tidal Flat D	Sta. 15	Sta. 20	Sta. 21
17-27 Mar.	26.0/29.5		27.5/33.0	28.5/32.0	28.0/32.0	27.0/32.5	28.0/29.0	28.0/32.0	28.0/31.5
27 Mar- 2 Apr.	26.5/29.0		27.0/32.5	28.5/32.0	29.0/32.5	26.0/31.5	27.0/29.0	28.0/32.0	28.0/31.0
2-9 Apr. 76	27.5/30.0		27.0/33.0	28.0/32.5	29.0/32.5	28.0/31.0	27.0/29.0	28.0/32.0	28.0/32.0

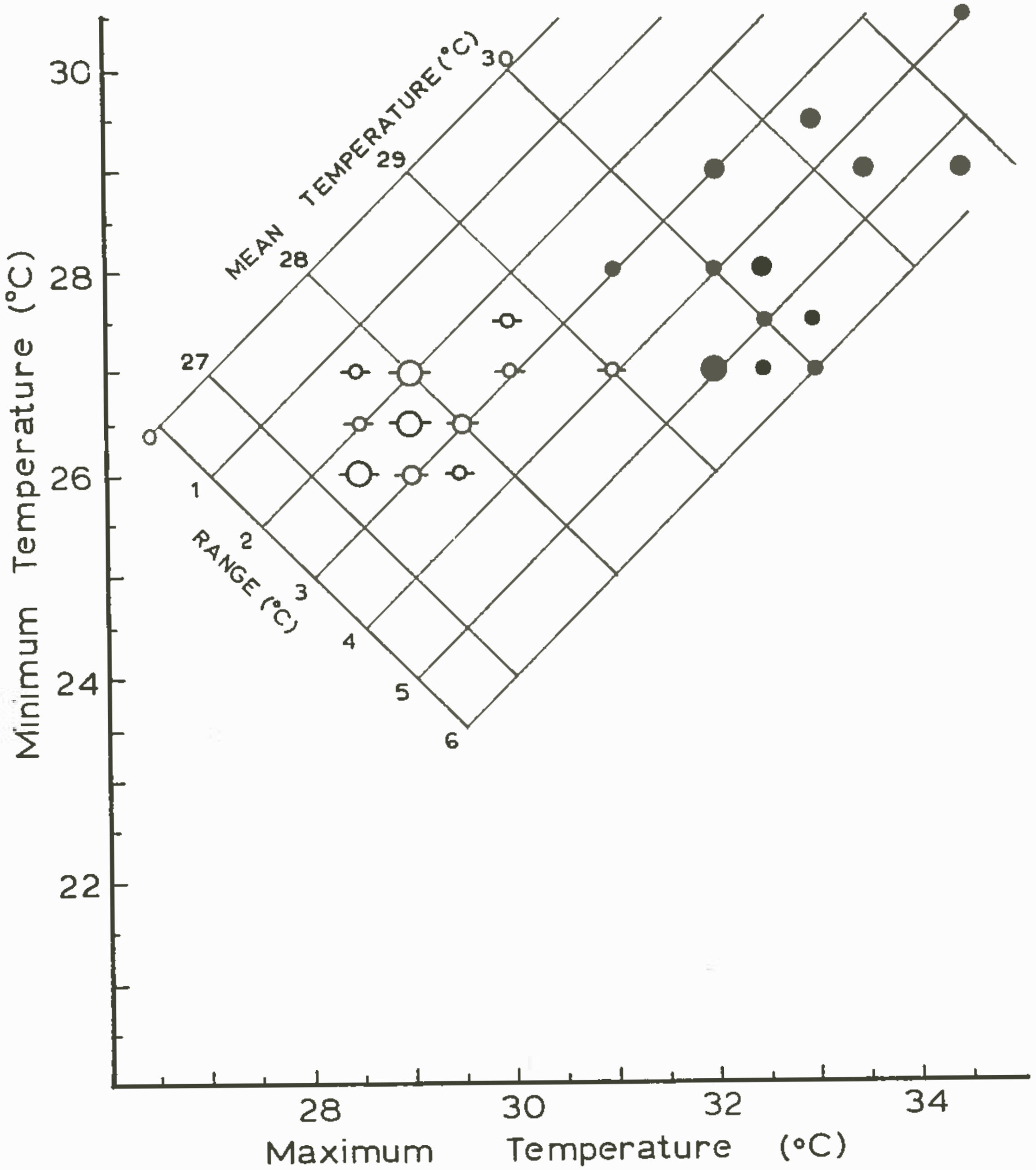


Figure 11. Maximum and minimum temperatures occurring between 26 November 1975 and 9 April 1976 at the Cabras intake (-o-) and Station 18 (●). The size each symbol is proportional to the number of replicate data points, (o = 1, O = 2, ◯ = 3). Coinciding data points from differing stations are slightly offset for clarity. The actual values are given in Table 2.

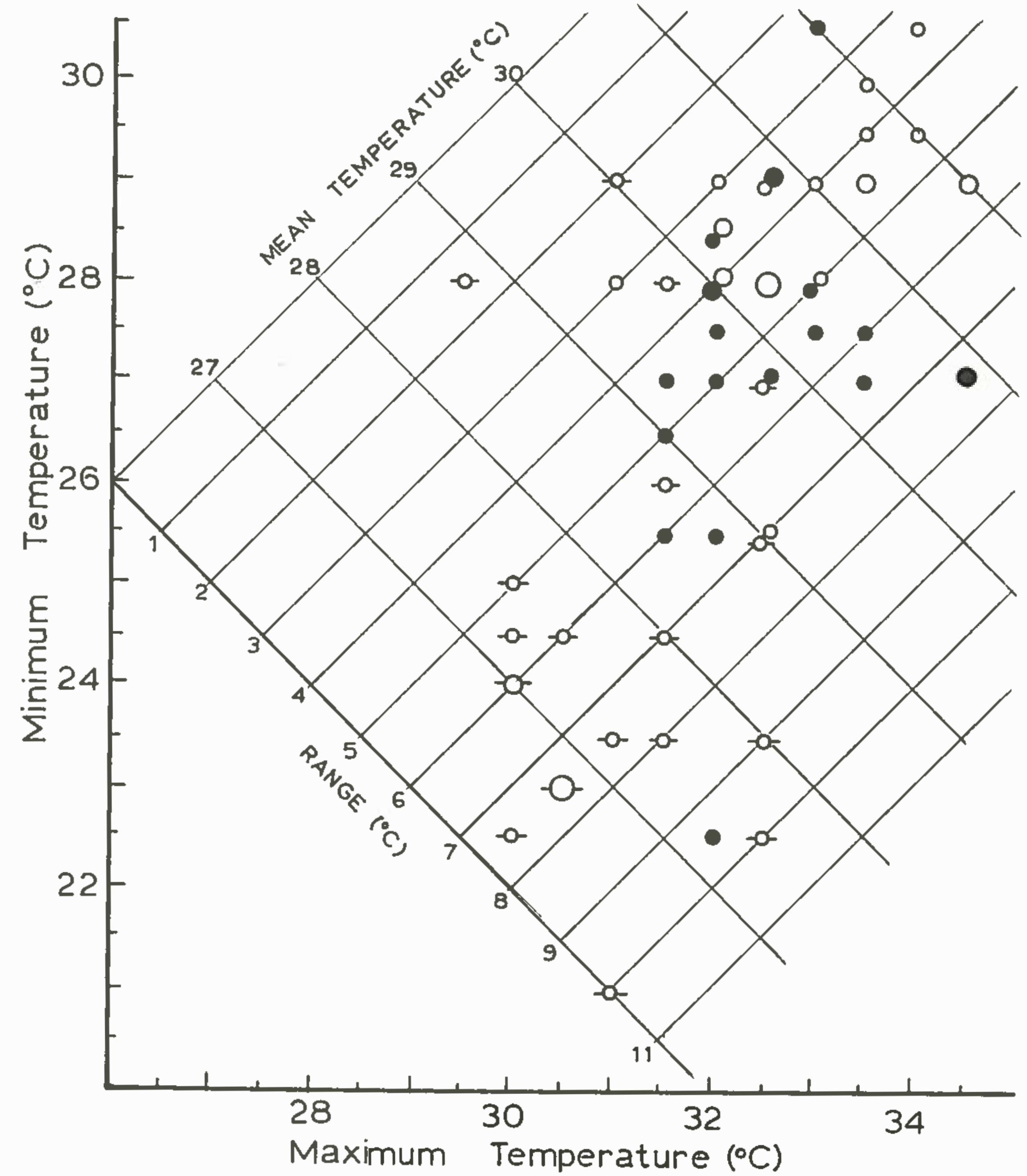


Figure 12. Maximum and minimum temperatures occurring between 26 November 1975 and 9 April 1976 on Tidal Flats B (o), C (●) and D (-o-). The size of each symbol is proportional to the number of replicate data points, (o = 1, O = 2, ◯ = 3). Coinciding data points from differing stations are slightly offset for clarity. The actual values are given in Table 2.

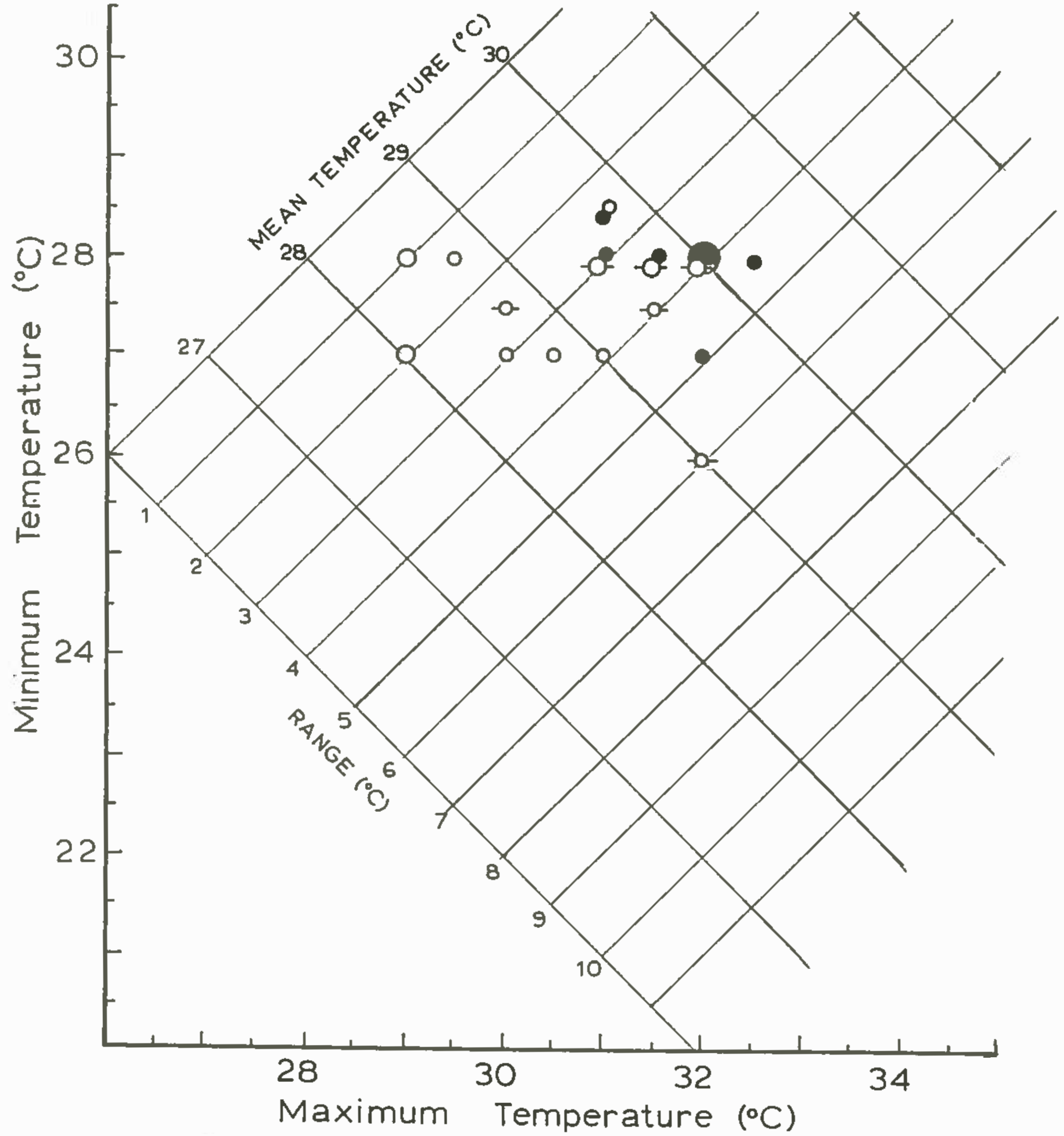


Figure 13. Maximum and minimum temperatures occurring between 5 February 1976 and 9 April 1976 at artificial reefs near Stations 15 (o), 20 (●) and 21 (-o-). The size of each symbol is proportional to the number of replicate data points (o = 1, O = 2, ◯ = 4). Coinciding data points are slightly offset for clarity. The actual values are given in Table 2.

Solar heating alone sometimes raises temperatures as high as those caused by power-plant influence, but the natural temperatures fall back to lower levels at night. The average temperature encountered on Flat D does not differ significantly from that of the intake water (27.8°C, S.D. = 1.1, vs. 27.9°C, S. D. = 0.5, respectively) however, short-term fluctuations are much greater on Flat D than in the intake (6·4°C, S.D. = 2.2, vs. 2.6°C, S.D. = 0.6, respectively).

Thermometers maintained at Stations 15, 20 and 21 in the outfall lagoon and in Piti Channel (Fig. 13), show a relative constancy of both maximum and minimum temperatures within a given station from January to April 1976. These thermometers were located on the bottom, at depths of 1-2 m. The data from both Stations 20 and 21 almost always show higher maximum temperatures than those from Station 15, which is located in an area of the outfall lagoon exposed to influence from the Piti Plant but not the Cabras Plant. The minimum temperatures are generally similar at all three sites. There is no general tendency toward lower maximum or minimum temperatures at Station 21, even though it is located in Lower Piti Channel and might be expected to show such a tendency.

Temperature Records at the Cabras Outfall Site

A YSI multi-channel telethermometer was connected to a recorder maintained at the downstream end of the Cabras outfall channel from November 1975 to February 1976. Thermistor sensors were placed at various sites in or near the outfall stream for continuous temperature records. These observations confirmed the previously observed pattern of assymterical flow of heated water down the axis of the outfall canal, with warmer water forming a plume on the north side of the channel. Once the water leaves the channel it tends to stay close to the seawall that forms the northern edge of the outfall lagoon at that point.

Some representative temperature records for surface waters in the middle of the outfall channel are presented in Figs. 14-15. Fig. 14 show the general diurnal nature of the temperature patterns seen on all the records. The lowest temperatures usually are between 31° and 33°C and occur between 0100 and 0600 hours. After 0600 hours there is a steady temperature rise which continues throughout the morning. Peak temperatures occur in the afternoon or early evening hours and may fall anywhere between 1300 and 2100 hours, more generally occurring between 1500 and 2000 hours. Maximum temperatures are usually greater than 34°C and often go above 36°C. Temperatures of 37°C are not unusual. These continuous temperature records are generally in agreement with observations from the maximum/minimum thermometers and the isotherm plots.

Examples of another pattern which we have commonly seen are shown in Fig. 15. This shows interruptions of gradually changing temperature tracings with sudden changes wherein actual temperatures may drop or rise as much as 2°C. The new temperature levels usually persist for a while and then change again. Sometimes a sudden drop may be followed by another sudden drop after a period of time. We do not know what causes

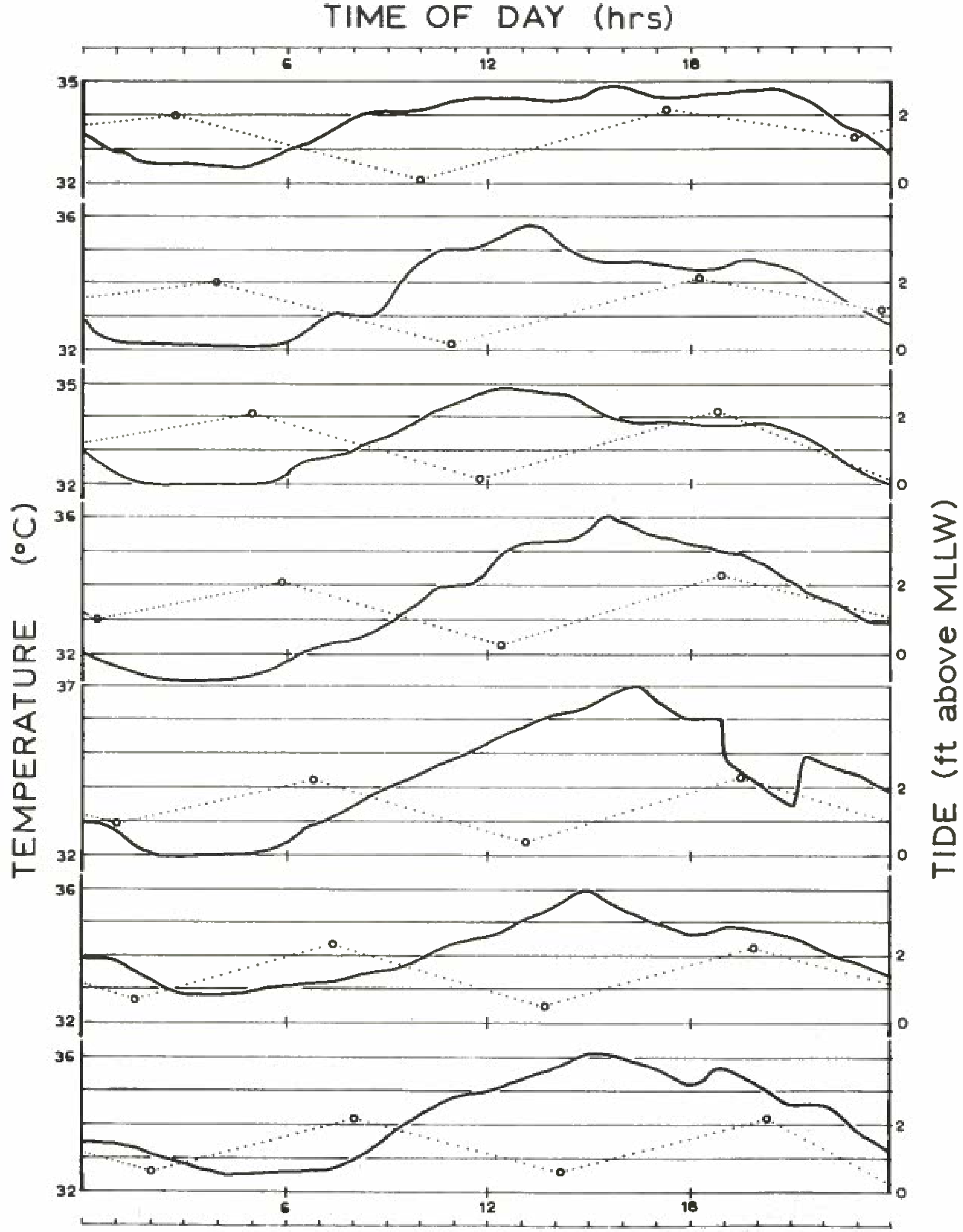
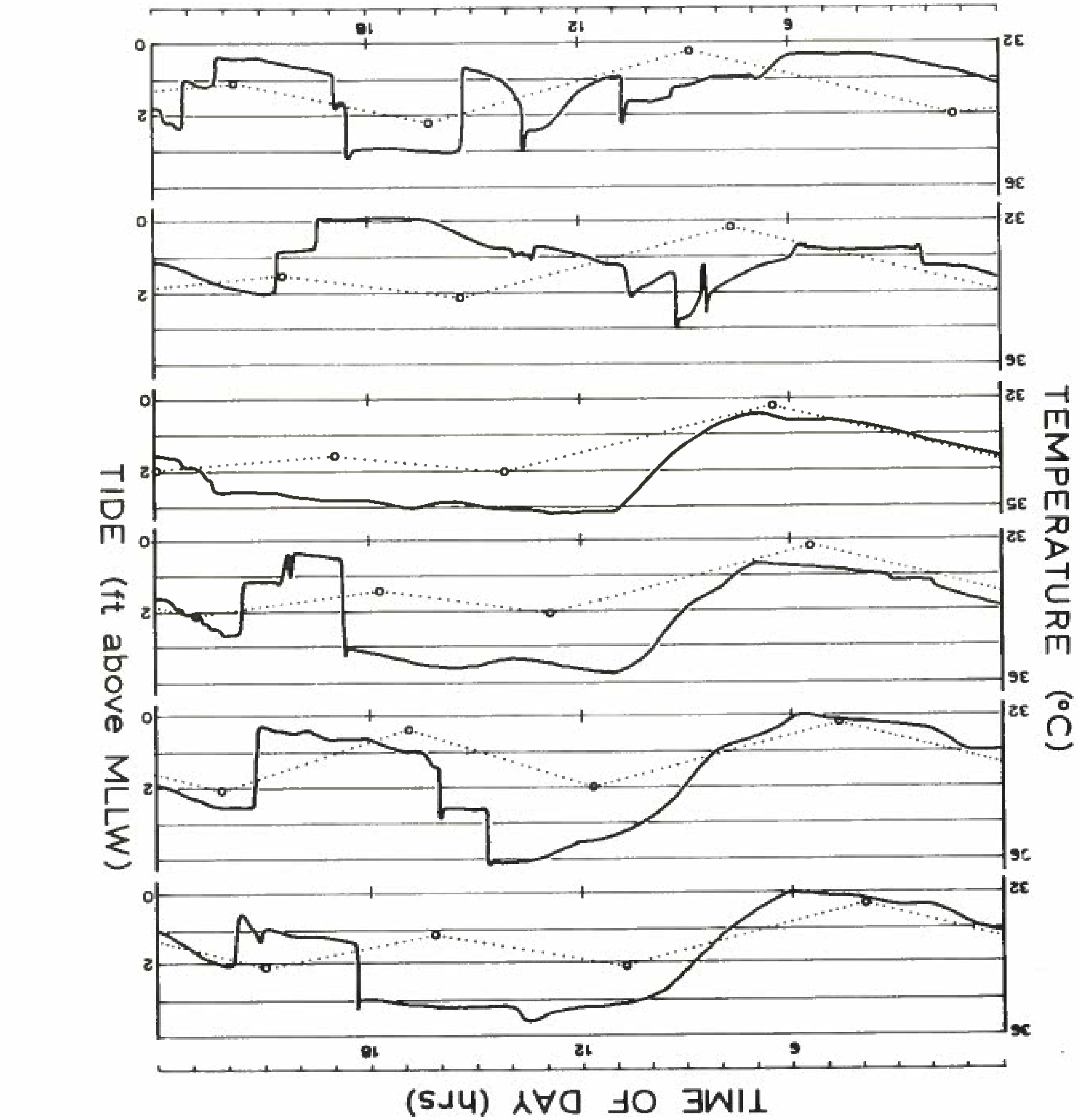


Figure 14. Surface temperatures (°C) and predicted tides (ft. above MLLT) in the Cabras outfall on 15 (above) -21 (below) September 1976.



Figs. 14 and 15 present data for September 1975, the year indicated in the legends is in error. Note that Fig. 15 was also printed upside down.

these abrupt temperature changes, but they might be caused by parallel circulating pumps being cut in or out of the cooling-water system. Such changes are not confined to the afternoon hours illustrated in Fig. 15, but they do occur more commonly at these times.

Vertical Profiles

In our previous report (Marsh and Doty, 1975) we presented temperature-depth profiles for stations at the eastern and western ends of the Commercial Port area and noted the lack of a previously described strong vertical gradient, with warmer extending to the bottom on some occasions, rather than being confined to surface layers. On other occasions there were strong vertical gradients, with warmer temperatures confined to the upper 2-3 m. Additional observations made since our last report are presented in Fig. 16. All observations are for low tides when warmer waters from the power plants have their maximum extension into the Commercial Port area. Fig. 16a & b show profiles for 28 August 1975. At the eastern end of Commercial (Port Sta. 24M) there was a very marked vertical stratification, with surface waters being 3°C warmer than deeper waters. The general pattern also occurred at the western end of the area (Sta. 26), except that surface waters were only about 1.5° warmer than deeper waters. The warmer layer was confined to the upper 1.5 m in both cases. Fig. 16c & d also show profiles for 27 March 1976 at the mouth of Piti Channel (Sta. 23) and the eastern end of the Commercial Port area (Sta. 24M). Temperatures generally were lower on 27 March 1976 than on 28 August 1975, but there was nevertheless a warmer surface layer of water confined to the upper 2 m at the mouth of Piti Channel. This did not extend into the eastern end of the Commercial Port, however, where cooler temperatures (below 28°C) prevailed throughout the water column. On 2 April 1976 (Fig. 16e & f) there was strong vertical stratification at the mouth of Piti Channel (Sta. 23) with warmer water in the upper 2 m, but this did not extend as far as the western end of the Commercial Port area (Sta. 26). We have not found warmer waters extending deeper than 2 m since our last report.

The Problem of Defining "Ambient Temperature"

Water quality standards for thermal discharges are usually defined in terms of "ambient temperature." This necessitates a satisfactory definition of the term "ambient temperature." For the discharge area affected by the Piti and Cabras Power Plants it is difficult to arrive at a satisfactory definition. Obviously the power plants raise the temperature of cooling water passing through their condensers. This cooling water comes from Piti Canal, and ultimately most of it comes from Tepungan Channel. These waters are subject to strong circulation in the intake area during part of the tidal cycle. The intake water thus consists of a mixture of cooler oceanic waters from outside the reef and waters which have been warmed by solar insolation on the shallow reef flat of West Piti Bay. Data on the actual temperatures of the intake waters were presented earlier in this report and in previous reports.

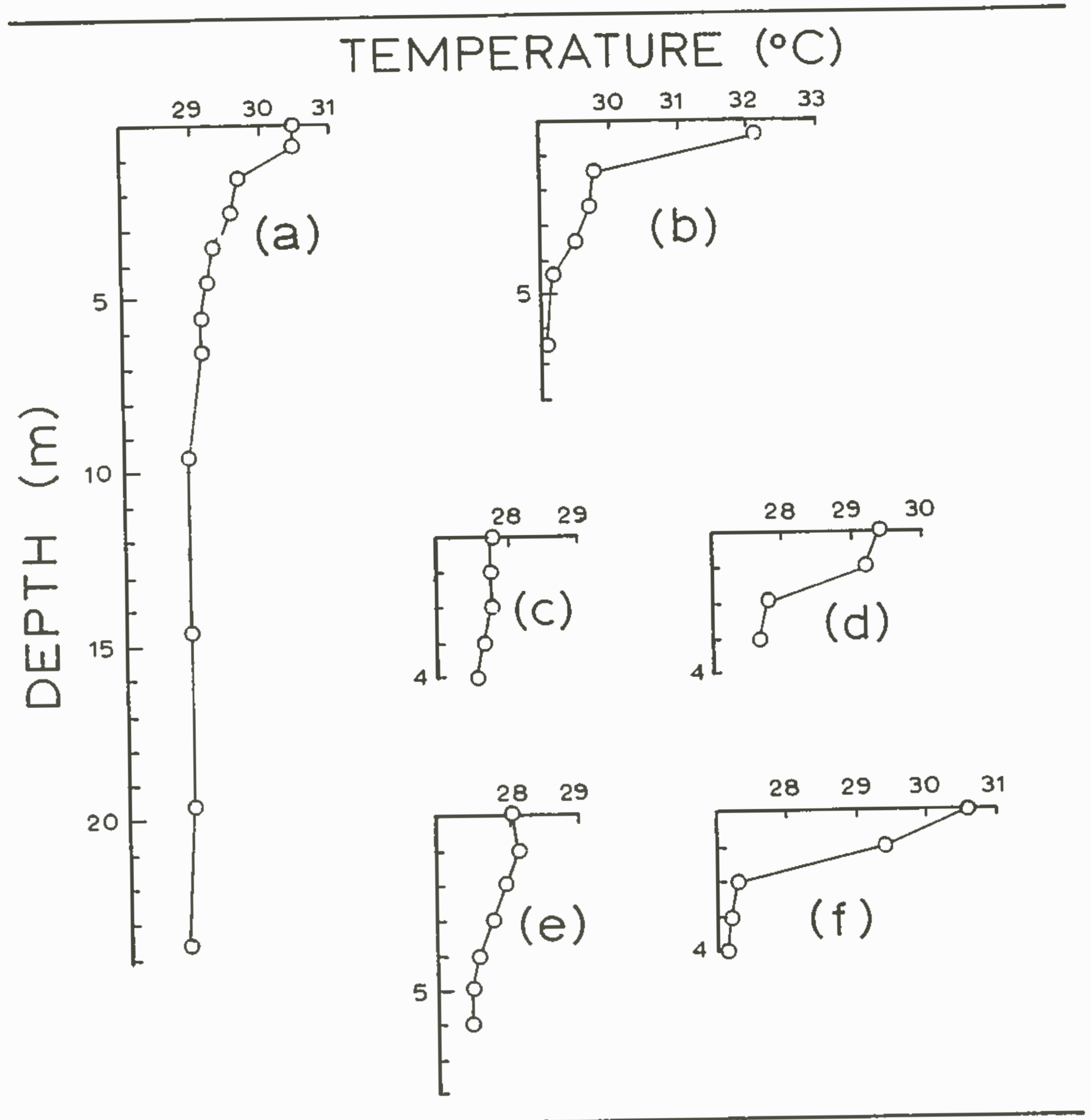


Figure 16. Temperature/depth profiles. (a) 28 August 1975 at Station 26. (b) 28 August 1975 at Station 24M. (c) 27 March 1976 at Station 24M. (d) 27 March 1976 at Station 23. (e) 2 April 1976 at Station 26. (f) 2 April 1976 at Station 23. Station locations are shown in Figure 3A. All measurements were taken at low tides.

Once the cooling water has passed through the power plants it is passed out into the cul-de-sac area which forms the outfall lagoon and Piti Channel. Some of this water passes onto the shallow tidal flats, where solar heating is intense. Solar heating alone sometimes raises temperatures on Tidal Flat D to almost 35°C, which is comparable with the temperature coming from the power plants at least part of the time. Because the channels and outfall lagoon are somewhat deeper, it would not be expected that solar insolation alone would raise temperatures there as high as on the tidal flats. On the other hand, the channels do receive water draining from the tidal flats on falling spring tides. If there were no power plant operations it is likely that waters on the tidal flats and in the channels would occasionally get just as warm as is now the case; however, these areas would not be subjected to the warmer temperatures as much of the time as is the case with the power plants operating.

Temperatures in the Commercial Port area receive water from the power plants and water draining from the tidal flats via the channels during falling tides. The thermal regime of the harbor is thus affected by solar heating on the tidal flats and by water coming from the power plants. At any given time temperatures in the harbor may be warmer or cooler than temperatures on the tidal flats and in Tepungan Channel of West Piti Bay. Hence, water which passes through the power plants may or may not have the chance to cool to its original temperatures as it flows westward in Piti Channel and enters the harbor. How is "ambient temperature" to be defined in this case?

"Ambient temperature" might be variously defined as the temperature of waters in West Piti Bay, in the deeper parts of the harbor, in shallow areas of the harbor obviously removed from possible influence of the power plants (e.g., the mangrove and tidal flat areas south of Dry Dock Peninsula referred to earlier in this report), or temperature in the channels and on the tidal flats of the study area if they were not subject to any thermal influence from the power plants. In the latter case it is obviously difficult to say what the temperatures would be if there were no effect from the power plants. The fact that the power plants also greatly enhance water circulation in an area that would otherwise be subject only to tidal exchange further complicates the definition. Clearly, there is a thermal influence from the power plants; statements of the magnitude of this influence and a proper definition of ambient temperature are more difficult to achieve.

BIOLOGICAL OBSERVATIONS

Outfall Lagoon

In our previous report (Marsh and Doty, 1975) we discussed the flora and fauna of the outfall lagoon in general. The power plant effluents and topography of the lagoon floor subdivide the lagoon into several sub-regions with distinct benthic communities.

One of the most diverse communities in the effluent area occurs in the region within 100 m of the Piti Power Plant effluents. Turbulence produced by the outfalls has removed the fine sediments and consequently produced a significant area of limestone rubble substratum with low sedimentation. The rock surfaces are covered with the algae *Gracilaria salicornia*, *Padina tenuis*, *Halimeda opuntia*, *Sargassum polycystum* and *Rhodymenia* sp. The molluscan fauna is diverse. *Drupa ricina*, *Planaxis sulcata* and *Trochus niloticus* are abundant. *Cypraea moneta*, *C. tigris* and *Conus rattus* are common. The echinoderm fauna is more diverse here than anywhere else in the effluent area and appears to be increasing in abundance and diversity. Juvenile *Actinopyga echinites* have been observed in the area, indicating a reproducing population of this species. Furthermore, two additional species of holothurians, *Holothuria impatiens* and *Euapta tahitiensis* have recently appeared.

The sand-bottomed area downstream from the Piti effluent area comprises the largest subregion of the outfall lagoon. Bottom relief is provided by burrowing organisms which build large cones of sediment excavated from their burrows. The continual reworking of the sediments keeps the bottom in flux and probably is a major factor in determining the nature of the benthic community as a whole. The epibenthic flora consists of a cover of filamentous red algae (*Hypnea esperi* and *Champia* sp.) which form mats and provide food for the strombid gastropods *Strombus luhuana* and *Lambis lambis*. The sedentary medusa *Cassiopeia* sp. has been seen in this area.

Two deep areas were dredged out along the southern shore to provide dry-docking facilities used when the area was a fishing port in past years. Relic live corallia of *Porites lutea* occur in the western-most (deeper) of these two areas and scattered around its margin. These corallia are not as abundant as in the past, as evidenced by the abundance of dead corallia; and most of the living corallia are mere portions of larger growths. We have not previously reported live corals in the outfall lagoon.

We do not know if the live corallia will persist. The major factors in their survival would seem to be temperature and light. The bottom temperatures in these deep areas are consistantly significantly lower than surface temperatures. Furthermore, transplant studies of Porites lutea (discussed later in this report) have shown that corallia can persist in the warmer surface-temperature waters of the Piti-influenced portions of the outfall lagoon. Light penetration to these depths is low but probably increasing as the effluent currents gradually clear the area of finer sediments and continue to supply relatively clear reef-derived water. Therefore, it is conceivable that if the Piti Power Plant continues to pump through water at temperatures comparable to those monitored during the past year, the corallia in the deep areas may eventually increase in cover. Whether or not new corallia of this or other species will become established in the area cannot be predicted, but colonization seems doubtful.

The area lying between stations 15, 16, 17 and 18 (Figs. 3-5) is primarily influenced by the Cabras Power Plant effluent. Since onset of Cabras Plant operations, the area has become partially excavated. Scattered rocks have been exposed inside of and immediately in front of the outfall canal. Outside the zone of scattered rocks, two shallow bars similar to those lying in front of the Piti effluents have formed. Most of the substratum within 60 m of the Cabras outfall is bare sand, except for the seagrass Halophila minor which forms a sparse cover in patches. Halophila was not present in this area last year. We can reasonably expect the sediments in this area to continue shifting until sorting by the effluent current is completed. At that time, we expect the substratum within 10 m of the outfall to be primarily limestone rubble and the associated benthic community in this area should be similar to that now present in the Piti outfall area.

The community which has developed on the concrete walls and exposed limestone rubble in the Cabras outfall canal during the past year may be a good indication of what we can expect to develop in the area immediately outside the canal. A thick turf of algae, primarily Padina tenuis, now covers the hard substrata inside the canal. The turf is significantly reduced outside the canal and eventually disappears. A rich association of gastropod molluscs occurs with the turf and includes Drupa ricina, Pincta martensii, Strombus mutabilis, Cypraea erosa, Cypraea marginata, Cymatium nicobaricum, and Trochus niloticus. The sea cucumber Holothuria leucospilota is present in adult and juvenile stages. Schools of fish are abundant (same species as at the Piti outfalls). The diversity of mature organisms in the canal reflects conditions, existing during normal operation of the Cabras Plant. However, unusually large numbers of shells of dead juvenile molluscs have been observed in the canal. Thus we suspect the periodic occurrence of short-term episodes of high stress. These episodes may consist of periods of high temperature or release of caustic chemicals.

Biological Transects in Piti Channel

In addition to general biological observations in various parts of the study area, we conducted quantitative biological sampling in Piti Channel. This was a repeat of last year's observations and was intended to reveal changes which might have occurred in the intervening time period. The transect observations were begun on 29 December 1975 and concluded on 4 February 1976, as compared with last year's observations from 6 December 1974 to 29 January 1975.

The procedures were the same as those followed previously. Transect lines were laid down on the bottom along the long axis of the channel and approximately centered in the deeper portion, thus ignoring organisms in the intertidal zones. The transects generally paralleled water flow and were placed end-to-end from the Piti Plant outfall area to the mouth of Tepungan Channel where it enters the Commercial Port area. Transect locations are shown in Fig. 17. There were 16 transects, with each transect being 100 m long.

For each transect the general nature of the substrate was noted along the entire line segment, and the percentage of the transect occupied by the different substrate types was thus determined. Organisms which lay underneath the transect line and in contact with it were identified, and the percentage of the transect occupied by each was determined. Many organisms were numerous but too small to have significant contact with the transect line. The presence of such organisms in the general region of the various segments was noted and an estimate made of the percentage representation by different such biological regions. In addition, a set of 5 1-m^2 quadrats was laid out at the 50-m mark of each numbered transect and counts made of the number of individuals of each species within the quadrats. This gave results directly comparable to those obtained last year.

For increased accuracy and precision in assessing the density of small organisms not well represented by the line-intercept method, we added a new procedure not employed in the previous year's work. Using the transect line as a guide, we counted all organisms in contiguous strips 1 m wide and 5 m long and immediately adjacent to the line.

Results are presented in Fig. 18, which is comparable with Fig. 12 of last year's report (Marsh and Doty. 1975). There are some similarities and some differences between the results for the two years. The quantitative similarities are most notable for the sand cones, shrimp-goby burrows, and the algae Padina tenuis and Halimeda opuntia. For all of these structures or organisms the peak abundances occurred at the same or approximately the same distances from the Piti outfalls in both years. For the sand cones, shrimp-goby burrows, and Padina tenuis, the absolute density or percent cover was lower in the latter sampling than the earlier sampling, however. In the case of Halimeda opuntia the percent cover was greater the second time than the first time.

The shrimp-goby burrows are characteristic of Piti Channel for its entire length, beginning in small numbers within 100 m of the Piti Plant outfalls. These burrows vary somewhat in size, but their diameter approximates 2 cm. Each burrow is inhabited by a single shrimp and a single goby, each usually less than 5 cm in length. The burrow is maintained by the

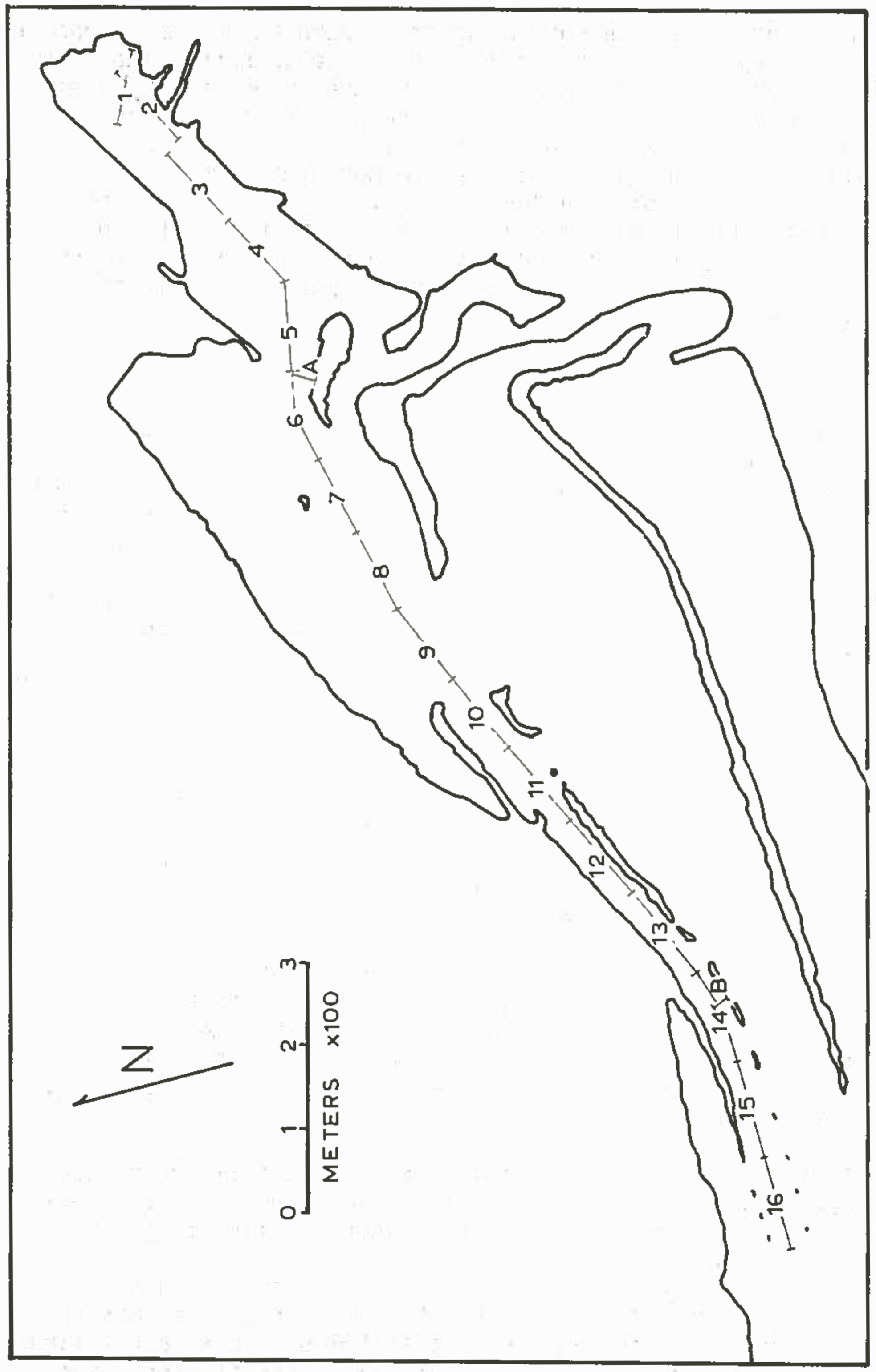


Figure 17. Location of biological transects in December 1975 and January 1976.

shrimp, which can often be found removing small pebbles or shell fragments from the hole and depositing these in a pile at the opening. The shrimp-goby pairs have been common throughout Piti Channel since our studies began in 1972. Away from the Piti outfall the number of burrows increases to a significant degree in Transect 3. In the middle of Transect 6, the density suddenly increases to more than 100 per 5 m^2 and remains at this high level through Transects 7 and 8. This then drops off to fewer than 50 per 5 m^2 in Transect 9 and only 2 per 5 m^2 in Transect 10. Density remains less than 25 per 5 m^2 through Transect 13 and then increases again to 62 and 83 burrows per 5 m^2 in Transects 15 and 16 respectively.

The sand cones are another characteristic feature of almost the entire length of Piti Channel. These cones, or mounds, range in size from approximately .1-.2 m across to .5 m across, with the larger ones rising up to .25 m above the prevailing substrate level. We do not know what organism causes these but suspect that it may be some species of polychaete worm. The cones first appear about 100 m away from the Piti outfalls and become common (6 per 5 m^2) in Transect 3. They continue in lower densities than 10 per 5 m^2 through Transect 6, then disappear from the quadrat counts in Transects 7 and 8. They reappear in Transect 9 (8 per 5 m^2) and Transect 10 (1 per 5 m^2), disappear in the next two transects, and occur again in densities less than 10 per 5 m^2 in Transects 14-15.

The brown alga Padina tenuis has its greatest abundance in the outfall lagoon within 100 m of the Piti outfalls (greater than 25% cover), continues for two more transects, then reappears along the transect line only in Transects 9 and 11. However, it is present with a patchy occurrence throughout the channel, even though not appearing along the transect line in every segment.

The calcareous green alga Halimeda opuntia is present in the outfall lagoon within 100 m of the Piti outfalls but first occupies a significant percent cover (ca. 5%) in Transect 9. It does not appear in Transect 10 but again occupies approximately 5% cover in Transects 11 and 12. This increases to more than 25% cover in Transect 13, declines in the next transect, and then disappears from the transects, but not from the general area, in the last 200 m.

Notable differences in the transect results of the two years occur for the red algal mat, the sponge Spirastrella vagabunda, and the seagrass Halophila minor. The algal mat, composed primarily of Hypnea esperi and Champia sp., was much less abundant in the second sampling in all segments except Transect 15, where about 60% of the transect line passed through areas with patches of the mat. This is in marked contrast to the first sampling, when more than 50% of the transect line passed through areas of algal mat patches in all transects except the first three (where it was not found) and Transect 8 (with ca. 40% of the line passing through algal mat patches). The differences between the two years may be partly a sampling variation (since patches of the mat may be well or poorly developed and thus more or less obvious to a diver) but probably also reflect a real decline the second year. The probable decline is not obviously related to any particular cause.

In the case of Spirastrella vagabunda the sampling data indicate a smoothing out of peaks and dips in abundance in the second year, with a more even distribution of the organism along the transect line in all segments. Since the sponge was obviously in great abundance (though with patchy distribution) during the second sampling period, and since the differences apply primarily to percent cover, but the number per 5 m^2 shows peaks in the same places as last year's percent cover did, we suspect that the apparent differences are more likely to be sampling variations than real differences.

The differences in Halophila minor between the two years' sampling are definitely not due to sampling artifacts. We are confident that the seagrass was not present in the outfall lagoon within 200 m of the Piti outfalls during the first year's sampling, but it was there during the second sampling. We have also recently found it growing near the mouth of the Cabras outfall canal. It was present along the other line segments in the same regions (Transects 9, 10, 11, 15, and 16) both years and with percent coverage which was not significantly different between the two sampling times.

In our last report (Marsh and Doty, 1975) we distinguished three groups of organisms in Piti Channel on the basis of our longitudinal transect data. The first group consisted only of the red alga Gracilaria salicornia and the brown alga Padina tenuis. These were the dominant organisms in the outfall area immediately adjacent to the Piti Plant outfalls; but they were not confined to this area since they occurred elsewhere in Piti Channel and on the tidal flats. The second group was common throughout the length of Piti Channel and consisted of Halimeda opuntia, the shrimp-goby association, the cone structures, Spirastrella vagabunda, and the red algal mat. We considered the third group or organisms to be confined to Lower Piti Channel. This included the seagrass Halophila minor, the sea cucumber Bohadschia bivittata, and massive corals of the genus Porites.

On the basis of the new observations in this report, we still recognize the first two groups of organisms as we described them last year. All organisms of the third group, however, have now been seen in at least one subregion of the outfall lagoon. Hence, these organisms might more properly be added to the second group, that of widely occurring species.

Also in our last report the data were summed over 100-m intervals and therefore tended to smooth out peaks. Fig. 18 in which the data were summed over 10-m intervals gives a better indication of where peak abundances actually occur. For example, the limits of the greatest densities of shrimp-goby burrows exactly coincide with the limits of Upper Piti Channel.

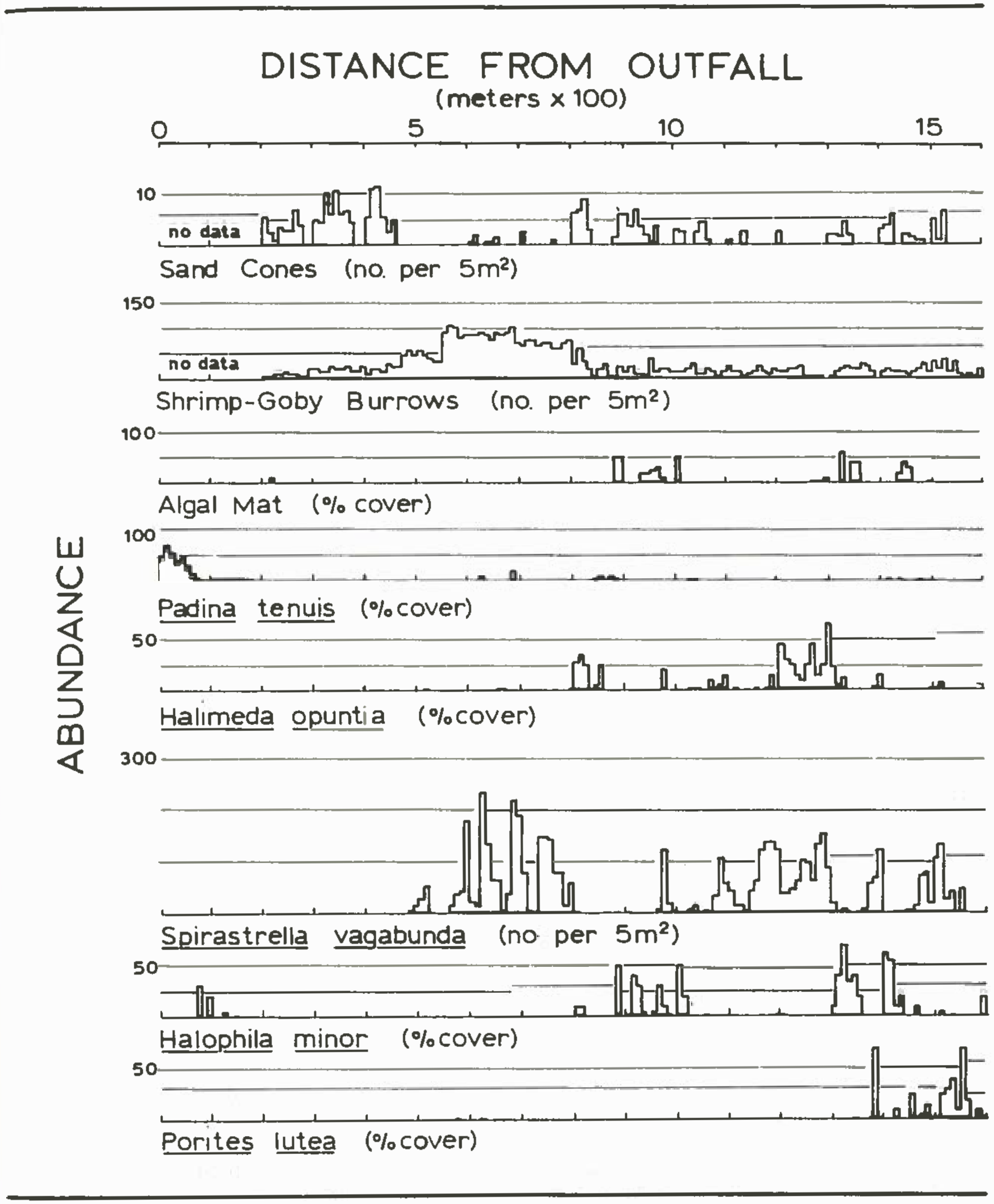


Figure 18. Abundance of major benthic features and organisms in Piti Channel December 1975 to January 1976.

The longitudinal transects discussed above gave quantitative biological information for the deeper part of Piti Channel throughout its longitudinal axis. We also ran two transverse transects across the channel perpendicular to its long axis and extending from the south shore to the middle of the channel where the longitudinal transect line had previously been located. These transverse transects thus included intertidal organisms as well as those living in the deeper part of the channel. A transect line was laid down across the channel and used as a guide in establishing a strip 1 m wide. This was then divided into 1 m^2 quadrats, and counts of organisms present in each of these quadrats were recorded. Transect A was located in Upper Piti Channel near Sta. 18, and Transect B was located in Lower Piti Channel near Sta. 22 (see Fig. 17).

For comparison, the 1 m^2 quadrats along each transect were pooled into 6 half-meter depth zones beginning at the +0.5 to 0.0 m (relative to MLLT) level and ending at the -2.0 to -2.5 m level. The species observed in each of these zones is shown in Table 3. More species occurred in the intertidal zones I and II (i.e., +0.5 m to -0.5 m) than in the subtidal zones III through VI. It is therefore not surprising that the greatest number of species co-occurring in Transects A and B occurred in this zone. However, Table 3 also shows a significant disparity in the proportion of co-occurring species found in the intertidal (43.4%, S.D. = 0.5%) and subtidal (83.5%, S.D. = 16.8%) zones. Although most of the species recorded from only Transects A or B do occur in both regions, we feel that our data accurately reflect differences in frequency.

Other Regions

Three major tidal flats are located in the study area. These are delineated by a series of dredged channels and dredge-tailing dikes. The substratum on the three flats is sand with intermixed coral rubble (largely Acropora). Flat D appears to have less rubble and finer sand than the other two flats. Flats D and C are similar biologically while Flat D is noticeably different. Flat D has a greater abundance of Gracilaria salicornia and Enhalus acoroides. Flats B and C have a greater abundance of the sponge, Spirastrella vagabunda. Several individuals of Cassiopiea medusa were seen on Flat B in November 1975 but disappeared after a month.

There are also three peripheral channels in the effluent area: the secondary channel, the connecting channel, and the moat. The secondary channel appears similar to Lower Piti Channel in its benthic community. The connecting channel is similar to Upper Piti Channel except that loosely attached or unattached clumps of Padina tenuis and the associated synaptid holothurian, Opheodesoma grisea, are more common in the connecting channel. This difference is probably a result of less water motion there than in Upper Piti Channel. The arm of the moat which connects the outfall lagoon with Upper Piti Channel is similar to Upper

Table 3. Depth-distribution of organisms occurring along two transects across Piti Channel. A, found on Transect A. B, found on Transect B. Transect locations are shown in Figure 17.

ZONE	I	II	III	IV	V	VI
DEPTH (in above MLLT)	0.5 0.0	0.0 -0.5	-0.5 -1.0	-1.0 -1.5	-1.5 -2.0	-2.0 -2.5
ORGANISMS COMMON TO A AND B						
Malleus malleus	AB					
Planaxis sulcatus	AB					
Clibanarius humilis	AB					
Feldmannia indica	AB					
Clibanaria striolatus	B	AB				
Cerithium ravidum	AB	A	A			
Calcinus latens		A				
Padina tenuis		AB				
Halimeda opuntia		B	A	B	B	B
Spirastrella vagabunda			B	B	AB	AB
Polychaete			A	A	A	AB
Sand Cones						AB
Shrimp-goby Burrows	AB	AB	AB	AB	AB	AB
ORGANISMS ON A ONLY						
Acanthochitin sp.	A					
Septifer bilocularis	A					
Trochus niloticus	A					
Gracilaria salicornia		A				
Schizothrix sp.		A				

Table 3. (continued)

ZONE	I	II	III	IV	V	VI
DEPTH (in above MLLT)	0.5 to 0.0	0.0 to -0.5	-0.5 to -1.0	-1.0 to -1.5	-1.5 to -2.0	-2.0 to -2.5
ORGANISMS ON B ONLY						
Crossostrea culculletta	B					
Gafrarium tumidum	B					
Nerita reticulata	B					
Peristernia sp.	B					
Polysiphonia tepida	B					
Rivularia polyotis	B					
Morula uva		B				
Halimeda macroloba		B				
Sponge sp. A		B				
Sponge sp. B		B				
Pavona obtussata		B				
Porites lutea		B	B			
Strombus luhuana			B			
Pinna sp.			B			
Polinices pyriformis						B
Halophila minor						B
TOTAL NUMBER OF ORGANISMS IN ZONE	16	14	8	4	4	7
FOUND ON TrA AND TrB	7	6	5	4	4	5
FOUND ONLY ON TrA	3	2	0	0	0	0
FOUND ONLY ON TrB	6	6	3	0	0	2
PROPORTION OF ORGANISMS IN ZONE (PERCENT)						
FOUND ON TrA and TrB	43.8	42.9	62.5	100	100	71.4
FOUND ONLY ON TrA	18.8	14.3	0	0	0	0
FOUND ONLY ON TrB	37.5	42.8	37.5	0	0	28.6

Piti Channel itself. Spirastrella vagabunda predominates in this area. We do not have sufficient data at this point to characterize the benthic community in the cul-de-sac portion of the moat. We believe the bottom in this area to consist of fine sediments covered with a turf of Caulerpa verticillata and Halophila minor.

In October 1975, we investigated the shoal area immediately south of the mooring site for reserve craft (on Dry Dock Peninsula). The water here was very murky. Porites lutea, Sargassum polycystum, Malleus malleus and Holothuria atra were abundant. Other organisms common in the area include Halimeda opuntia, Padina tenuis, 3 spp. of coral (including Pocillopora damicornis), 1 soft coral, 4 spp. of sponge (including Spirastrella vagabunda and Cinachrya australiensis), echinoderms (including Diadema setosum, and Bohadschia bivittata), and molluscs (including Cypraea cylindrica and C. mappa).

The Cabras Power Plant intake area in Piti Canal is developing a benthic community similar to that found in an inner reef flat. During the past year, large numbers of Pocillopora damicornis planulae settled here. Most of the resultant corallia died before growing more than a few centimeters but many remain. In addition to these new corallia, fragments of Acropora aspera coral, broken off of thickets elsewhere in the canal during periods of heavy swell, have become established in the Cabras intake area. Nine species of holothurians and four species of echinoids have also been observed in the area.

Coral Transplants

We have already noted the presence of corals in Lower Piti Channel and their absence in Upper Piti Channel and the outfall lagoon, except for a few scattered small corallia of Porites lutea in the southwestern part of the latter area. In order to determine if the paucity of corals in the outfall lagoon and Upper Piti Channel is due to higher temperatures there than in Lower Piti Channel we did some coral transplants on 1 October 1975. Small colonies of Porites lutea were collected from Lower Piti Channel near Sta. 23 and transplanted to selected sites. Five colonies were placed at each site. The size of the colonies ranged from 3 to 15 cm in diameter, with most being near the larger end of this range. One of the transplant sites was adjacent to the collection area in Lower Piti Channel and served as a control. Other transplant sites were near the Piti and Cabras outfalls, Sta. 9, a submerged wooden platform near Sta. 14, and one of the concrete supports for the GORCO pipeline near Sta. 21. These sites are shown in Fig. 10.

Since the corals were not attached to the substrate, they were somewhat unstable and shifted positions slightly because of strong currents (at the outfall sites) or disturbance by fish. However, corals at all sites were still alive in April 1976, with the exception of the Cabras outfall site. The corals there were bleached and probably dead within three weeks; they were obviously dead within a month after being transplanted. We think that death was probably caused by the high temperatures of the Cabras effluent water. The corals at the Piti outfall were subjected to somewhat lower temperatures (see earlier sections of this report) and survived.

The lack of suitable substrata can also be a factor preventing coral growth. Most corals require stable substrata such as consolidated limestone and cannot colonize areas of unstable silt or sand. Much of the outfall lagoon and Piti Channel has a sandy bottom, although there is much scrap metal and other scattered debris which might provide a stable base for coral growth. To provide sites suitable for additional coral transplants, we created three "artificial reefs" by placing a layer of limestone rocks in the approximate middle of the outfall lagoon, Upper Piti Channel, and Lower Piti Channel. These sites were located near Stations 15, 20, and 21, respectively, in water depths of 2-3 m. See Fig. 10 for the locations. On 12 December 1975 we transplanted a series of coral specimens to these artificial reefs from the live coral beds at the western end of Tidal Flat C. Some of the coral specimens were intact colonies and some were pieces broken off colonies. The colonies were wedged into crevices between the larger component rocks of the artificial reefs with their living surfaces oriented upward. There were 3-5 pieces of each species of coral, and each piece was smaller than 15-20 cm across. As much as possible, different pieces of the same species were grouped together and separated from other species on each artificial reef. The following species were transplanted: Porites lutea, Porites cocosensis, Pocillopora damicornis, Pavona (Polyastra) obusata, Pavona frondifera, and Lobophyllia corymbosa.

All of the transplanted corals at all three artificial reefs were still alive in April 1976. As in the previous case, some of the specimens which were not tightly wedged into crevices or which were subjected to movement by the smaller rocks underwent some shifting. These were restored to their original positions where possible. The only partial deaths in the coral colonies occurred when pieces fell onto the sediments surrounding the artificial reefs and became partially buried. Some of the corals were also shifted by fish, several species of which were immediately attracted to the artificial reefs when new habitat was created. The good survival rates of the transplanted corals suggests that adult corals can survive in most of the study area except in the immediate vicinities of the plant outfalls.

OTHER OBSERVATIONS

Results of sediment analyses for heavy metals, which were performed by the U. S. Navy's Fena Laboratory, are shown in Table 4. Locations of the six sampling stations are shown in Fig. 10. The results generally show high levels for all metals. We are not sure if this is linked to power-plant operations or to the prior history of the area as site for shoreside ship facilities. There is a considerable amount of metallic debris of various sorts scattered about the entire area.

Table 4 shows that iron and aluminum are the most common metals in the sediments by at least an order of magnitude in all cases and by two orders of magnitude in some cases. Mercury has the lowest concentrations, by an order of magnitude in some cases.

Station P-1, immediately in front of the Piti Plant outfall, has the highest levels of iron, zinc, and aluminum and shares the highest levels of chromium and lead with Station P-5, in Upper Piti Channel. In general there are downstream decreases in metal concentrations except for Sta. P-5, which shows an increase over the sampling sites upstream and downstream of it. The reason for this is unclear but may be related to larger amounts of submerged metal debris near this station than at other stations. Five of the metals tested (iron, chromium, nickel, mercury, and aluminum) had their lowest concentrations at Sta. P-6 in Lower Piti Channel, furthest downstream from the Piti Plant outfalls.

Stas. P-3 and P-4 respectively were chosen as paired stations to lie near the Cabras Plant outfall and at a site away from the outwash of that outfall but equally distant from the Piti outfalls. The Cabras outfall station (P-3) had lower levels of copper, cadmium, zinc, and mercury and higher levels of iron, cromium, nickel, and aluminum.

Water samples for dissolved oxygen analysis were taken in conjunction with the diurnal temperature observations on 22-23 June 1975. Samples were taken at the surface and bottom at four stations in mid-afternoon on 22 June and just before dawn on 23 June. These times were selected to reflect expected maximum and minimum values respectively, taking into account daytime photosynthesis and nighttime respiration by the biological community. Results are shown in Table 5. The afternoon values were higher than the pre-dawn values, but even the minimum pre-dawn values were essentially at saturation levels. Values for the bottom samples were generally close to those for the surface samples. The results suggest no oxygen stress for organisms living in the area, a healthy sign.

Salinity levels were determined with a hand-held refractometer on 29 January 1976 at various stations in the study area. Results are shown in Fig. 19. Salinity values were generally at normal oceanic levels throughout the area except for the cul-de-sac portion of the moat. This

Table 4 . Analyses of heavy metals in the sediments at six sites sampled on 22 October 1975. Results are expressed as mg/kg (parts per million). The analyses were performed at the U. S. Navy's Fena Laboratory. See Fig.10 for sampling locations.

	Stations					
Metal	P-1	P-2	P-3	P-4	P-5	P-6
Iron	5,800	4,100	2,800	1,800	4,100	1,200
Copper	17	15	13	22	20	13
Cadmium	2.0	2.0	2.0	2.2	2.2	2.0
Chromium	76	66	64	56	76	46
Lead	40	30	20	20	40	20
Zinc	64	55	24	31.5	46	31.5
Nickel	16.4	17.6	13.6	12.6	17.6	11.4
Mercury	0.66	0.66	0.85	1.10	0.75	0.22
Aluminum	5,200	3,570	3,700	2,400	4,350	2,200

Table 5. Dissolved oxygen (mg/l) at the surface and bottom at four stations in the study area for two times of day. See Fig. 5 for station locations.

	STATION			
	10	15	21	24
22 June 75, 1500 hours				
Surface	7.31	7.58	8.08	6.87
Bottom	7.19	7.67	8.18	6.62
23 June 76, 0500 hours				
Surface	5.98	6.22	6.17	6.18
Bottom	6.04	6.28	5.86	6.62

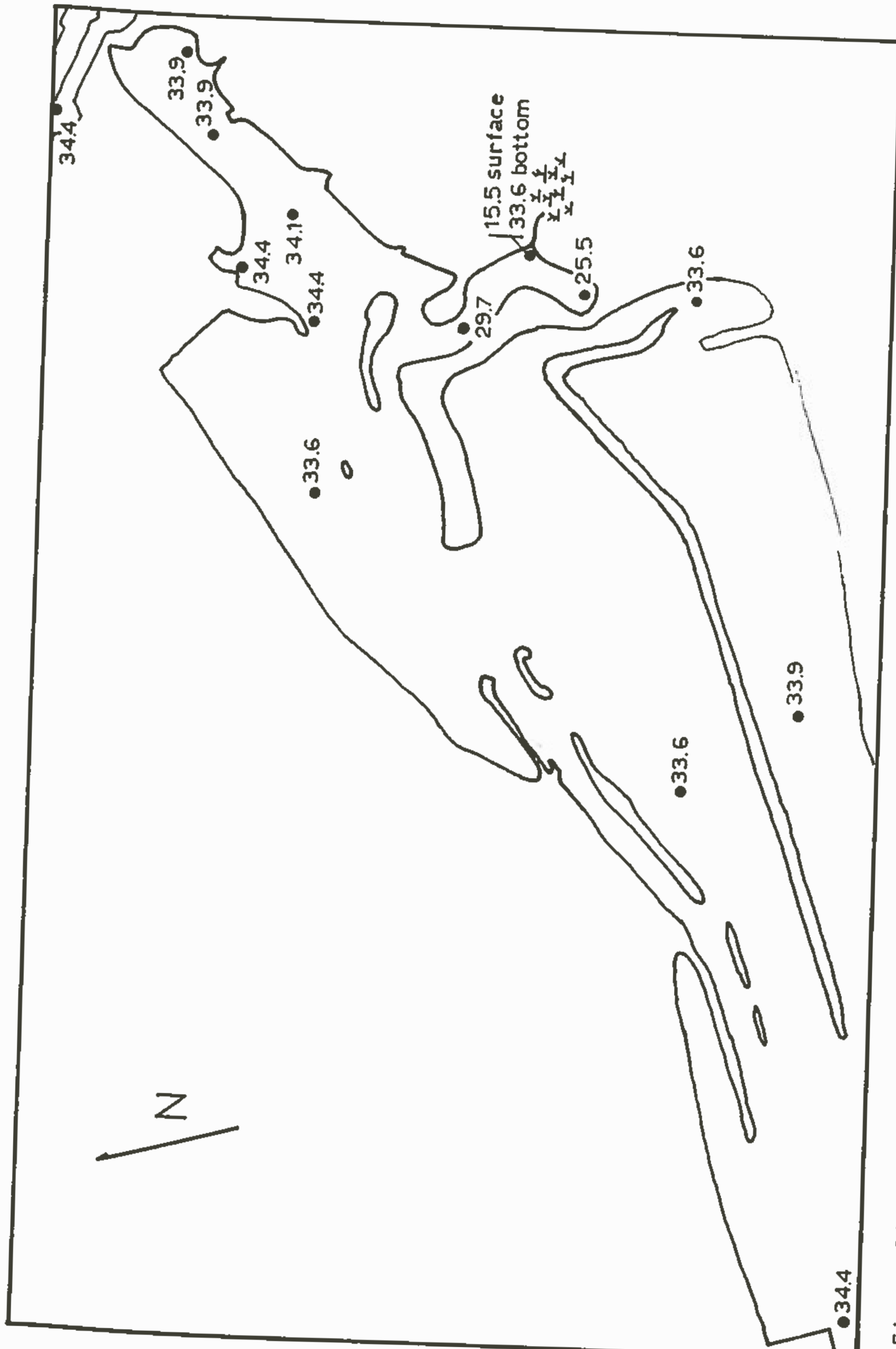


Figure 19. Salinity (ppt) in the Piti Channel area on 29 January 1976. (Measurements were taken 0.2-3 m below the surface unless otherwise noted) during a rising tide with squalls and heavy rains.

region had lowered salinity levels, indicating fresh-water runoff via the small stream that enters the moat. This region has little water exchange with the adjacent outfall lagoon. There had been heavy rains during the preceding week, and there was a squall at the time of the observations.

Construction of new fuel tanks has been going on during the past year on the land lying just to the south of the outfall lagoon (Fig. 4). The site has been graded, and this may have resulted in increased fresh-water drainage into the moat. Also, as noted in our last report, some construction debris was pushed into the moat. This has not been cleaned up.

On 15 September 1975 one of us (JED) discovered two steel containers marked "Danger: Radioactivity" on the shoreline near Sta. 19 at the edge of the Cabras Plant site. These containers appeared to have been abandoned. The label on one container indicated the material to be an isotope of iridium. We notified the Guam Environmental Protection Agency, who in turn notified a military command concerned with explosive ordnance disposal. The containers had been removed by 18 September 1975. Apparently the material was highly radioactive. We have been unable to find out why the material was there or how it was disposed of.

There continue to be occasional fish kills in the outfall lagoon. We have observed several of these ourselves and have learned of others from the occupant of a sailboat which is sometimes moored near Sta. 15. There are usually fewer than 25 dead fish seen, and there have been perhaps a dozen incidents in the past year. Goatfish and mullet are the commonest species involved. We do not know what causes the fish kills but suspect that they may be due to episodic discharges of some chemical, perhaps chlorine, from the power plants.

There continues to be significant recreational use of the general study area. The most common use is as a picnicing area. Fishermen, using either nets or poles and lines, are often present on the various tidal flats and fishing in the channels. There are up to a dozen individuals fishing on weekdays and more on the weekends. Shell collectors and swimmers are seen regularly. Several sailboats have also been moored in the outfall lagoon from time to time,particularly during storms.

In previous reports we have mentioned the small raw sewer that empties into the outfall lagoon at its extreme eastern end (Sta. 13). This apparently serves the Piti Power Plant. Effluent from this sewer still enters the lagoon, as evidenced by seepages which can be seen at low tide.

Eastward flows in Lower Piti Channel, in contrast to the usual westward movement of water, have also been discussed previously. During the last year we have occasionally observed slow eastward flows near the bottom of this channel when there were westward flows at the surface. Not surprisingly, this seems to occur mostly on rising tides.

We have observed one plankton bloom in the study area during the last year. This was on 22 October 1975 and affected the entire Piti Channel area except for the lagoon immediately adjacent to the Piti outfalls. The water was colored yellowish-green, and visibility was less than a meter. There was no plankton bloom in the intake area in Piti Canal.

Finally, we occasionally observe oil at the surface of the water in the outfall lagoon. This is usually present in small amounts. There have been fewer than half a dozen such observations in the past year. We cannot be sure that the oil originates at the power plant sites but think that this must be the case. This points up the need for extreme care in all power plant observations to avoid a major incident. This is especially the case now that new large storage tanks have been constructed just south of the outfall lagoon.

SUMMARY

Outfall temperatures at the Cabras Power Plant range up to 37°C. This is higher than present temperatures at the Piti Power Plant outfall and higher than earlier temperatures at the Piti Plant before the Cabras units went into operation. The Piti Plant outfall is generally cooler now than it was before the Cabras Plant began operations.

The higher peak temperatures at the Cabras outfall are not reflected in higher peak temperatures downstream in Piti Channel. The areas enclosed by particular isotherms have not increased over what they were when only the Piti Plant was in operation. Increased temperature effects of the Cabras Plant over the pre-existing effects of the Piti Plant appear to be confined to the eastern part of the outfall lagoon adjacent to the Cabras Plant. The western (upstream) part of the outfall lagoon, which is subjected only to the influence of the Piti Plant, is exposed to generally lower temperatures than previously.

Higher temperatures occur a greater proportion of the time on Tidal Flats B and C, which are subject to thermal influence from the power plants, than on Tidal Flat D, not directly subject to such influence. Data from maximum/minimum thermometers in place from November 1975 to April 1976 show higher maximum temperatures for Flats B and C than for the other tidal flat; however, the recent maximum temperatures for Flats B and C do not exceed the historical maximum for Flat D. Minimum temperatures are lower on Flat D than on the other tidal flats. The major thermal impact of the plants on the tidal flats and Piti Channel is to impose a temperature regime which is more constant than would be the case under natural conditions. Nighttime temperature drops are prevented from going as low as they otherwise would, and daytime temperatures are raised somewhat; but the temperature range is not as great in areas not subject to power plant impact.

There is a diurnal temperature pattern, for the outfall locations and for the tidal flats, channels, and Commercial Port area. Minimum temperatures occur between midnight and dawn. Maximum temperatures occur in the afternoon or early evening hours at the outfalls and in the afternoon over the rest of the study area.

Occurrence and abundance of organisms was studied in a series of transects that began at the Piti Plant outfalls and extended downstream in Tepungan Channel all the way to the Commercial Port area. This resulted in an updating of information obtained in a similar series of transects a year ago. We recognized two groupings of organisms this year, in contrast to the three groupings we utilized last year. The first of the two groups consists of the algae *Gracilaria salicornia* and *Padina tenuis*, which are particularly abundant in the lagoon area immediately adjacent to the Piti outfalls. This confirms last year's observations. The second

group of organisms consists of common species which occur throughout the transects. These include the sponge Spirastrella vagabunda, the green alga Halimeda opuntia, a symbiotic shrimp-goby species pair which lives in burrows in the substrate, the seagrass Halophila minor, coral of the genus Porites, and sand cones formed by an unidentified organism. Scattered small Porites colonies have been found in the southwestern region of the outfall lagoon in the past year. These colonies were there previously but had not been found because of their low densities. The major biological change that has occurred in the past year is the appearance of Halophila minor in the outfall lagoon, including colonization of the bottom in areas adjacent to both the Cabras and Piti outfalls.

The region of Piti Channel with the highest biological diversity is Lower Piti Channel downstream of the GORCO pipeline. The channel bottom here is periodically overlain by lower temperature water than in Upper Piti Channel. The second highest biological diversity occurs in the upper part of the outfall lagoon within 100 m of the Piti outfalls. There is also high biological diversity in Piti Canal, on the cooling-water intake side.

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