MARINE SURVEY OF TANAPAG, SAIPAN: THE POWER BARGE "IMPEDANCE"

Edited By

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

UNIVERSITY OF GUAM MARINE LABORATORY

Technical Report No. 33

March 1977

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TABLE OF CONTENTS

[Cover Photo: Able Dock at low tide. View is looking northeast with the power barge "Impedance" and Baker Dock in the background.]

FIGURES

TABLES

1. INTRODUCTION

By

JAMES A. MARSH, JR.

This report presents results of a marine environmental survey in Tanapag Harbor, Saipan, with reference to operations of the power barge "Impedance." In addition, attempts are made to relate the observations to the broader issue of general harbor usage. This report supersedes an interim progress report which was submitted in April 1976, presenting new observations since that time and a general synthesis of all observations. Field work was carried out on six field trips from February through June 1976.

The scope of work was set forth in a contract between the Marianas District, Trust Territory of the Pacific Islands, and the University of Guam Marine Laboratory. The contract was finalized on January 14, 1976. The following studies were specified:

1. collection of data on
    a. current patterns,
    b. water temperatures,
    c. dissolved oxygen values;

2. a biological survey of the harbor area adjacent to the power barge, including a quantitative analysis of corals, fishes, marine plants, and major invertebrates at various discrete locations;

3. a preliminary assessment of whether power barge operations are likely to cause significant alterations in the marine environment.

The scope of work was prepared and the contract drawn up after a preliminary site visit by Marine Laboratory personnel in November 1975. This was necessary for a realistic work plan to be designed. A log of research activities is presented in Table 1.1. This closely follows the tentative schedule of field work proposed in the contract.

Field work was performed by four-man teams during three-day study periods. Additional information and assistance on Guam was provided by other Marine Laboratory personnel.

Dredging and other site preparation for the barge, as well as mooring operations, were carried out before our studies began. Preliminary testing operations had begun by the time of our reconnaissance visit in November 1975. Normal power production operations had begun before our first full-scale data-gathering visit in February 1976. Hence, we can make only limited statements about the nature of the marine environment in the immediate vicinity of the barge before it was there. The fact that the "Impedance" was operating at one-fourth to one-third of its maximum rated capacity during our field studies allowed us to develop some understanding of the marine environment in the general vicinity before it was much affected by barge operations, however.

Wind and wave patterns tend to adversely affect the stability of the barge, especially under heavy weather conditions. This has led to a consideration of additional modifications at the mooring site to correct the problem. It is thus possible that there will be additional environmental impact in the area besides that caused by normal production operations. Our study provides baseline information necessary to assess such an impact at a later date.

Barge Operations

Hourly power production peaked at about 10 megawatts and dipped to about 5 MW during our field work and showed a distinct daily cycle. Peak loads occurred approximately at noon and in the early evening (1900-2000 hours). Minimum demand occurred between midnight and dawn. The maximum rated capacity of the "Impedance" is 30 MW, utilizing two boilers. However, only one boiler was being fired during the study period.

The maximum rated capacity of each of the two main cooling-water pumps is 20,000 gallons per minute (28,800,000 gallons per day). However, these pumps presently operate at a lower setting and pump only about 16,000 gpm of seawater through the condensers. A maximum water velocity for all intakes is 1.1 ft/sec (0.34 m/sec), and retention time of cooling water in the barge is 1.5 minutes. The maximum temperature increase of discharge water over intake water is 12°F (ca. 6.7°C), according to design specifications.

Boiler feed water and water for on-board sanitary facilities and deck wash is fresh water and is drawn from the island supply system. Waste water from the deck wash goes over the side and amounts to about 1,000 gpd. Waste water from the sanitary facilities is discharged to the island sewer system through a connecting hose and amounts to approximately 2,000 gpd. Bilge wastes are also discharged to the island sewer system.

Further consideration of barge operations relative to their impact on environmental temperatures is given in Chapter 5.

Acknowledgements

In the following report, we have given the major scientific contributors the credit due them as the authors of their respective sections. However, we are also indebted to many others on Saipan and Guam who, during the course of this survey, made personal contributions beyond the normal expectations of day-to-day business. These people are Thomas Sheehan, Marianas Planner, Government of the Northern Mariana Islands (GNMI); Gerry Maier, our liaison with GNMI; Anthony Tenorio of the GNMI Public Works Office; Bill Brewer of the Trust Territory Environmental Protection Board; James Payne, President of the China Sea Corporation; Mr. Higa and Mr. Arnez, Superintendants of the "Impedance"; Art Roquel, Engineer and Shift Supervisor for the "Impedance"; Mr. Zalameda, Chemist for the "Impedance"; Ben C. Concepcion, local dive shop owner who provided SCUBA tanks in an emergency; Dr. Roy T. Tsuda and Dr. Lucius G. Eldredge, Ms. Elaine Faria, Ms. Terry Balajadia, and Ms. Mary Mariano of the Marine Laboratory.

Table 1.1. Log of activities.

Dates	Activities
28-29 November 1975	Reconnaissance trip for site inspection to serve as basis of contract preparation.
1 January 1976	Contract signed by Marianas District Administrator.
14 January 1976	Contract signed by President, University of Guam.
6-9 February 1976	First field study; current and temperature observations; survey of fishes and algae. Field trip postponed by one week because of bad weather.
20-23 February 1976	Second field study; current and temperature observations; survey of substrate types, algae, and noncoralline invertebrates.
19-22 March 1976	Third field study; current and temperature observations; survey of dissolved oxygen and nutrient levels.
14-17 April 1976	Fourth field study; current, temperature and salinity observations; survey of biological communities at Unai Sadog Tase and A Dock.
15 April 1976	Progress report submitted: Doty, James E. and James A. Marsh, Jr. (eds.), 1976. Marine Survey of Tanapag Harbor: Power Barge Study Progress Report. University of Guam Marine Laboratory Miscellaneous Report No. 18. i+74 pp.
14-17 May 1976	Fifth field study; current and temperature observations; resurvey of corals and algae.
11-14 June 1976	Sixth field study; detailed current and temperature observations.

2. GENERAL SITE DESCRIPTIONS

By

JAMES E. DOTY

Tanapag Harbor (Fig. 2.1) is located 15°14' North Latitude and 145°43' East Longitude on the western shore of Saipan in the Mariana Islands. The harbor consists of a 160-hectare basin 10-15 meters deep dredged within a 1300-ha lagoon area behind a barrier reef. The shore of the harbor is fringed by shallow flats composed of sand, coral rubble, and live coral bottoms which end abruptly in a steep dredge face. Wreckage, primarily dating from World War II and shortly thereafter, provides a major substratum in and around the harbor. Several land-fill piers have been constructed which extend across the flats to the dredged basin, thus subdividing the shoreline into several small embayments.

The piers and bays are described below. Standard names, as derived from charts and maps or from common usage, are used where these are available. This is the case for most of the various docks, with their military-derived designations. Where no names were known to us we devised our own (as for the small embayments). This was done for our own purposes, and we do not mean to imply that these are official names.

Range Light Bay

This bay is a small bay (ca. 1 ha) about .3-.5 m deep formed between the sea plane ramps on the north and Echo Dock on the south. We have derived its name from the lower range light for the harbor entrance which is located on the shore of this small bay. The bay sediments are coral rubble and sand. The sea grass *Enhalus acoroides* appears to be the dominant organism. A diversity of holothurians also occur here in significant numbers.

Echo Dock

This is a small point of land about 100 m southwest of the seaplane ramps. Although it is no longer used as a dock, remains of wood pilings and a concrete seawall can be seen. Therefore, we have derived its name, for our purposes, in keeping with the alphabetical designations already in use. A sewer line runs along the southwestern side of the point to an outfall near the end of the dock. The effluent is apparently raw sewage.

Echo Bay

This bay (ca. 2.5 ha) lies between Echo Dock on the north and Delta Dock to the south. An abandoned concrete pipeline runs from the shore to the edge of the dredged area near the southern end of the bay. The metallic remains of a small launch are located near the pipeline and serve as a means of locating it during periods of high tide or turbidity. A small stream empties into the harbor at the southern end of the bay.

Delta Dock

This dock is the small point just north of Charlie Dock (see below). We have derived its name for our purposes in keeping with the alphabetical designations already in use.

Charlie Dock

This is the main commercial port area for the island. It is an L-shaped concrete pier. A USGS bench mark (Tidal Mark 2, Elev. 1.294 m) is located here.

Charlie Bay

This is the semi-enclosed area (ca. 2.5 ha) between Charlie and Baker Docks (Fig. 2.2). Approximately one-half of the bay is sheltered from wave action by Charlie Dock. The unprotected (south-western) half receives relatively heavy turbulence due to the direct impingement of waves from seaward and the reflection of waves from the northwestern side of Baker Dock. The complementary effect of these two sources is to double some wave heights in this area. The entire shore of the bay is fringed with the sunken remains of barges which were apparently used formerly as floating docks. These remains have provided excellent habitat diversity and substrate for coral growth. A sunken barge in the sheltered portion of the bay is almost completely covered with coral. Sunken barges in the exposed portion are less densely covered by coral and are further deteriorated. The areas near Baker and Charlie Docks have been dredged and have bottoms composed of fine sediment. The areas that have been neither dredged nor covered by metal debris (primarily in the sheltered northeastern half) support a mixed coral community consisting primarily of *Pocillopora damicornis*, *Millepora dichotoma* and *Porites lutea*.

Charlie Bay receives runoff from Charlie Dock, including the waste from a small cook house used by port employees. Discharge into the water includes undetermined amounts of domestic water, detergents, and wet garbage.

Baker Dock

This dock is located southwest of Charlie Dock and Charlie Bay. It consists of coral fill bounded primarily by iron pilings. A sunken barge lies off the seaward end. Broken into several sections, the barge lies on the sloping dredge face with one end covered by limestone boulders recently added to the end of Baker Dock. The other end of the barge lies at a depth greater than 10 m. A decaying wood-piling dolphin is also located at the end of the dock. The northeastern side of the dock is exposed to direct wave action.

The power barge "Impedance" is moored along the southwestern side of the dock with its stern (cooling water intake end) ca. 20 m from shore and its bow (effluent end) ca. 10 m from the end of the dock (Fig. 2.1). The southwestern side of Baker Dock is faced with iron pilings except for a short section near shore which is faced with cut limestone. The pilings drop vertically to a narrow bench of coral rubble lying about .3 m below MLLW. Approximately 1-2 m from the dock the bottom has been recently dredged to 7 to 10 m, creating a steep coral rubble slope.

Baker Bay

This bay (ca. 1.7 ha) lies between Baker Dock and Able Dock (Fig. 2.4). The bottom has been dredged near the two docks and consists primarily of fine sand and silt with occasional rocks and metal debris. Significant diversity of bottom-dwelling organisms is encountered only along the shore of the bay and increases away from Baker Dock. The bay is spanned by several cables and chains which serve to moor the power barge (Fig. 2.5). These chains lie on the bottom and have become buried in some places in the fine silt substratum.

The sunken remains of a converted minesweeper, the "Four Winds", lie at the outer edge of Baker Bay near Baker Dock. A wooden mast formerly extended above the water. The vessel is in an advanced stage of decay. All that remain are the wooden ribs, which crumble easily when touched.

Able Dock

This dock lies southwest of Baker Dock and formerly had a concrete facing descending vertically to the coral rubble bottom. Most of the dock facing northwest, toward the harbor, has subsided. The area is now characterized by concrete slabs arrayed in various attitudes in a zone extending from above high water to about 2 m below MLLW (cover photo). Beyond the concrete is a sloping terrace of boulders, metal debris and coral rubble. The terrace ends in a steep dredge face.

Iron Pilings

The iron pilings lie in 11 parallel rows of 57 pilings each, immediately southwest of Able Dock. These pilings formerly supported a wharf which was part of A Dock. They are steel I beams standing vertically in water about 5 m deep. A few of the pilings have fallen over and lie or the bottom of lean against other pilings. The pilings support a good growth of corals and algae.

Dump Bay

This the small (ca. 1 ha) bay behind (south of) the iron pilings. The shore in this area is currently being used as the island's only dump.

Unai Sadog Tase

This is a large shallow bay (20 ha in area, 1-2 m deep) west and southwest of the iron pilings and the dump. The shore along this bay is fine silt and clay covered by blue-green algae. Approximately 20-30 m from the high tide line the bottom becomes sandier and is dominated by the seagrass Enhalus acoroides, which forms a band about 150 m wide. Seaward of the Enhalus zone is a zone of sand with some coral rubble. The seagrasses Halophila minor and Halodule uninervis are the predominant macrophytes in this zone. A coral community dominated by Pocillopora damicornis typifies the area within 100 m of the dredge face.

The name Unai Sadog Tase apparently refers to the beach alone. We have adopted the name to encompass the entire bay.

Previous Descriptive Studies

The maps contained in this report are derived primarily from the Saipan Photo Contour maps (D.N.B.Y.D. Drawings 11614, 11619 and 11620) which are excellently detailed in their coverage of shallow-water bottom types. Further information on bottom contours and the relative positions of buoys and lights was obtained from the navigational chart of "Saipan Harbor" (U.S.N.O.O., 1971). Details of Baker Dock including the moorings for the power barge are contained in a map prepared by Juan C. Tenorio & Associates (Saipan), Inc., for the Marianas District Department of Public Works.

Biological information from the study area is scanty. Preston Cloud, Jr. (1959) made an investigation of the submarine topography and shoal-water ecology of the entire island in which some generalized data are presented for the harbor. More recently, FitzGerald and Tobias (1974), Gawel (1974) and Gordon (1974) performed surveys along the seaward margin of the harbor and lagoon. However, no quantitative or detailed biological observations have been made in the study area prior to this report.

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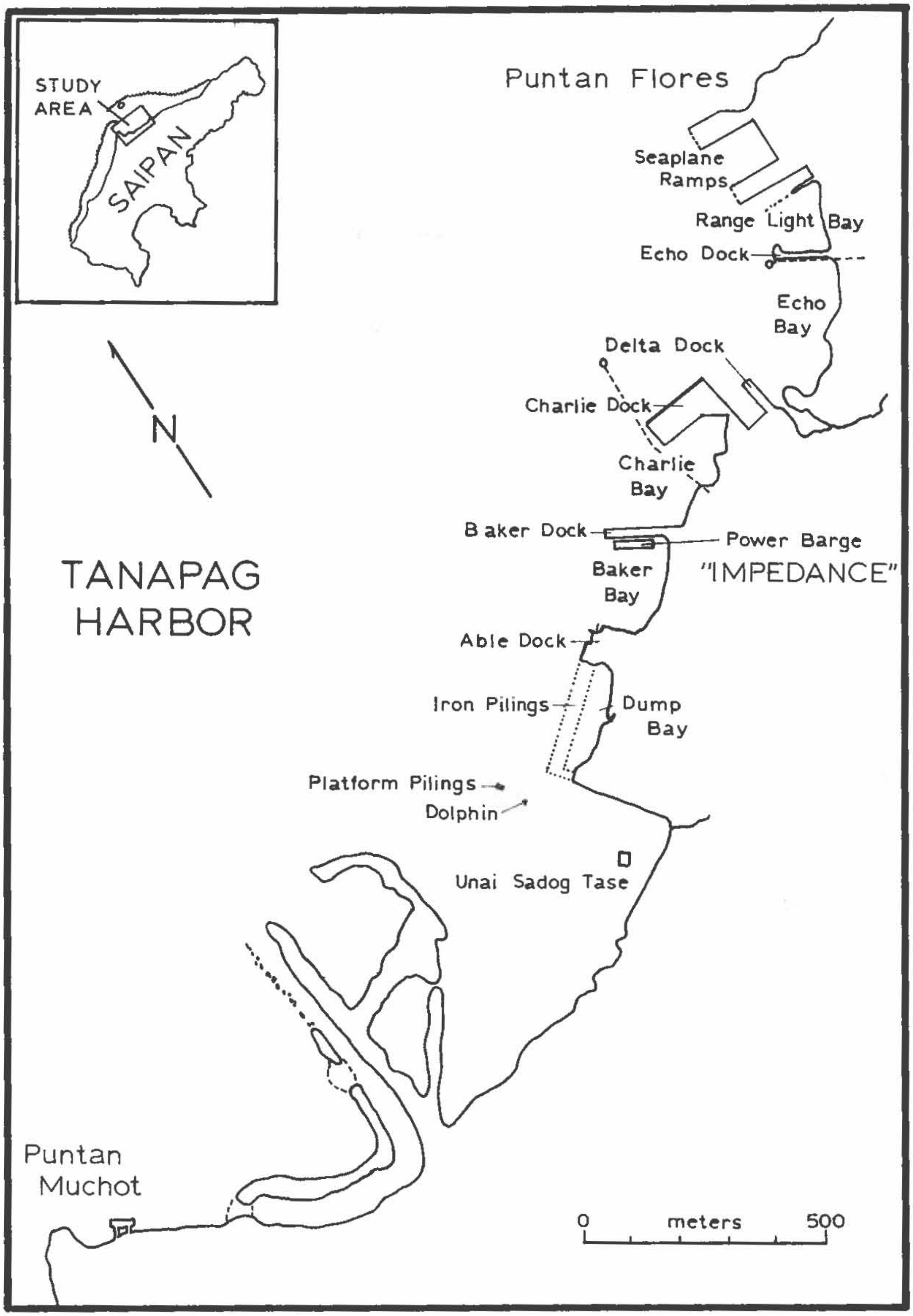


Figure 2.1. Map of Tanapag Harbor, Saipan.

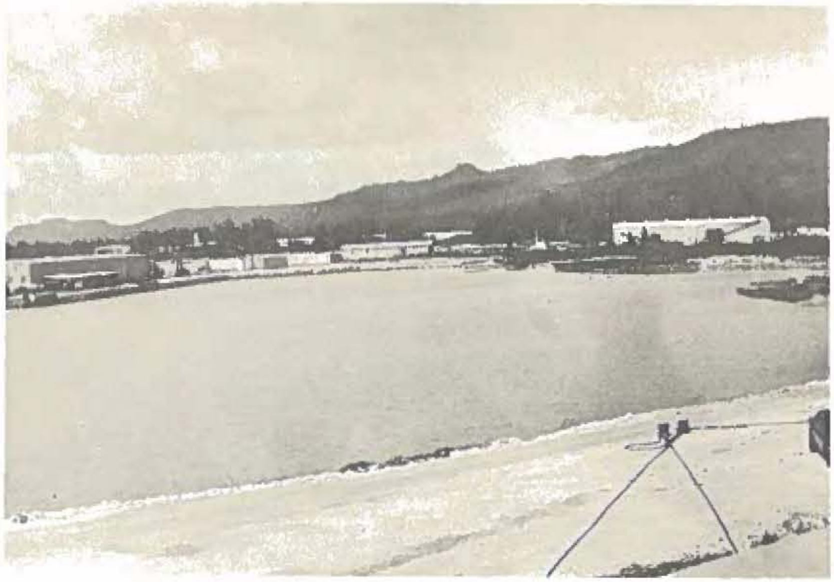


Fig. 2.2. View of Charlie Bay looking eastward from the bridge of the "Impedance."

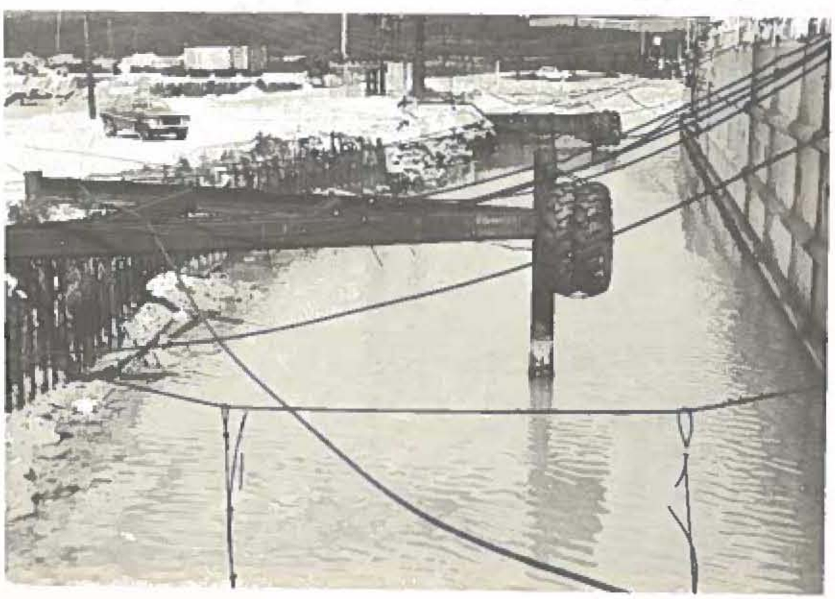


Fig. 2.3. View of the southwestern side of Baker Dock from the gangplank of the "Impedance."

Fig. 2.4. View of the shoreline of Baker Bay looking south from the "Impedance."

Fig. 2.5. Northeastern side of Able Dock. Note mooring chain for the "Impedance" and *Millepora dichotoma* exposed by extreme low tide.

3. DESCRIPTION OF SEDIMENTS

By

RUSSELL N. CLAYSHULTE

General substratum descriptions were made from field observations. Further analyses of sediments from some areas were performed on samples returned to the laboratory. The samples were collected in the field by scooping four handfulls (200-300 g) from the upper surface and placing them in a plastic bag. The samples were preserved in 70% ethanol.

Laboratory analyses of the samples were made for particle size and general composition. An estimate of the amount of fine particles present was obtained by washing 10-g portions through a 200-mesh sieve. Larger particles were placed on a 1-mm grid and examined under a dissecting microscope to determine sediment texture and composition. Insoluable residues were examined by treating a portion of the samples with 20% HCl. Portions thus treated were checked with concentrated HCl prior to examination to insure complete removal of the soluable portion.

Charlie Bay

The sediments in Charlie Bay were studied along the same transect used for other benthic studies. This transect extended 100 m into Charlie Bay from a point on the shore in line with the end of Charlie Dock. A profile of the transect is shown in Fig. 3.1.

The sediments within 14 m of shore are terrigenous sand and gravel of recent origin. The slope is composed of coarse to fine gravel with some medium to fine sand toward the bottom. The material is predominantly limestone. The grains are subangular to well rounded. The sediments in a slight trench at the shoreward edge of the barge are medium to fine gravel intermixed with fine sand, silt and clay. Fine silt forms a thin, easily disturbed veneer on the surface of the substratum.

The sediments 40-60 m from shore are predominantly biogenous sands, with terrigenous deposits still prominent in isolated locations. Both types of sediments tend to be well sorted coarse to fine grained sands, showing angular to subrounded textures. The sediment samples show a considerable amount of organic detritus, which produces an anaerobic black mud layer 7-25 cm below the sediment interface. The sediments in this area contain small amounts of silts and clays, which tend to be restricted to the top several inches in open areas and in pockets of shallow depth (60-90 cm). The finest material occurs in the area of the sunken barge. The foraminifera found were, for the most part, intact, with Marginopora possibly alive when collected. Large Marginopora, 3-6 mm, were observed in the area 45-75 m from shore. The foraminifera found in this zone were as follows:

Baculogypsina sphaerulata, rare
Marginopora vertebralis, very common
Sorties marginalis, rare
Homotrema rubrum, found on coral rubble
Elphidium sp., rare
Trioculina sp., rare.

The sediments 75 m from shore are predominantly terrigenous sands of recent origin. The sands are very well sorted medium-grained sands to moderately well sorted fine-grained sands. The grains are subangular to rounded. The sands are composed of 20-30% fragments of a yellow-to-pink limestone, as found along the shoreline of Charlie Bay (apparently recent fill). The samples also contain large numbers of sponge spicules, micromollusc shells, bryozoan fragments and foraminifera tests.

The foraminifera found in this zone were as follows:

Baculogypsina sphaerulata, rare
Marginopora vertebralis, abundant
Homotrema rubrum, found on coral rubble
Sorties marginalis, common
Trioculina sp., common.

Baker Bay

A general survey of sediments was made by swimming across the bay. The distribution of sediments is shown in Fig. 3.2.

A sample of the substratum was collected at a depth of 7.5 m ca. 10 m off the bow of the power barge. This area is overlain with a thick (5-60 cm) layer of silty mud or ooze consisting of very fine sands, silts and clays loosely compacted and very easily disturbed. The material is well sorted with only occasional large (up to 0.5 mm) fragments of anthracite. The sediment also contains small coral framents, sponge spicules and foraminifera tests. The latter are too fragmented for specific identifications; however, tests of Marginopora and some Calcarinidae are present. Below the silt layer here and elsewhere in Baker Bay is a layer of gravel containing large rubble mixed with medium to fine sand.

The surface silt layer is ca. 0.5 m deep under the barge and decreases to ca. 0.25 m at a distance of 50 m from the barge in Baker Bay.

A sample was collected at a depth of 4.5 m from the side of Baker Dock near the seaward end. The bottom here is a tallus slope produced by the recent dredging operations. The sediment is terrigenous gravel in which white to pink limestone predominates. Below the surface gravel there are Halimeda plates and coral rubble. Both of these sediments are poorly sorted and show little reworking.

A sample was collected from near the base of the talus slope at a depth of 6 m. The sediments here are fine to coarse sand with poor sorting and include coral rubble, Halimeda plates, and mollusc shells. There is only a thin film of silt and clay on the sediment. Currents, noticeable in the area, are apparently transporting the fine material to other areas. Fragmental and whole foraminifera tests are present in the sediments and include the following foraminifera:

Baculogypsina sphaerulata, rare
Marginopora vertebralis, common
Spirolina arietina, rare
Globigerina sp., rare.

Able Dock

A sample of sediments was collected 10.5 m off the seaward edge the dock. The sediments are predominantly terrigenous sand, gravel and limestone blocks. The sand is poorly sorted with coarse to medium, angular to well-rounded grains. Halimeda plates comprise 30-40% of the deposit. The limestone fragments are yellow, pink, dark to light red and white subangular grains. Coal was very abundant in the sample, with fragments of 4-5 mm common. The coal was 2-5% of the total material. Comparative mineralogy tests indicate the coal to be anthracite or high grade bituminous. It leaves a slightly oily residue when heated on a glass plate, barely smokes, burns slowly, scratches black, has crystalline indices and a hardness in the range of anthracite.

Five grams of material were treated with HCl for examination of the insoluable fraction. Quartz, anarthite, orthoclase, pyrenes (augite and hypersthene) and iron flakes were found.

Also contained in the sample were calcite, sponge spicules, living sponge material, Fungia corallites, small mollusc shells, and the tests of the foraminifera Baculogypsina sphaerulata and Marginopora vertebralis.

The area has a very thin veneer of coarse silt to clay that becomes moderately deep (15-30 cm) at 12 m. The sediments at 12 m are medium to fine sands with large rubble, including coral and concrete blocks.

The sediments at 3 m are coarse gravels, with large fragments of coral rubble. The sediments are poorly sorted and range from silt and fine sand (in small pockets) to limestone boulders.

Unai Sadog Tase

The sediments were studied along the same transect used for other benthic studies. This transect extended from the shore near a sunken barge and ended at the Platform Pilings (see Fig. 2.1). A profile of the transect is shown in Fig. 3.3.

The beach is composed of unconsolidated terrigenous sands of recent origin. The sediments are predominantly pink, white and yellow limestone fragments, recent coral fragments, and mollusc shells. The sediments are well sorted and range from medium to very fine sands. There is a black mud layer below the surface, and there are large accumulations of organic detritus on the surface and subsurface. The shore material graduates into an area of fine sands that contain high percentages of silt (10-15%). At 15-30 m from shore the sediments are well sorted fine sands very rich in organic detritus. The black mud layer is 1-3 cm below the surface. At 30-65 m the black mud layer is 3-10 cm below the surface. The sediments are fine sands, generally poorly sorted, containing fragments of iron and limestone rubble.

Between 60 and 90 m from shore the black mud layer lies 1-6 cm below the surface. The surface sediment is fine sand with large amounts of silt and clay. Below the surface (20-30 cm) is a fine gravel layer which contains larger rubble of coral and mollusc shells.

The sediments 90-150 m from shore are medium to very fine, well sorted sand. The sediment contains less detritus than shoreward and the black mud layer is 30-35 cm below the surface. In some areas the black mud layer was not reached. The upper 20 cm of sediment appears to be well mixed and loosely packed, probably due to the activities of infaunal organisms such as the polychaetes common in the area.

The sediments 150-200 m from shore are clean, with very small amounts of detritus and low percentages of silt. The sediment is medium sand with sparse to large amounts of rubble. Fragments of foraminifera tests, coral and anthracite appear in noticeable quantity in this area.

Marginopora vertebralis is found in samples taken 100 m from shore and becomes common at 150-200 m. Tests of *Baculogypsina sphaerulata* and *Spirolina arietina* were also found.

The sediments 200 m from shore are coarse to medium sand well to medium sorted. There are coral heads and larger coral rubble in the area. The sediments are composed primarily of limestone fragments, Halimeda plates, mollusc shells, coral fragments, anthracite and some foraminifera tests. This material shows a good deal of reworking, with some angular fragments of coral and mollusks, but rounded to well rounded limestone sand predominates. Two foraminifera species were common in the sample, Baculogypsina sphaerulata and Marginopora vertebralis.

The sediments 300 m from shore (i.e., at the fuel dolphin) are terrigenous and biogenous sand of recent origin. The sediments consist of very well sorted medium sand to moderately sorted fine sand. The grains are subangular to rounded and show reworking by the environment. The material is limestone with large amounts of Halimeda plates, coral fragments, mollusc shells, sponge spicules and foraminifera tests. A large portion of the material has been stained by iron oxides, giving it a reddish tint. Some particles were identified tentatively as anthracite. The foraminifera tests found were as follows:

Baculogypsina sphaerulata, common
Calcarina spengleri, rare
Homotrema rubrum, rare
Marginopora vertebralis, common
Sorties marginalis, rare
Spirolina arietina, rare.

The sediment 385 m from shore (i.e., at Platform Pilings) is poorly sorted fine to medium sand. It shows a great deal of reworking, being subrounded to well rounded. The sediment contains Halimeda plates, coral fragments, mollusc shell fragments, anthracite, and foraminifera tests. There is not a great deal of iron oxide stain on the sediments. The predominant foraminiferan is Marginopora vertebralis. Only two other foraminifera were found, Baculogypsina sphaerulata and Sorties marginalis.

Summary

The substratum in Charlie Bay is essentially a terrigenous deposit of recent origin, due mainly to the previous activities of man. The small amount of biogenous material deposited is predominantly a result of entrapment in the vicinity of the sunken barge. The low percentage of biogenous sediments in this bay indicates a slow reestablishment of reef-associated flora and fauna.

The sediments in Baker Bay and at Able Dock are predominantly a result of dredging activities. This has resulted in an accumulation of fine detritus, fine sands and silts on the substratum in this area. There is apparently insufficient water movement in Baker Bay and along the lower talus slope of Able Dock to effect removal of the fine detritus, which tends to remain as a colloidal suspension in the water column. Halimeda appears to be an important stabilizer of the sediments in the outer section of Baker Bay and the lower talus slope of Able Dock.

The substratum in the inner portion of Unai Sadog Tase is predominantly composed of terrestrial detrital sediments of recent deposition. There is a moderate to low percent accumulation and subsequent intermixing of biogenous sediments in the inner portion of the embayment. The slow water movement in the inner bay has allowed the accumulation of fine detrital sediments and organic detritus, producing an anaerobic layer beneath the sediment interface which gradually declines toward the outer portion of the embayment. The substratum beyond the embayment is typically biogenous sediments, with a definite influence from terrestrial depositional sources and previous human activities in the area.

The substratum found in the study area indicates extensive previous disturbance due to the activiites of man. The sediment depositional features will probably remain in their present state, with some slow stabilization of the substratum continuing in the future.

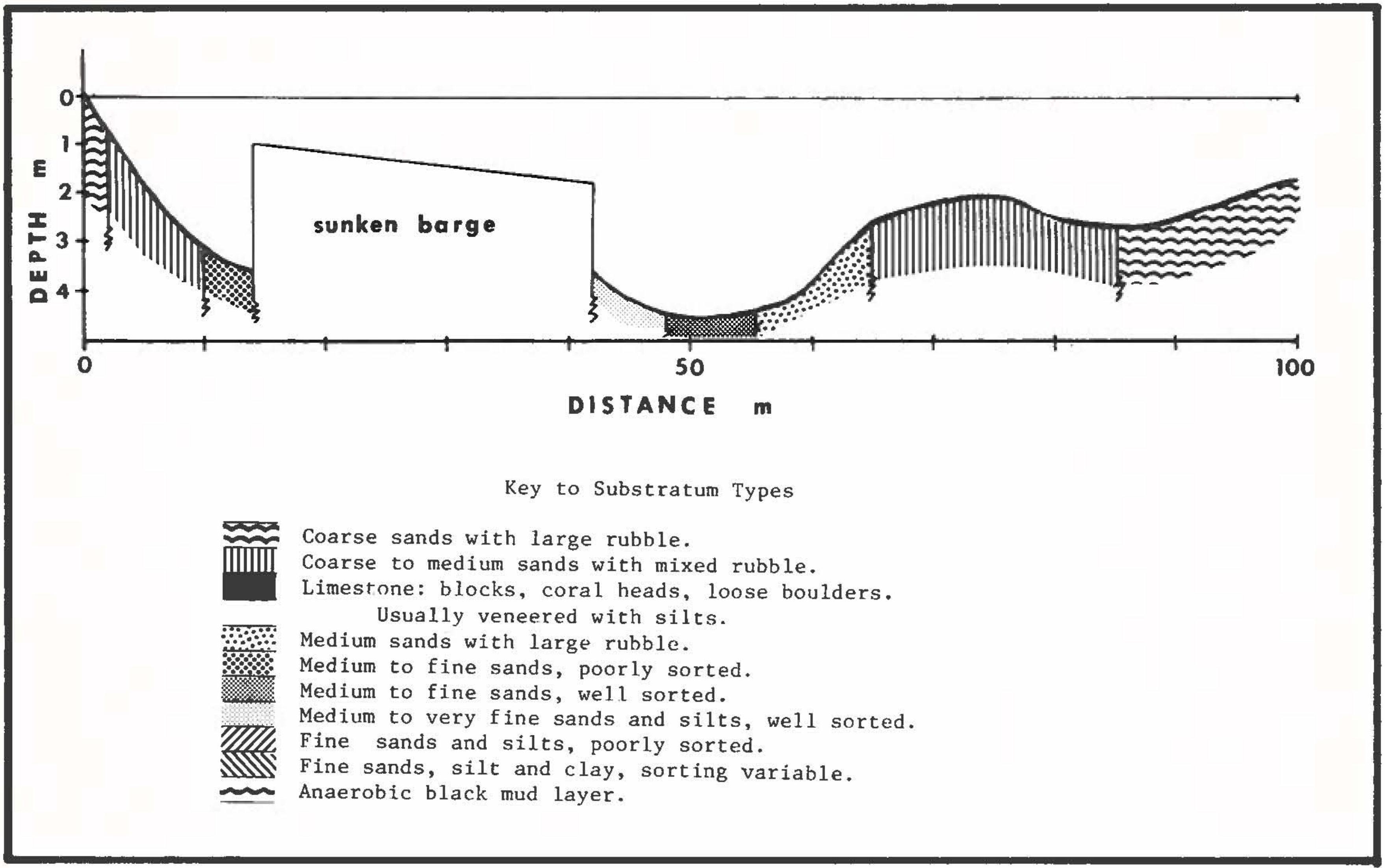
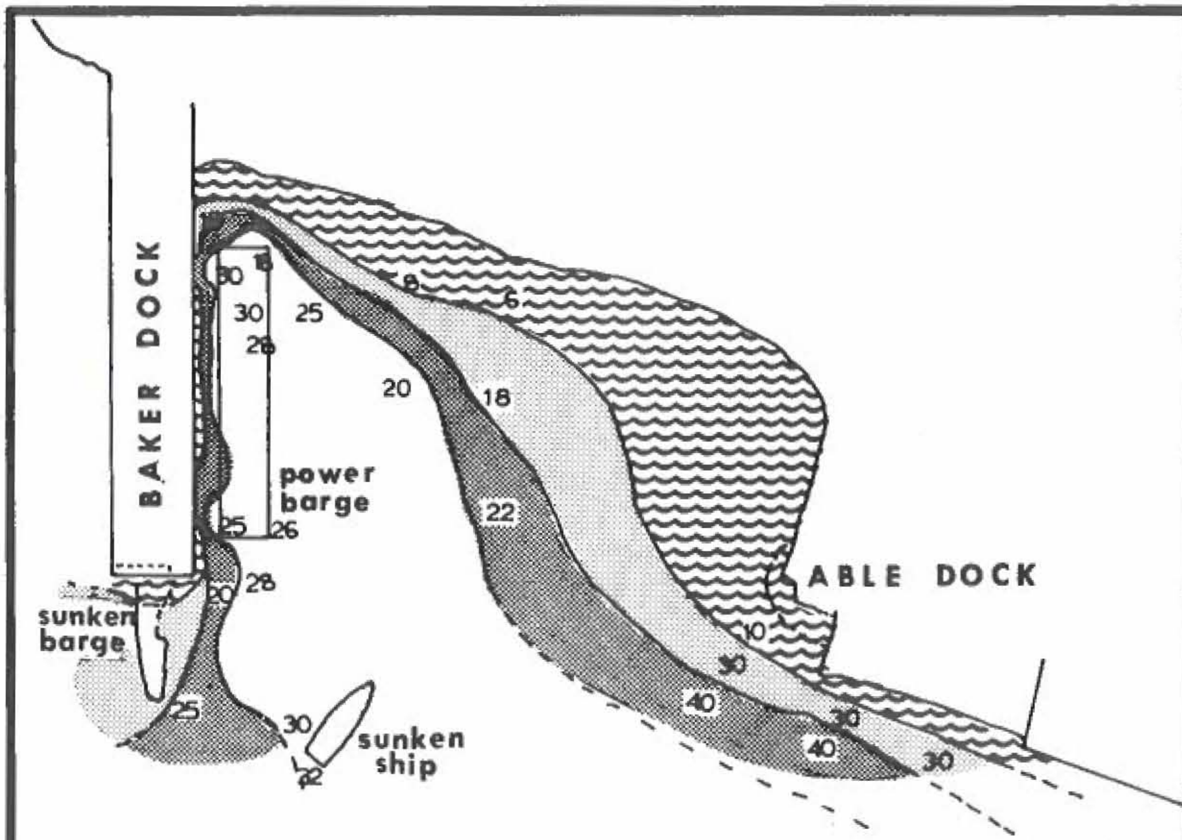


Figure 3.1. General sediment interface and subsurface characteristics along Charlie Bay transect.



Key to Substratum Types

- Coarse to medium sand and gravel, thin veneer of silts.
- Fine to medium sand with coral and limestone rubble, 5-15 cm layer of silts, abundant Halimeda plates.
- Fine to medium sand with rare rubble, 15-30 cm layer of silts.
- Fine sand and silt, gravel layer beneath ooze, 30-60 cm layer of silts.

Figure 3.2. General sediment interface characteristics of Baker Bay and Able Dock. Depths in feet.

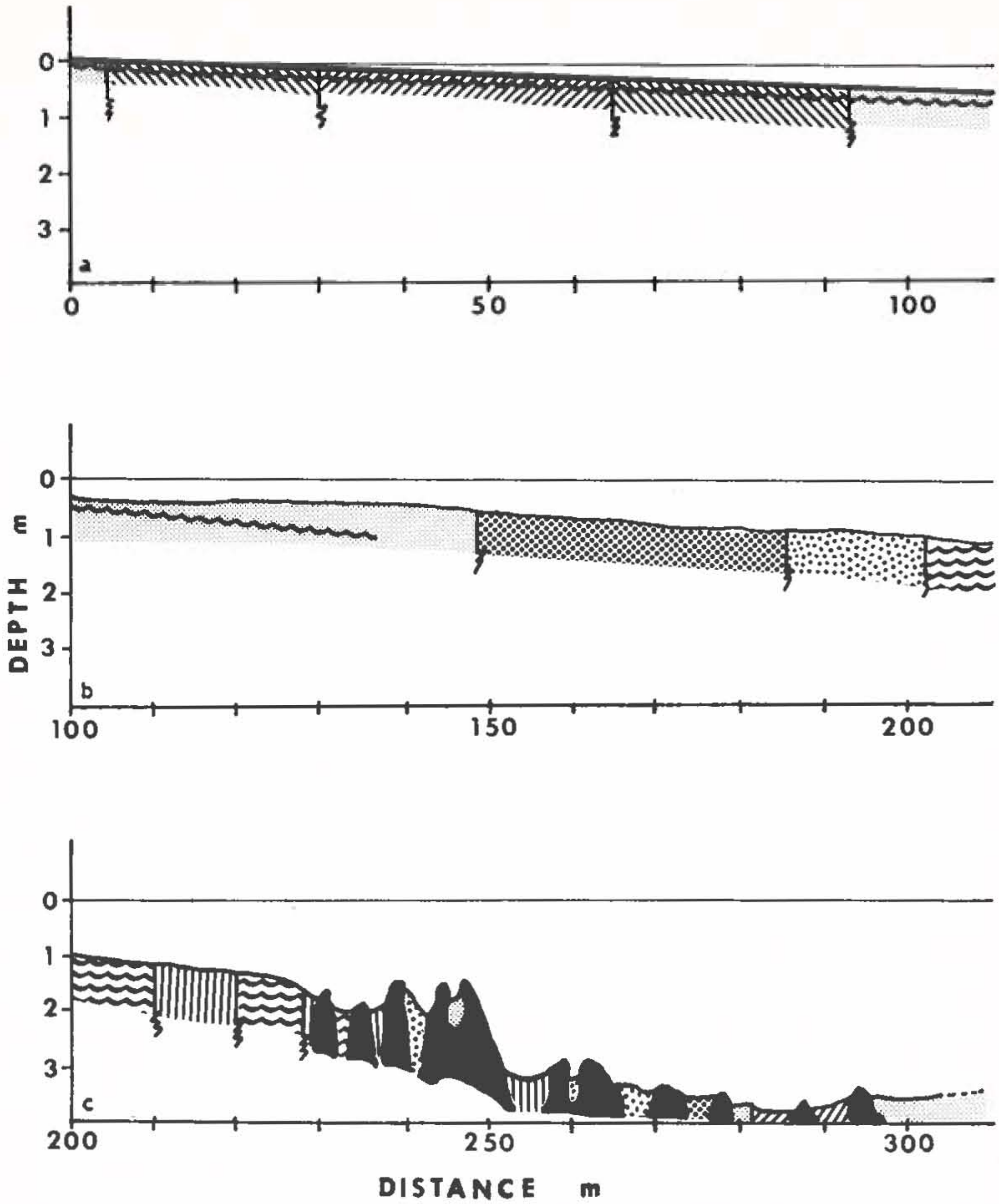


Figure 3.3. General sediment interface and subsurface characteristics along Unai Sadog Tase transect. a- supralittoral zone to 100 m. b- 100-200 m. c- 200-300 m, between the fuel dolpin and platform pilings. For key see Fig. 3.1.

4. WATER MOTION AND RELATED FACTORS

By

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

The movement of water in Tanapag Harbor was studied by recording the movement of drift drogues and dye patches. The drift drogues consisted of a metal vane (0.6 m tall and 0.2 m wide) suspended from a buoy by a line. The length of the line was varied to allow variation in the depth at which the vanes were suspended. Vane depths of 1 and 5 m were used in this study. Since the greatest portion of the drogue's cross-sectional area is produced by the vane (63% minimum vs. 24% maximum for the buoy and 13% maximum for the line) it is assumed that the movement of the buoy is primarily effected by the movement of the water at the level of the vane. The drogues were released at approximately 2-hr intervals at a spot about 10 m directly in front (seaward) of the power barge (Fig. 4.1). During the April, May and June study periods, a 5-m drogue was also released at a spot approximately 15 m seaward of the end of Baker Dock.

The positions of the drogues were plotted approximately 1, 1.5 and 2 hr after release, primarily through the use of a surveyer's transit located on the bridge of the power barge. At each sighting, each buoy's bearing relative to a fixed point (the quick-flashing buoy at the harbor entrance) and declination below the horizon were recorded. These data, combined with predetermined information on the position of the fixed point relative to North and the elevation of the transit above the sea surface, were used to compute the range and bearing of the buoys relative to North and to the power barge. During the night and at sunset (when glare precluded observations from the power barge), a hand-held compass (Saura Marine Instruments Co., Ltd., type HB-65) was used to determine the drogues' positions by triangulation.

In shallow water and restricted areas, water motion was studied with fluorescein dye. This method allowed observation of vertical as well as horizontal movement. Wherever possible, speed of movement was determined by timing the movement of dye patches over a known distance. However, the currents were often too slow to allow such measurements.

Wind and tide observations were made concurrently with the current studies. Wind speed and direction during all but the first study period were measured from the bridge of the power barge with a hand-held anemometer (Belfort Instrument Company wind measuring set, catalogue No. 6052). During the first study period, wind was estimated to be 20-25 knots (10-13 m/sec) from the northeast (heading

040°). Tidal fluctuations were monitored on a graduated tide staff mounted on a piling near the end of Baker Dock during the first study period and directly on Baker Dock near the power barge intake during subsequent study periods. The latter position allowed standardization between the study periods by placing the staff at the same position relative to the dock. The observed wind and tides are recorded in Table 4.1 and Figs. 4.2-4.4. The observed times of high and low tides were within about 30 minutes of those predicted in the tide tables for Guam, and the tidal ranges were similar.

Current observations were made for one complete tidal cycle (i.e., high-to-high or low-to-low) during each study period except the first one, when damage to the outboard motor on our boat prevented observations after 1230 hours. The times of our study periods were chosen to allow observations during maximum spring tides. Thus, our observations represent currents under maximum tidal influences.

Observations

Water Movement Away From the Power Barge

The drogue drift paths are plotted in Figures 4.5-4.10. Table 4.2 summarizes overall drift direction (the angle from North formed by a line drawn from the release point to the endpoint of each drift path), drift speed along the actual path followed (not necessarily the straight line used for determining overall drift direction), net tidal change, and wind speed and direction for each drogue set. It should be noted that drogue drift direction indicates the direction toward which the drogue is moving and wind direction, the keeping with meteorological convention, refers to the direction from which the wind is coming. In some cases, the drogues moved in a definite arc. These are indicated with an asterisk (*). Since the actual path of movement in these cases is somewhat different than would be interpreted from the table, the reader should noted the paths indicated in the respective figures. In two cases, Set H of 21 February and Set A of 20 March, the 5-m drogue traveled in a complete circle and returned to the release point. For these two cases, the drift direction is indicated as 000°.

The highest winds were encountered on 7 February 1976. They were estimated at 20-25 knots (10-13 m/sec). Drogue movement on this day was also the most unidirectional (Fig. 4.5). The 1-m drogue consistently moved parallel to the wind toward Unai Sadog Tase. The 5-m drogue consistently moved parallel to the storm swells into the southwest corner of Baker Bay.

On 21 February (Fig. 4.6), the 1-m drogue moved generally toward Puntan Muchot. All 5-m drogues except one remained in the vicinity of the power barge. These drogues either moved toward the intake end of the barge or circled around the "Four Winds" and returned to the release point. The only drogue which did not remain near the power barge impinged upon the Baker Bay side of Able Dock.

Drogue movement during 20 March (Fig. 4.7) showed the greatest variation of the study periods. The 1-m drogue paths varied from one which impinged upon Able Dock to another toward Managaha Island. The 5-m drogues also showed variation of movement. The first and third drogues released circled around the "Four Winds" and returned to the barge. The second drogue moved past the end of Baker Dock and toward Charlie Dock. The fourth and fifth drogues moved into Baker Bay. The sixth drogue did not move for one hour. The last drogue moved very slowly toward the "Four Winds."

Experimental variation in the release point of a second 5-m drogue on 15 April showed that such variation was probably the cause of variations in drift paths noted on 20 March. Drogues released closer than 10 m from the power barge consistently ended up against its hull. Consequently, greater care was taken during the April, May and June study periods to release the drogues from the same location (slightly more than 10 m from the power barge) each time.

During the April, May and June study periods, the drift drogues consistently moved offshore toward the harbor entrance or Managaha Island (Figs. 4.8-4.10). Drogue movement was primarily downwind. The 1-m drogues traveled approximately 10 times the speed of the 5-m drogues.

Tidal currents may have been responsible for some lateral shift, especially in the movement of the 5-m drogues. However, no evidence was found indicating tides to be a significant factor in drogue movement.

Movement of Oil Away from Charlie Dock

At 1010 on 15 May 1976, an oil slick was observed extending westward from Charlie Dock. By 1200 the slick had formed a continuous band from Charlie Dock ca. 30 m wide which extended from Charlie Dock more than 2 km toward the harbor entrance. The slick's location at this time was plotted in the same manner as were the drift drogues (i.e., using the transit). At 1300 an oil containment boom was placed across the western end of Charlie Dock. (Another boom was placed across the eastern end at an undetermined time.) By this time the slick had broken up into discrete patches of heavy oil floating in a single wider, thinner slick. General movement was toward the harbor entrance and the patch reefs which lie to the south of the entrance channel. No visible slick ever reached Baker Dock. We later learned that the spill occurred from an oil line on Charlie Dock which ruptured during off-loading of fuel oil from a barge moored at the dock.

Water Movement Adjacent to the Power Barge

Water movement adjacent to the power barge (within 5 m of the barge) was studied by dropping patches of fluorescein dye from the deck into the water and observing the direction of movement. Most of the observations were made on 12 and 13 June 1976 and were timed to cover the tidal range. Generalized water movements are indicated in Fig. 4.11.

The strongest and most consistent water movement occurs on the starboard side of the barge in the relatively narrow stretch of water between the barge and Baker Dock. Surface water movements next to the barge are consistently toward the stern, where the main cooling-water intake is located. This movement extends for almost the entire length of the barge, occurring as far forward as the gangplank which crosses from the shoreline to the forward deck of the barge. Maximum speed observed was approximately 0.12 m/sec; speed at all points along the starboard side was generally much slower than this but movement toward the stern was always clearly detectable. Further away from the barge on the starboard side the water movement was slower and was not detectable next to the shoreline of Baker Dock. It is clear from the pattern of water movement on this side of the barge that some water can be recycled from the starboard cooling-water outfall at the bow to the main cooling-water intake at the stern.

Water movement next to the barge on the port side was found to be much more variable in its direction and usually slower than on the starboard side. Dye patches often moved so slowly as to make speed measurements impossible. The major influence on water movement on the port side of the barge is the cooling-water outfall for internal machinery (not to be confused with the outfalls for the main condensers), which is located about one-third of the barge length forward of the stern. (A similar outfall on the starboard side of the vessel is utilized only occasionally.) This machinery cooling-water outfall creates a complex eddy system next to the barge, and water movement on either side of the eddy was observed to be either forward or aft, with no consistent pattern (Fig. 4.11). There is no evidence for any tidal pattern in the variation of the water movement. It is clear that, unlike the starboard side, there is no general water transport from the bow outfall to the stern intake along the port side of the barge.

Surface movement at the stern of the barge is generally toward the centrally located main cooling-water intake. However, this movement is of variable speed; and there is some evidence of eddy patterns in the stretch of water between the stern of the barge and the shoreline of Baker Bay.

Water motion at the bow of the barge is strongly influenced by the two main cooling-water outfalls. These outfalls are located directly on the bow of the vessel and direct the effluent water downward. This water strikes the bottom, where it has excavated shallow depressions under each outfall, and then swirls laterally and vertically in two complex eddy patterns. These eddy regions are manifested at the water's surface off the bow corners of the barge rather than directly forward of the outfalls themesleves (Fig. 4.11). The eddies also entrain some surface water in a generally downward movement, as revealed by dye releases; but most of the heated effluent water quickly rises to the surface and moves away from the outfall region. The dominant movement on the surface is seaward and away from the barge but there is some movement towards Baker Dock. Forward (seaward) of the barge, water movement on the bottom (at a depth of about 5-6 m) is either undetectable or very weakly toward the outfalls, as revealed by colored streamers which were attached to buoyed lines that in turn were anchored to the bottom (Fig. 4.11). Under the barge, bottom water moves away from the outfalls, as revealed by diver's observations.

Water Movement in Baker Bay

General water movement in Baker Bay, aside from that immediately adjacent to the power barge, was also observed by dropping dye patches and observing their direction of movement. Only near the shoreline were speeds great enough to be measured, though there was generally no question about the direction of movement. General patterns are shown in Figs. 4.12-4.14. It may be seen in Fig. 4.12 that nearshore water movement was generally seaward at velocities ranging from 0.03 to 0.12 m/sec. The direction and velocity of movement did not appear to be influenced by tidal state.

Water movement in the middle portions of Baker Bay was generally indetectable or weak but was generally seaward when it could be detected (Figs. 4.13 and 4.14). Within 50 m of the barge there was detectable inward (shoreward) water movement on some occasions in the northeastern half of the bay. Such inward movement was more likely to be detected on a rising tide.

Possible bottom-water movement was searched for in Baker Bay by releasing dye at intervals along one of the mooring chains stretching across the bottom of the bay. No such movement could be detected.

Water Movement around Baker Dock

Water movement around Baker Dock was also observed by dropping dye patches. As shown in Fig. 4.12, movement in Charlie Bay within 10 m of Baker Dock was seaward regardless of the tidal state, with the greatest speeds being 0.08 m/sec. At the seaward end of Baker Dock, seaward-moving water from both the Baker Bay and Charlie Bays converged and continued seaward. This direction did not change with tidal state; velocity was somewhat variable but also showed no clear relation to tide.

Summary

Wind speed and direction primarily control the movement of surface waters and flotsam in the harbor. Drogues released near the outfall of the power barge moved generally downwind toward the west or southwest. This pattern was more consistent for the 1-m drogues than for the 5-m drogues. The 5-m drogues moved in circular paths when placed within about 10 m of the outfall, reflecting the eddy system caused by the outfall itself. The 1-m drogues moved faster than the 5-m drogues; the maximum average speed observed was .13 m/sec (.26 knots). Oil spilled from Charlie Dock eventually reached the patch reefs south of the Harbor entrance channel.

There are two complex eddy systems near the two outfalls. Effluent water may move away from the starboard outfall along the starboard side of the barge and re-enter the cooling-water intake. Some water moves from both outfalls toward the cooling-water intake underneath the hull. Though movement into Baker Bay was slow during our observation periods, it is clear that effluent water from the barge can move into this area. Despite the fact that observations were timed to coincide with strongly rising and falling spring tides, there was no evidence for tidal influence in any of the major water movements.

Table 4.1. Wind and tide observations. Datum for tide heights is approximately MLLW as determined by visually fitting the observed tidal curves to the predicted curves for Guam. Wind speeds in parentheses are gust speeds. One knot is approximately 0.5 m/sec. Wind bearing is the direction from which the wind is blowing.

Observation		Tide	Wind	
		Height	Speed	Bearing
Day	Hour	(ft)	(knots)	(o)
21 Feb	0506	1.1	3.5	082
	0555	1.2	-	-
	0712	1.4	4.0	059
	0812	1.7	6(7.5)	065
	0920	-	7(10)	049
	1100	2.3	-	-
	1106	-	6(15)	054
	1214	-	10(13)	054
	1304	-	7(12.5)	054
	1310	2.2	-	-
	1415	1.9	10(13)	059
	1531	1.4	10(13)	059
	1630	1.1	-	-
	1709	-	7(9)	059
	1748	0.6	-	-
	1806	0.5	-	-
	1814	-	6(6)	059
20 Mar	0445	1.5	4.5	114
	0555	1.4	4.0	084
	0630	1.6	-	-
	0640	-	5.0	091
	0700	1.7	-	-
	0815	1.9	8.5	045
	0830	2.2	-	-
	0844	-	8.0	049
	0850	2.3	-	-
	0945	2.4	6.0	089
	1120	2.3	-	-
	1125	-	5.0	064
	1215	2.2	6.5	069
	1315	1.6	12(16)	043
	1355	1.2	14(16)	046
	1420	1.0	12	051
	1510	0.8	15(16)	029
	1545	0.5	15	049
	1615	0.3	16(17)	049
	1700	0.2	16(18)	054
	1800	0.2	6.5(9)	054
	1910	0.6	-	-
	2100	1.5	-	-
	2315	2.2	-	-

Observation		Tide	Wind	
		Height	Speed	Bearing
Day	Hour	(ft)	(knots)	(o)
21 Mar	1015	2.3	-	-
	1050	2.2	-	-
	1145	2.1	-	-
	1215	2.1	-	-
	1220	2.1	-	-
	1320	1.8	-	-
	1420	1.0	-	-
	1630	0.0	-	-
15 Apr	0620	2.3	-	-
	0640	2.4	4.5	081
	0715	2.5	-	-
	0730	-	5(7)	074
	0800	-	5.5(8)	084
	0830	2.4	7(11)	084
	0900	2.1	8(11)	087
	0915	2.1	-	-
	0940	2.0	5(7.5)	093
	0945	2.0	-	-
	1015	1.7	6.5(11)	093
	1025	1.7	-	-
	1145	0.8	3.0	090
	1200	-	2.5	077
	1215	0.6	-	-
	1235	0.3	3(3.5)	111
	1305	0.2	2.5(4)	088
	1340	0.0	3.5	062
	1400	-0.1	5.5	069
	1430	-0.1	7.0+	061
	1500	-0.1	3.5	071
	1540	0.0	4.0	079
	1615	0.4	3.0	069
	1630	0.5	-	-
	1700	0.9	3.0	059
	1815	1.5	3.0	084
	1830	1.7	2.0	079
	1850	1.9	-	-
	1930	2.0	-	-

Table 4.1. (continued)

Time of Observation Day	Hour	Tide Height (ft)	Wind Speed (knots)	Wind Bearing (°)
15 May	0640	2.1	7.5(8)	076
	0706	2.3	-	-
	0745	2.3	8.5	074
	0815	2.2	-	-
	0830	-	8.5(9.5)	054
	0900	2.1	10(15)	079
	0930	1.7	8(14)	068
	0955	1.6	11(17)	069
	1030	1.3	11(15)	070
	1105	1.0	8(12)	149
	1140	0.7	10(12)	101
	1215	0.3	13(15)	064
	1235	0.1	12(14)	054
	1305	-0.2	14	054
	1335	-0.4	-	-
	1437	-0.6	-	-
	1455	-	10	069
	1515	-0.5	-	-
	1545	-	10	069
	1615	-0.3	12(15)	084
	1645	0.0	-	-
	1705	0.1	8.0	094
	1730	0.3	-	-
	1800	-	8.0	069
	1835	1.1	5(7)	074
	1900	1.3	5(10)	091
	2000	1.8	5(10)	059
	2100	2.1	6(9)	089
	2130	2.3	7(11)	069
	2200	2.3	5(7)	060

Time of Observation Day	Hour	Tide Height (ft)	Wind Speed (knots)	Wind Bearing (°)
15 June	0615	2.3	-	-
	0630	-	7.0	084
	0700	2.3	6.0	094
	0730	2.2	6.0	094
	0800	2.0	8(9)	064
	0830	1.8	7(12)	113
	0900	1.5	5(7)	107
	0915	1.4	-	-
	0930	1.3	7(9)	089
	1000	1.0	7(12)	079
	1030	0.6	8(9)	099
	1100	0.4	9(12)	079
	1130	0.0	10(15)	099
	1200	-0.3	10(11)	089
	1230	-0.4	-	-
	1300	-0.6	10(11)	079
	1330	-0.7	6(7)	159
	1400	-0.6	5.0	149
	1500	-0.4	4.5(8)	157
	1530	-0.2	5.0	114
	1605	0.1	5(6)	099
	1645	0.5	5(6)	139
	1700	0.6	5(6)	119
	1730	1.0	5.0	114
	1800	1.3	3(4)	099
	1830	1.6	3.0	089
	1910	2.0	2.5	165
	1930	2.1	-	-
	2000	2.3	2.5	166
	2040	-	3.0	159
	2100	2.4	1(2)	159
	2130	2.4	2(3)	159
	2200	2.3	1	184
	2240	2.1	-	-
13 June	1000	1.3	-	-
	1100	1.2	-	-
	1200	0.3	-	-
	1230	0.2	-	-
	1410	-0.7	-	-
	1440	-0.7	-	-
	1500	-0.6	-	-
	1550	-0.4	-	-
	1635	-0.1	-	-
	1700	0.1	-	-
	1730	0.5	-	-
	1800	0.8	-	-

Table 4.2. Movement of drift drogues correlated with tide and wind observations. All speeds are averages. The direction of drogue movement is the angle from release point to endpoint relative to True North. Asterisks indicate circular drogue paths. A direction of 000° indicates the drogue returned to the release point. Wind directions are those from which the wind is blowing.

Time of Set				Avg. Drogue Movement						
			Drift	1 m Deep		5 m Deep		Tide	Avg. Wind	
			Time	Speed	Dir	Speed	Dir.	Change	Speed	Dir.
Day	Hour	Set	(mm)	(m/sec)	(∘)	(m/sec)	(∘)	(cm)	(m/sec)	(∘)
7 Feb	0520	A	130	0.070	233	0.010	188*	6	-	-
	0730	B	30	0.088	218	0.050	169	3	-	-
	0930	C	110	0.084	221	0.024	186	12	-	-
	1130	D	60	0.128	225	0.046	196	-	-	-
21 Feb	0506	A	39	0.103	267	0.005	093	3	1.8	082
	0545	B	81	-	-	0.003	166*	6	-	-
	0712	C	60	0.104	258	0.003	093	9	2.1	059
	0812	D	52	-	-	0.005	166*	6	3.1	065
	0912	E	114	0.037	254	0.024	214	12	3.3	052
	1116	F	112	0.043	233	0.006	127*	- 3	4.4	054
	1316	G	135	0.079	233	0.005	127*	-30	5.1	059
	1609	H	122	0.016	238	0.014	000*	-22	3.3	059
20 Mar	0430	A	130	0.029	292	0.013	000*	-	2.2	099
	0640	B	125	0.044	309	0.015	359	18	3.5	068
	0845	C	160	0.070	263	0.002	175*	3	3.6	069
	1125	D	110	0.056	250	0.012	135*	-21	3.0	066
	1315	E	105	0.031	221	0.014	164	-24	6.7	047
	1500	F	130	0.042	219	-	-	-18	8.2	045
	1710	G	50	0.058	239	0.006	285	-	3.3	054
15 Apr	0635	A	85	0.057	255	0.007	344*	-	2.6	080
	0825	B	110	0.006	268	0.018	282	-21	3.4	084
	1035	C	120	0.131	278	0.033	329	-42	1.4	094
	1250	D	70	0.061	285*	0.033	281	- 9	2.0	073
	1430	E	105	0.067	268	0.031	281	15	2.3	070
	1630	F	120	0.063	268	0.023	279	37	1.4	074
15 May	0635	A	115	0.079	285	0.035	280	-	4.2	068
	0855	B	95	0.110	189*	0.037	265	-24	5.1	072
	1100	C	125	0.070	279	0.029	306	-24	5.7	084
	1310	D	105	0.095	285	0.029	289	-12	5.2	069
	1500	E	75	0.081	340*	0.009	290	6	5.7	076
	1700	F	95	0.094	256	0.016	267	30	3.6	079
	1900	G	60	0.033	248	0.019	139*	15	2.6	075
	2030	H	90	0.080	274	-	-	6	3.1	073

Table 4.2. (continued

Time of Set				Avg. Drogue Movement						
			Drift	1 m Deep		5 m Deep		Tide	Avg. Wind	
			Time	Speed	Dir.	Speed	Dir.	Change	Speed	Dir.
Day	Hour	Set	(mm)	(m/sec)	(°)	(m/sec)	(°)	(cm)	(m/sec)	(°)
12 June	0630	A	95	0.058	282	0.011	196*	- 9	3.5	080
	0808	B	109	0.103	279	0.030	262	-30	3.2	103
	1000	C	122	0.080	293	0.022	302	-21	4.5	089
	1230	D	95	0.115	308	0.042	323	- 6	3.6	129
	1410	E	120	0.101	315	0.040	342*	15	2.5	123
	1635	F	125	0.059	317	0.019	329	40	2.2	113
	1850	G	58	0.041	316	0.023	319	12	1.3	165
	1950	H	50	0.031	332	0.026	307*	-	1.0	165

Figure 4.1. Drift drogues being released. Photo taken from the bridge of the "Impedance."

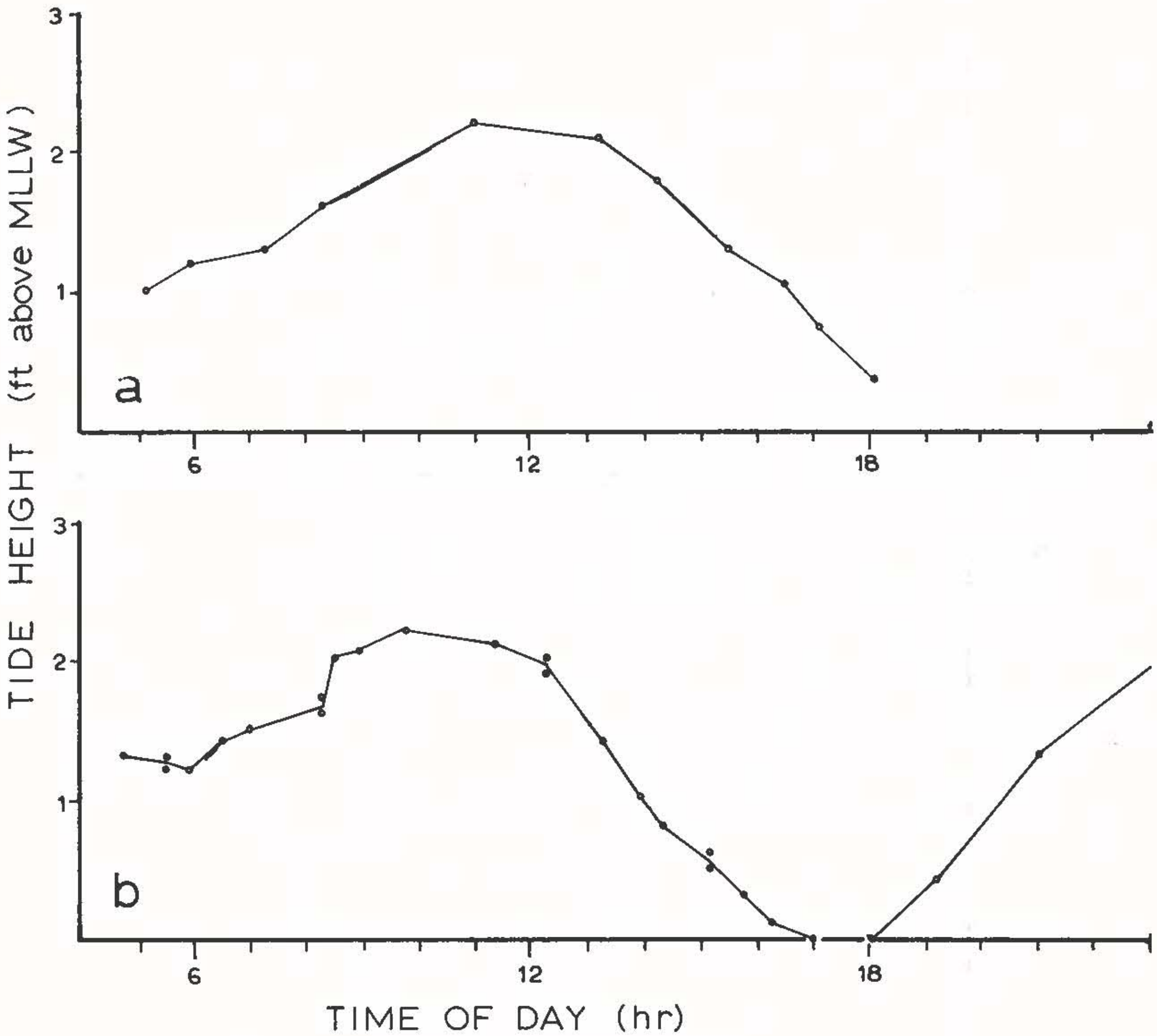


Figure 4.2. Tides in February and March. a. 21 February 1976.
b. 20 March 1976.

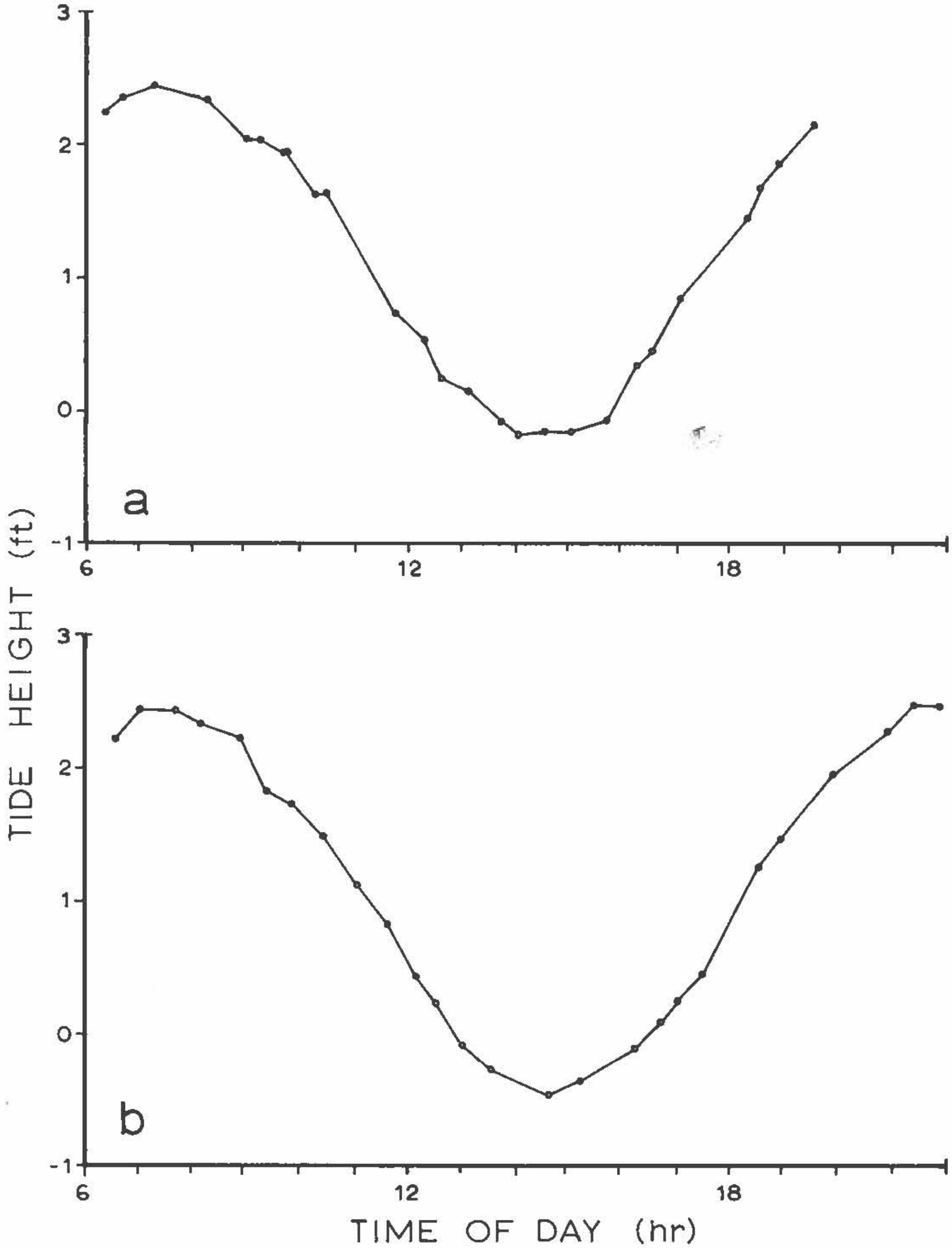


Figure 4.3. Tides in April and May. a. 15 April 1976. b. 15 May 1976.

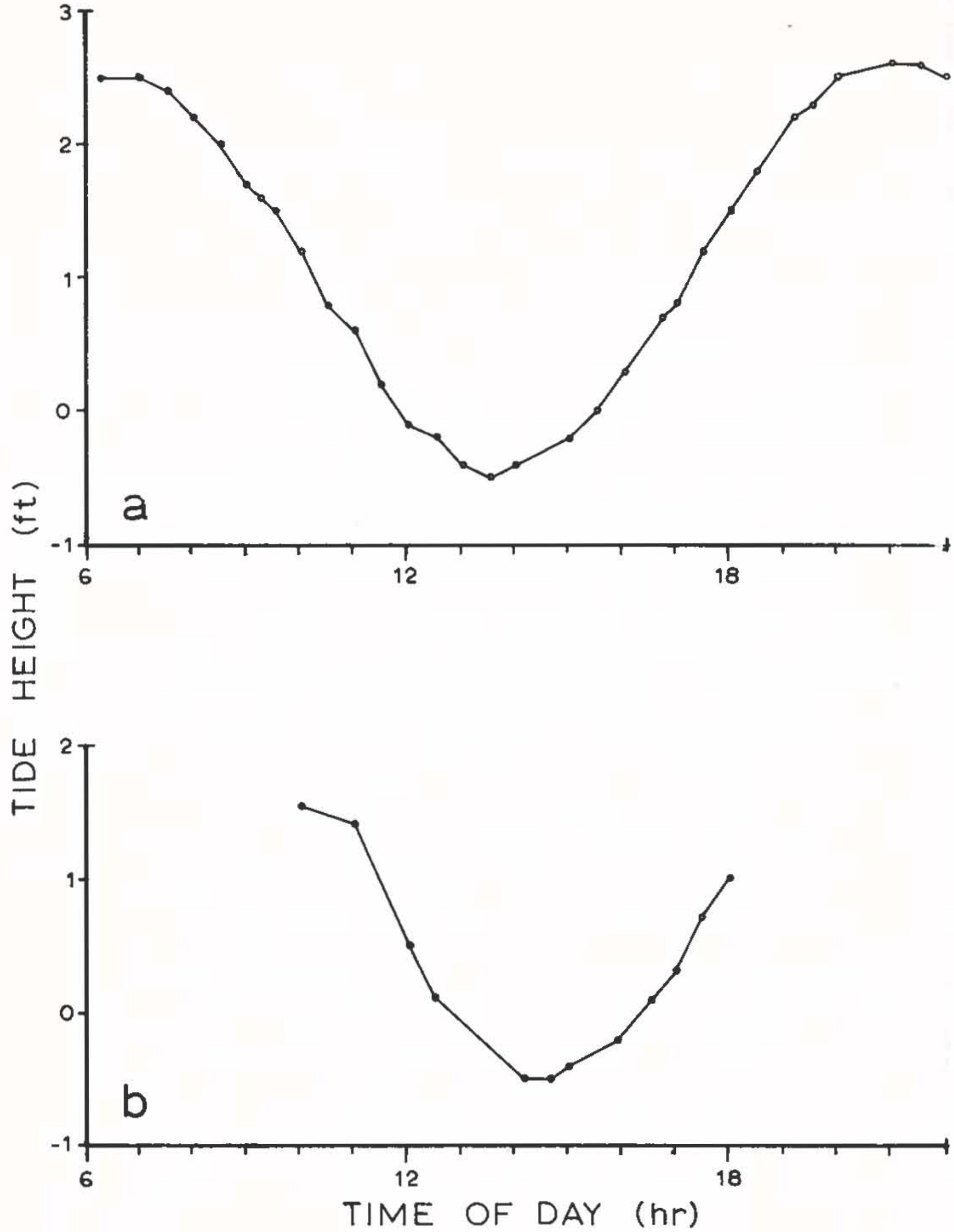


Figure 4.4. Tides in June. a. 12 June 1976. b. 13 June 1976.

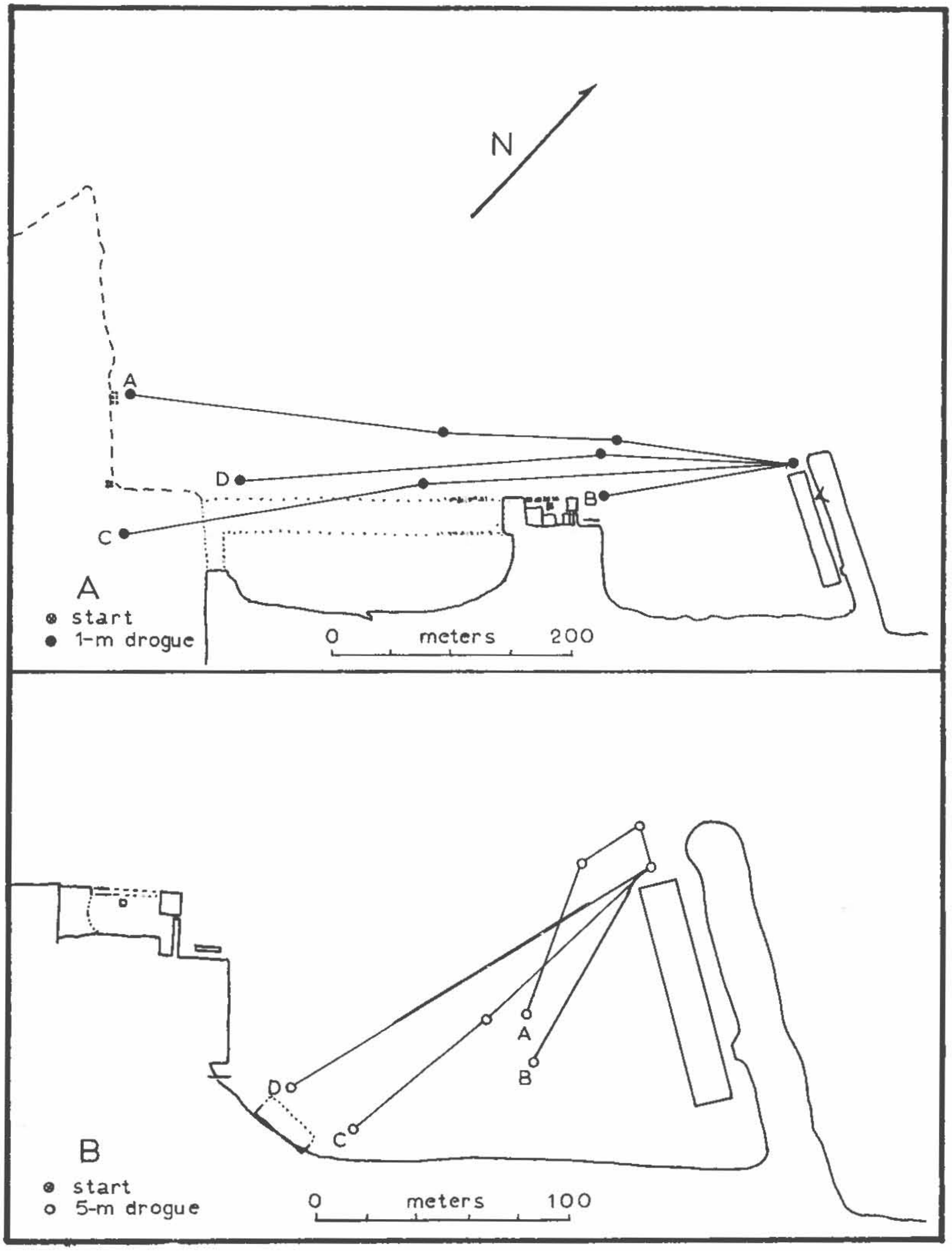


Figure 4.5. Drogue drift paths for 7 February 1976.

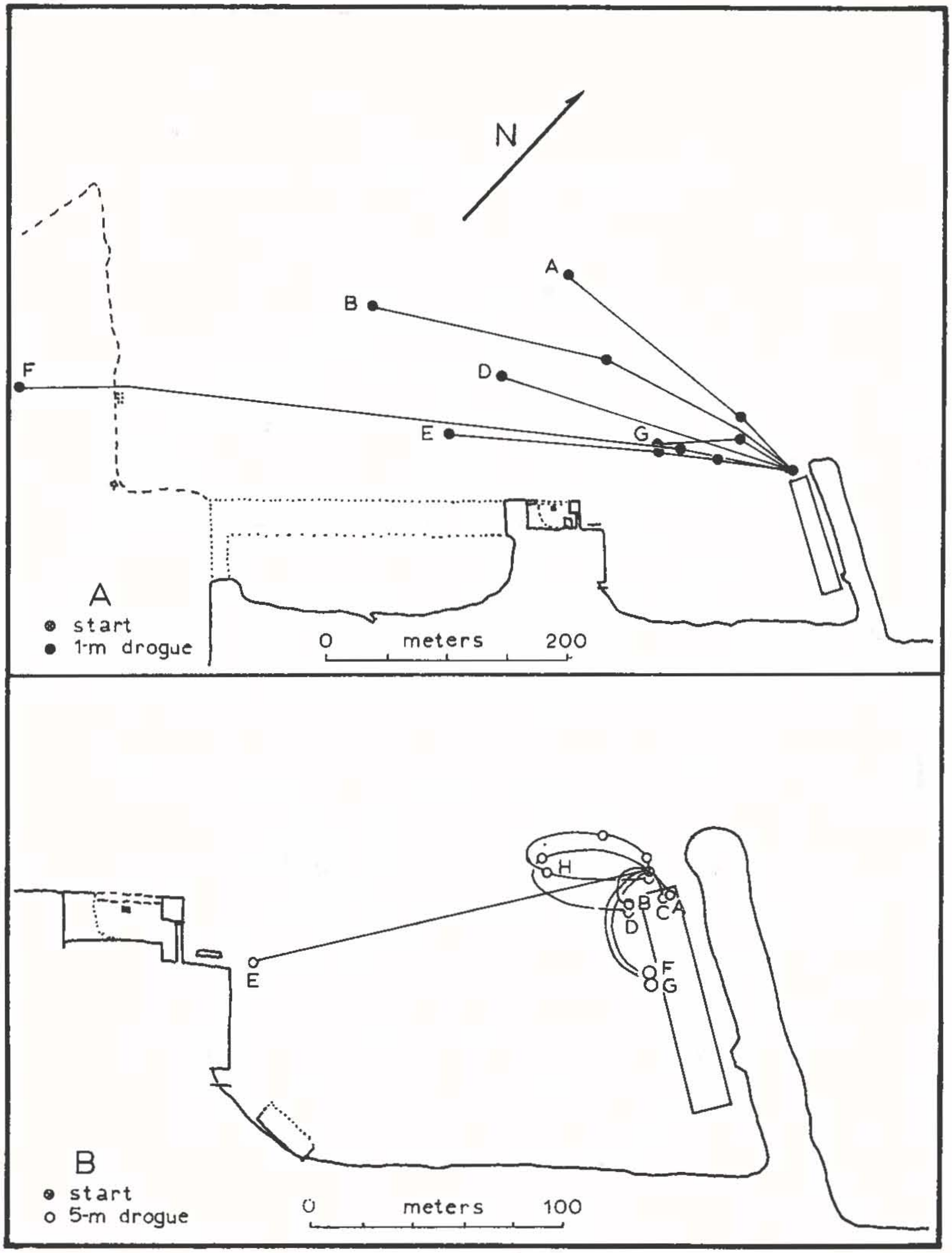


Figure 4.6. Drogue drift paths for 21 February 1976. See Table 4.2 for release times.

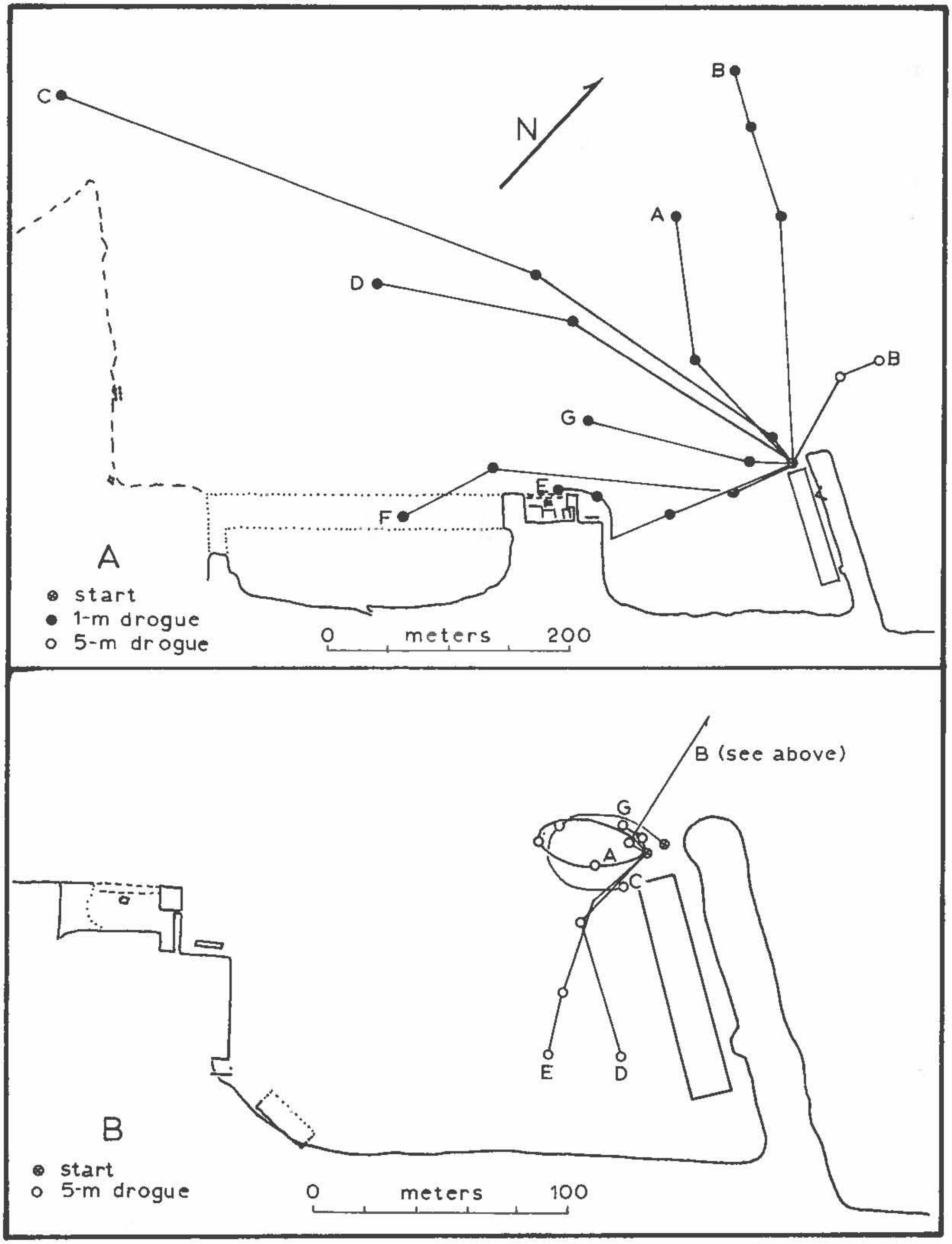


Figure 4.7. Drogue drift paths for 20 March 1976. See Table 4.2 for release times.

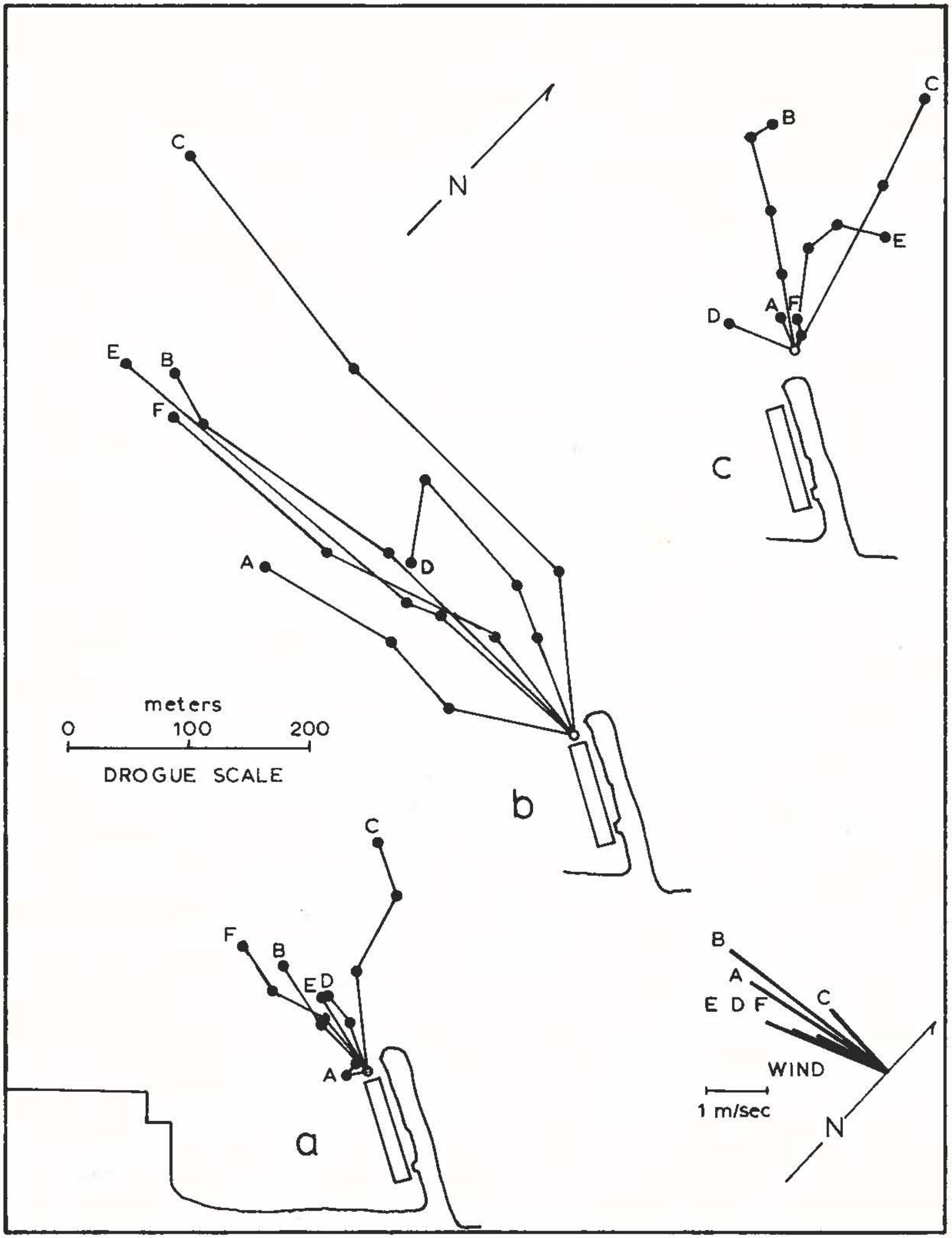


Figure 4.8. Drogue drift paths for 15 April 1976. a and c. 5-m drogues. b. 1-m drogue.

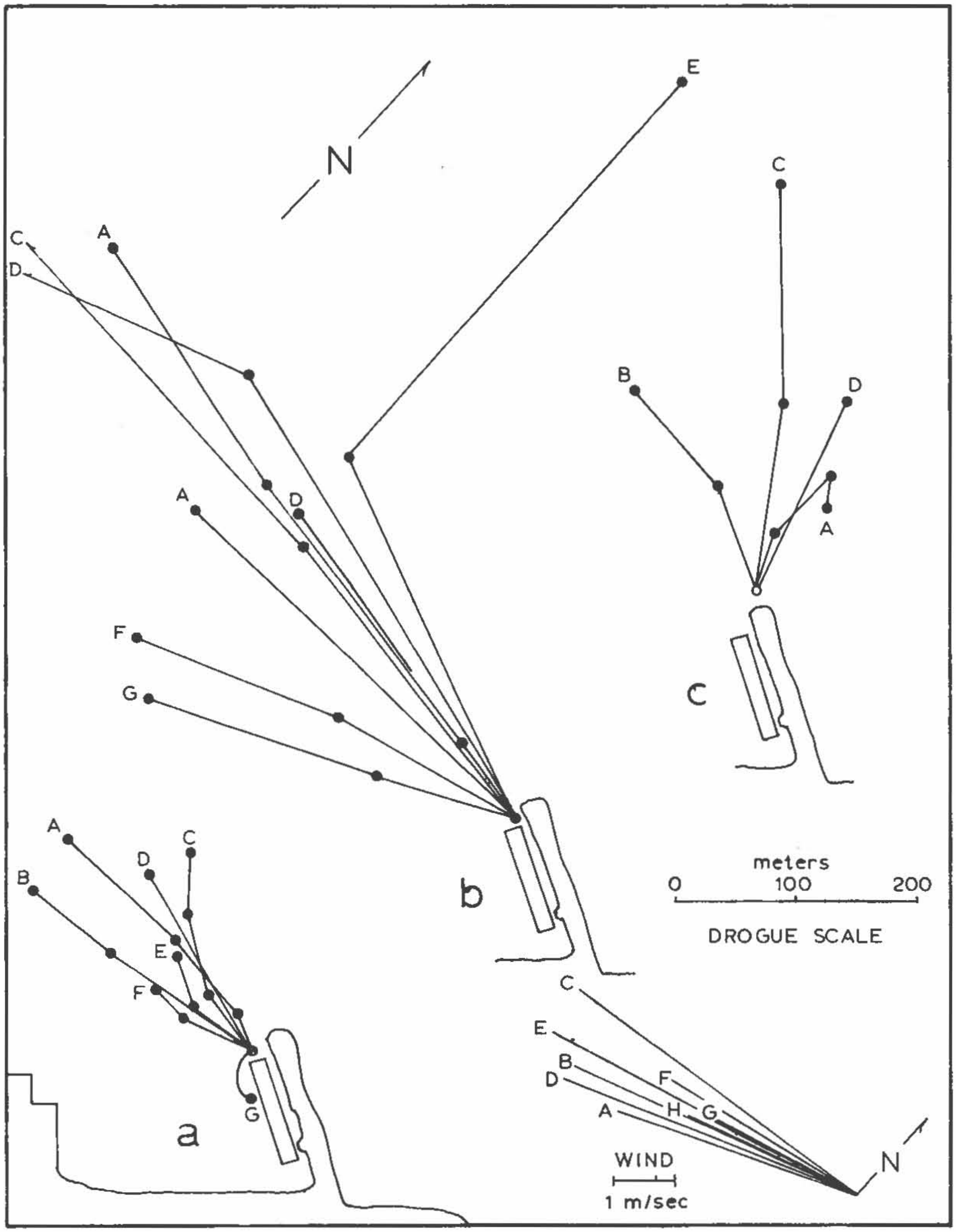


Figure 4.9. Drogue drift paths for 15 May 1976. a and c. 5-m drogues. b. 1-m drogues.

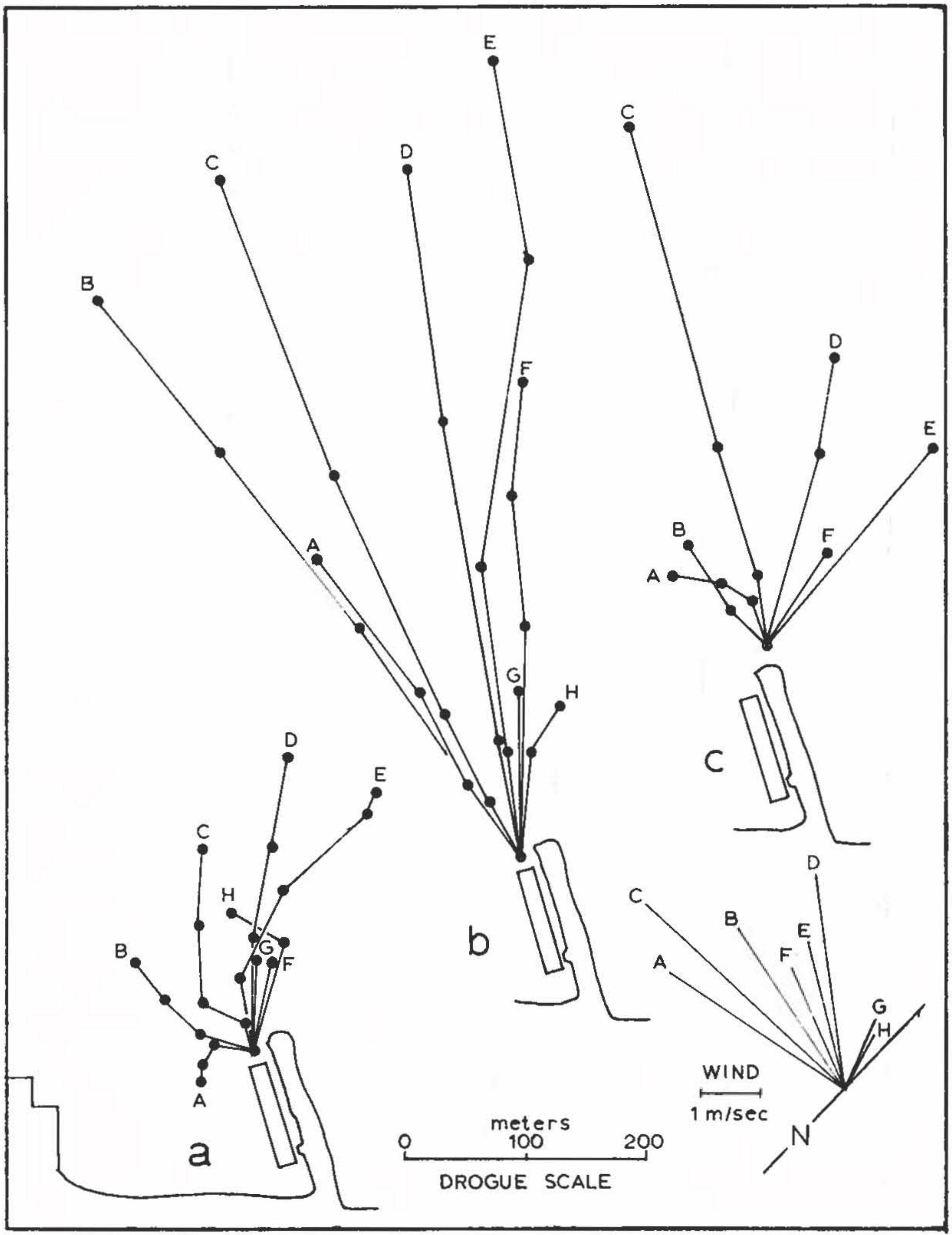


Figure 4.10. Drogue drift paths for 12 June 1976. a and c. 5-m drogues. b. 1-m drogue.

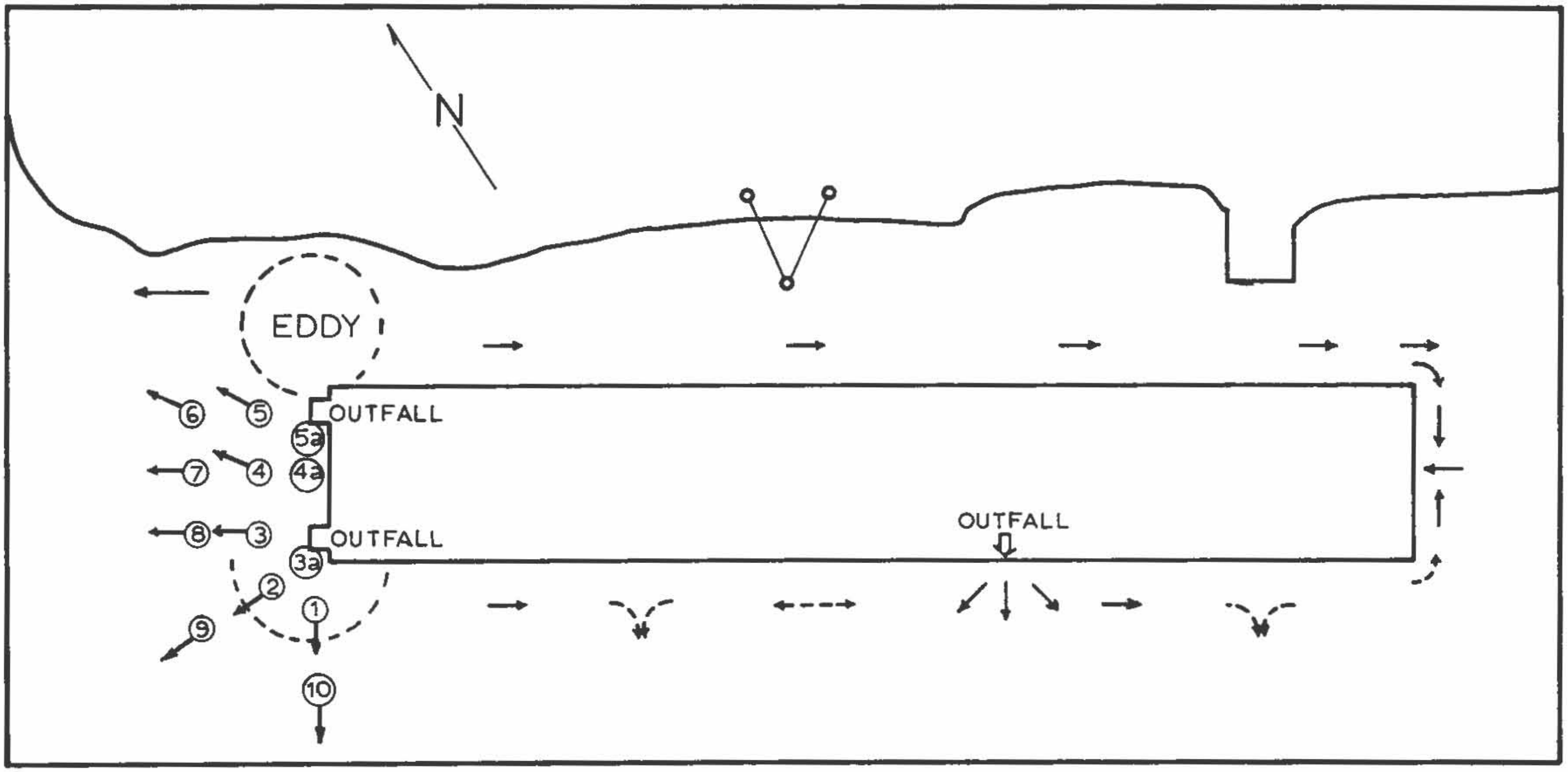


Figure 4.11. Current patterns near Baker Dock and the "Impedance." Circled numbers indicate location of buoy stations. Dashed arrows indicate variable water movements.

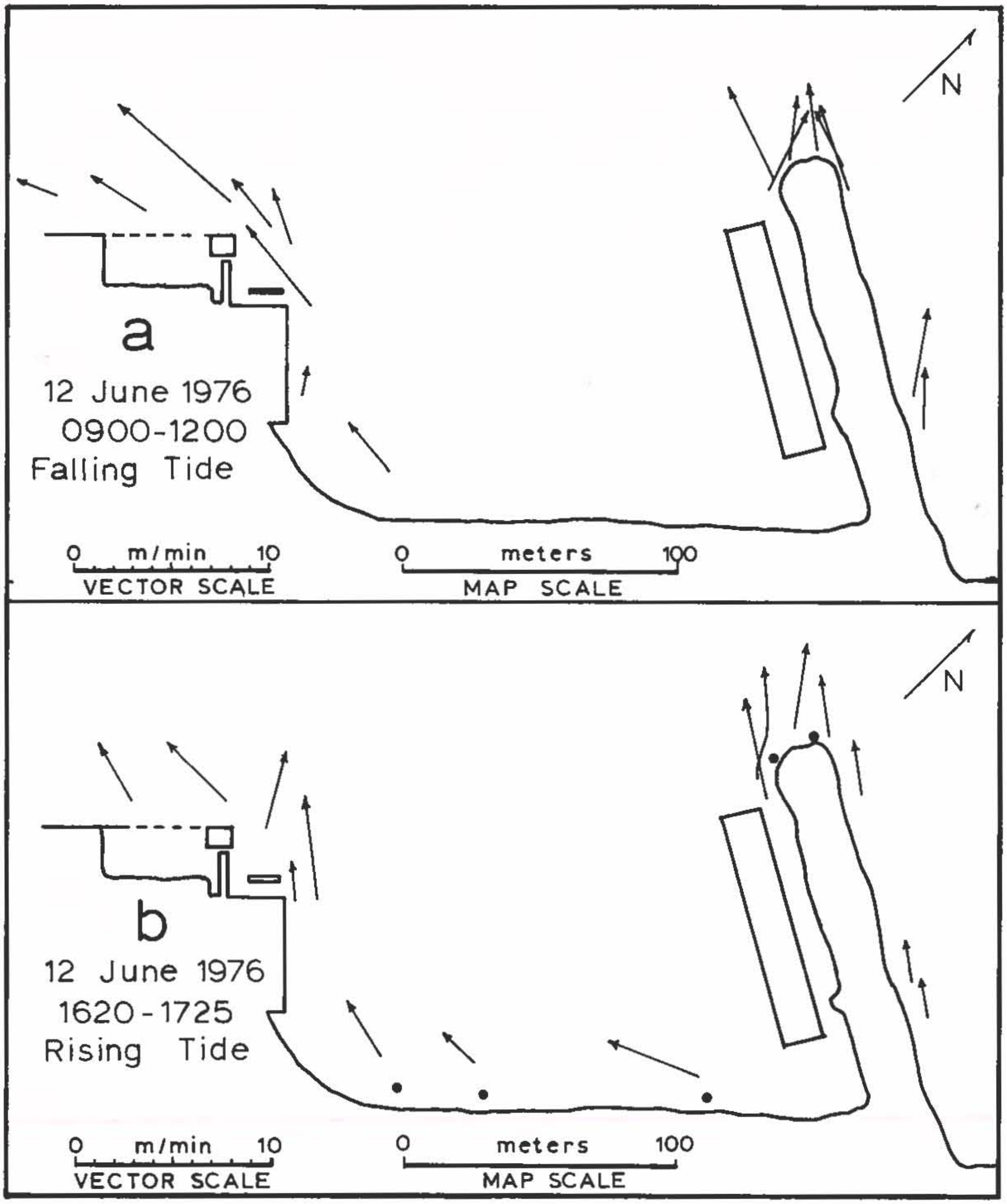


Figure 4.12. Currents in and near Baker Bay. Arrow lengths are proportional to current speed. ● = no movement.

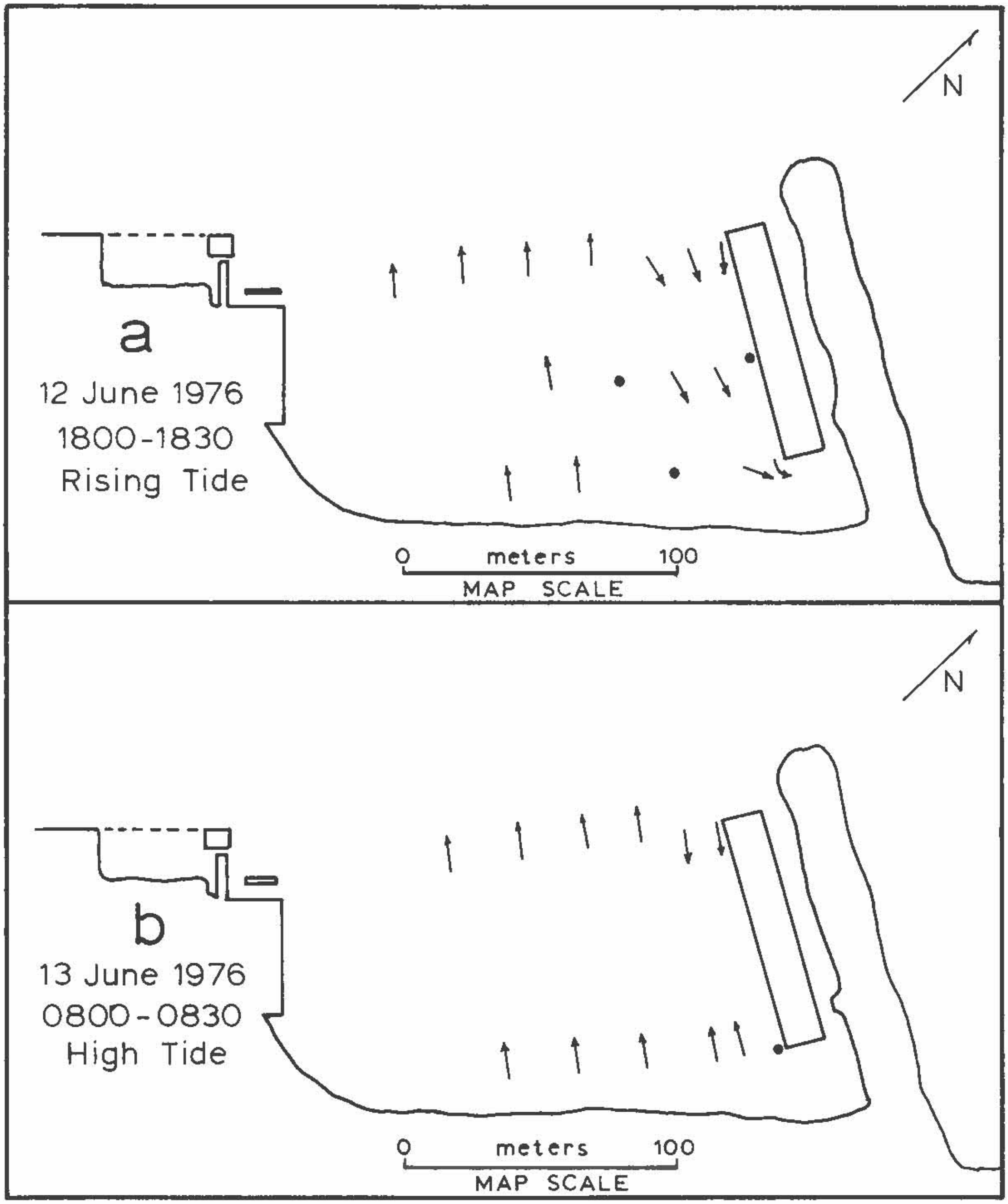


Figure 4.13. Currents in Baker Bay. Arrows indicate direction only.
• = no movement.

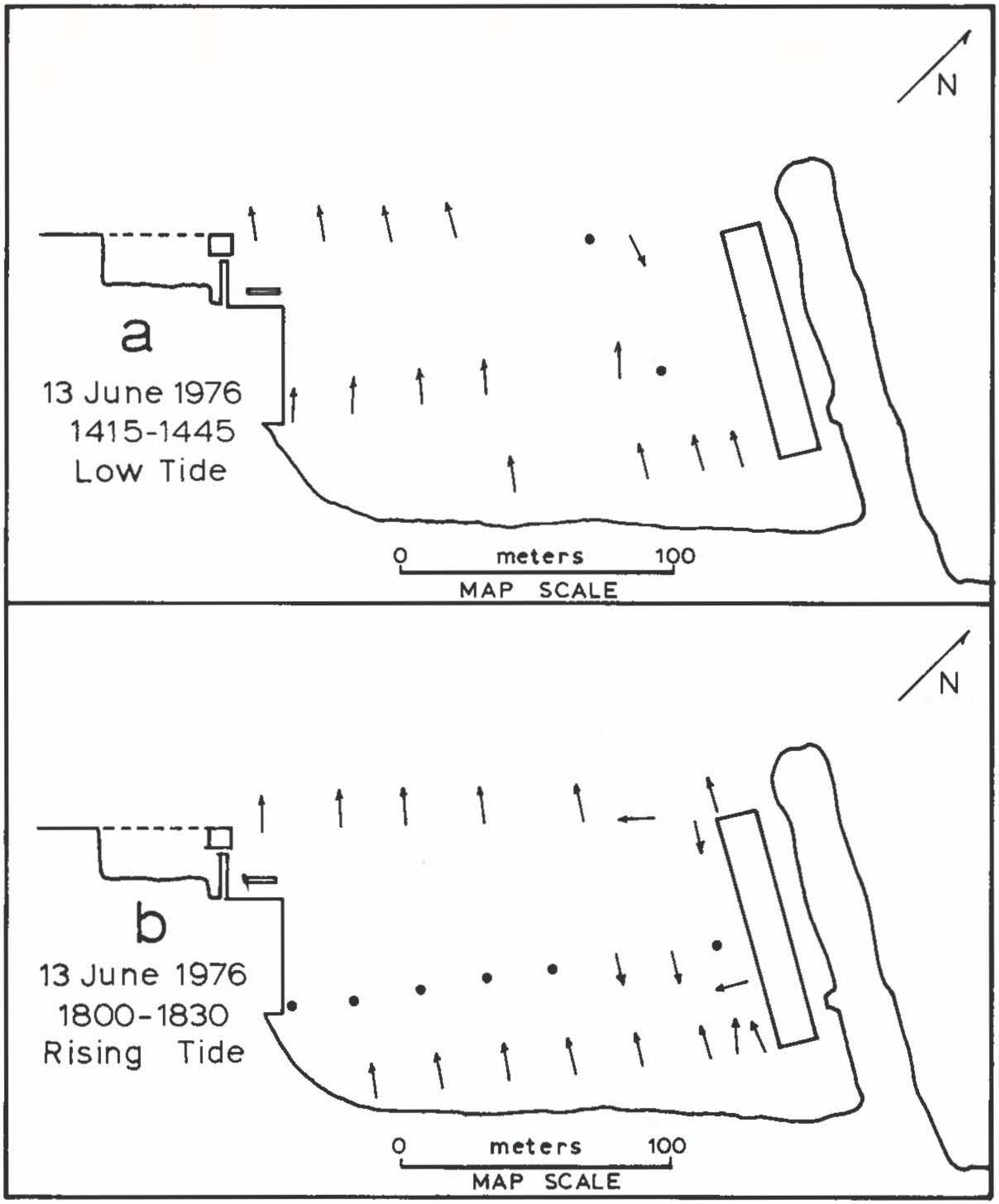


Figure 4.14. Currents in Baker Bay. Arrows indicate direction only.
• = no movement.

5. WATER TEMPERATURES AND PLANT OPERATION

By

JAMES E. DOTY

The power barge "Impedance" is expected to influence the marine environment primarily through the introduction of heated water. Therefore a major effort was made to define the thermal regime around the power barge. Since shallow tropical waters such as those surrounding the barge naturally undergo significant variations in temperature within small spans of time or space, precise definition of the power barge's thermal influence is not easily obtained. The primary objective here is to make some general statements about the thermal influence of the barge by comparing observations made near the barge with similar observations in areas beyond barge influence.

Three kinds of temperature data were collected. Surface temperatures were determined to the nearest 0.1°C using a mercury-column bucket thermometer. Temperature-depth profiles were determined to the nearest 0.1°C using thermistor probes (usually a Yellow Springs Instrument Company model 46TUC telethermometer with a 21-m probe). Benthic maximum and minimum extreme temperatures were recorded to the nearest 0.5°C by mercury/alcohol-column maximum/minimum recording thermometers (Taylor Instrument Company).

Observations

Water Temperatures

The lowest surface temperature recorded during our study (26.2°C) was recorded in deep water off the end of Baker Dock (Table 5.1 and Fig. 5.1). Minimum surface temperatures averaged 27.4°C and generally occurred in deep water or near Charlie Dock. The maximum surface temperature recorded during our study was 30.0°C. This temperature was recorded along the southwestern side of Baker Dock near the power barge effluent (Table 5.2). Maximum surface temperatures averaged 29.0°C and were consistently found along the southwestern side of Baker Dock. Temperatures along this side of the dock averaged 0.5°C warmer than along the northeastern side. Similarly, temperatures in Baker Bay tended to be warmer than in Charlie Bay. Temperatures in both Baker and Charlie Bays were warmer than temperatures in the deeper water outside the bays.

Vertical temperature-depth gradients measured in Charlie and Baker Bays were milder and more stable than gradients measured in deeper water outside the bays and at Able Dock (Table 5.3). Generally, surface temperatures were 0.3°C warmer than bottom temperatures during the morning high tide. During the afternoon low tide, surface temperatures were elevated approximately 1°C. Bottom temperatures were also elevated but to a lesser degree. By the time of the evening high tide, surface temperatures had cooled off but bottom temperatures remained somewhat elevated. The net result was a lesser gradient (ca. 0.1°C) between surface and bottom temperatures in the evening than in the morning.

Vertical profiles examined around the power barge generally showed wider temperature ranges and less stability than at the stations discussed above (Table 5.4). Approximately 1 m from each of the outfalls, temperatures tended to be elevated at the surface (e.g., 28.9°C), somewhat cooler at mid-depths and reached their maximum (e.g., 30.3°C) at the bottom. Midship profiles show a lens of heated water on the starboard (Baker Dock) side of the barge which extends to a depth equal to the draft of the hull (3.0-4.5 m). Above this depth on the port (Baker Bay) side of the barge, temperatures are significantly cooler. Below the draft of the barge, port and starboard temperatures are both near ambient temperatures for comparable depths. Temperatures are more uniform from surface (e.g., 28.6°C) to bottom (e.g., 28.0°C) at the stern intake grill.

Additional vertical profiles were examined at 10 locations near the bow of the barge in a study of the thermal plume there (Table 5.5). Five marker buoys were anchored 10 m from the outfalls and 5 more 20 m from the outfalls. At each of these stations, water temperature was measured at 1-m depth intervals from the surface to a depth of 5 m. Plastic flags were placed on each buoy line just below the surface and just above the bottom to determine current direction. Two series of observations were made: one during the morning falling tide and one during the afternoon rising tide of 12 June 1976. During the afternoon, three additional stations were established: one at each outfall and one midway between the outfalls.

Our observations indicate that the thermal plume rises to the surface within 10 m from the outfalls (Fig. 5.2). Bottom temperatures remain close to ambient levels as near as 3-4 m from the outfalls. Surface temperatures 20 m from the barge are similar to surface temperatures recorded in the middle of Baker Bay. The plume is also displaced toward Baker Dock where higher surface temperatures occur further from the outfalls.

Maximum and minimum bottom temperatures were recorded at monthly intervals at seven locations in the harbor (Table 5.6). The highest maximum bottom temperature recorded (33°C) occurred at a shallow depth on the end of Baker Dock. This station is located in an area periodically influenced by the thermal plume from the power barge. The lowest recorded bottom temperature (22°C) occurred in the Enhalus bed in Range Light Bay. This temperature probably occurred during subaerial exposure of the instrument by low tides. The most constant temperatures were recorded in Baker Bay, the deepest station, where the bottom temperature varied only 1°C during one month. The highest average temperature (i.e., the average between the maximum and minimum) was recorded at Baker Dock, again presumably due to influence from the barge. The lowest mean (25.5°C) was recorded in the Enhalus bed in Range Light Bay.

Plant Operation

During the period of our observations, plant load increased from an average hourly load of 6 MWH to 9 MWH. Daily peak loads increased from 8 MWH to 10 MWH. Variations in plant load show a typical diurnal pattern (Fig. 5.3). Minimum load occurs from 0300 to 0500 hours. Load increases through the morning to a small peak at 1100 to 1200 hrs, decreases slightly and then reaches the maximum for the day at 1900 to 2000 hours.

Intake and outfall temperatures are monitored and recorded hourly by plant personnel. Their records show an average heating of coolant water of about 2.5°C. However, these records seem unreliable. During our the June observation period, the instruments indicated that outfall temperature was cooler than that of the intake.

Pumping rates, as indicated by discharge pressure, do not seem to have varied much during the observation periods. We do not know whether this is indeed the case. By the end of our study period, the discharge pressure from only one of the two pumps was being recorded due to a failure in the second guage.

Comparisons of plant load records with our observations of intake and outfall temperatures show an average heat rate of 0.174°C elevation in coolant-water temperature per MWH plant load. At this rate, a peak load of 30 MWH would produce a 5.2°C increase in effluent water temperature over intake temperatures. This estimate is close to the temperatures projected in the design specifications.

Conclusions

Operation of the power barge "Impedance" has produced a region of elevated temperatures (0.5-1.5°C above ambient) along the entire southwestern side of Baker Dock. The power barge is also probably responsible for slightly elevated temperature in Baker Bay. No evidence of thermal influence from the power barge was found north of Baker Dock or south of Able Dock. A peak load of 30 MWH may result in an increase of effluent water temperature 5.2°C above intake temperature. Since the barge intake lies within the region where temperatures are elevated by the effluent, effluent temperatures during periods of peak load can be expected to be more than 5.2°C above ambient temperatures.

Table 5.1. Surface temperatures ($^{\circ}C$) in Tanapag Harbor. All observations were made in 1976. Station locations are shown in Fig. 5.1. L = low tide, F = falling, R = rising, H = high.

Date	21 Feb.	21 Feb.	14 April	15 April	14 May
Time	0555-0630	1320-1400	1500-1600	1235-1300	1400-1500
Tide	L	F	R	F	L
Station					
15	-	-	-	-	-
16	-	-	-	-	28.9
17	-	-	-	-	28.9
18	-	-	-	-	28.1
19	-	-	-	28.0	27.8
20	-	-	-	-	27.8
21	-	-	-	29.9	27.9
22	-	-	-	27.9	27.9
23	26.4	27.0	-	28.1	-
24	-	-	-	27.9	27.7
25	-	-	-	27.9	27.8
26	26.2	26.8	-	28.1	28.4
27	27.4	27.2	28.0	-	28.3
28	26.9	27.1	27.8	28.0	-
29	26.9	26.8	28.5	28.0	-
30	-	-	27.7	28.0	28.2
31	26.6	27.1	27.6	28.0	28.1
32	26.4	26.8	27.8	27.8	28.2
33	-	-	-	28.0	27.9
34	-	-	27.7	28.4	28.2
35	-	-	-	28.5	28.3
36	26.8	27.0	-	-	28.2
37	26.6	26.9	28.1	-	27.9
38	26.4	26.8	27.7	-	27.9

15 May 0715-0743 H	15 May 1330-1413 L	15 May 2116-2230 H	12 June 0627-0700 H	12 June 1313-1340 L	12 June 2036-2104 H
27.1	29.3	26.9	27.9	28.7	28.1
26.8	28.9	27.1	26.9	28.9	28.0
27.4	29.1	27.1	27.6	29.2	28.2
27.3	28.0	27.3	28.0	28.5	28.1
27.5	27.9	27.3	28.0	28.8	28.1
27.5	28.1	27.3	28.0	28.9	28.1
27.3	28.1	27.2	27.9	28.6	28.0
27.3	28.1	27.2	27.7	28.6	28.0
27.4	28.0	27.3	28.1	29.0	28.2
27.4	27.8	27.4	28.1	28.6	28.2
27.3	27.8	27.4	28.0	28.6	28.3
27.8	28.5	28.0	28.2	28.6	28.2
28.2	28.7	28.3	28.7	29.0	29.0
27.8	28.2	27.7	28.4	28.6	28.5
27.8	28.5	27.6	28.5	29.1	28.6
28.0	28.2	27.7	28.6	29.3	28.9
27.9	27.9	27.6	28.4	28.7	28.6
28.1	28.2	27.8	28.5	28.8	28.6
27.5	27.8	27.5	28.2	28.6	28.2
27.8	28.4	27.6	28.5	29.1	28.5
27.7	28.4	27.6	28.2	29.2	28.4
27.7	28.3	27.5	28.3	29.2	28.3
27.5	27.8	27.4	28.2	28.5	28.3
27.5	28.0	27.4	28.1	28.6	28.2

Table 5.2. Surface temperatures (°C) along both sides of Baker Dock. All observations were made in 1976. Station locations are shown in Fig. 5.1.

Date	7 Feb.	21 Feb.	15 April	15 May	15 May	12 June	12 June	12 June
Time	1540	1700	1240-1300	0800-0815	1520-1535	0823-0837	1420-1430	2145
Tide	F	L	F	H	L	H	L	H
Station								
1	-	27.0	28.3	27.7	28.6	28.3	29.0	28.0
2	-	26.7	28.0	27.5	28.6	28.2	29.1	28.2
3	26.5	26.8	28.0	27.5	28.5	28.1	28.9	28.2
4	-	26.7	28.0	-	-	-	-	-
5	-	26.7	27.9	27.5	28.3	28.2	28.7	28.2
6	26.5	26.7	27.7	27.5	28.3	28.1	28.7	28.3
7	26.7	26.9	27.9	-	-	-	-	-
8	-	27.6	27.6	28.2	28.6	28.9	29.5	29.1
9	-	28.0	28.5	-	-	-	-	-
10	28.0	27.8	28.5	28.7	29.2	29.2	29.8	29.5
11	27.7	27.8	28.4	28.5	29.1	29.7	30.0	29.4
12	-	27.6	28.3	28.4	29.1	29.3	30.0	29.1
13	27.5	27.4	28.3	28.3	28.8	29.0	29.7	29.0
14	-	27.4	28.3	28.2	28.7	29.1	29.7	28.9

Table 5.3. Temperature-depth profiles at 5 locations away from the "Impedance." Temperatures are in Centigrade degrees. All observations were made on 12 June 1976. See Fig. 5.1 for station locations.

Time of Day	Depth (m)	Stations 23	24	31	33	36
0700-0757	0	28.2	28.1	28.4	28.4	28.3
	1	28.2	28.1	28.3	28.4	28.2
	2	28.2	28.1	28.2	28.4	28.1
	3	-	28.1	28.2	28.2	28.0
	4	-	27.9	28.1	28.1	28.0
	5	-	27.9	28.0	28.1	28.0
	6	-	27.9	28.0	28.1	28.0
	7	-	-	-	28.0	28.0
	8	-	-	-	28.0	27.9
	9	-	-	-	27.9	27.9
	10	-	-	-	27.9	-
1338-1433	0	29.1	28.9	28.8	28.7	29.1
	1	28.2	28.9	28.5	28.7	28.4
	2	-	28.3	28.4	28.4	28.4
	3	-	28.3	28.4	28.3	28.4
	4	-	28.3	28.4	28.3	28.3
	5	-	28.4	28.1	28.4	28.3
	6	-	28.3	-	28.4	28.3
	7	-	-	-	28.4	28.3
	9	-	-	-	28.4	28.3
	10	-	-	-	28.4	-
2108-2145	.3	28.3	28.3	28.5	28.3	28.4
	1	28.2	28.2	28.5	28.4	28.4
	2	-	28.2	28.5	28.4	28.4
	3	-	28.1	28.4	28.4	28.4
	4	-	28.1	28.4	28.4	28.4
	5	-	28.1	28.4	28.4	28.4
	6	-	28.1	28.4	28.4	-
	7	-	28.1	-	28.4	-
	8	-	-	-	28.4	-

Table 5.4. Temperature-depth profiles at 5 locations adjacent to the "Impedance." Temperatures are in Centigrade degrees. All observations were made in 1976. Stbd = Starboard side.

Date and Time	Depth (m)	Effluent Stbd	Effluent Port	Midship Stbd	Midship Port	Intake
21 Feb 76						
1700	0	27.9	27.4	27.6	27.0	26.9
	1	27.7	27.4	27.6	27.1	26.8
	2	27.7	27.5	27.5	26.9	26.7
	3	27.7	27.8	27.4	26.8	26.6
	4	27.6	27.6	26.7	26.7	26.6
	5	28.0	27.5	26.7	26.7	26.6
	6	28.2	28.2	26.7	26.7	26.6
15 April 76						
1330-1430	0	28.2	28.3	28.5	27.8	27.8
	1	28.1	28.3	28.5	27.7	27.6
	2	28.0	28.2	28.4	27.5	27.5
	3	28.0	28.2	27.7	27.5	27.4
	4	28.0	28.2	27.7	27.4	27.4
	5	29.0	27.3	27.4	27.4	27.4
	6	–	29.1	27.4	27.4	27.4
15 May 76						
1240-1245	0	28.3	28.4	–	–	–
	1	27.8	28.4	–	–	–
	2	27.5	28.3	–	–	–
	3	27.3	28.2	–	–	–
	4	27.4	28.2	–	–	–
	5	28.5	28.6	–	–	–
15 May 76						
1500-1555	0	28.8	28.6	28.6	28.2	27.6
	1	28.5	28.5	28.6	27.7	27.4
	2	28.5	28.4	28.2	27.6	27.4
	3	28.5	28.4	27.6	27.6	27.4
	4	28.6	28.4	27.5	27.5	27.4
	5	29.6	28.4	27.5	27.5	27.4
	6	–	29.4	27.5	27.5	–
	7	–	29.5	–	–	–

Table 5.4. (continued)

Date and Time	Depth (m)	Effluent Stbd	Effluent Port	Midship Stbd	Midship Port	Intake
12 June 76						
0710-0753	0	28.9	28.7	29.0	28.2	28.4
	1	28.8	28.7	29.0	28.2	28.1
	2	28.9	28.8	29.0	28.1	28.1
	3	28.8	28.8	28.8	28.0	28.1
	4	28.7	28.8	28.0	28.0	28.1
	5	29.0	29.0	28.0	27.9	28.0
	6	30.0	29.2	28.0	27.9	28.0
12 June 76						
1310-1345	0	29.3	29.1	30.2	28.8	28.6
	1	29.3	29.1	29.5	28.4	28.0
	2	29.1	29.1	29.1	28.1	28.0
	3	29.3	29.0	28.2	28.1	28.0
	4	29.3	29.0	28.1	28.1	28.0
	5	30.3	29.4	-	-	28.0
	6	-	-	-	-	-
12 June 76						
2020-2130	0	29.2	29.2	29.2	28.4	28.6
	1	29.3	29.0	29.2	28.4	28.4
	2	29.3	29.1	29.2	28.4	28.3
	3	29.2	29.0	29.0	28.2	28.1
	4	29.4	29.0	28.3	28.2	28.1
	5	29.9	29.2	28.2	28.2	28.1
	6	30.4	29.8	28.2	28.2	28.1

Table 5.5. Temperatures (°C) at 1-m depth intervals at 10 stations near the "Impedance" outfalls. Series A was taken at 1034-1124. Series B was taken at 1600-1658. See Fig. 5.2 for station locations.

Depth (m)	Stations 1	2	3	3a	4	4a	5	5a	6	7	8	9	10
Series A													
0	28.8	28.9	29.2	-	29.2	-	29.0	-	29.4	28.9	28.9	28.8	28.7
1	29.0	28.9	28.9	-	29.1	-	29.2	-	29.1	29.0	28.8	28.8	28.7
2	28.4	28.6	28.8	-	28.6	-	28.7	-	28.4	28.5	28.3	28.5	28.5
3	28.3	28.3	28.2	-	28.3	-	28.8	-	28.3	28.3	28.3	28.3	28.3
4	28.1	28.1	28.1	-	28.1	-	28.7	-	28.2	28.2	28.2	28.1	28.2
5	28.1	28.2	28.1	-	28.1	-	28.1	-	28.2	28.2	28.2	28.1	28.1
Series B													
0	28.8	28.8	28.9	29.1	29.0	29.4	29.3	29.7	29.3	29.0	28.7	28.9	28.7
1	28.6	28.5	28.8	29.3	28.7	29.5	28.9	29.6	28.5	28.8	28.6	28.8	28.7
2	28.3	28.3	28.3	29.3	28.8	29.5	28.5	29.3	28.4	28.3	28.3	28.3	28.5
3	28.3	28.3	28.3	29.2	28.6	29.6	28.3	29.3	28.5	28.3	28.3	28.3	28.4
4	28.2	28.2	28.1	29.1	28.2	29.6	28.2	29.5	28.2	28.2	28.2	28.2	28.2
5	28.2	28.2	28.2	29.6	28.2	29.6	28.2	30.2	28.2	28.1	28.2	28.2	28.2

Table 5.6. Maximum/minimum temperatures (°C) recorded in Tanapag Harbor. All observations were made in 1976. The approximate depth in meters of each instrument below MLLW is indicated in parentheses at the top of each column.

	Stations						
Observation Interval	Range Light Bay (0.0)	Echo Bay (0.3)	Charlie Bay (1.3)	Baker Dock (0.3)	Baker Bay (3.0)	Able Dock (0.3)	Dolpin (0.6)
6 Feb.-20 Feb.	22/29	24/27.5	-	26/28	-	26/27.5	25/27
20 Feb.-19 Mar.	24/30	24/28.5	-	26/33	-	26.5/28	26/28
19 Mar.-14 Apr.	-	-	26/27.5	-	27/28	25/30	26/28
14 Apr.-14 May	-	-	26.5/29	-	27/28	27.5/30	-
14 May-13 June	-	-	26/30	-	27/29	-	-

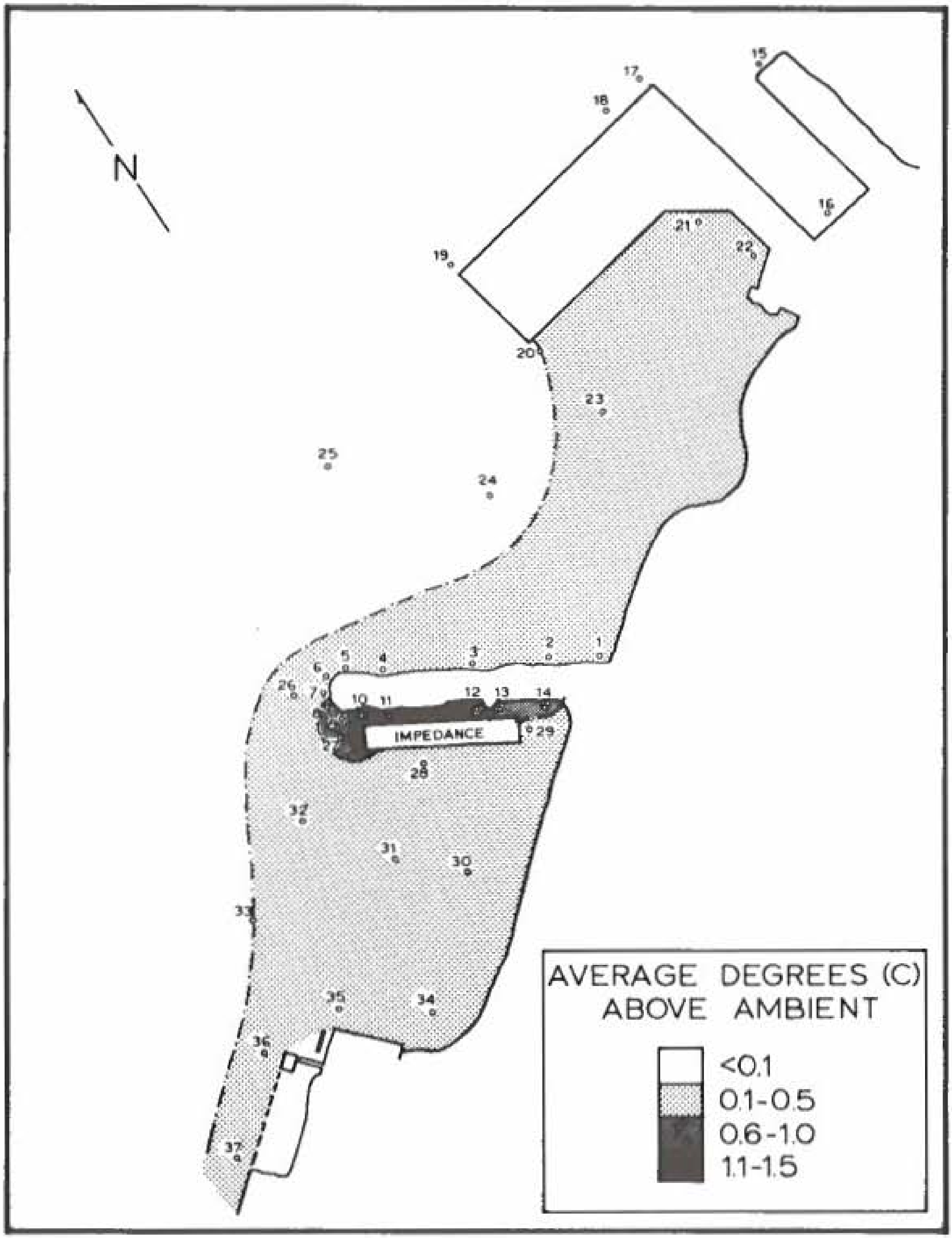


Figure 5.1. Average elevation of surface temperature (^{o}C) above ambient temperatures. The numbers indicate station locations where temperature observations were made.

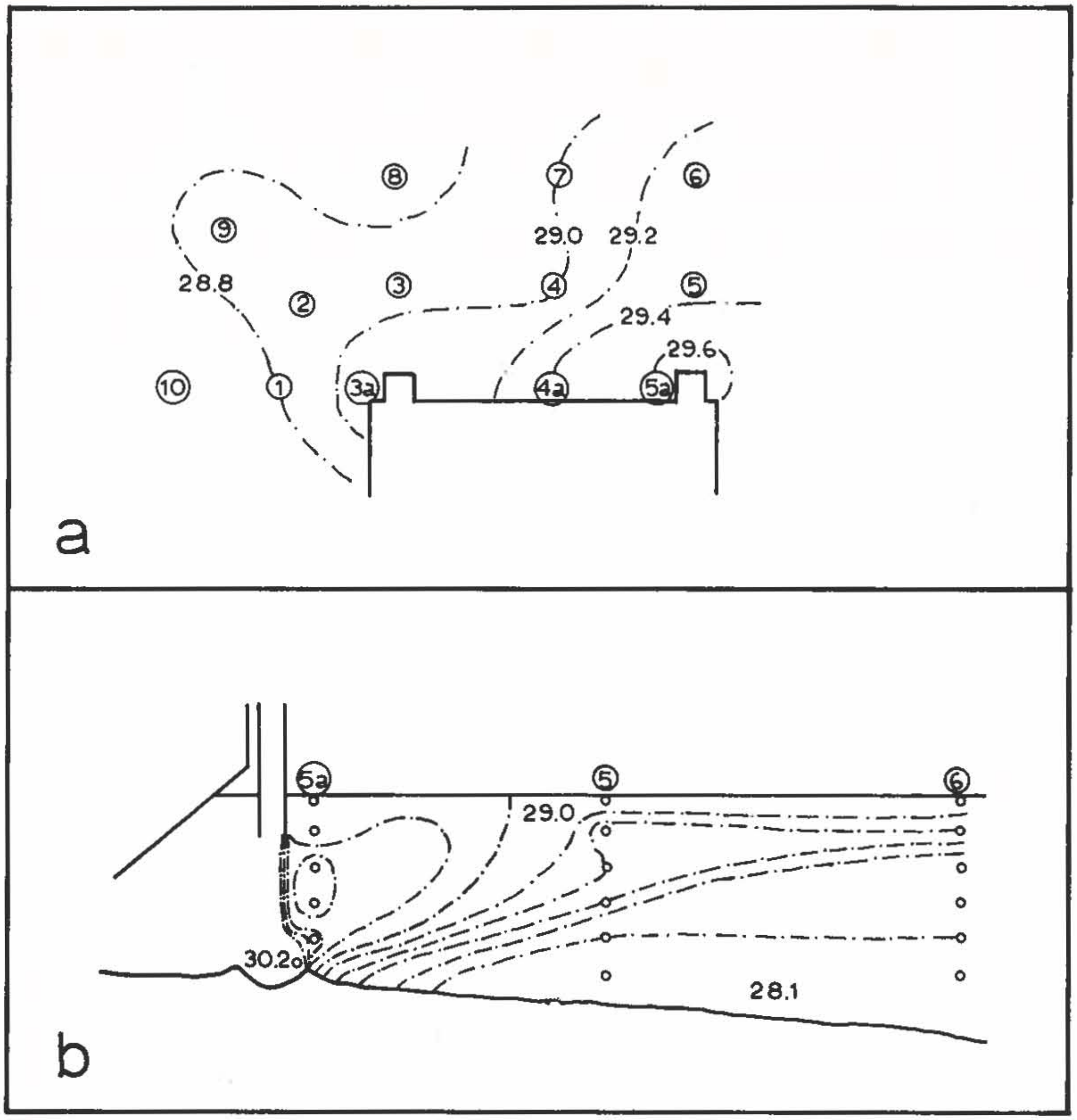


Figure 5.2. Thermal plume from "Impedance." Data are from 1600-1658 13 June 1976 (see Series B, Table 5.5). a. Surface temperatures. b. Vertical profile through starboard outfall. 0.2°C isotherms are shown. Station locations are shown by encircled numbers.

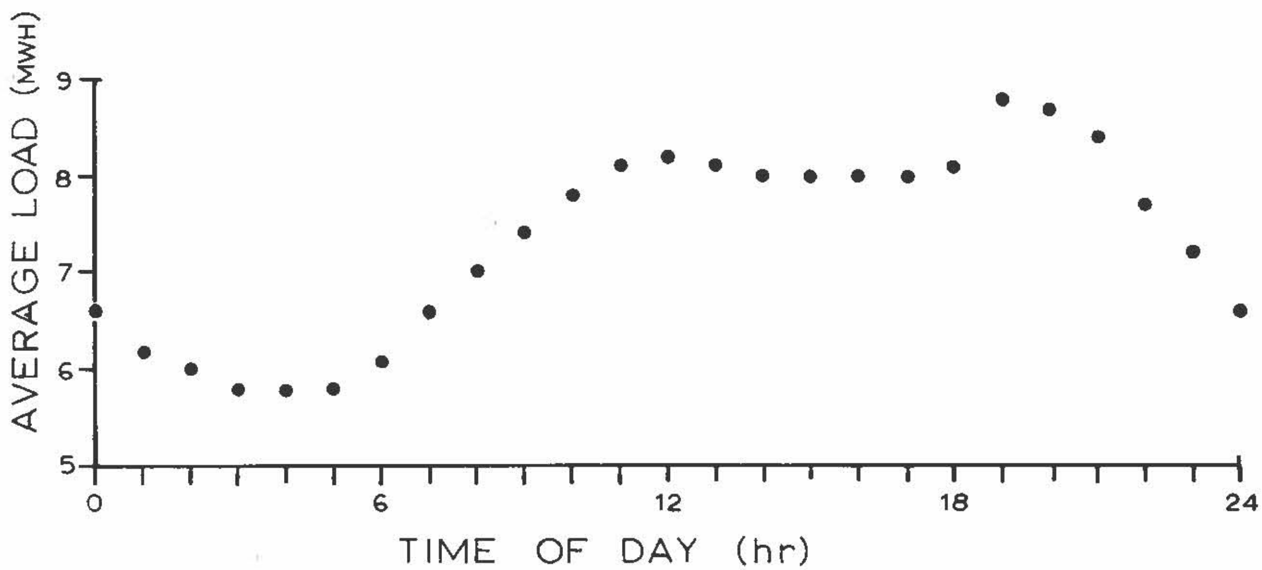


Figure 5.3. Hourly fluctuations in plant load (MWH) during average day. The curve is based on hourly records for 6-9 and 20-23 February, 19-21 March, 14-17 May, 14-17 April and 12 June 1976.

6. OXYGEN AND NUTRIENTS

By

JAMES A. MARSH, JR. AND ROBERT M. ROSS

Surface samples for determination of dissolved oxygen, nitrite and nitrate nitrogen, and phosphate phosphorus were collected at discrete locations (Fig. 6.1) at various times of day on March 20, 1976. Sample sites were chosen to represent the range of expected conditions. Three of the stations (Stas. 3, 4, and 8) were sampled for oxygen determinations at seven sampling times between 0440 and 2335 hours to get an indication of diurnal variation. Stations 3 and 4, in Charlie and Baker Bays respectively, were chosen as paired samples in adjacent areas, one of which was subject to influence of the power barge and one of which was not. Station 8, in the portion of Unai Sadog Tase dominated by seagrass beds, was chosen because it was expected to have large diurnal variations in dissolved oxygen as a result of metabolic activity of the natural biological community. All eight stations were sampled near the times of high and low tides for nutrient determinations.

Sampling was accomplished by dipping a plastic bucket over the upstream side of a small boat and as far away from the boat as possible to avoid contamination. Water was then siphoned into BOD bottles for oxygen determinations and into chemically cleaned plastic bottles for nutrient analyses. Temperatures were taken with a bucket thermometer. The plastic bottles were immediately put into an ice chest and later placed in a freezer. The frozen samples were transported back to Guam for nitrite, nitrate, and phosphate analyses according to the laboratory methods of Strickland and Parsons (1968). Duplicate analyses were made for each sample, and excellent replication was obtained. A hand-held refractometer was used to determine salinity of these samples. The oxygen samples were immediately fixed in the field with Winkler reagents and later titrated in the laboratory of the power barge. The azide modification of the standard Winkler procedure was employed (APHA, 1971). We thank Mr. Bill Brewer, Trust Territory Environmental Specialist, for the loan of BOD bottles and Mr. Zalameda, chemist on the "Impedance" for the use of laboratory facilities on the power barge.

Dissolved Oxygen

Results of the oxygen analyses are shown in Tables 6.1 and 6.2 and in Fig. 6.2. The lowest oxygen level for any station at any time of day was found in the seagrass bed in Unai Sadog Tase (Sta. 8) at 0550 hours and amounted to 4.68 milligrams per liter (mg/l) of dissolved oxygen, or approximately 69% of the saturation value. Dissolved oxygen content then increased to 10.83 mg/l, or approximately 160% saturation, at 1545 hours. Thereafter, dissolved oxygen levels at this station declined.

A similar diurnal pattern of daytime increase and nighttime decrease was seen in Charlie Bay (Sta. 3), where the benthic community was dominated by corals, except that the magnitude of the increase and decrease was much less than for the seagrass community. The oxygen increase also began later in the morning in Charlie Bay. In Baker Bay, where the benthic community consists primarily of silt-burrowing animals and few green plants, there was little diurnal change in dissolved oxygen; and the values remained near saturation levels at all times.

Other stations were sampled only three times, during the pre-dawn hours and during the daytime high and low tides. All showed pre-dawn levels which were similar to each other and to Stations 3 and 4 discussed above. These levels were at least 85% of saturation values in all cases, although exact saturation levels cannot be calculated because of insufficient temperature and salinity data. Daytime oxygen levels were higher than pre-dawn levels in all cases, except for Station 1 near the seaplane ramps, which had a slightly lower value at the morning high-tide sampling time. This station then showed a marked increase at the afternoon low-tide sample. Station 2, near the sewer outfall at Echo Dock, showed a similar increase between the morning and afternoon samples. Station 5, near Alpha Dock, showed a steady increase between pre-dawn, noon, and afternoon samples. Station 6, overlying the shallow coral community in the outer part of Unai Sadog Tase, showed a marked increase from the pre-dawn sample to the noon high-tide sample, followed by a marked decrease in the afternoon sample. Station 7, located in shallow water between the dump and the pilings near Alpha Dock, almost exactly paralleled Station 6 in dissolved oxygen values.

<u>Nutrients</u>

Results of the nutrient analyses are shown in Table 6.2. Elevated levels of nitrite nitrogen, relative to the other stations observed, were found near the sewer outfall at Echo Dock (Sta. 2) at both high and low tides. Values in Table 6.2 suggest slightly elevated levels at the dump site (Sta. 7), but this is not statistically significant for the number of samples taken. Nitrite levels at other stations were low, with no significant differences between stations or between tide levels at the same stations.

There were elevated phosphate phosphorus levels at the Echo Dock sewer outfall at both high and low tides. Other stations had relatively low levels, with no significant differences between stations or between tide levels at the same stations. Hence, both phosphate and nitrite levels were influenced by sewage input.

Elevated nitrate nitrogen levels occurred with lowered salinity levels at both high and low tides. There was an intermediate nitrate level associated with an intermediate salinity level at Station 2 at high tide. An exception to the general trend occurred in the seagrass beds (Sta. 8) at high tide, where a lowered salinity level coincided with a low nitrate level (not significantly different from zero). Presumably, lowered salinity levels and higher nitrate levels indicate ground-water runoff from adjacent shorelines.

Salinity levels at the various stations were not necessarily correlated with tidal state; in fact, at Stations 4 and 8 lower salinities occurred at high tide than at low tide. Stations 1 and 3 had lower salinities than the remaining stations at both low and high tide but were not subject to obvious groundwater runoff.

Summary

Dissolved oxygen levels are generally high throughout the study area, lying near saturation levels at most sampling times. This is a healthy sign. Large diurnal changes occur in the seagrass bed of Unai Sadog Tase, reflecting metabolic activity of the natural biological community.

Nitrite and phosphate levels are generally what could be expected of unpolluted waters except for the elevated levels near the sewer outfall at Echo Dock. Nitrate levels are higher for lower-salinity waters and probably reflect land-derived input into the marine environment. Neither salinity variations nor nutrient levels reflect a tidal influence.

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Strickland, J. D. H., and T. R. Parsons. x 1968. A Practical Handbook of Seawater Analysis. FRBC Bulleting 167. Fisheries Research Board of Canada, Ottawa, Canada.

Table 6.1. Dissolved oxygen levels at selected sites near the power barge "Impedance" in Tanapag Harbor at various times of day on 20 March 1976. See Fig. 6.1 for station locations.

Station	Time	Temp., °C	Dissolved Oxygen, mg/l
1	0440	-	6.10
2	0445	-	5.72
3	0450	-	5.83
4	0455	-	6.30
5	0500	-	6.15
6	0505	-	6.00
7	0535	-	5.72
8	0550	-	4.68
3	0810	26.2	5.28
4	0815	26.6	6.28
8	0830	26.0	5.97
1	1035	26.5	5.94
2	1050	26.5	5.67
3	1130	26.4	5.79
4	1145	26.9	6.36
5	1200	26.8	6.64
6	1215	26.8	7.46
7	1255	27.1	7.43
8	1305	27.6	8.17
3	1510	26.9	6.70
4	1515	27.1	6.57
8	1545	28.9	10.83
1	1715	27.7	7.33
2	1720	27.0	6.64
3	1730	26.7	6.56
4	1740	26.9	6.51
5	1745	26.9	6.74
6	1750	27.0	7.02
7	1820	26.6	6.59
8	1840	27.5	8.73
3	2050	26.3	5.93
4	2055	27.0	6.99
8	2135	26.4	6.19
3	2300	26.2	5.47
4	2310	27.0	6.57
8	2335	26.4	5.42

Table 6.2. Nutrient and oxygen levels at selected sites near the power barge "Impedance" in Tanapag Harbor at times of high and low tides on 20 March 1976. See Fig. 6.1 for station locations.

Station	Time	Temp., °C	Salinity, ppt	NO_2 µg-at/l	NO_3 µg-at/l	PO_4 µg-at/l	Dissolved O_2 mg/l	Dissolved O_2 % saturation
High Tide								
1	1035	26.5	27.8	0.06	5.41	0.13	5.94	87
2	1050	26.5	31.1	0.31	0.27	1.44	5.67	89
3	1130	26.4	28.9	0.04	1.13	0.14	5.79	87
4	1145	26.9	24.4	0.02	5.86	0.13	6.36	93
5	1200	26.8	34.4	-0-	0.14	0.12	6.64	103
6	1215	26.8	33.3	-0-	0.17	0.11	7.46	117
7	1255	27.1	33.3	0.07	0.22	0.14	7.43	116
8	1305	27.6	24.4	0.02	0.03*	0.16	8.17	120
Low Tide								
1	1715	27.2	28.3	0.02	13.5	0.08	7.33	109
2	1720	27.0	26.6	0.18	11.9	1.78	6.64	98
3	1730	26.7	28.9	0.02	10.7	0.14	6.56	97
4	1740	26.9	35.0	0.01	0.24	0.10	6.51	101
5	1745	26.9	35.0	0.04	0.12	0.10	6.74	105
6	1750	27.0	35.5	0.02	0.20	0.09	7.02	109
7	1820	26.6	35.5	0.09	0.39	0.09	6.59	103
8	1840	27.5	33.3	-0-	0.15	0.06	8.73	136

* Not significantly different from 0.

1 µg-at/l of PO_4-P (phosphate phosphorus) = 31 µg/l of P = .031 mg/l of P = .031 ppm (parts per million) of P.
Alternatively, 1 ppm of PO_4-P = 1 mg/l of P = 1000 µg/l of P = 1000/31 = 32.2 µg-at/l of P.

1 µg-at/l of NO_3-N (nitrate nitrogen) or NO_2-N (nitrite nitrogen) = 14 µg/l of N = .014 mg/l of N = .014 ppm of N.
Alternatively, 1 ppm of NO_3-N or NO_2-N = 1 mg/l of N = 1000 µg/l of N = 1000/14 = 71.4 µg-at/l of N.

For dissolved oxygen, 1 mg/l = 1 ppm.

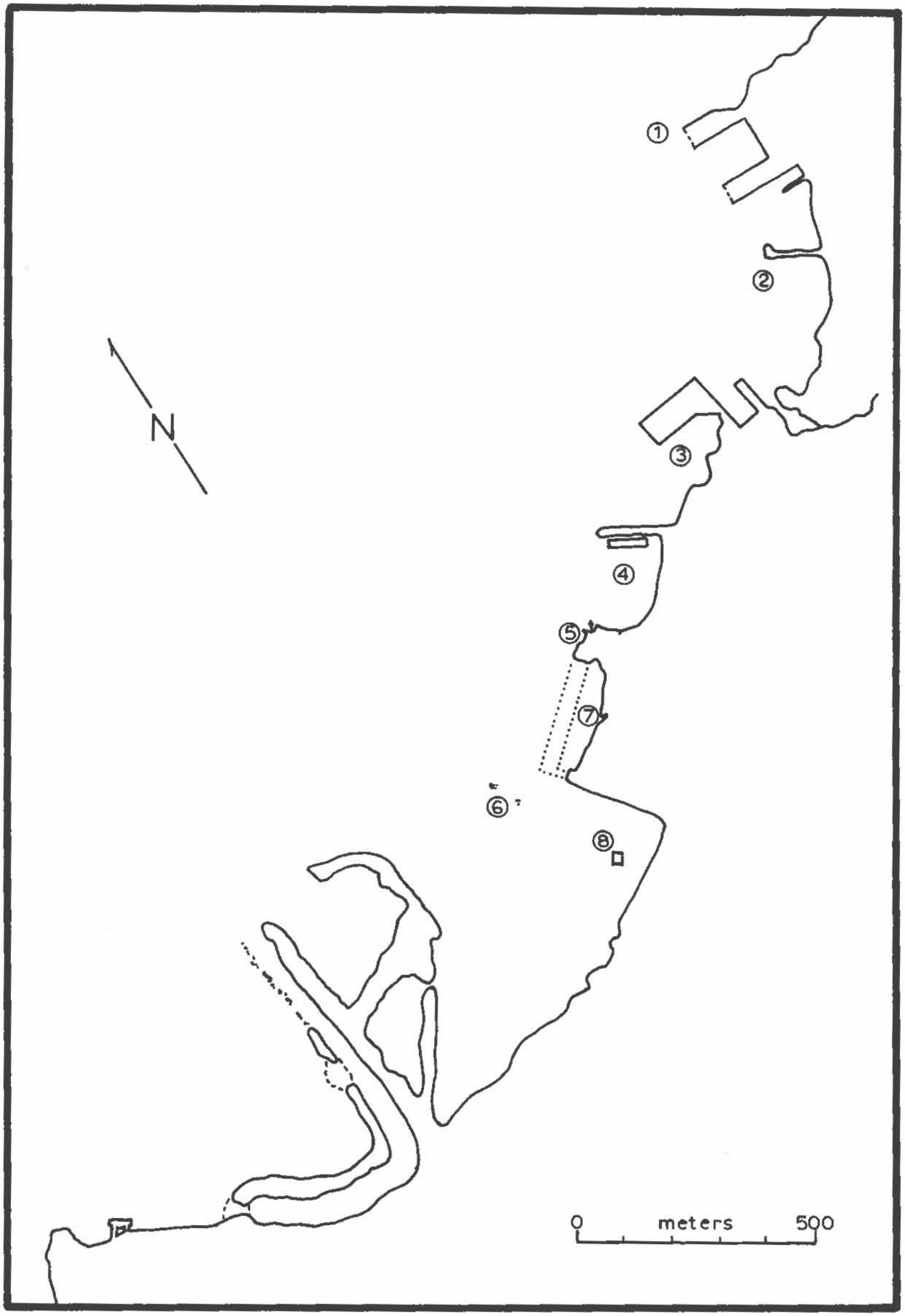

Figure 6.1. Water sampling stations.

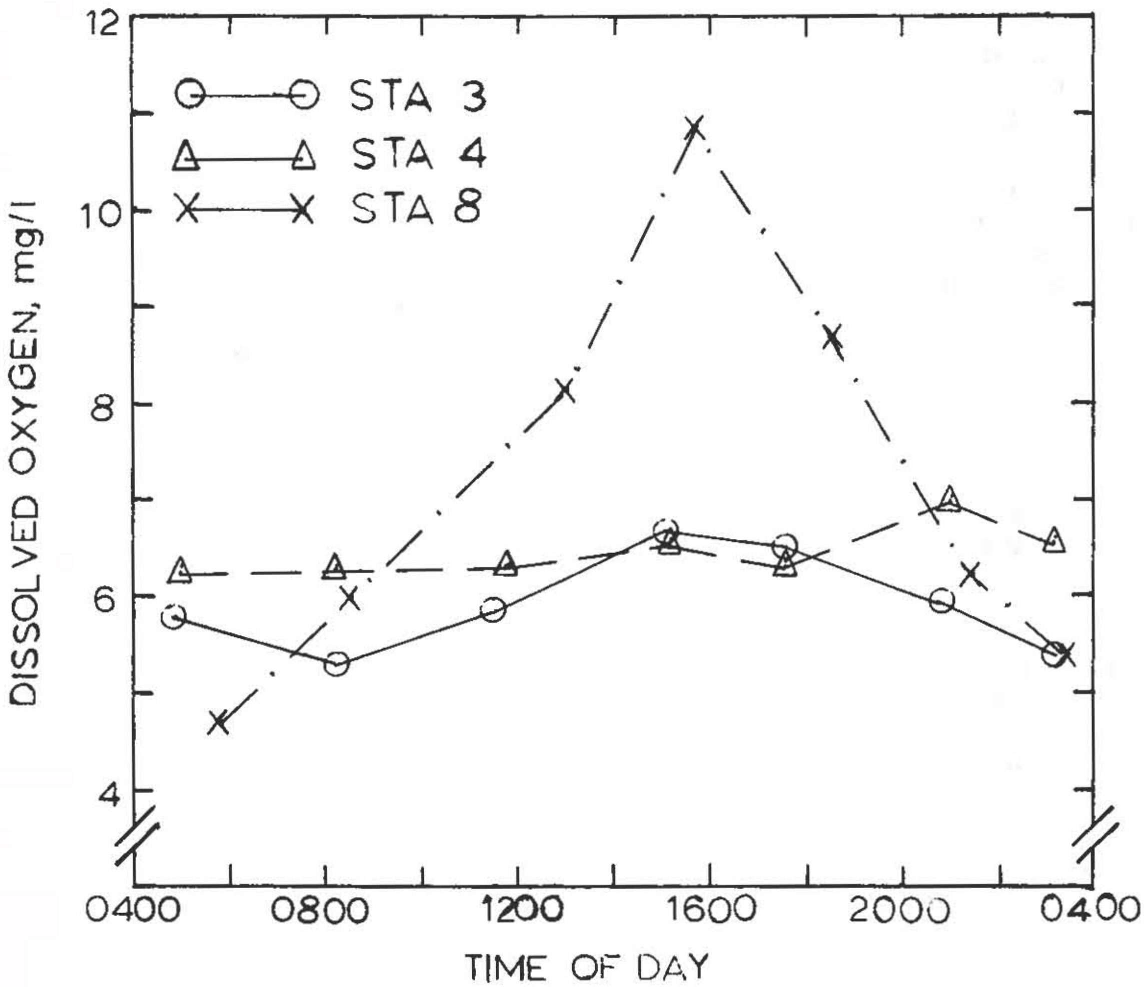

Figure 6.2. Dissolved oxygen at three stations at different times of day on 20 March 1976. See Fig. 6.1 for station locations.

7. MARINE PLANTS

By

WILLIAM J. TOBIAS

Quantification of macrobenthic marine plants was accomplished by a modified point-quadrat method. A quadrat frame 25 cm x 25 cm was subdivided with a 5-cm grid, creating 16 interior points. A stratified random sample was taken by tossing the quadrat within 5 m of each side of a transect line. The quadrat was tossed 20 times in each visually homogeneous zone along the transect. Twenty tosses were considered adequate to sample a single zone. Where there was no zonal change in a 100-m segment of transect, only 20 tosses were made for that entire segment. For each toss, the number of points overlying each algal species present was recorded. If a point did not overlie an alga, then whatever was present (e.g., sand, dead coral, coral rubble, live coral, or other invertebrate) was recorded.

From these data, relative abundance and relative frequency were calculated for each algal species. Relative abundance (RA) for a given species was calculated as the number of points overlying that species divided by the total number of points overlying all algae. Relative frequency (RF) was calculated by dividing the number of quadrats in which a given algal species occurred by the total number of quadrats in which any algae occurred. The percent cover (PC) formed by algae versus that provided by other substrata and organisms was calculated by considering every item recorded for all points. These values, RA, RF and PC, are all expressed as percentages.

A 5-cm^2 quadrat frame was employed to quantify the algal turf community on the horizontal surfaces of the concrete blocks off A Dock. The algal turf enclosed by the quadrat was scraped off and placed in a plastic bag. The species present in each sample were identified by microscopic examination in the laboratory. Relative abundance was determined by a point-sampling technique by placing the sample in a gridded petri dish and applying the same procedure used for the larger quadrats.

Observations

Range Light Bay

The predominant marine plant in Range Light Bay is the seagrass *Enhalus acoroides*, which provides 30% cover near shore and 60% cover away from shore. Sandy patches in the bay have 90% cover by *Schizothrix calcicola*. Other algae in the area are *Microcoleus* lyngbyaceus, Halophila minor, Halimeda macroloba and Padina tenuis.

The marine plants were quantified along an 85-m transect across the mouth of the bay. This transect crossed two zones. Zone A is a 20-m wide band running along the northern shore of the bay. The macrophytes in Zone A are S. calcicola, Hypnea esperi and Halimeda spp. Zone B consists of Enhalus and patches of sand and rubble in the center of the bay. The quadrat method of quantification was used only in Zone A. Table 7.1 contains these data. Quantification in Zone B was accomplished by determining the proportion of various substrate types intercepted by a measuring line. This zone contained 73% E. acoroides, 19% sand and 8% concrete rubble with the alga Gracilaria salicornia.

Echo Bay

A quantitative assessment of the marine plants in Echo Bay was not made. However, a brief survey was conducted February 6, 1976 along an underwater sewer pipe which bisects the bay. The dominant macroalgae were Halimeda gigas, Halimeda opuntia, Dictyota bartayresii, and Hypnea esperi. Also common were Polysiphonia scopulorum, Gelidium pusillum, and Lobophora variegata. A fine covering of Schizothrix calcicola was found on the pipeline and adjacent sandy area. The sea grasses Enhalus acoroides and Halophila minor were also present.

Charlie Bay

The marine plants in the inner portion of Charlie Bay were quantified along two transects, one perpendicular to the shore in line with the end of Charlie Dock and a second parallel to the length of Charlie Dock.

The first transect, 100 m in length, was divided into three zones: Zone A (shore to 14 m), Zone B (14 to 45 m), and Zone C (45-100 m) (Table 7.2). A profile of this transect is shown in Fig. 3.1. Water depth varied from .25 to 4 m.

The only alga present in Zone A is Schizothrix calcicola. This alga represents a pioneer species which characteristically is among the first to colonize disturbed marine benthic substrata. It aids in sediment stabilization, allowing subsequent colonization by other algae.

Zone B of the transect crosses a sunken barge. The barge is covered with living and dead coral. Polysiphonia scopulorum (growing luxuriantly on the dead coral Acropora aspera) and Schizothrix calcicola represent more than 60% of the algal cover in this area.

Zone C typifies the algal communities found in shallow, turbid harbors and bays. Coral cover (33%) slightly exceeds algal cover (29%). Coral rubble (26%) and sand (12%) predominate in the remainder of the area.

The second transect, 84 m in length, was established across a shallow reef platform, 1.5-2.5 m in depth, in the inner bay. Marine plants showed a 63 percent cover of the bottom substratum (Table 7.3). A mixture of Schizothrix calcicola and sand had the highest percent cover and relative frequency, 34 and 24, respectively, forming a fine, filamentous covering over the sandy substratum. A combination of Gelidium pusillum/rubble (PC = 9) and Halimeda opuntia (PC = 9) were also common. Live coral represented 36% of the benthic substratum, with Acropora aspera, Pocillopora damicornis, and Millepora dichotoma being the dominant species present.

The marine plants in the outer Charlie Bay area were quantified along a 84-m transect line established across a shallow reef platform, approximately 100 m from Baker Dock. Water depth ranged from 2-5 m.

Halimeda opuntia and Schizothrix calcicola (PC = 11 and 5, respectively) were the most common macroalgae present in this area (Table 7.4); however, total plant cover was a relatively low 23%. The substratum consisted primarily of coral rubble (PC = 44) interspersed with sand (PC = 15). Live coral represented 17 percent cover.

The bottom in the deeper areas of Charlie Bay (15-20 m in depth) is comprised predominantly of fine sediments with scattered coral and algal communities associated with metal debris. Halophila minor, Caulerpa serrulata, and Caulerpa racemosa were irregularly found in the sediment areas, and Dictyota bartayresii and Caulerpa verticillata were associated with areas of greater relief.

Baker Dock

The benthic algae were quantified on the iron-piling bulkhead forming the northeast side of Baker Dock and on the adjacent bottom. Water depth was approximately 2.5 - 4.0 m. Marine plants represented 84% coverage with Sphacelaria novaehollandae, Halimeda opuntia, and Polysiphonia scopulorum as the most abundant species (PC = 22, 18, and 15, respectively) (Table 7.5). Polysiphonia scopularum was most common, forming a fine turf on rocks near the iron pilings; Halimeda opuntia and Halimeda gigas were also common in that area. Gelidium pusillum and Sphacelaria novaehollandiae formed an intertidal band of algae on the iron bulkhead. Generally, large areas of the bulkheading were devoid of fleshy macroalgae, with live coral (PC = 11) and coralline algae (PC = 4) more predominant.

The benthic algal community was quantified along a narrow dredged shelf (approximately .5 - 2.0 m in depth) on the southwest side of Baker Dock on two separate occasions, February 2 and May 14, 1976.

During the February survey, sedimentation in the area was heavy and most of the transect quantified (ca. 75 m) was devoid of large algae. Halimeda gigas and Halimeda opuntia occurred near the seaward end of the dock. The substatum consisted mostly of coral rubble and rocks covered with a fine turf of Gelidium pusillum (RA = 31%) and Spacelaria tribuloides (RA = 29%) overlain by sediments. The blue-green alga Schizothrix calcicola predominated areas not covered by turf. Overall, algae provide 91% cover in this area (Table 7.6).

The same transect was quantitatively resurveyed on May 14, 1976. The percent cover of marine plants was approximately the same (91% in February and 85% in May); however, several major specific changes in flora had occurred (Table 7.7). Gelidium pusillum and Schizothrix calcicola decreased in relative abundance from 31% to 6% and 12% to 4%, respectively. Spyridia filamentosa increased in relative abundance and relative frequency from RA = 1% and RF = 4% in February to RA = 31% and RF = 22% in May.

Spyridia filamentosa was observed growing in dense clumps from the effluent end of the power barge to midships in shallow water of approximately 1 m depth. Dense growths were also found on the adjacent iron bulkheading often exposed during low spring tides. The greatly increased abundance of S. filamentosa from February to May may indicate its seasonality in the shallow harbor waters.

The dominant algae forming luxuriant growths on the power barge anchor chains were Spyridia filamentosa, Ectocarpus breviarticulatus, and Schizothrix calcicola.

Baker Bay

Because of the contours and zonation of algae in Baker Bay, the marine plants were quantified in two zones (Table 7.8).

Zone A (50 m in length) comprised a shallow intertidal sand/rubble shelf in the northeastern corner of Baker Bay directly behind the intake end of the power barge. Water depth over the sand shelf was less than .25 m; however, away from the shelf the bottom contour slopes sharply to 6 m in depth. This area was dredged in late 1975 to accommodate the power barge. The marine plants represented only 22% cover in this area. Ectocarpus breviarticulatus (PC = 11%) was the predominant alga. The sides of the sloping area are primarily of coral rubble (PC = 23%), which provided attachment for growths of Spyridia filamentosa (PC = 8%). Sand represented 55% cover of bottom substratum. The finer particles of sand were held in place by Schizothrix calcicola (PC = 3%).

Zone B comprised a rocky platform approximately 3.5 m deep which paralled the central shoreline of Baker Bay. The bottom was strewn with deteriorating scrap metal with heavy sedimentation. Marine plants represented 81% cover, predominantly of Halimeda gigas (RA = 23%) and mixed Schizothrix calcicola/sand (RA = 23%), along a 100-m transect in this zone. Dictyota bartayresii, Spyridia filamentosa, Lobophora varigiata, and Halimeda opuntia were also common. Hypnea esperi and Schizothrix calcicola were most abundant on rocks and metal debris nearshore.

Able Dock

The marine plants were quantified along a 100-m transect established parallel to the northeast side of Able Dock. Transect depth was .5 - 2 m; and the bottom was composed primarily of rock and coral rubble strewn with scrap iron debris.

Of the 64% marine plant cover, Lobophora varigiata, Halimeda gigas, and Schizothrix calcicola were the dominant macrophytes (PC = 14%, 12%, and 12% respectively) (Table 7.9). Coralline algae and Halimeda opuntia were also common. The percent cover of live coral increased from 8% in Baker Bay Zone B to 20% along the northeast side of Able Dock.

The marine plants were quantified on the rocky slope at the base of the concrete wall which runs along the seaward end of Able Dock. The depth was approximately 2 - 4 m. The most abundant form of plant cover (RA = 52%) was a low turf consisting of Polysiphonia upolensis and Sphacelaria tribuloides in undetermined proportions (Table 7.10).

The turf community on the sunken concrete seawall sections was analyzed by a modified point-sampling technique similar to that used on the macroalgae. Samples 5 cm x 5 cm were scraped or chipped off the substratum and placed in a 10% HCl solution to remove the carbonates. The algae were then placed on a gridded petri dish for quantification using the petri dish grid points. Algal cover in this area was calculated to be 96% and rock cover 4% (Table 7.10). The most abundant algae were Sphacelaria tribuloides (RA = 42%) and Gelidium pusillum (RA = 37%). Algal height (measured as thallus length) averaged 0.5 cm, indicating cropping by herbivorous fishes.

Iron Pilings

Quantification of the marine plants by the line transect-quadrat technique was not possible at the station adjacent to the Iron Pilings southeast of Able Dock because of the clumped distribution of the few algal species present. These algae were concentrated on the scattered pieces of metal debris which provided relief above the sand/silt bottom.

An alternate method of quantifying the algae present was employed April 16, 1976. This consisted of selectively placing the quadrat over the algal-debris community. Water depth ranged from 6 to 9 m.

Dictyota bartayresii and Halimeda opuntia were the most abundant algal species (RA = 30 and 25, respectively). Polysiphonia scopulorum, Galaxaura filamentosa, and Halimeda gigas were also present. Sponge and live coral represented approximately 19% and 13% cover, respectively.

Unai Sadog Tase

A 400-m transect was established from shore to the Platform Pilings on the seaward edge of Unai Sadog Tase. The profile of this transect is shown in Fig. 3.3. Algal zonation along this transect is striking (Table 7.11).

The predominant algae near the shore (0 to 22 m from shore) are Schizothrix calcicola (RA = 54%) and Polysiphonia sphaerocarpa (RA = 43%). Chaetomorpha indica is also present (RA = 3%).

Enhalus acoroides is the predominant plant 22 to 150 m from shore reaching a maximum density of 95% cover between 67 and 100 m. The Enhalus is covered with an aufwuchs (attached algal community) of Heteroderma subtilissima, Microcoleus lyngbyaceus, Cladophoropsis sp., Rivularia atra and numerous benthic diatoms.

Small white, pedicellate male flowers of Enhalus acoroides were observed floating on the water surface on April 16 in Unai Sadog Tase. Enhalus will flower only in places where it is uncovered for a short period of time during spring ebb tides, during the daytime a few days after the new and full moon (Den Hartog, 1970). A spring tide of -.4 ft was recorded at 1300 hrs on April 16.

The smaller sea grasses Halophila minor and Halodule uninervis and the blue-green algae Microcoleus lyngbyaceus and Schizothrix calcicola predominate 150 to 252 m from shore. This is an open, sandy (ca 30% sand cover) zone. Live corals first begin to appear in the outer regions of this zone.

Coral rubble increases from 0.5% cover 200-252 m from shore to 18% cover 252-300 m from shore. Dictyota bartayresii (RA = 51%) predominates the flora in this zone, with Lobophora variegata (RA = 16%), Halimeda opuntia (RA = 10%) and Schizothrix calcicola (RA = 10%) also abundant. Coral cover increases in this zone from 3.5% to 7%.

Along the edge of the reef flat (320 to 400 m from shore) between the two sets of pilings (referred to as the "dolphin" and the "platform pilings"; see Fig. 2.1), plant cover decreases to 27% with Schizothrix calcicola being the most abundant alga (RA = 48%). Coral cover increases to 24%.

Conclusion

An overall list of organisms in the study area is presented in Table 7.12. At the present thermal effluent discharge rate of 3200 gpm, the effects on the marine plants in the immediate vacinity of the power barge appear to be minimal. The only noticable change in the marine flora during the study period occurred on the southwest side of Baker Dock. If the thermal effluent is continuously discharged into this somewhat confined area, subsequent recolonization or natural seasonality changes of the marine flora may be inhibited. Further research would be necessary to determine the prolonged effect of thermal effluent on the benthic algal community.

Literature Cited

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Table 7.1. Composition of bottom cover and benthic flora in Zone A of Range Light Bay on February 8, 1976. Data are based on 10 quadrats. PC = Percent cover, RA = Relative abundance, RF = Relative frequency.

Species	Zone A (shore) PC	RA	RF	Zone B (middle) PC
Marine Plants	68			73
Schizothrix calcicola		30	26	
Hypnea esperi		25	23	
Halimeda opuntia		12	15	
Halimeda gigas		12	12	
Enhalus acoroides		10	14	73
Hypnea nidulans		6	12	
Halimeda macroloba		4	4	
Liagora farinosa		1	4	
Rock	4			
Sand	28			19
Concrete rubbe with				
Gracilaria salicornia				8

Table 7.2. Composition of bottom cover and benthic flora along a transect in inner Charlie Bay, February 22, 1976. Data are based on 20 quadrats per zone. PC = Percent cover, RA = Relative abundance, RF = Relative frequency.

Species	Zone A (shore)	Zone B (Barge) PC	Zone B (Barge) RA	Zone B (Barge) RF	Zone C (middle) PC	Zone C (middle) RA	Zone C (middle) RF
Marine Plants		62			29		
Polysiphonia scopulorum			73	68		18	18
Schizothrix calcicola	present		26	27		41	31
Dictyosphaeria cavernosa			1	5			
Halimeda opuntia						15	27
Gelidium sp.						14	12
Dictyota bartayresii						8	6
Halimeda gigas						4	6
Live coral (hermatypic)		37			33		
(Alcyonacea)					1		
Coral rubble		1			25		
Sand					12		

Table 7.3. Composition of bottom cover and benthic flora in inner Charlie Bay, May 15, 1976. Data are based on 22 quadrats. PC = Percent cover, RA = Relative abundance, RF = Relative frequency.

Species	PC	PC	RF
Marine Plants	63		
Schizothrix calcicola/sand		34	24
Gelidium pusillum/rubble		9	14
Halimeda opuntia		9	10
Polysiphonia scopulorum		6	8
Dictyota bartayresii		3	4
Halimeda gigas		1	2
Neomeris annulata		.7	4
Ralfsia pagoensis		.2	2
Unidentified coralline algae		.2	2
Live coral (hermatypic)	36		
Sponge	1		

Table 7.4. Composition of bottom cover and benthic flora in outer Charlie Bay, May 15, 1975. Data are based on 20 quadrats. PC = Percent cover, RA = Relative abundance, RF = Relative frequency.

Species	PC	PC	RF
Marine Plants	23		
Halimeda opuntia		11	16
Schizothrix calcicola		5	3
Gelidium pusillum		3	3
Halimeda gigas		2	5
Dictyota bartayresii		1	3
Neomeris annulata		.6	3
Coral rubble	44		
Live coral (Hermatypic)	17		
Sand	15		
Gastropod (*Lambis lambis*)	1		
Sponge	.4		

Table 7.5. Composition of bottom cover and benthic flora on the northeast side of Baker Dock, May 14, 1976. Data are based on 11 quadrats. PC = Percent cover, RA = Relative abundance, RF = Relative frequency.

Species	PC	PC	RF
Marine Plants	84		
Sphacelaria novaehollandae		22	10
Halimeda opuntia		18	13
Polysiphonia scopulorum		15	9
Halimeda gigas		7	10
Schizothrix calcicola		7	6
Galaxaura filamentosa		4	3
Coralline		4	6
Gelidium pusillum		3	6
Neomeris annulata		2	6
Peysonnelia rubra		1	3
Microcoleus lyngbyaceus		1	3
Live coral (hermatypic)	11		
Sand	2		
Echinoid	2		
Sponge	1		

Table 7.6. Composition of bottom cover and benthic flora along the southwestern side of Baker Dock on February 2, 1976. Data are based on 11 quadrats. PC = Percent cover, RA = Relative abundance, RF = Relative frequency.

Species	PC	RA	RF
Marine Plants	91		
Gelidium pusillum		31	23
Sphacelaria tribuloides		29	18
Schizothrix calcicola		12	18
Halimeda gigas		9	13
Halimeda opuntia		9	13
Microcoleus lyngbyaceus		7	4
Spyridia filamentosa		1	4
Ralfsia pagoensis		1	4
Neomeris annulata		1	4
Live coral (Hermatypic)	5		
Hydroids	2		
Rock	2		

Table 7.7. Composition of bottom cover and benthic flora off the southwest side of Baker Dock on May 14, 1976. Date are based on 12 quadrats. PC = Percent cover, RA = Relative abundance, RF = Relative frequency.

Species	PC	PC	RF
Marine Plants	85		
Sphacelaria tribuloides		33	18
Spyridia filamentosa		26	22
Halimeda gigas		10	18
Gelidium pusillum		5	7
Halimeda opuntia		5	3
Schizothrix calcicola		3	3
Feldmannia indica		3	3
Coral rubble	6		
Sand/Silt	6		
Hydroids	2.5		
Live coral	.5*		

*Live coral not abundant enough to be adequately sampled by this technique.

Table 7.8. Composition of bottom cover and benthic flora in Baker Bay on May 15, 1976. Data based on 10 quadrats for Zone A and 20 quadrats for Zone B. PC = Percent cover, RA = Relative abundance, RF = Relative frequency.

Species	Zone A			Zone B		
	PC	PC	RF	PC	PC	RF
Marine Plants	22			81		
Halimeda gigas					23	23
Schizothrix calcicola/sand		3	5		23	15
Ectocarpus breviarticulatus		11	14			
Dictyota bartayresii					10	11
Spyridia filamentosa		8	19		6	8
Lobophora variegata					7	8
Halimeda opuntia					6	4
Polysiphonia scopulorum					3	1
Neomeris annulata					1	4
Padina tenuis					1	1
Laurencia papillosa					.2	1
Microcoleus lyngbyaceus					.2	1
Caulerpa serrulata					.2	1
Dictyosphaeria versluysii					.2	1
Sand	55			2		
Coral rubble	23			2		
Live coral (hermatypic)				8		
Rock				6		
Sponge				1		

Table 7.9. Composition of bottom cover and benthic flora along the northeast side of Able Dock on May 15, 1976. Data are based on 20 quadrats. PC = Percent cover, RA = Relative abundance, RF = Relative frequency.

Species	PC	PC	RF
Marine Plants	64		
Lobophora variegata		14	13
Halimeda gigas		12	12
Schizothrix calcicola/sand		12	9
Coralline		8	6
Halimeda opuntia		6	6
Polysiphonia scopulorum		4	5
Gelidium pusillum		3	2
Microcoleus lyngbyaceus		2	3
Sphacelaria tribuloides		2	3
Dictyota bartayresii		1	3
Halimeda nacroloba		.3	2
Live coral (hermatypic)	20		
Rock	8		
Coral rubble	3		
Sand	2		
Sponge	2		
Crab	.3		

Table 7.10. Composition of bottom cover and benthic flora off the seaward end of Able Dock on February 21, 1976. Data are based on 10 quadrats per zone. PC = Percent cover, RA = Relative abundance, RF = Relative frequency.

Species	Seawall PC	Seawall RA	Seawall RF	Slope PC	Slope RA	Slope RF
Marine Plants	96			67		
Sphacelaria tribuloides		42	26			
S. tribuloides with *Polysiphonia upolensis*					52	38
Gelidium pusillum		37	26			
Ralfsia pagoensis		8	18		25	19
Ceramium sp.		8	14			
Dictyosphaeria versluysii		5	16			
Halimeda opuntia					10	12
Schizothrix calcicola					8	19
Galaxaura filamentosa					6	12
Live coral (hermatypic)				24		
Sponge				3		
Echinoid				1		
Rock	4			5		

Table 7.11. Composition of bottom cover and benthic flora along a 400-m transect in Unai Sadog Tase. Data for 0-22 m and 150-400 m are based on 20 quadrats per zone. Data for 22-150 m are based on line intercept values. PC = Percent cover, RA = Relative abundance, RF = Relative frequency. See Fig. 2.2 for the location of the transect.

Species	0-22 m			22-29	29-67	67-100	100-150	150-200			200-252			252-300			320-400		
	PC	RA	RF	PC	PC	PC	PC	PC	RA	RF	PC	RA	RF	PC	RA	RF	PC	RA	RF
Marine plants	86							64			67			54			27		
Schizothrix calcicola		54	52						16	13		20	17		10	12		48	32
Polysiphonia sphaerocarpa		43	38																
Chaetomorpha indica		3	10																
Enhalus acoroides				30	80	95	59												
Halophila minor							12		50	46		23	13						
Microcoleus lyngbyaceus									18	17									
Halimeda macroloba									6	11		.5	2		2	5			
Halimeda gigas									1	2					1	2			
Spyridia filamentosa									4	2									
Gracilaria lichenoides									1	2									
Avrainvillea obscura									1	2		3	3						
Halodule uninervis												26	19						
Lobophora variegata												7	13		16	24			
Polysiphonia scopulorum												6	6		2	2		16	16
Dictyota bartayresii												6	8		51	31			
Halimeda opuntia												4	9		10	14		6	5
Hypnea esperi												2	2						

Table 7.11. (continued)

Species	0-22 m PC	0-22 m RA	0-22 m RF	22-29 PC	29-67 PC	67-100 PC	100-150 PC	150-200 PC	150-200 RA	150-200 RF	200-252 PC	200-252 RA	200-252 RF	252-300 PC	252-300 RA	252-300 RF	320-400 PC	320-400 RA	320-400 RF
Dictyosphaeria cavernosa												1	2		6	5			
Gracilaria lichenoides												.5	2						
Neomeris annulata												.5	2		2	5		1	5
Calothrix crustacea												.5	2						
Gelidium sp.																		10	16
Coraline algae																		8	11
Polysiphonia sp. 1																		7	5
Ralfsia pagoensis																		3	5
Schizothrix mexicana																		1	5
Live coral (hermatypic)								1			3.5			7			24		
Sponge																	2		
Holothuria atra								2			1								
Coral rubble											.5			18					
Sand	14			70	20	5	29	32			28			21			37		
Rock								1											

Table 7.12. List of marine plants found in the study areas.

			CHARLIE BAY		BAKER BAY			ABLE DOCK			UNAI SADOG TASE			
	RANGE LIGHT BAY	ECHO BAY	INNER	OUTER	NE SIDE	SW SIDE	BAKER BAY	NE SIDE	ABLE END	IRON PILINGS	*Schizothrix* Zone	*Enhalus* Zone	*Halophila-Halodule* Zone	*Dictyota*-Coral Zone
Cyanophyta														
Calothrix crustacea Thuret									x				x	
Hormothamnion enteromorphoides Bornet & Flahault											x			
Microcoleus lyngbyaceus (Kutz.) Crouan	x		x		x	x	x	x	x	x		x		
Schizothrix calcicola (Ag.) Gomont	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Schizothrix mexicana Gomont														x
Chlorophyta														
Acetabularia moebii Solms-Laubach	x			x										
Avrainvillea lacerata Gepp				x										x
Avrainvillea obscura J. Ag.												x	x	
Boodlea composita (Haru,) Feldmann									x					
Caulerpa racemosa (Forskal) J. Ag.				x										
Caulerpa serrulata (Forskal) J. Ag.				x			x		x					
Caulerpa taxifolia (Vahl) C. Ag.							x							
Caulerpa verticillata J. Ag.	x			x	x									
Chaetomorpha indica Kutz						x			x		x			
Dictyosphaeria cavernosa (Forskal) Boerg.			x									x	x	x
Dictyosphaeria versluysii Weber van Bosse	x						x		x					
Enteromorpha tubulosa (Kutz.) Kutzina									x		x			
Halimeda gigas Taylor	x		x	x	x	x	x	x		x		x		
Halimeda macroloba Decaisne	x	x	x		x			x				x	x	x
Halimeda opuntia (L.) Lamouroux	x	x	x	x	x	x	x	x	x	x		x	x	x
Neomeris annulata Dickie	x	x	x	x		x	x			x			x	x
Rhizoclonium samoense Setchell									x					
Udotea geppi Yamada									x					
Valonia ventricosa J. Ag.		x												

Table 7.12. (continued)

	RANGE LIGHT BAY	ECHO BAY	CHARLIE BAY INNER	CHARLIE BAY OUTER	BAKER BAY NE SIDE	BAKER BAY SW SIDE	BAKER BAY	ABLE DOCK NE SIDE	ABLE DOCK ABLE END	IRON PILINGS	UNAI SADOG TASE Schizothrix Zone	UNAI SADOG TASE Enhalus Zone	UNAI SADOG TASE Halophila-Halodule Zone	UNAI SADOG TASE Dictyota-Coral Zone
Phaeophyta														
Dictyota bartayresii Lamouroux	x	x	x	x	x		x	x	x	x	x	x	x	x
Ectocarpus breviarticulatus J. Ag.							x				x			
Feldmannia indica (Sonder) Womersley & Bailey				x	x	x			x	x				
Lobophora variegata (Lamx.) Womersley	x	x	x				x	x				x	x	x
Padina tenuis Bory	x					x					x			
Ralfsia pagoensis Setchell			x	x		x			x					x
Sphacelaria novaehollandiae Sonder					x				x					
Sphacelaria tribuloides Meneghini				x	x	x		x	x		x			
Turbinaria ornata (Turner(J. Ag.			x											
Rhodophyta														
Acanthophora spicifera (Vahl) Boerg.												x		
Amphiroa foliacea Lamouroux									x					
Antithamnion sp.									x					
Callithamnion marshallensis Dawson						x			x					
Centroceras sp.			x		x					x				
Ceramium marshallense Dawson			x									x		
Ceramium vagabunda Dawson			x						x					
Ceramium sp.			x						x					
Coralline sp.			x	x	x			x						
Galaxaura filamentosa Chou					x				x	x				
Galaxura marginata Lamx.					x									
Gelidium pusillum (Stackh.) Le Jolis		x	x	x	x	x		x	x					
Gelidium sp.														x
Gracilaria lichenoides (L.) J. Ag.												x	x	
Gracilaria salicornia (Mert.) Grev.	x				x								x	
Heteroderma subtilissima (Foslie) Foslie									x					
Hypnea esperi Bory	x	x					x			x		x	x	

Table 7.12. (continued)

			CHARLIE BAY		BAKER BAY			ABLE DOCK			UNAI SADOG TASE			
	RANGE LIGHT BAY	ECHO BAY	INNER	OUTER	NE SIDE	SW SIDE	BAKER BAY	NE SIDE	ABLE END	IRON PILINGS	*Schizothrix* Zone	*Enhalus* Zone	*Halophila-Halodule* Zone	*Dictyota-Coral* Zone
Hypnea nidulans Setchell	x													
Jania capillacea Harvey					x	x								
Laurencia papillosa (Forskal) Grev.							x					x		
Liagora farinosa Lamouroux	x								x	x				
Peyssonelia rubra (Grev.) J. Ag.					x									
Polysiphonia sphaerocarpa Boerg.											x			
Polysiphonia scopulorum Harvey		x	x	x	x		x	x		x			x	
Polysiphonia upolensis (Grunow) Hollenberg									x					
Polysiphonia sp.														x
Spyridia filamentosa (Wulf.) Harvey.		x				x	x					x		
Spermatophyta														
Enhalus acoroides (L.f.) Royle	x	x									x			
Halodule uninervis (Forsk.) Ascherson											x	x		
Halophila minor (Zoll.) Hartog	x	x		x			x				x	x	x	

8. CORALS

By

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Introduction

Corals occupy critical niches in tropical marine benthic communities. Their influences on nutrient flow and physical structure can produce profound effects in both the biotic and physical nature of an area. Coral abundance and diversity was therefore studied in 13 areas along the shore of Tanapag Harbor. Richard H. Randall made an initial survey of most of the areas discussed herein on 6-9 February 1976, and is responsible for the classifications and nomenclature used. Michael J. Wilder carried out intensive sampling in Charlie and Baker Bays on 14-17 May 1976. James E. Doty wrote the text and is responsible for the interpretations of the data.

Methodology

Quantitative analyses of coral abundance and diversity were made using the point-quarter method of Cottam, et. al. (1953), as described by Cox (1972). The terminology of Cox has been altered somewhat here (i.e., "Average size" herein refers to Cox's "Average dominance," "Cover" to "Dominance" and "Relative cover" to "Relative dominance"). The maximum distance searched from each sampling point was 2 m.

The point-quadrat method (Tsuda, 1972) was used to determine the frequency and relative cover of corals along the northeastern side of Baker Dock. At 22 randomly selected locations along the seawall, a .25 m^2 square quadrat frame was placed against the seawall. The frame was subdivided by an orthogonal grid of wires which intersected at 16 points. The coral species underlying each point was noted each time the frame was positioned against the seawall. Where no coral underlay a point, this was noted also. Relative cover was calculated as the number of points overlying a given coral species divided by the total number of points sampled (352) and expressed as a percentage. Frequency was calculated as the number of times a given coral species underlay at least one point in the quadrat divided by the number of quadrats sampled (22). Relative frequency was calculated by dividing the frequency of a given species by the sum of the frequencies of each species expressed as a percentage.

In addition to these quantitative analyses, qualitative observations were made in each of the areas and also in Echo Bay.

Observations

Echo Dock

A 100 m transect was established across the end of Echo Dock and Rangelight Bay. *Pocillopora damicornis* was the most frequently encountered coral along the transect. *Millepora dichotoma* occurs in very large heads along the transect and is especially abundant off the end of the dock where it covers several pilings. *Montipora lobulata* was found nearly as often as *M. dichotoma*. *Porites lutea*, encountered only occasionally along the transect, became more abundant toward the lagoon slope. *Montipora verrilli* and *Acropora aspera* were also present.

Echo Bay

A survey was made of the corals along an abandoned pipeline which extends across the reef flat at the southern end of the bay. Coral diversity increases with distance from shore. At the lagoon slope coral cover is good but appears to diminish down-slope. The predominant coral is *P. damicornis*, in purple-brown and yellow-brown color forms. Globular clusters of this species range up to 30 cm across here and aggregations form even larger masses. Numerous small colonies and living fragmented pieces were also observed. *Millepora dichotoma* is abundant in this area. *Acropora aspera* is common in arborescent patches in the mid-to-inner part of the reef flat. Overall, the corals in this part of the bay surveyed are patchy in distribution, forming areas of relief 30 cm or so higher than the surrounding substratum.

Charlie Bay

The corals in Charlie Bay are primarily restricted to metal debris and shoals of sand and coral rubble. Three areas were studied in Charlie Bay: a sunken barge which lies a few meters from shore at approximately the center of the shoreline, a shoal area which constitutes the major part of inner Charlie Bay (that part of Charlie Bay which is enclosed by Charlie Dock) and a sandy shoal approximately 20 m wide by 50 m long which extends from shore in the center of outer Charlie Bay.

The sunken barge supports a thick growth of *A. aspera* and *M. dichotoma*. The latter is especially luxuriant on the seaward edge of the barge, while *A. aspera*, both living and dead, forms a thick bed on the horizontal surface of the barge. *Pocillopora damicornis* and *M. verrilli* also occur here. The barge is almost entirely covered with coral, especially at the western end, and little of its metal deck is visible.

Acropora aspera also occurs on the sand-and-rubble bottom of inner Charlie Bay but with less frequency (Table 8.1). Pocillopora damicornis and M. dichotoma are the predominant corals in this area. Other species occurring in the area are listed in Table 8.2.

Coral growth in outer Charlie Bay (Table 8.1) begins 5 m from shore and at a depth of 1 m and extends offshore 30 m to a depth of 5 m. Diversity is greater offshore with P. damicornis predominating in large heads (30 cm) and larger aggregations. Millepora dichotoma is found in patches throughout the shoal. Occasional Porites lutea heads and small beds of A. aspera occur amongst the Pocillopora heads. Along the seaward slope A. aspera and Acropora palifera occur. The Acropora beds are quite small and eventually give way to a sand substratum which levels off at a depth of 15 m.

Baker Dock

Three areas were surveyed around Baker Dock: the vertical iron revetment along the northeastern (Charlie Bay) side, the seaward end of the dock, and the iron revetment and narrow shelf along the southwestern side of the dock.

Coral abundance decreases rapidly with distance away from the northeastern side of Baker Dock; therefore only the coral community on the vertical wall and along its base was sampled. Pocillopora damicornis was the most frequently encountered coral (Table 8.1). Porites lutea and M. lobulata were encountered with equal frequency but P. lutea covered much more area. Millepora dichotoma was much less frequent but provided even more cover than P. lutea. Overall diversity is high in this area (17 spp.) and is surpassed only by the diversity found on the Iron Pilings (20 spp.). Two species, Pavona (Polyastra) obtusata and Millepora platyphylla, were found only in this area.

The largest and best developed coral growth in the area occurs off the end of the dock. Here P. damicornis is the predominant coral. Millepora dichotoma is abundant, with some heads reaching 0.75 m in diameter. Porites lutea encrusts the barge and boulders, forming large heads. Psammocora (Stephanaria) togianensis and Stylocoeniella armata are also present.

The southwestern side of Baker Dock is the side to which the "Impedance" is moored. The coral community along this side is by far the least developed in the vicinity. Cover is sparse and diversity low. Growth is limited to a 0.5 m high section of the seawall and a narrow shelf no more than 2 m wide along the seaward half of the dock. Pocillopora damicornis is the predominant species, with some heads reaching 30 cm across toward the seaward end of the dock. These heads get progressively smaller toward shore and do not occur beyond a point midway along the dock. Porites lutea and M. dichotoma are common here as encrustations on the seawall, boulders and metal debris. Leptastrea purpurea was also found on the seawall and less frequently on boulders all along the dock.

Baker Bay

The corals in Baker Bay are primarily restricted to a narrow band 5-50 m from shore and to depths less than 4 m. Diversity and abundance decreases with depth and increases with distance away from the "Impedance." Pocillopora damicornis predominates but forms heads generally smaller than those in Charlie Bay (Table 8.1). Porites lutea was the second most frequently encountered species and was observed both as encrustations and in the form of microatolls. Goniastrea retiformis and, less frequently, M. dichotoma were found in small encrusting patches. Montipora lobulata and L. purpurea were also found.

Able Dock

The northeastern (Baker Bay) side and the seaward-facing side of Able Dock were surveyed separately.

Seven species of coral were observed along the northeastern side of Able Dock (Table 8.1). Growth occurs directly against the concrete seawall in meter-deep water and extends into Baker Bay approximately 20 m on the steep slope to a depth of 5 m. Pocillopora damicornis, as in other areas, is the predominant species. Porites lutea is the second most dominant coral in the area.

Pocillopora damicornis and P. lutea were also the predominant corals along the seaward-facing side of Able Dock (Table 8.1). Leptastrea purpurea, infrequent on the Baker side of the dock, was encountered quite frequently on this side and appears to be a more important part of the coral community. Millepora dichotoma does not appear in the quantitative data but occurs in large heads on several pilings at the northern corner of the dock. Acropora nasuta (Fig. 8.1), small stands of A. palifera and several Fungia fungites individuals were also noted. Overall, coral diversity in this area (15 spp.) is significantly higher than in most of the other areas surveyed.

Iron Pilings

The greatest diversity of all the areas surveyed was found on the Iron Pilings. Twenty species have been found in this area. However, relative coral cover appears to be less than at Able Dock. Both diversity and abundance decrease towards the shore south of the pilings. Pocillopora damicornis and M. lobulata are the predominant corals. The greatest coral cover is on the pilings and on metal debris which is abundant here.

Unai Sadog Tase

No corals were found within 200 m of shore. Beyond 200 m coral abundance and diversity increases to a maximum along the edge of the dredge slope and then decreases rapidly downslope. Two zones can be discerned in this area: an inner zone predominated by *Porites cocosensis* and an outer zone without this species.

The inner zone begins about 200 m from shore and extends to within ca. 30 m of the dredge slope. Coral cover in this zone is sparse (Table 8.1). Large heads of *P. damicornis* and *P. cocosensis* predominate. As has already been noted, *P. cocosensis* was found only in this zone. *Acropora aspera* is fairly abundant in the inner zone, with branches extending ca. 10-15 cm above the substratum. *Porites lutea* also occurs here.

The outer zone begins about 320 m from shore and extends in a band along the edge of the dredge slope. Although the same number of species (9) was found in this zone as in the inner zone, *Stylocoeniella armata* occurred only in this zone and *P. lutea* was more abundant (Table 8.1). In fact, coral cover in this zone is very patchy and only a third of the observed species occurred in our random samples.

Discussion

To our knowledge, no previous surveys have been made of the corals along the shore of Tanapag Harbor. Cloud (1959) has reported the results of a general survey of the entire island which, because of its wide scope, lacks detailed information on any one site. Gawel (1974) has surveyed the corals along the barrier reef and in areas near Puntan Flores and Puntan Muchot. These areas appear beyond the range of influence of the power barge except under extraordinary circumstances.

Although significantly lower than the 80.7% coral cover reported by Gawel (1974) from a patch reef near Managaha Island, our findings are similar to his for most of the sites he describes (e.g., 24% cover on a patch reef near Puntan Muchot and 5.1% cover in Garapan Lagoon), and are similar to measurements of cover on lagoon fringing reefs studied in Guam (Randall, et. al., 1975), Yap (Amesbury, et. al., 1976) and Palau (Birkeland, et. al., 1976). Of the areas studied in detail in this report, Charlie Bay had the greatest coral cover (inner = 32.5% and outer = 27.1%) followed by the northeastern side of Able Dock (20.0%), Baker Bay (13.7%) and the outer zone at Unai Sadog Tase (12.8%). The seaward face of Able Dock and the inner zone at Unai

Sadog Tase had the least coral cover (8.4% and 4.5% respectively). As in other areas, diversity and abundance increases toward the margin of the fringing reef and then decreases with depth on the lagoon slope. This pattern is especially evident at Unai Sadog Tase. The presence of iron scrap generally enhances coral development in the area (Fig. 8.2).

Three species, Pocillopora damicornis, Porites lutea and Millepora dichotoma, occur everywhere along the shore (Table 8.2). Pocillopora damicornis is by far the most predominant. Our data indicate that M. dichotoma is more abundant than P. lutea north of Baker Dock but south of the dock the reverse relationship occurs. We do not know why this is so. Diversity is highest in areas exposed to the prevailing swells and where significant hard substratum is available.

No conclusive evidence of heat-related coral mortality was found during this survey. The area near the power barge, which has an abnormally poor development of coral, was subjected to extensive dredging and some heating from the power barge prior to this survey. However, the lack of recently killed coralla and the presence of silt deposits and more or less uncolonized rock surfaces cause us to believe that the dredging operations have had a greater influence on the area than operation of the power barge to date.

Studies of thermal tolerances by Jones et. al (1976) indicate that sustained exposure to temperatures in excess of 31 to 32°C is lethal to most coral species. Furthermore, their work indicates that P. damicornis is killed at lower temperatures (31-32°C) than P. lutea (32-32.5 C). Marsh and Doty (1976 and later unpublished work) have observed that P. lutea indeed survives in thermal regimes lethal to P. damicornis. Although Jones et. al., did not test M. dichotoma, Millepora platygyra was found to be less tolerant of heat than P. damicornis. Thus we expect elevation of water temperatures in the harbor above 31°C would have a significant impact on developing (e.g., Baker Dock) or existing (e.g., Able Dock) coral communities. Further, we expect this impact would be manifested in part by the reduction of P. damicornis and M. dichotoma in favor of increased predominance of P. lutea. Since such a change would entail a decrease in the amount of branching corals and therefore a simplification in the microtopography of the area, changes in the abundances of other organisms (e.g., pomacentrid fishes) would be expected.

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Table 8.1. Analysis of coral cover, size, density and frequency in Tanapag Harbor. n = numbers of individuals, SD = standard deviation.

	n	DENSITY (n/m^2)	SIZE (cm^2) AVG.	SIZE (cm^2) SD	COVER (%)	FREQUENCY
INNER CHARLIE BAY						
SPECIES						
Pocillopora damicornis	15	3.72	430	1096	11.70	0.95
Millepora dichotoma	13	0.92	992	1220	9.13	0.40
Acropora aspera	6	0.46	1940	1930	8.94	0.20
Porites lutea	7	0.05	440	445	2.29	0.30
Montipora lobulata	1	0.06	573	-	0.34	0.05
Acropora nasuta	1	0.06	154	-	0.09	0.05
TOTAL		5.73			32.48	
OUTER CHARLIE BAY						
SPECIES						
Pocillopora damicornis	66	6.22	286	434	17.80	1.00
Millepora dichotoma	6	0.55	710	1200	3.91	0.29
Porites lutea	5	0.47	739	1280	3.47	0.19
Acropora aspera	2	0.16	802	733	1.28	0.10
Leptastrea purpurea	3	0.31	10	4	0.03	0.14
Montipora lobulata	1	0.08	707	-	0.57	0.05
Stylocoeniella armata	1	0.08	3	-	0.00	0.05
TOTAL		7.87			27.06	
NE SIDE OF BAKER DOCK						
SPECIES						
Pocillopora damicornis	53	-	-	-	-	0.91
Porites lutea	43	-	-	-	-	0.50
Millepora dichotoma	57	-	-	-	-	0.05
Montipora lobulata	1	-	-	-	-	0.50
Goniastrea retiformis	4	-	-	-	-	0.14
Leptastrea purpurea	4	-	-	-	-	0.09
Platygyra daedalea	2	-	-	-	-	0.09
Psammocora togianensis	4	-	-	-	-	0.05
Pavona obtusata	2	-	-	-	-	0.05
Favia sp.	2	-	-	-	-	0.05
Acropora convexa	1	-	-	-	-	0.05
TOTAL					49.14	

Table 8.1. (Continued)

	n	DENSITY (n/m^2)	SIZE (cm^2) AVG.	SD	COVER (%)	FREQUENCY
SHORE OF BAKER BAY						
SPECIES						
Pocillopora damicornis	95	4.16	165	200	6.87	1.00
Porites lutea	9	0.39	1540	4100	6.02	0.30
Goniastrea retiformis	8	0.35	11	9	0.04	0.27
Millepora dichotoma	3	0.13	407	358	0.53	0.10
Montipora lobulata	3	0.13	309	327	0.07	0.10
Leptastrea purpurea	1	0.04	370	-	0.15	0.03
TOTAL		5.21			13.68	
NE SIDE OF ABLE DOCK						
SPECIES						
Pocillopora damicornis	96	8.86	205	984	18.15	1.00
Porites lutea	10	0.92	36	26	0.33	0.07
Acropora nasuta	5	0.46	140	84	0.64	0.02
Millepora dichotoma	2	0.19	431	325	0.82	0.02
Goniastrea retiformis	5	0.46	13	11	0.06	0.03
Leptastrea purpurea	1	0.09	7	-	0.01	0.01
Favia sp.	1	0.09	3	-	0.00	0.01
TOTAL		11.08			20.02	
ABLE DOCK, SEAWARD SIDE						
SPECIES						
Pocillopora damicornis	6	3.36	169	115	5.68	0.57
Porites lutea	5	2.91	75	75	2.17	0.71
Leptastrea purpurea	10	5.66	8	11	0.47	0.71
Stylocoeniella armata	5	2.91	3	3	0.08	0.29
Goniastrea pectinata	1	0.57	7	-	0.04	0.14
TOTAL		15.29			8.45	
UNAI SADOG TASE, INNER ZONE						
SPECIES						
Pocillopora damicornis	14	1.15	650	2077	2.92	0.88
Porites cocosensis	13	1.08	208	443	0.87	0.63
Acropora aspera	2	0.15	538	511	0.32	0.25
Porites lutea	1	0.08	1195	-	0.36	0.13
Montipora lobulata	1	0.08	201	-	0.06	0.13
TOTAL		2.56			4.54	
UNAI SADOG TASE, OUTER ZONE						
SPECIES						
Pocillopora damicornis	31	3.92	312	342	12.22	1.00
Porites lutea	4	0.50	117	78	0.59	0.22
Stylocoeniella armata	1	0.14	13	-	0.02	0.11
TOTAL		4.56			12.82	

Table 8.2. The distribution and abundance of corals in Tanapag Harbor. The numbers listed are the relative importance values calculated as the sum of the relative density, cover and frequency of each coral at each site. The values for the northeast side of Baker Dock are based on relative cover and frequency only and have been multiplied by a factor of 1.5 to produce values directly comparable to other data in the table. Letter designations indicate qualitative observations: D = predominant, A = abundant, C = common, O = occasional, U = uncommon, R = rare, and P = present.

ANTHOZOA	Echo Dock	Echo Bay	Charlie Bay Inner	Charlie Bay Outer
Acropora aspera (Dana)	6	C	38	13
Acropora convexa (Dana)	-	-	-	-
Acropora nasuta (Dana)	-	-	4	-
Acropora palifera (Lamarck)	-	-	-	P
Echinophyllia asper (Ellis & Solander)	-	-	-	-
Favia danae Verrill	-	-	-	-
Favia pallida (Dana)	-	-	-	-
Fungia fungites (Linnaeus)	-	-	-	-
Goniastrea parvistella (Dana)	-	-	-	-
Goniastrea pectinata (Ehrenberg)	-	-	-	-
Goniastrea retiformis (Lamarck)	-	-	-	-
Leptastrea purpurea (Dana)	-	-	-	12
Lobophyllia costata (Dana)	-	-	-	-
Montipora lobulata Bernard	56	C	5	6
Montipora verrilli Vaughan	P	U	P	P
Montipora sp. 1	-	U	-	-
Pavona obtusata (Quelch)	-	-	-	-
Platygyra daedalea (Ellis & Solander)	-	-	-	-
Pleurogyra sinuosa (Dana)	-	-	-	-
Pocillopora damicornis (Linnaeus)	153	D	155	200
Porites cocosensis Wells	-	-	-	-
Porites lutea Milne Edwards & Haime	26	R	27	29
Psammocora (Stephanaria) togianensis Umbgrove	-	R	-	-
Stylocoeniella armata (Ehrenberg)	-	-	-	4
Symphyllia valeciennesii Milne Edwards & Haime	-	-	-	-
Tubastraea aurea (Quoy & Gaimard)	-	-	-	-
HYDROZOA				
Millepora dichotoma Forskaal	59	A	76	37
Millepora platyphylla Hemprich & Ehrenberg	-	-	-	-
TOTAL SPECIES	6	8	7	8
TOTAL COVER (%)			32.5	27.1

Baker Dock				Able Dock			Unai Sadog Tase		
NE Side	End	SW Side	Baker Bay	NE Side	End	Iron Pilings	Inner Zone	Outer Zone	Number of Occurrences
-	-	-	-	-	-	-	25	P	6
5	-	-	-	-	-	P	-	-	2
-	-	-	-	9	P	P	-	-	4
-	-	-	-	-	P	P	P	P	5
-	-	-	-	-	-	P	-	-	1
5	-	-	-	2	P	P	-	-	4
P	-	-	-	-	-	P	-	-	2
-	-	-	-	-	P	P	-	-	2
-	-	-	-	-	P	P	P	P	4
-	-	-	-	-	10	-	-	-	1
12	U	U	22	7	P	P	-	-	7
9	0	70	4	2	72	24	-	-	8
-	-	-	-	-	-	P	-	-	1
32	-	-	9	-	P	116	10	P	10
0	0	P	-	-	P	-	-	-	9
-	-	-	-	-	-	-	-	-	1
5	-	-	-	-	-	-	-	-	1
8	-	-	-	-	-	P	-	-	2
P	-	-	-	-	-	P	-	-	2
101	D	178	186	257	113	114	153	256	13
-	-	-	-	-	-	-	92	-	1
68	C	29	69	16	74	P	17	33	13
6	-	-	P	-	-	-	P	P	5
P	C	C	-	-	32	51	-	11	7
-	-	-	-	-	-	P	-	-	1
P	-	-	-	-	P	-	-	-	2
53	A	22	12	8	A	P	P	P	13
P	-	-	-	-	-	-	-	-	1
17	7	7	6	7	15	20	9	9	28
49.2			13.7	20.0	8.4		4.5	12.8	

Fig. 8.1. Acropora nasuta on Able Dock. Note also the thick algal turf.

Fig. 8.2. Pocillopora damicornis on the wreck of the "Four Winds."

9. MOLLUSCA AND OTHER BENTHIC INVERTEBRATES

By

RICHARD "E" DICKINSON

The molluscs and other benthic invertebrates found during the marine survey of Tanapag Harbor were sampled using many techniques to assure as complete an evaluation as possible. Each study site is briefly described and the sampling method is explained. The more common organisms found are noted within the text for each site. A complete listing of all invertebrates from all stations can be found in Table 9.1.

Observations

Charlie Bay

The molluscs and other invertebrates in Charlie Bay were sampled by conducting timed searches along a transect in each of two sites in the bay. The first, or inner zone was sampled by a 45-minute search along a 100-m transect extending from shore at a point opposite the end of Charlie Dock. The substratum at the shoreward end of the transect was loose rubble which graded into a silt-sand substratum where the water deepened. No invertebrates were found there. However, approximately 50 m from shore, the transect crossed a sunken barge covered by many corals. The fire coral *Millepora dichotoma* was noted there and the oyster *Saxostrea mordax* was found attached to some of the colonies. The parthenopid crab *Daldorfia* sp. and numerous gall crabs *Hapalocarcinus marsupialis* were noted on the coral *Pocillopora damicornis*. The last part of the transect crossed over sandy patches and the gastropods *Lambis lambis* (numerous), *Cypraea erosa*, and *Rhinoclavis asper* were noted.

A second 20-minute search for echinoderms in the coral and sand shoal area of inner Charlie Bay revealed single individuals of the starfish *Linckia laevigata* and *Culcita novaeguineae* and the holothurian *Bohadschia bivittata*. *Holothura atra* was more common,with four individuals found in the search.

The second area sampled in Charlie Bay was a shallow coral and sand patch south of the inner zone and near the mouth of the bay. A 30-minute search along a 100-m transect was conducted. The only gastropod noted was *Lambis lambis* and the gall crab *Hapalocarcinus marsupialis* was common on the coral *Pocillopora damicornis*. Two individuals of the pillow starfish Culcita novaeguineae were also found.

A 20-minute swim with SCUBA was made parallel to shore and across the deeper part of outer Charlie Bay towards Baker Dock. The water was between 8 and 10 m deep and the substratum was mostly a thick mud-sand ooze. There was some debris including pipes and two large anchors but no epibenthic invertebrates were observed.

Baker Dock

Baker Dock is a man-made causeway composed of coral rubble and supported on all sides by a metal retaining wall. The access road to the power barge runs along the top and the causeway itself provides the support for most of the starboard (north) mooring lines to the power barge.

The invertebrates along the northeast side of Baker Dock were sampled by conducting a 1-hour swim with SCUBA from the seaward end towards the shore. The metal retaining wall provided the only solid substratum and the water depth was approximately 4-5 m. The gastropod Chicoreus penchinati and top shell Trochus niloticus were common. The high intertidal littorine Littorina scabra was also noted. The oyster Saxostrea mordax, was found attached to corals and to the fire coral Millepora dichotoma. Other invertebrates noted clinging to the retaining wall were the sea urchins Mespilia globulus, Tripneustes gratilla, and Echinometra mathaei.

The end of Baker Dock is composed of large boulders and rubble. There were few gastropods noted here and among them were Littorina scabra and Chicoreus penchinati. The grapsid crab Percnon sp. was common on the sides and under the boulders.

The southwest side of Baker Dock is composed of the retaining wall and also a shallow and narrow rubble shelf which drops off steeply into the deeper water directly beneath the power barge. The molluscan fauna was sampled during a 1-hour search conducted by swimming from the seaward end of Baker Dock along the narrow shelf to the shoreward end (stern) of the power barge. No aggregates were noted but individuals recorded more than once included: Littorina scabra (on the retaining wall), Chicoreus penchinati, Lambis lambis and Cantharus fumosus. There were few bivalves in the area, probably due to the fairly recent dredging and the unconsolidated nature of the rubble along the causeway. One notable exception was a Tridacna maxima found in this rubble area adjacent to the barge.

The sea urchins Mespilia globulus and Echinometra mathaei were noted on the undersides of large boulders and on the retaining wall in densities of up to 10 per m^2. Echinothrix diadema was also noted in the area. Stichopus chloronotus was found in abundance (up to 4 per m^2). Holothuria leucospilota and Stichopus horrens were also seen.

Also noted here were the grapsid crabs Grapsus tenuicrustatus (common on the retaining wall above water level) and Percnon sp. (on boulders just below water level).

Baker Bay

The power barge is moored in Baker Bay. The bay was dredged to accommodate the barge and the sediments in the deeper part of the bay are mostly fine silt and mud. Along the shallower periphery, some coral development has occurred and the substratum is more consolidated.

The molluscs were sampled during a 1-hour SCUBA dive made parallel to shore along the shallow,stern (inner) mooring chain of the power barge to the southern shore and returning across the bay to the power barge along the deeper,bow (outer) mooring chain.

The inner area was mostly mud and silt with numerous holes from various burrowing organisms and with occasional small Porites lutea and Pocillopora damicornis colonies growing on debris. Coral abundance and diversity increased with distance away from the barge (see Chapter 8). The molluscs Chicoreus penchinati and Lambis lambis were very common in the shallower area near Able Dock. Also noted were Gafrarium pectinatum, Conus virgo, and Cerithium nodulosum.

The holothurians Stichopus chloronotus and Bohadschia bivitata were found here. Stichopus chloronotus occurred with an overall density of 0.35 per 10 m^2 but with peak densities as high as 4.5 per 10 m^2 in local aggregations. Bohadschia bivittata was much less common (0.05 per 10 m^2). In general, holothurian density increased with distance away from the power barge and decreased with depth below 1-2 m.

The outer (deeper) area was also mostly mud and silt substratum and no molluscs were found. Some hermit crabs were collected from the silty bottom at a depth of 8 m approximately halfway between Able and Baker docks and the hermit crab Calcinus latens was collected from the bottom directly beneath the port side effluent of the power barge.

Able Dock

Able Dock is composed of a concrete dock which faces Baker Bay on the northeast side and Tanapag Harbor on the other.

A 30-minute swim along the northeast side was conducted and few molluscs were found. However, the gastropods Lambis lambis and Chicoreus penchinati were very common. Two holothurians occurred there also: Stichopus chloronotus (0.20 per 10 m^2) and Holothuria atra

(0.05 per 10 m).

The molluscs along the seaward end of Able Dock were sampled by conducting a 45-minute search, recording all molluscs in the area and collecting unknown individuals for later identification. No aggregates of gastropods were found, but the muricids Morula uva, Drupa ricinus, and Chicoreus penchinati were common on the wave-washed boulders. Also noted more than once were Trochus niloticus, Lambis lambis, Australium petrosum and the oyster Saxostrea mordax. Two small individuals of an unknown species of octopus were also seen.

Other invertebrates noted here included the parthenopid crab Daldorfia sp., the anemone crab Lybia sp., the two grapsid crabs Grapsus tenuicrustatus and Percnon sp., the lobster Panulirus versicolor, the cleaner shrimp Stenopus hispidus, and the sea urchin Tripneustes gratilla.

The harbor face of Able Dock supports a more diverse echinoderm fauna. On the subtidal slope, Mespilia globulus is very common (ca. 2 per 10 m^2) and Echinometra mathaei is common (ca. 0.5 per 10 m^2). One starfish, Linckia laevigata, was seen. One each of the holothurians Holothuria atra, H. leucospilota and Bohadschia argus were also seen. Mespilia globulus is also common in the intertidal area as is Holothuria difficilis.

Iron Pilings

The iron pilings referred to are the remains of an old dock and there was considerable industrial debris found scattered on the fine silt and mud substratum. The debris was composed mostly of steel fittings, pipes, and automobile parts.

The invertebrate fauna of this area was sampled during a one-hour swim using SCUBA. A 100-m transect tape was laid parallel to the shore and near the most seaward row of pilings. This tape was used as a reference point while searching for invertebrates. Water depth was approximately 6 m.

The silty substratum was devoid of any significant coral development and few invertebrates were encountered. The most common gastropod was the strombid Lambis lambis. Also noted were the cone shells Conus rattus, Conus lividus and Conus litteratus. Two individuals of the pearl oyster Pinctada margaritifera were found, one of which contained a pair of the shrimp symbionts Conchodytes melegrinae.

Enchinoderms were counted and summed over the area falling between 12 pilings (ca. 111 m^2). Seven counts were made in all,starting near Able Dock and proceeding toward Unai Sadog Tase. Bohadschia bivittata was common (0.32 per 10 m^2) and became more common towards Unai Sadog

Tase. Bohadschia argus was less common (0.039 per 10 m^2). One individual of Holothuria impatiens was seen. Mespilia globulus (0.064 per 10 m^2) and Culcita novaguineae (0.013 per 10 m^2) were also seen.

Holothuria atra, Bohadschia bivittata and Tripneustes gratilla occurred in the small cove behind the iron pilings.

Unai Sadog Tase

The invertebrate fauna of Unai Sadog Tase was sampled along a 400-m transect line which extended from near a barge on the shore and ended at the Platform Pilings (Fig. 2.1). A 10-minute search was conducted at 10-m intervals for the first 300 m of the transect. The last 100 m of the transect was sampled by a single 30-minute search along the entire transect. The density of gastropod aggregates was measured using a 0.25 m^2 quadrat. Echinoderm densities were measured with nested quadrats of varying size depending on visual assessments of an adequate sample. Additionally, six 0.25 m^2 plots were sampled to a depth of 25 cm from within the Enhalus acoroides beds. Two of the plots were taken from the inner edge of the E. acoroides zone (30 m from shore), two from the middle of the grass bed (100 m from shore) and two from the seaward edge (150 m from shore). All molluscs and the E. acoroides from each plot were collected and evaluated for species densities and biomasses (Table 9.2).

The inshore (0-30 m) area was composed mostly of mud-sand bottom with occasional blue-green algal mats. There were numerous individuals of Cerithium sp. (averaging 4 per quadrat) in the blue-green algal cover. Shell fragments of many bivalve species were also collected. The fragments were typical of living bivalves collected, as noted in Table 4.6. Also noted inshore, though not on the transect, was the gastropod Natica gualtieriana and two species of crabs, Calappa hepatica and the portunid Thalamita sp. No echinoderms were noted in this zone.

Further from shore (30-150 m) extensive sea grass beds (Enhalus acoroides) were the dominant cover. Sea grass beds of this type are typical of sheltered coasts in shallow water and on sandy and muddy bottoms (den Hartog, 1970). The thick stable sediments of grass beds provide an excellent habitat for burrowing organisms and consequently there is an extensive infaunal population. The leaves of the grasses also form a protective habitat for epifaunal forms (Taylor & Lewis, 1970).

Large numbers of Cerithium sp. were found attached to the leaves of the E. acoroides and on the sand substratum. Quadrat sampling of these aggregates showed a density of 137 per 0.25 m^2. This value is believed to be a low estimate because of difficulty in counting individuals on the undersides of leaves or partially covered by the silt. Interestingly, the density of this species is highest at 30 m from shore,with a density of 406 per m^2,and gradually lower to seaward. At 150 m from shore there were 10 per m^2, though the E. acoroides patches were still present (Table 9.2).

There were four species of hermit crabs found in the sea grass beds. One of them, Calcinus laevimanus, was found near an old barge approximately 60 m from shore. The other three, Calcinus latens, Clibinarius humilis, and Clibinarius striolatus were found within the E. acoroides patches. The density of the latter two showed a trend similar to the Cerithium sp., that is, greater density inshore and gradually decreasing to seaward. Conversely, the density of Calcinus latens increased slightly seaward (Table 9.2).

At 100 m from shore, Holothuria atra is abundant (14.4 per 10 m^2), as is Stichopus horrens (2 per 10 m^2). Mespilia globulus and Holothuria hilla were common (0.8 and 04 per 10 m^2 respectively). One juvenile Lambis lambis was seen.

At the seaward margin of the E. acoroides bed, the holothurian density reached the highest seen during the study: Holothuria atra, 150 per 10 m^2 and Stichopus horrens, 135 per 10 m^2. In the sandy patches in the margin of the Enhalus zone, the holothurian density was significantly lower (H. atra, 14.3 per 10 m^2 and S. horrens, 0.21 per 10 m^2).

Beginning at 150 m from shore, there were broad sandy areas. The gastropod Rhinoclavis asper was commonly found there, partially buried beneath the sediment surface. Other gastropods in this zone included the algal grazer Cypraea moneta found under small coral boulders and an active algal detritus feeder, Strombus gibberulus. The bivalve Pinna muricata was found in the sand. It lives vertically, almost wholly buried in the sediment with only the gaping posterior valve edges protruding above the surface. Also common (25 per 0.25 m^2) in the sandy patches was the hermit crab Clibinarius sp.

The sandy area graded into a rubble zone beginning about 200-230 m from shore. Scattered living corals (Porites cocosensis and Pocillopora damicornis) occurred there and increased in density with distance away from shore. Only a few gastropods were found there including Conus lividus, Conus virgo, Strombus mutabilis, Lambis lambis, and Cymatium nicobaricum. Only one bivalve, the pearl oyster Pinctada margaritifera, was found. It was found approximately 250 m from shore. Callianassid shrimps were common (2 per 0.25 m^2). Two crabs, a portunid and Calappa hepatica, were also seen. Holothuria atra was common there but in densities decreasing from 66 per 10 m^2 at approximately 200 m from shore to 14.4 per 10 m^2 about 250 m from shore. Holothuria hilla (0.4 per 10 m^2) occurs under boulders in this zone.

The last 100 m of the transect extended between the dolphin and Platform Pilings (Fig. 2.1). Only a small number of molluscs were found there; among them were Cantharus fumosus, Drupella cornus, Morula biconica, Pusia pardalis, Lambis lambis, and Pinctada margaritifera. A parthenopid crab, Daldorfia sp.; a portunid crab, Lupocyclus sexspinosus; and numerous gall crabs, Hapalocarcinus marsupialis (in Pocillopora damicornis) were also noted. Occasional individuals of the sea urchins Echinometra mathaei and Mespilia globulus were found along with a single individual of the pillow starfish Culcita novaguineae. Two holothurians, Holothuria atra and Bohadschia bivittata, occurred there in approximately equal densities (1 per 25 m^2). Their distributions were patchy due to the patchy occurrence of sandy substratums on which they were usually found. The bright yellow tunicate Ascidia gemmata occurred here in densities of 10 per 15 m^2.

Discussion

The six sites studied for the marine survey of Tanapag Harbor exhibited a variety of invertebrate assemblages. Five of the sites have experienced extensive dredging either within the study area or in nearby adjacent waters. The exception, Unai Sadog Tase, had not been as heavily disturbed and the existing consolidated substratum and sea grass beds reflect the more stable environment.

The effects of the dredging are most dramatic within Baker Bay where the only invertebrates noted were a few hermit crabs and some burrowing organisms. The silt-mud substratum was stirred easily and on many occasions visibility for SCUBA divers was limited to the tip of the outstretched hand. The shifting sediments and turbid water of this bay inhibit colonization by most macroinvertebrates. Occurrence of molluscs and density of echinoderms increased with distance from the power barge.

Charlie Bay had a similar silty substratum with the important exception of the sunken barge and shoal-like areas. These provided a stable surface and the corals and coral associates found there have already been noted. However, benthic community development was limited and Charlie Bay was similar to Baker Bay. During windy days, when both bays experience choppy waves, the bottom silt becomes stirred and the resulting suspended particles are constantly shifted. Such sedimentation prevents the growth of corals except for species tolerant of siltation (e.g., Pocillopora damicornis).

The Iron Pilings also had an unconsolidated substratum, but the pilings provided the solid surface necessary for invertebrate attachment. More invertebrates were noted here than at Baker or Charlie Bays. It is also believed that the pilings reduce wave-induced surge and the substratum tends to be more stable than at Baker or Charlie Bays. The occurrence of the burrowing pearl oyster and Conus sp. on the sediment confirm this suggestion.

Baker Dock had a unique feature which might explain why this was the only station where grapsid crabs were found. The boulders forming the causeway extend from sea level upwards to about 2 m. The small holes formed between the boulders provide shelter for the crabs; this is especially important for those grapsid crabs which molt out of the water (Knudsen, 1968). The holes and crevices provide concealment and protection for molting crabs. Besides protecting these crabs, the boulders, retaining wall and the barge itself protect the narrow shelf from strong wave action. This is a factor explaining why the sea urchin *Mespilia globulus* was found here in higher densities than at all other stations.

Able Dock also had a unique habitat and a group of gastropods were found only at this station. A cluster of wave-washed boulders has formed along the seaward side of Able Dock. These boulders lie within the intertidal zone; they are partially exposed at low tides and fully submerged during high tides. This, plus the exposed location of Able Dock, provided the habitat typical for many gastropods, especially the muricids *Drupa ricinus* and *Morula uva* (Cernohorsky, 1972) and the top shells, *Trochus niloticus* and *Trochus maculatus*. Three of these (excluding *Morula uva*) were found only at this station. The occurrence of high densities of *Mespilia globulus* is also believed to be a function of this more exposed and subsequently sediment-free location. Heavy siltation has occurred in the adjacent deeper water but the shallower areas tended to have less sediment. Waves breaking against Able Dock act to stir the sediments and much of the finer silt is carried off with the tides while heavier particles settle out in the deeper water. This cleansing action enables filter feeding invertebrates such as oysters (*Saxostrea mordax*) and corals and clinging organisms such as various echinoderms to gain a foothold. These were not found in the silty areas of Charlie and Baker Bays nor on the moderately consolidated substratum of the Iron Pilings. Octopus and a lobster were noted here, which might also be indicative of less siltation.

Unai Sadog Tase was the largest and most complex site studied. The range of habitats, from the inner blue-green algal mats and sea grass beds to the outer broad sandy patches and coral rubble, provided a series of unique microhabitats. The invertebrate species and densities here were different from those at the other stations and reflect the different habitats. The absence of heavy siltation and the more extensive and consolidated substratum might help to explain the differences. The gastropod *Cerithium* sp. was found only at this station and in very high densities. This was true also for the bivalve *Dosinia* sp. Holothurian density was also higher here than at any of the six stations. Other molluscs which were found only here, though not in great density, included the bivalves *Glycodonta marica*, *Morula biconica*, and *Natica gualtieriana*.

The most frequent mollusc noted during this study was *Lambis lambis* which occurred at each of the six sites. This animal is typical of shallow and sandy bays (Abbott, 1961). The next most common gastropod, occurring at four of the sites, was *Cypraea erosa*. This animal is commonly found under stones in quiet water. The most common bivalve was *Saxostrea mordax*, which was noted at four of the six study sites.

The most frequent echinoderms were the sea urchin *Mespilia globulus* and the holothurian *Holothuria atra*. Each occurred at four of the six stations. *Mespilia* was most abundant in the narrow rubble zone of Baker Dock while *Holothuria atra* was most abundant in the grass beds at Unai Sadog Tase. Neither of these two were found at Baker Bay. The only other invertebrate that was very common was the gall crab *Hapalocarcinus marsupialis*, which occurred at each of the six stations. The female of this species lives in a gall-like enclosure amongst the branches of coral. The coral grows up and around the female thus imprisoning her. The coral species *Pocillopora damicornis* is commonly a host for this crab and *Pocillopora* was also found at each station.

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Table 9.1. Distribution of major invertebrate species (excluding corals) in Tanapag Harbor. Numbered stations under Unai Sadog Tase refer to consecutive 100-m transects beginning at the shore.

	C	B	A	IRON	UNAI SADOG TASE			
	BAY	DOCK	DOCK	PILINGS	1	2	3	4
COELENTERATA (corals excluded)								
Scyphozoa								
Cassiopeia sp.	-	-	-	-	-	x	-	-
Hydrozoa								
Orange clavid	-	x	-	-	-	-	-	-
Halocordyle tiarella (McCrady)	-	x	x	-	-	-	-	-
Thyroscyphus fruticosus (Esper)	-	x	-	-	-	-	-	-
ARTHROPODA								
Anomura								
Calcinus gaimardi (H. Milne Edwards)	-	x	-	-	-	-	-	-
Calcinus latens (Randall)	-	x	-	-	-	-	-	-
Calcinus laevimanus (Randall)	-	-	-	-	x	-	-	-
Clibanarius striolatus (Dana)	-	-	-	-	x	-	-	-
Clibanarius sp. (cf. *C. humilis* (Dana) or *C. viriscens* (Krauss)	-	-	-	-	x	-	-	-
Munida sp.	-	-	-	-	-	-	-	x
Brachyura								
Calappa hepatica (Linnaeus)	-	-	-	-	x	-	-	-
Conchodytes melegrinae Peters	-	-	-	x	-	-	-	-
Daldorfia sp. [cf. *D. horrida* (Lannaeus)]	x	-	x	-	-	-	-	x
Grapsus tenuicrustatus (Herbst)	-	(bay)	-	-	-	-	-	-
Hapalocarcinus marsupialis Stimpson	x	-	x	x	-	-	-	x
Lupocyclus sexspinosus Leene	-	-	-	-	-	-	-	x
Lybia sp.	-	-	x	-	-	-	-	-
Percnon sp.	-	(bay)	-	-	-	-	-	-
Trapezia cymodoce (Herbst)	-	-	-	-	x	x	-	-
Portunid (cf. *Thalamita* sp.)	-	-	-	-	x	x	-	-
Palinura								
Panulirus versicolor (Latreille)	-	-	x	-	-	-	-	-
Natantia								
Stenopus hispidus (Olivier)	-	-	x	-	-	-	-	-

Table 9.1. (continued)

	C BAY	B DOCK	A DOCK	IRON PILINGS	UNAI 1	SADOG 2	TASE 3	4
ECHINODERMATA								
Echinoidea								
Echinometra mathaei (de Blainville)	-	x	x	x	-	-	-	x
Echinothrix diadema (Linnaeus)	-	-	x	-	-	-	-	-
Mespilia globulus (Linnaeus)	-	x	x	x	-	-	-	x
Tripneustes gratilla (Linnaeus)	-	x	x	-	-	-	-	-
Asteroidea								
Culcita novaeguineae Muller & Troschel	x	-	-	x	-	-	-	x
Linckia laevigata (Linnaeus)	x	-	x	-	-	-	-	-
Holothuroidea								
Bohadschia argus Jaeger	x	x	x	x	-	-	-	-
Bohadschia bivittata Mitsukuri	x	(bay)	x	x	-	-	-	x
Holothuria atra Jaeger	x	-	x	-	x	x	x	x
Holothuria difficilis (Semper)	-	-	x	-	-	-	-	-
Holothuria hilla Lesson	-	-	-	-	-	-	-	x
Holothuria impatiens (Forskal)	-	-	-	x	-	-	-	-
Holothuria leucospilota Brandt	-	x	x	-	-	-	-	-
Stichopus chloronotus Brandt	x	x	x	-	-	-	-	-
Stichopus horrens Selenka	-	x	-	-	x	-	-	-
MOLLUSCA								
Bivalvia								
Arca ventricosa Lamarck	-	-	-	-	-	-	-	x
Arcopagia robusta (Hanley)	-	-	-	-	-	x	x	-
Dosinia sp. [cf. D. japonica (Reeve)]	-	-	-	-	-	x	x	-
Cardita leana Dunker	-	-	x	-	-	-	-	-
Chama sp.	-	-	-	x	-	-	-	-
Chlamys sp.	-	x	-	-	-	-	-	-
Febulina sp. [cf. F. minuta (Lischke)]	-	-	-	-	-	x	-	-
Fragum fragum (Linnaeus)	-	-	-	-	-	x	-	-
Gafrarium pectinatum (Linnaeus)	-	(bay)	-	-	x	x	x	-
Gloripallium pallium (Linnaeus)	-	-	x	-	-	-	-	-
Glycodonta marica (Linnaeus)	-	-	-	-	-	x	x	-
Lioconcha sp. [cf. L. lorenzlana (Dillwyn)]	-	-	-	-	-	x	-	-
Periglypta puerpera (Linnaeus)	-	x	-	-	-	x	x	-
Pinctada margaritifera Linnaeus	-	-	-	x	-	-	-	x
Pinna muricata Linnaeus	-	-	-	-	-	x	-	-

Table 9.1. (continued)

	C BAY	B DOCK	A DOCK	IRON PILINGS	UNAI 1	SADOG 2	TASE 3	4
Quidnipagus palatam Iredale	-	-	-	-	-	x	-	-
Saxostrea mordax (Gould)	x	x	x	-	-	-	-	-
Septifer bilocularis (Linnaeus)	-	-	-	-	-	x	-	-
Tellinella virgata (Linnaeus)	-	-	-	-	-	-	-	x
Tridacna maxima (Roeding)	-	x	-	-	-	-	-	-
Cephalopoda								
Unknown octopus sp.	-	-	x	-	-	-	-	-
Gastropoda								
Australium petrosum (Martyn)	-	-	x	-	-	-	-	-
Cantharus fumosus (Dillwyn)	-	x	-	-	x	-	-	x
Cerithium nodulosum Bruguiere	-	(bay)	-	-	-	-	-	x
Cerithium sp. (cf. C. ravidum Philippi or C. tenellum Sowerby)	-	-	-	-	x	x	-	x
Chicoreus penchinati (Crosse)	-	x	x	-	-	-	-	-
Conus litteratus Linnaeus	-	-	-	x	-	-	-	-
Conus lividus Bruguiere	-	-	-	x	-	-	x	-
Conus rattus Hwass	-	-	x	x	-	-	-	-
Conus virgo Linnaeus	-	(bay)	-	-	-	-	x	-
Cymatium nicobaricum (Roeding)	-	-	-	-	-	x	-	-
Cypraea asellus Linnaeus	-	-	-	-	-	-	-	-
Cypraea erosa Linnaeus	x	x	x	-	-	-	x	-
Cypraea moneta Linnaeus	-	-	x	-	-	x	-	-
Drupa ricinus (Linnaeus)	-	-	x	-	-	-	-	-
Drupella cornus (Roeding)	-	x	-	-	-	-	-	x
Lambis lambis (Linnaeus)	x	x	x	x	-	x	-	x
Latirus sp.	-	-	x	-	-	-	-	-
Littorina scabra (Linnaeus)	-	x	-	-	x	-	-	-
Mitra cucumerina Lamarck	-	-	x	-	-	-	-	-
Mitra sp. 1	-	-	-	-	-	-	x	-
Mitra sp. 2	-	-	x	-	-	-	-	-
Morula biconica (Blainville)	-	-	-	-	-	-	-	x
Morula uva (Roeding)	-	x	x	-	-	-	-	-
Natica gualtieriana Recluz	-	-	-	-	x	-	-	-
Phyllidia sp.	-	-	-	x	-	-	-	-
Pusia pardalis (Kuester)	-	-	-	-	-	-	-	x
Rhinoclavis asper (Linnaeus)	x	-	-	-	x	x	x	-
Smaragdia rangiana (Recluz)	-	-	-	-	x	-	-	-
Strombus gibberulus Linnaeus	-	-	-	-	-	x	x	-
Strombus mutabilis Swainson	-	-	-	-	-	x	x	x
Tectus pyramis (Born)	-	-	x	-	-	-	-	-
Trochus maculatus Linnaeus	-	-	x	-	-	-	-	-
Trochus niloticus Linnaeus	-	x	x	-	-	-	-	-
Trochus sp.	-	-	-	-	-	-	x	-
CHORDATA								
Ascidiacea								
Ascidia gemmata Sluiter	-	x	x	x	-	-	-	x

Table 9.2. Abundance of organisms in three parts (Inner, Middle, and Outer) of the *Enhalus acoroides* bed. *Enhalus* data are in g dry weight per m^2; all others are numbers per m^2.

	Inner	Middle	Outer
Enhalus acoroides	78.2	104.6	65.8
Blades	50.3	59.4	59.7
Rhizones	27.9	45.2	6.1
Infauna			
Mound builders	0.56	0.08	0.00
Dosinia sp.	0	2.0	138
Fragum fragum	0	0	2
Gafrarium pectinatum	4	10	4
Glycodonta marica	0	0	2
Septifer bilocularis	0	2	4
Tube worms	588	588	588
Epifauna			
Cerithium sp.	404	16	10
Nerita sp.	0	0	4
Clibanarius humilis	30	0	0
Clibanarius striolatus	96	2	0
Calcinus latens	14	16	36
Holothuria atra	0	1.44	15
Stichopus horrens	0	0.20	13.5
Mespilia globulus	0	0.08	0.25

10. THE ZOOPLANKTON OF TANAPAG HARBOR

By

STEVEN S. AMESBURY AND JAMES E. DOTY

Introduction

Because of their small size and intimate relationship with their seawater environment, zooplankton organisms can be sensitive indicators of water quality. In addition, many benthic and pelagic marine fishes and crustaceans spend their early larval lives as members of the zooplankton, and the relative abundance of these larval forms may be indicative of nursery areas of important marine species.

A brief survey was conducted to provide some baseline information on the composition of zooplankton communities in Tanapag Harbor. As little is yet known of the extent of areal and temporal variation in zooplankton communities in the tropics, the results of this survey must be considered superficial.

Methods

Daytime and nighttime plankton tows were made in three areas. Shallow-water tows were made in Baker Bay from the northern corner of Able Dock to the stern of the power barge and in Charlie Bay from the seaward end of Baker Dock to the northeastern end of Charlie Bay. Outer harbor samples were taken in tows made between two large mooring buoys there.

A 20" diameter net fitted with #1 mesh (.4 mm apertures) netting was used. Start and end points for the tows in Baker Bay and Charlie Bay were plotted,allowing the total water volume filtered to be calculated. We were unable to plot the endpoints of the tows in the outer harbor and so only relative abundance of plantonic organisms could be determined for these collections.

Results

In the inner harbor areas (Baker and Charlie Bays) the number and volume of zooplankton were greater during the day than at night while the opposite pattern was observed in the outer harbor (Table 10.1). The composition of the plankton underwent a significant change from day to night. In the inner stations, copepods comprised more than than 90% of the plankton numbers during the day, while at night larval crabs and shrimps dominated. In the outer harbor, copepods were never abundant, and crustacean larvae dominated the catches, particularly at night when crab zoea made up 76% of organisms collected.

Of the two inner harbor locations, Baker Bay showed the greatest abundance of plankton, both day and night. The largest concentration of larval forms (crustacean larvae, fish larvae, and fish eggs) appears to be in the outer harbor, based on relative composition of the catch.

Conclusions

The zooplankton of tropical reefs has three major components: 1) oceanic planktonic species characteristic of the particular water mass within which the reef is located, 2) inshore planktonic species, members of self-perpetuating autochthonous populations living within the reef system, and 3) larval stages of non-planktonic reef species which may be seasonal in their abundance. The abundance and relative importance of these three components in any particular reef system can be indicative of the importance of various types of food chains, the origin and circulation patterns of the water, and the productivity of nursery areas.

The limited amount of information presented in this study suggests some generalizations. Zooplankton abundance is rather high (tows with the same net in the Marshall Islands collected 24 organisms/m^3 in oceanic waters off Majuro and 617 organisms/m^3 in in nutrient-rich lagoon waters off Ebeye (Amesbury et. al., 1975a, b). Plankton feeding may be an important nutritional niche in Tanapag Harbor marine communities. Certainly the high abundance of plankton-feeding fishes (*Chromis caerulea*, *Dascyllus aruanus*, *Abudefduf coelestinus*, and *Pomacentrus pavo*) suggests this. The sharp differences between the plankton composition of the inner harbor and outer harbor suggests that there is relatively little mixing between these waters. If this is indeed the case, warm water or other effluents released in the inner harbor waters may be expected to undergo less dispersion and dilution than would be the case if there was a high rate of mixing throughout Tanapag Harbor. Apparently the inner harbor waters are less productive in larval stages of fishes and crustaceans than are the outer harbor waters.

A more thorough study on the zooplankton communities in Tanapag Harbor would be needed before the validity of the above generalizations could be demonstrated.

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Table 10.1. Plankton organisms collected in Tanapag Harbor, June 12, 1976. Abundance in number of organisms/m^3 of water filtered. Percent composition of total catch given in parentheses. For outer harbor tows, only percent composition is given.

Plankton Group	Baker Bay Day 1045 hr.	Baker Bay Night 2000 hr.	Charlie Bay Day 1100 hr.	Charlie Bay Night 2015 hr.	Outer Harbor Day 1630 hr.	Outer Harbor Night 2045 hr.
foraminifera				.7(0.4)	(0.6)	(0.7)
medusas	5.5(0.8)		1.4(0.3)	.7(0.4)	(0.6)	
siphonophores					(1.8)	
gastropods				1.4(0.8)		
copepods	656.8(92.4)	71.3(33.2)	381.5(92.5)	64.9(35.6)	(4.9)	(0.4)
mysids	3.3(0.5)		4.9(1.2)			
isopods	1.1(0.2)					
amphipods						(0.2)
stomatopods				.4(0.2)		
<u>Lucifer</u>					(19.6)	(11.4)
crab zoea	2.2(0.3)	55.9(26.0)	7.8(1.9)	73.0(40.0)	(24.5)	(76.0)
shrimp zoea	19.7(2.8)	45.0(20.9)		22.6(12.4)	(25.8)	(4.4)
unident. crustaceans			.7(0.2)	.7(0.4)		
mites		1.1(0.5)				
chaetognaths	5.5(0.8)	2.2(1.0)	8.5(2.1)	4.9(2.7)		
larvaceans	14.3(2.0)	38.4(17.9)	6.3(1.5)	9.5(5.2)	(3.1)	
fish eggs	2.2(0.3)		.7(0.2)	1.4(0.8)	(19.0)	(6.4)
fish larvae		1.1(0.5)	.7(0.2)	2.1(1.2)		(0.4)
est. no collected	32,400	9800	29,250	12,925	8150	22,750
est. no./m^3	710.5	214.9	412.6	182.3	- - -	- - -
est. vol. collected	12.1 ml	8.9 ml	9.6 ml	8.1 ml	8.4 ml	12.6 ml
est. vol./m^3	.265 ml	.195 ml	.135 ml	.114 ml	- - -	- - -

11. THE FISHES OF TANAPAG HARBOR

By

STEVEN S. AMESBURY, MICHAEL E. MOLINA, AND ROBERT M. ROSS

Introduction

The composition of the fish communities in Tanapag Harbor may undergo changes as a result of changing temperature regimes caused by the release of heated waters from the power barge "Impedance." In order to asses such possible changes, the fish communities in this area were censused over a period of four months early in 1976 to provide baseline information on the distribution and abundance of fish species.

Methods

Tanapag Harbor was visited three times during early 1976, February 6 to 8, April 14 to 16, and June 11 to 13. Six areas were surveyed by means of quantitative transect counts: area I, to the north, including the seaplane ramp, Rangelight Bay, and Echo Bay; area II, Charlie Bay; area III, the south side of Baker Dock in the immediate vicinity of the power barge; area IV, Baker Bay, excluding the area adjacent to the power barge; area V, the seaward end of Able Dock and the row of iron pilings extending to the south; and area VI, Unai Sadog Tase. Within each area, one or more measured transects were established, and fish species were censused by a diver swimming the length of the transect line, counting fishes within a meter on either side of the line (Fig. 11.1). Censuses were repeated after two- to four-month intervals on four of the transects. During the February transect surveys (Series 1), visibility was very poor because of the large amount of suspended material in the water. This no doubt affected the accuracy of the counts,as censuses along some of the same transects done in April (Series 2) and June (Series 3) generally recorded more species and more individuals than were recorded in February.

Results

More than 5000 fishes of some 75 species were censused in the Tanapag Harbor area (Table 11.1). The damselfishes (Pomacentridae) were the most abundant group, with the two species Chromis caerulea and Dascyllus aruanus accounting for approximately 50% and 20%, respectively, of the fishes seen. The sharp-backed puffer (Canthigasteridae) Canthigaster solandri was the most ubquitous fish, occurring on 15 of the 18 transects. Other frequently observed fishes and the number of transects on which they were seen were Dascyllus aruanus (14), Chromis caerulea (10), and the surgeonfish (Acanthuridae) Ctenochaetus striatus (10).

Northern area (Seaplane Ramp, Rangelight Bay, and Echo Bay; Area I)

This area was surveyed only during the February transect series. On Transect A, along the south edge of the southern seaplane ramp, a small number of fishes were seen, principally the sharp-backed puffer Canthigaster solandri. No fishes were seen along a 150-m transect through Rangelight Bay because the dense stands of sea-grass and the suspended silt in the water limited visibility to a few inches. Gill net fishermen captured a number of small fish in this bay including the goatfish Mulloidichthus samoensis. A short, random search in Echo Bay revealed seven species of fish: some unidentified surgeonfishes, Canthigaster solandri, Chaetodon trifasciatis, Lutjanus vaigiensis, Zanclus cornutus, Chromis caerulea, and Dascyllus aruanus. The latter two species were by far the most numerous.

Charlie Bay (Area II)

Three transects were run in Charlie Bay. Transect B was set along the north side of Baker Dock, an area dominated by encrusting Porites and Millepora, with considerable scrap littering the bottom (Fig. 11.2). A moderate number and diversity of fishes was observed. Transect C ran from the beach out 50 m toward Charlie Dock parallel to the end of the dock. This was an area of rubble and sparse corals and only twelve fishes of two species were seen. Transect D was an extension of C and ran from 68 m to 100 m from the beach. Here the water was clearer and more corals were present. Fish density and diversity was considerably greater along this transect than along the more shoreward Transect C.

Baker Dock-Power Barge Mooring (Area III)

This area has been dredged to accommodate the power barge, though corals are beginning to become re-established in a number of locations. Transects E and F were run in February (Series I) and again in June (Series 3). The number of species observed and their abundance was consistently higher in the June series. This is probably due to the poor visibility in February rather than to increased fish colonization over the four-month interval, although this latter possibility can not be completely dismissed. Transect E in June had the highest fish density of any of the transects run.

Baker Bay (Area IV)

Millepora dominates a coral assemblage growing on various pieces of ship wreckage and on the margin of Able Dock in the southwest part of Baker Bay (Transect H). A rather sparse coral community is present in the southeast part of the bay (Transect I), and is dominated by *Pocillopora*, *Porites*, and *Millepora*. The alga *Halimeda macroloba* is abundant. The more coral-rich southwest portion supports a more diverse and numerous fish assemblage.

Cement Facing of A Dock and Iron Pilings (Area V)

Transects J and K were both run in February and again in April. Again, because of the poor visibility in February, the later survey recorded more species in greater abundance. A total of 42 species of fish were observed along the iron pilings during the course of the two surveys, making it the most species-rich area censused.

Unai Sadog Tase (Area VI)

Transect L ran around the perimeter of the wrecked barge located near shore. A moderate diversity of fishes was found here. Transects M and N traversed the northeast part of this bay where the water was 2 to 4 meters in depth. Pomacentrids dominated the fish fauna in this area, particularly those species associated with coral heads: *Chromis caerulea*, *Dascyllus aruanus*, *Pomacentrus pavo*, and *Pomacentrus* sp. A. Many small *Chromis* (enumerated as *C. caerulea* but possibly *C. atripectoralis*) were also seen in small "swarms" in grooves and crevices in the substrate.

Discussion

The fish surveys reported here should provide sufficient baseline information on the fish communities in Tanapag Harbor so that any significant future changes in the species composition and abundance of fishes can be assessed. There are undoubtedly a considerable number of fish species which occur in Tanapag Harbor which were not observed during this study, particularly roving predators such as jacks (Carangidae), snappers (Lutjanidae), and goatfishes (Mullidae), seasonally abundant fishes, such as rabbitfishes

(Siganidae), nocturnally active fishes, such as squirrelfishes (Holocentridae) and cardinal fishes (Apogonidae), and cryptic or secretive fishes (Gobiidae, Blenniidae, Scorpaenidae, and various eels). The fishes which are best represented in these surveys are those fishes most closely tied to specific defended territories or limited home ranges. It is these species, by the consistency in their occurrence, which make the best indicators of changing water quality. Sharp declines in diversity or abundance of these fishes could well be a sign of deteriorating environmental conditions.

Table 11.1. Checklist of fishes observed in Tanapag Harbor, Saipan. For area and transect location see text. Series (1) = February 6-8, 1976; Series (2) = April 14-16, 1976; Series (3) = June 11-13, 1976.

Area	I	II			III					IV		V				VI		
Transect	A	B	C	D	E	E	F	F	G	H	I	J	J	K	K	L	M	N
Series	(1)	(3)	(1)	(1)	(1)	(3)	(1)	(3)	(3)	(3)	(3)	(1)	(2)	(1)	(2)	(2)	(1)	(1)
Transect Length (m)	140	155	50	32	40	50	60	60	--	110	100	260	260	85	85	95	86	80
Acanthuridae																		
Acanthurus achilles Shaw						1												
A. glaucopareius Cuvier		4				3												
A. lineatus (Linnaeus)		2				1									3			
A. mata (Cuvier & Valenciennes)									6		4	3	29		12	9		
A. nigrofuscus Forskal		6			1	1		3			1		18	1	9	8		
A. triostegus (Linnaeus)		4																
A. xanthopterus Cuvier & Valenciennes		5				10	6				2	9	27			4		
Ctenochaetus striatus (Quoy & Gaimard)		14		2	10	6	5	1				2	17			3		8
Naso literatus Bloch & Schneider					2								5		4			
Zebrasoma flavescens (Bennett)		4		1		8				1			1		7			
Z. veliferum (Bloch)		2				1											2	
unidentified acanthurids																		
Apogonidae																		
Apogon aroubiensis Hombron & Jacquinot													12			17		
Paramia sp.																	2	
Aulostomidae																		
Aulostomus chinensis (Linnaeus)		3						2	2									
Balistidae																		
Rhinecanthus aculeatus Linnaeus													2			1	1	
Blenniidae																		
Meiacanthus atrodorsalis (Gunther)													26					
unidentified blenniid													3					
Canthigasteridae																		
Canthigaster solandri (Richardson)	23	8		2	6	4	4	1			1	2	13	4	10	7	4	2

Table 11.1. (Continued)

Area	I	II			III					IV		V				VI		
Transect	A	B	C	D	E	E	F	F	G	H	I	J	J	K	K	L	M	N
Series	(1)	(3)	(1)	(1)	(1)	(3)	(1)	(3)	(3)	(3)	(3)	(1)	(2)	(1)	(2)	(2)	(1)	(1)
Transect Length (m)	140	155	50	32	40	50	60	60	--	110	100	260	260	85	85	95	86	80
Carangidae																		
Caranx sp.															6			
Chaetodontidae																		
Chaetodon auriga Forskal		2		1		2				2	1	3	20		1			3
C. bennetti Cuvier												3	11					
C. citrinellus Cuvier		1																
C. ephippium Cuvier						2					1		16		1	5		
C. lunula (Lacepede)		2			4	1	1		1		1	7	28			3		
C. ornatissimus Cuvier & Valenciennes		2				1							8					
C. trifasciatus Mungo Park		6		1	3	8				7		4	10		7		1	
C. ulietensis Cuvier		3										3	30		1			
Heniochus acuminatus (Linnaeus)													12					
H. chrysostomus Cuvier													21					
Eleotridae																		
Ptereleotris c.f. *microlepis* Bleeker																		3
Fistulariidae																		
Fistularia petimba Lacepede								1										
Gobiidae																		
Amblygobius phalaena (Valenciennes)													9			6		
Holocentridae																		
Adioryx spinifer (Forskal)													21					
Adioryx sp.										2								
Flammeo sp.					1			1		2			18			3		
Myripristis sp.										2								

Table 11.1. (Continued)

Area	I	II			III					IV		V				VI		
Transect	A	B	C	D	E	E	F	F	G	H	I	J	J	K	K	L	M	N
Series	(1)	(3)	(1)	(1)	(1)	(3)	(1)	(3)	(3)	(3)	(3)	(1)	(2)	(1)	(2)	(2)	(1)	(1)
Transect Length (m)	140	155	50	32	40	50	60	60	--	110	100	260	260	85	85	95	86	80
Labridae																		
Cheilinus sp.														1			1	
Gomphosus varius Lacepede										1		4			3			
Halichoeres trimaculatus (Quoy & Gaimard)						3		1		1						14		3
Hemigymnus melapterus (Bloch)						1									3			
Labroides dimidiatus (Cuvier & Valenciennes)		7		1		2				2	2		15		2			2
Stethojulis bandanensis (Bleeker)														1	2	7	3	
Thalassoma hardwicki (Bennett)													5		4	5		
juvenile labrids	2				1							1		1			3	
Lutjanidae																		
Macolor niger (Forskal)						2							1					
Lutjanus fulviflamma (Forskal)													10					
L. monostigmus (Cuvier & Valenciennes)																5		
L. vaigiensis (Quoy & Gaimard)													11			11		
Monacanthidae																		
Oxymonacanthus longirostris (Bloch & Schneider)										1								
Mugilidae																		
unidentified mugilid																32		
Mullidae																		
Mulloidechthys auriflamma (Forskal)													6			6		
Parupeneus cyclostomus (Lacepede)				1														
Parupeneus sp.		8				9				2	1							

Table 11.1. (Continued)

Area	I	II			III					IV		V				VI		
Transect	A	B	C	D	E	E	F	F	G	H	I	J	J	K	K	L	M	N
Series	(1)	(3)	(1)	(1)	(1)	(3)	(1)	(3)	(3)	(3)	(3)	(1)	(2)	(1)	(2)	(2)	(1)	(1)
Transect Length (m)	140	155	50	32	40	50	60	60	--	110	100	260	260	85	85	95	86	80
Pomacentridae																		
Abudefduf coelestinus (Cuvier)		5				11			40	1	2	4				21		2
A. septemfasciatus (Cuvier & Valenciennes)						1							6		4	8		
A. sordidus (Forskal)		3				3			1	1			5		7	6		
Chromis atripectoralis Welander & Schultz						3												
C. caerulea (Cuvier)		39		70		240				210	65	1500	500+		100+		65	30
Dascyllus aruanus (Linnaeus)	2	84	4	44	8	74		8		45	76	349	200+		3		19	211
Eupomacentrus albifasciatus (Schlegel & Muller)					1		1						4					
E. lividus (Bloch & Schneider)		1				8		3		5							5	1
E. nigricans (Lacepede)			8		1	1												
Glyphidodontops leucupomus (Lesson)													20				2	
Plectroglyphidodon leucozona (Bleeker)		2				2	1	1			2					7	1	
Pomacentrus pavo (Bloch)		2				9			1		5	54	23		2			25
Pomacentrus sp. A		1		3	1	4		1					6	2				14
Pomacentrus sp. B		5																
Scaridae																		
Scarus sordidus Forskal (juvenile)		4								1	1		1		8		1	
Other juvenile scarids						1					1						2	
Siganidae																		
Siganus argenteus (Quoy & Gaimard)								8		100								
Syngnathidae																		
Corythoichthys intestinalis (Jordan & Seale)		2																

Table 11.1. (continued)

Area	I	II			III					IV		V				VI		
Transect	A	B	C	D	E	E	F	F	G	H	I	J	J	K	K	L	M	N
Series	(1)	(3)	(1)	(1)	(1)	(3)	(1)	(3)	(3)	(3)	(3)	(1)	(2)	(1)	(2)	(2)	(1)	(1)
Transect Length (m)	140	155	50	32	40	50	60	60	--	110	100	260	260	85	85	95	86	80
Synodontidae																		
unidentified synodontid											1							
Zanclidae																		
Zanclus cornutus (Linnaeus)	1	10				3		1	1		1		18		3	3		
Total Fish	30	237	12	126	39	426	18	32	52	382	174	1948	1188+	10	208+	185	112	304
Total Density (n/m^2)	.11	.76	.12	1.97	.49	4.26	.15	.27	--	1.74	.87	3.75	2.28+	.06	1.22+	.97	.65	1.90
Total Species	5	28	2	10	12	32	6	13	6	16	21	15	39	6	24	22	15	12

Fig. 11.1. R. M. Ross making fish census in extreme southern corner of Charlie Bay. Object under left ankle appears to be a 500 lb bomb.

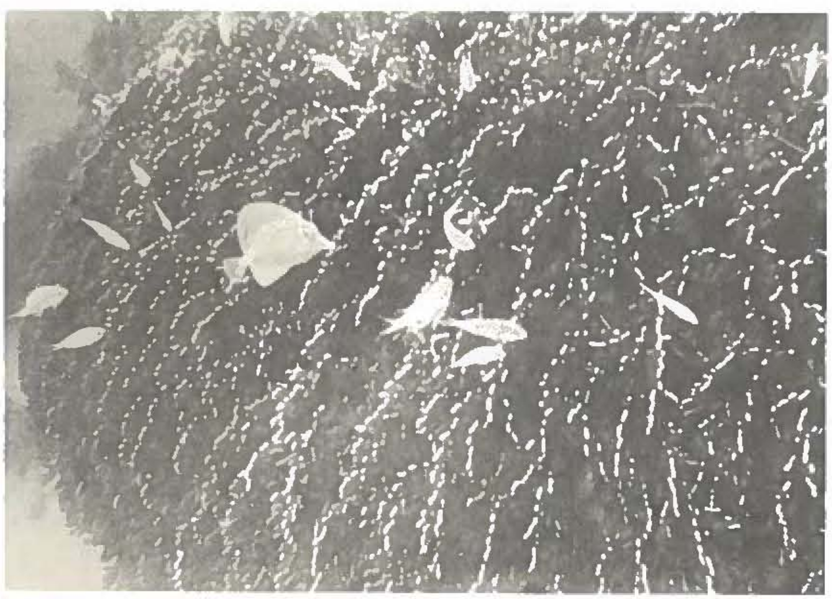


Fig. 11.2. Zebrasoma flavescens and Chromis sp. around Millepora dichotoma colony off end of Baker Dock.

12. SUMMARY

By

JAMES E. DOTY

A survey was made during six three-day periods from February to June 1976 to collect basic environmental data in Tanapag Harbor, Saipan. The data were collected in order to make an assessment of whether operation of the power barge "Impedance" is likely to cause significant alterations in the marine environment. Site preparation, including dredging of the mooring area, and operation of the power plant had begun prior to the start of the survey.

Tanapag Harbor is located at 15°14' North Latitude and 145°43' East Longitude on the western shore of Saipan in the Mariana Islands. The harbor consists of a 160-hectare basin, 10-15 meters deep, dredged within a 1300-ha lagoon area behind a barrier reef. The shore of the harbor is fringed by shallow reef flats which end abruptly in a steep dredge face. Wreckage, primarily dating from World War II and shortly thereafter, provides a major substratum on the shallow flats. Several land-fill piers have been constructed across the flats to the edge of the dredged basin, thus subdividing the shoreline into several small embayments.

A superficial examination of the sediments in embayments reveal them to be primarily limestone sands of marine origin with some terrigenous material. Anthracite, presumedly spilled from ships, and iron fragments are also common. The bottom in Baker Bay, where the "Impedance" is moored, and in the dredged harbor basin is covered with fine silt.

Surface currents in the harbor generally flow in the direction of the winds. Surface water from the Baker Dock area generally moves towards the mouth of the Harbor. Deeper currents move generally in the same direction as surface currents but are slower. Water motion within 10 m of the bow of the barge is generally influenced by the cooling water outfalls. Bottom water in this area moves toward the outfalls of the barge from the harbor and toward the intakes from the outfalls.

A region of elevated water temperature has been produced along the entire southwestern side of Baker Dock. Temperatures in this area range from 29 to 30°C, or 1-2° above ambient (outer harbor) temperatures. Temperatures also tend to be slightly higher in Baker Bay than in Charlie Bay. No evidence of thermal influence from the power barge was found north of Baker Dock or south of Able Dock.

Chemical analyses of harbor water samples from various locations indicate that dissolved oxygen levels are generally high throughout the area. Nitrite and phosphate levels are generally what could be expected of unpolluted waters except for elevated levels at a sewer outfall near Echo Dock. Nitrate levels are higher in lower-salinity waters and probably reflect land-derived input into the marine environment. Neither salinity variations nor nutrient levels were observed to reflect a tidal influence.

The effects on marine plants in the immediate vicinity of the power barge appear to be minimal. The only noticeable change in the marine flora occurring during the study was on the southwestern side of Baker Dock, where there was a shift in relative abundance of different species. This may reflect natural seasonality changes or power barge influence; if the latter is the case it is likely to continue in the future.

Coral abundance and diversity in the harbor in general is similar to that on lagoon fringing reefs studied throughout Micronesia. The presence of iron scrap enhances coral development in many areas of the harbor. Coral development was abnormally reduced in Baker Bay due to recent disturbances, primarily dredging. Because the predominant species of coral (*Pocillopora damicornis*, *Porites lutea* and *Millepora dichotoma*) have differing thermal sensitivities, elevation of water temperatures above 31°C would probably produce significant changes in the biota in the area.

Benthic invertebrate assemblages were studied in six areas. The only species occurring in all areas studied was the gastropod mollusc *Lambis lambis*. Other common organisms were the gastropod *Cypraea erosa*, the bivalve *Saxostrea mordax*, the echinoid *Mespilia globulus*, and the holothurian *Holothuria atra*. The greatest diversity was found from Able Dock to Unai Sadog Tase. Baker Bay and deeper parts of Charlie Bay both were similarly poor in invertebrate fauna but the shoal areas in Charlie Bay were relatively richer. Molluscs and echinoderms were found more frequently with distance away from the dredged area around the power barge. Shifting fine sediments and turbid water resulting from the dredging probably inhibit colonization of Baker Bay by most macroinvertebrates.

Zooplankton abundance in both shallow and deep areas in the harbor is high and indicates that plankton feeding may be an important niche in Tanapag Harbor marine communities. Sharp differences between the composition of samples taken from shallow and deep harbor areas suggests that there may be relatively slow mixing of these waters. The shallow harbor waters contained fewer larval stages of fishes and crustaceans than the deeper harbor waters.

More than 5000 fishes of some 75 species were counted in the area. The damselfishes (Pomacentridae) were the most abundant group, with the two species Chromis caerulea and Dascyllus aruanus accounting for approximately 50% and 20%, respectively, of the number of fishes seen. The sharp-backed puffer, Canthigaster solandri (Canthigasteridae), was the most ubiquitous fish. The surgeonfish Ctenochaetus striatus (Acanthuridae) was also frequently seen.

Minor fish kills (i.e., scattered individuals) were observed in the region between the power barge and Baker Dock. These apparently resulted from air embolisms, or the ingestion of microscopic air bubbles caused by lowered solubility of contained gases in water which was heated by the barge.

Tanapag Harbor, in general, was found to contain a significant abundance and diversity of marine life which has been inhibited in localized areas due to recent disturbances. The present impact of the power barge is limited to the southwestern side of Baker Dock and the northern half of the shoreline of Baker Bay. Most of this impact is due to past dredging although some thermal influence is now being exerted.

13. CONCLUSIONS AND RECOMMENDATIONS

By

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

This study focused on the power barge "Impedance" and its impact on the marine environment in Tanapag Harbor. However, it also included a number of more general considerations related to planning and development of the harbor area. We have carried out a reconnaissance survey of most of the shallow-water areas of the harbor. This provides baseline information against which conditions may be compared at some future time. Observations have been presented in the preceding chapters; this chapter presents conclusions related to the power barge specifically and the shallow, near-shore areas of the harbor generally.

The Power Barge and Related Activities

Impact

Thermal impact of the barge has been relatively light so far and is likely to remain so. We observed a maximum temperature increase between intake and outfall temperatures for turbine condenser cooling water of 2.2°C and a minimum increase of 1.2°; most values were less than 2°. Data from a maximum/minimum recording thermometer in the outfall plume indicated a high of 33°C on one occasion during our study period, but we think that such a peak temperature was rather unusual during this time. Our calculations and design specifications for the barge suggest that the maximum temperature increase if the barge reaches full generating capacity (30 MW) will be at least 5.2°C. This could raise prevailing temperatures in the immediate vicinity of the barge outfalls from the present level of approximately 30° to a new level of about 33°. Sustained temperatures at the higher level could be of concern on biological grounds if they impinged on bottom communities dominated by corals, since temperatures above 30 or 31° can adversely affect some coral species. However, the thermal effluent does not presently impinge on a coral community and is not likely to do so, and the highest temperatures will continue to be confined to the immediate vicinity of the barge. These considerations are the basis for our optimistic conclusion regarding the thermal impact of the "Impedance."

Thermal effects are not likely to extend further than 400 m from the barge, and we expect that an area of less than 40 ha would be affected under worst conditions. Most of this area would be represented by a layer of less dense warmer water overlying deeper, cooler water and would not result in an impingement of heated water onto a coral community. Corals at the end of Baker Dock might be subjected to occasional pulses of heated water, but this should be only a short-term phenomenon and not lethal to the corals. Worst-case conditions would entail retention of heated water in Baker Bay and the inhibition or elimination of some coral species in a narrow band along the southeastern shoreline. Since the predominant species here, *Pocillopora damicornis*, is more heat-sensitive than many other corals, it could be eliminated. In this worst case, *Pocillopora* might or might not be replaced by other less sensitive coral species. Coral loss would in turn lead to a decrease in the population of damselfish associated with the corals. This would be unlikely to affect human fishing in the area, since most of the fish being caught are herbivorous or planktivorous. Again, we do not consider this worst-case projection to be very likely.

Dredging next to Baker Dock preparatory to mooring the "Impedance" has probably produced the most significant impact so far. It is difficult for us to document this statement, however, since we did not see the area before the dredging. Silt, presumably created by the dredging, remains in the area and will probably be a problem for some time to come, as it is being continually resuspended. This inhibits new colonization of corals in the bottom of Baker Bay because of reduced light penetration in the water column, lack of stable substratum for larval settlement, and probable smothering of any coral larvae which do manage to settle. Water exchange may eventually remove some of the silt from Baker Bay.

There is continual mechanical disturbance of the bottom of Baker Bay and resuspension of fine sediments by the mooring lines (chains and cables) which extend from the barge to Able Dock, since swell-induced movement of the power barge leads to movement of the mooring lines. The total disturbed area caused by the chains and cables maybe as great as the disturbed area created by dredging activities and actual placement of the barge itself. This mechanical disturbance of the bottom of Baker Bay could inhibit development of biological communities there except for colonization by some burrowing organisms and some settlement of organisms on the mooring lines themselves where they stretch above the bottom.

Oil spills are probably the biggest threat to the harbor at this time. Fuel oil is off-loaded from barges at Charlie Dock and stored at the Mobil Oil facility near Baker Dock. Fuel oil is provided to the power barge through a flexible hose suspended between the barge and the dock. There are no containment dikes around the fuel storage tanks. Oil spills at Charlie Dock, the Mobil facility, or Baker Dock are almost inevitable. Our observations of the response to a spill at Charlie Dock show that there is insufficient ability to respond with either speed or adequacy. A major oil spill could reach the resort area at Micro Beach, with disastrous financial results, and would almost certainly cause significant environmental damage.

The disposal of litter from the barge into Baker Bay is presently a minor problem but one which could become more serious. We saw only occasional pieces of litter on the bottom, but a gradual accumulation could eventually cause the area to resemble a dump. Some of this litter was not discarded directly from the barge but was blown in from the garbage disposal area on Baker Dock.

Recommendations

Maximizing water circulation is the key to minimizing the effects of thermal pollution. Any alternations in the power barge's immediate surroundings which reduce water circulation will probably increase the thermal effects of the barge. Therefore, if a breakwater is to be constructed at the end of Baker Dock, we recommend that it be of a floating design (e.g., suspended tires). If a design calling for concrete or coral fill is chosen, we recommend that large blocks or boulders be used and that culverts be placed through the structure. The large blocks would provide substantial sustratum for coral growth and attract other desirable marine life. Fish habitat could be increased by stacking the blocks in an irregular fashion, leaving nooks and crannies, rather than making a smooth facing. The culverts would allow water exchange between Baker Bay and the cooler harbor waters.

Regardless of whether or not Baker Dock is extended or a floating breakwater built, we recommend installing a culvert through Baker Dock near the barge intake. This would allow movement of water from Charlie Bay into Baker Bay and thus provide cooler water (approximately 0.5°C cooler) at the intake and would encourage movement of the barge effluent seaward. Another benefit would be providing a source of propagules for the establishment and maintainance in Baker Bay of a benthic community which more closely approximates a natural condition. Finally, increased water circulation in Baker Bay would help clear out fine suspended materials and improve water quality.

Oil lines should be inspected routinely and flexible sections replaced when worn. Oil containment booms should be placed between the "Impedance" and Baker Dock to isolate the area below the fuel oil line. Other oil containment booms should be kept close at hand; the present storage site on the shore of Baker Bay is a good one. There should be an adequate length of boom (at least 400 m) so that spills can, in fact, be contained. Containment dikes should be constructed around all storage tanks. Contingency plans should be developed for handling oil spills on Charlie Dock, along the shoreline, and wherever else large amounts of fuel are handled. Fuel in drums should be stored in areas that are diked or can quickly be diked. In the latter case, an emergency supply of sand or gravel should be located in a place where it could be quickly used for temporary dikes if needed. Practice alerts should be organized to improve response time to spills.

Careful records should be kept of intake and outfall temperatures and pumping rates. Instruments for maintaining these records should be kept in good repair and a supply of replacement parts stockpiled to minimize interruptions in the record.

The starboard fresh-water cooling discharge (machinery discharge) should not be used, as this adds heat to a region that already has heavy thermal loading. If this discharge must be used, but timing is elective, operation should occur during low heat periods (late night or early morning or during rainy weather).

Trash should not be discarded from the deck or ports of the power barge. Proper garbage containers should be placed on Baker and Charlie Docks and their use required for waste disposal by all personnel. The garbage containers should have tight-fitting lids and should not be susceptible to tipping over.

General Harbor Usage

Tanapag Harbor has undergone extensive disturbance and modification in the past, yet it retains a high environmental quality. One aspect of this is the fact that sunken barges and other metal debris in shallow waters form large pieces of stable substratum which support extensive coral growth. A 1949 aerial photograph (Cloud, 1959; cited in Chapter 8) shows that many of these pieces have been in place for at least 27 years. These artificial reefs, besides enhancing coral establishment, provide diverse physical habitat for fish and other organisms. The stable substratum thus provided counteracts somewhat the physical disturbances caused by other human activities, especially the creation of silt bottoms by dredging.

There is a need to identify a site for a permanent power plant for Saipan. One consideration is that the site choice should require a minimum of environmental disturbance. We understand that one possible area is near the old seaplane ramps at Puntan Flores. This site appears reasonable from an environmental standpoint and is probably preferable to any shoreline site adjoining the lagoon and most other sites in the harbor. Water circulation in the area is good, and waste heat from the power plant would be rapidly dispersed. If the outfall is properly located, the heated water from the condensers could be readily directed to the deeper part of the harbor and then allowed to rise and spread out as a less dense surface lens. Prevailing winds would carry this lens away from shoreline most of the time, and no heat load would be imposed on natural shoreline or bottom communities. The intake pipe, as well as the outfall, could be extended to the dredge margin at the edge of the deeper harbor, thus allowing cooler water to enter the plant than would be the case if the intake were located in shallow water subject to solar heating. This would increase the condenser efficiency and minimize the thermal load on the environment. A detailed study of currents at the particular location chosen for an outfall would be advisable.

Another important consideration in locating a power plant at Puntan Flores would be the question of air pollution. The site is upwind of the new hotel area, although removed by a considerable distance; and noxious fumes might be directed toward popular recreational and tourist attractions under certain wind conditions. However, it is reasonable to expect that this problem could be minimized; and Puntan Flores is as removed from the hotels as any harbor site can be. In addition, if the seaplane ramps are blocked from public access, alternate boat-launching facilities should be provided.

The sewer outfall located near Charlie Dock does not presently appear to have a major environmental impact, although this issue was not examined in detail in our study. The outfall is well removed from recreational and tourist areas and has a relatively small daily outflow. There appears to be rapid dispersal of the effluent. If a permanent outfall must be located somewhere in the harbor, the present location is probably as good as any. However, extension of the existing pipe further into the deeper waters of the harbor would be desirable. This would release the effluent further from shore and minimize the possibility of it washing back into shallow waters before mixing. Our observation of movement of the oil spilled at Charlie Dock indicates seaward-flowing currents on the surface under prevailing wind conditions.

An important point about the existing outfall is that it cannot be expanded indefinitely. Once a permanent commitment is made to this site, the temptation will be great to simply expand the flow rate as dictated by engineering considerations or other factors. However, there is a limit (unknown at this time) as to how much effluent can be assimilated by the harbor waters before public health and environmental problems are created. There could be a cautious expansion of the present outfall if necessary, along with extension of the pipe into deeper water; but plans for indefinite expansion should be avoided.

The small sewage outfall at Echo Dock is a health hazard and a nuisance. The connection for this outfall should be investigated and shut down, with the effluent being directed to the main sewer line.

Our study included short-term observations of wind and weather conditions. To enhance planning and future feasibility studies of various sorts, a weather station should be established somewhere in the harbor area to record long-term trends. Observations on wind, rainfall, water and air temperatures, and tides should be made as a minimum effort.

Unai Sadog Tase and adjacent waters constitute a particularly impressive recreational resource area. Local fishermen were often seen here during our study. There is a variety of shallow-water marine habitats such as seagrass beds and coral communities which are attractive for snorkelers. The area holds a particular advantage for snorkelers who are not strong swimmers and need the psychological security of shallow water but want to see a greater diversity of habitats and organisms than can be seen at the sandy areas immediately in front of the hotels. The horseshoe-shaped channel between Unai Sadog Tase and Micro Beach is suitable as a small-boat shelter and launching site and may be suitable for development of a marina. Such a marina would be readily accessible to local people and visitors and would be sufficiently removed from commercial harbor traffic at Charlie Dock and other incompatible operations such as a power plant and sewage treatment plant. Sailing and water skiing areas seaward of Unai Sadog Tase and Micro Beach would be readily accessible from the marina. The shallow area extending seaward of Unai Sadog Tase is apparently the best example of a lagoon fringing reef left on the island and might be considered for a conservation area incorporating a cross section of marine habitats.

One unadvisable shoreline use is the garbage dump between Able Dock and Unai Sadog Tase. This has serious implications for land, water, and air quality. Fumes from burning at the dump are often carried toward Micro Beach, and some floating garbage is carried away from the site. We understand that an alternate site for the dump is being sought; this should be located and developed as soon as possible.

We occasionally noted old ordnance, apparently dating from World War II, at scattered points. A careful search and clean-up operation would be advisable, although ordnance is likely to continue turning up from time to time.

Saipan is in a unique position for developing an overall plan for the harbor and nearby areas before uncontrolled growth and development lock specific sites into specific usages and create new and irreversible environmental problems. Careful planning can minimize negative aspects of development and possibly result in the enhancement of environmental quality in some cases. It can help resolve conflicts between different potential uses of specific areas and identify sites which are best suited for particular uses in the light of competing demands. Future military usage is a key element influencing planning. The more general issue of the desirable amount of growth and development and how the environment of Saipan can support this should also be considered. It is clear that social and political issues are involved as well as environmental and technical issues.

These thoughts and recommendations regarding general harbor usage and planning are by no means exhaustive and have environmental considerations as the main focus. We think these considerations must be taken into account but do not offer them as a substitute for overall local planning efforts. However, the physical and environmental constraints which set limits for healthy development should be examined, and there should be a realization that certain areas are naturally more suited for particular activities than other areas. We hope that this report will be useful in pointing out some of these considerations.

14. APPENDIX

FIELD GUIDE TO FISHES

OBSERVED AT TANAPAG HARBOR SURVEY SITES

By

STEVEN S. AMESBURY

This guide is designed to help the diver identify fishes underwater. The figures (1-37) are drawn to illustrate general body form and patterns of coloration and to emphasize certain field characteristics. They should not be considered definitive illustrations in that no attempt at precision in depicting various proportional measurements has been made. The numbers in parentheses refer to the illustrations at the end of this section.

ACANTHURIDAE-surgeonfishes

Acanthurus mata (1), *A. nigrofuscus* (2), *A. xanthopterus* (3), and *Ctenochaetus striatus* (4) all appear dark underwater. *A. mata* (1) and *A. xanthopterus* (3) have a white bar across the base of the tail, and *A. xanthopterus* (3) has thin blue lines along the dorsal and anal fins, and has yellow pectoral fins. On close inspection, thin dark horizontal lines can be observed along the sides of *C. striatus* (4). *A. nigrofuscus* (2) can be distinguished by the crescentic caudal fin, the spots on the face, and the two black spots, the larger one at the rear of the dorsal fin base and the smaller one at the rear of the anal fin base.

Zebrasoma flavescens (5) is easily recognized by the prolonged snout, the pure yellow pigmentation, and the white spine on the caudal peduncle.

Naso literatus (6) can be distinguished by the orange lines on the face, the yellow to red bands at the bases of the two caudal spines, and the tail streamers. The body color is dark brown to grey-blue.

APOGONIDAE-cardinalfishes

Paramia sp. (7) (possibly *P. quinquelineata*) is whitish with black, horizontal lines and a spot at the base of the tail.

BALISTIDAE-triggerfishes

Rhinecanthus aculeatus (15) is unique in its color pattern.

CANTHIGASTERIDAE-sharp-back puffers

Canthigaster solandri (16) is an attractive little fish whose body is almost entirely covered with dark-edged blue circles, this pattern even being present on the orange caudal fin.

CHAETODONTIDAE-butterflyfishes

Each of the five species observed, Chaetodon auriga (9), C. bennetti (10), C. lunula (11), C. trifasciatus (12), and C. ulietensis (13), has an easily recognized color pattern.

ELEOTRIDAE-sleepers

The Ptereleotris (23) observed (which seems to be P. microlepis) was a delicate shade of blue-green with no visible patterning. These fish often hover in midwater.

HOLOCENTRIDAE-squirrelfishes

Fishes of the genus Flammeo (8) are somewhat elongate with a large eye, a spine on the preopercle, and a pattern of alternating gold and black horizontal lines on the body. The upper sides are reddish.

LABRIDAE-wrasses

Cheilinus sp. (17) has a characteristic body shape and three large scales at the base of the tail.

Epibulus insidiator (18) comes in a variety of colors. The extraordinarily protrusible lower jaw identifies this species.

Gomphosus varius (19) may also come in several different colors and patterns, but the long, beak-like snout makes this fish readily identifiable.

Halichoeres trimaculatus (20) has an orange, or sometimes black, spot on the caudal peduncle. The pink "splash" radiating from the eye is more visible in larger individuals.

Labroides dimidiatus (21) is the familiar cleaner wrasse and is almost always found engaged in cleaning activities.

Stethojulis bandanensis (22 a & b) is sexually dichromatic. The females (and immatures) (22a) have a green or brown dorsal surface, sometimes a pink band below this, and a white belly. The adult male (22b) is green above and white below with a series of blue lines radiating from the eye and running along the body. The most distinctive feature of this species is the bright red patch above the pectoral fin present in both males and females.

LUTJANIDAE-snappers

The yellow body, black tail, and "snapper-like" shape distinguish Lutjanus vaigiensis (24).

MULLIDAE-goatfishes

The two goatfish species observed are both quite distinctive: Mulloidichthys auriflamma (26) has a yellow stripe down the side, and Parupeneus cyclostomus (27) is entirely yellow.

POMACENTRIDAE-damselfishes

Glyphidodontops leucopomus (28) is yellow with a blue line running across the upper sides, the posterior part of which surrounds a dark ocellus.

Plectroglyphidodon leucozona (29) is dark grey with a white, wedge-shaped bar down the side.

Abudefduf coelestinus (30) can be distinguished from other barred species of Abudefduf by the dark stripes along each lobe of the caudal fin.

Chromis caerulea (31) is bluish to greenish, often changing colors from one shade to another as it swims. This fish occurs very abundantly in swarms around coral heads. Another species, C. atripectoralis is almost identical, but has a small black mark at the base of the pectoral fin.

The black and white pattern of Dascyllus aruanus (32) makes it easily recognizable. This species also occurs in groups around coral heads, but generally in smaller numbers than does C. caerulea (31).

Eupomacentrus albifasciatus (33), E. lividus (34), and E. nigricans (35) are similar in habits and appearance. Members of these species are territorial and protect a small area around their living sites where certain species of algae are allowed to grow. Patches of algae in an otherwise closely grazed area of coral rubble or Acropora are indications of the presence of these fishes. E. nigricans (35) is completely dark and the black spot at the rear of the soft dorsal is often difficult to see. E. albifasciatus (33) is also dark but has a somewhat lighter vertical band across the sides. E. lividus is a lighter-colored fish and the dark area at the rear of the soft coral is generally visible.

Pomacentrus pavo (36) is bright blue with yellow on the rear of the soft dorsal and anal and a yellow caudal fin. The dark spot on the operculum is visible on examination.

The unidentified damselfish Pomacentrus sp. (37) is a dark blue, almost purplish color with a dark ocellus on the soft dorsal. The caudal fin is transparent.

SCARIDAE-parrotfishes

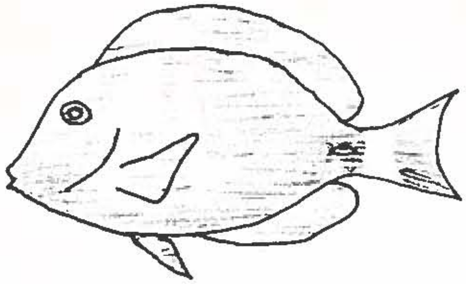
The general shape of the juvenile Scarus sordidus (25) is typical of all juvenile parrotfishes. S. sordidus is distinguished by a white caudal peduncle bearing a round dark spot.

SYNGNATHIDAE-pipefishes

The syngnathids are unmistakable, but identification to species, except for some bizarre forms, almost always requires capture of a specimen.

ZANCLIDAE-moorish idols

Zanclus cornutus (14) is easily identified by its shape and color pattern.



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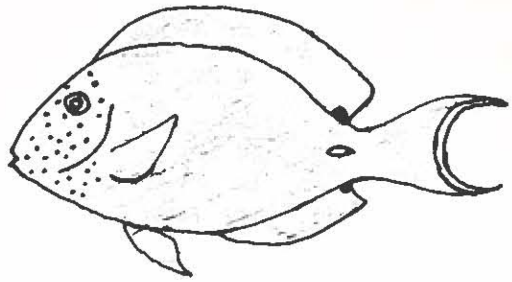

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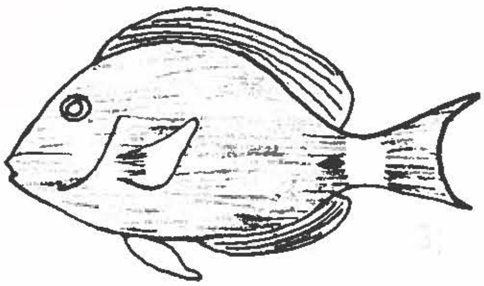

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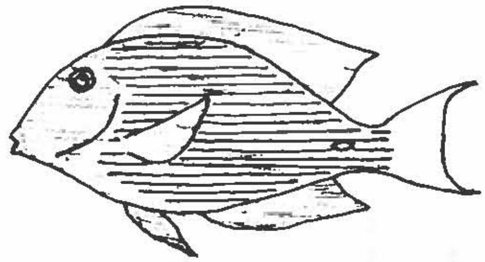

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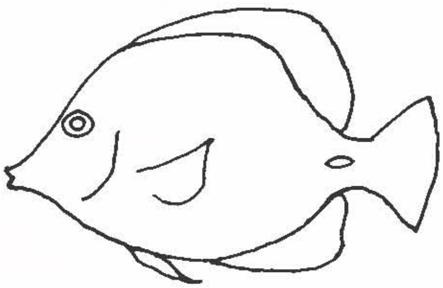

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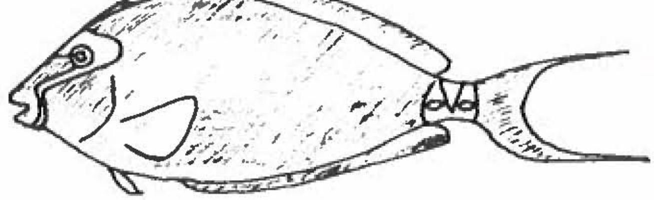

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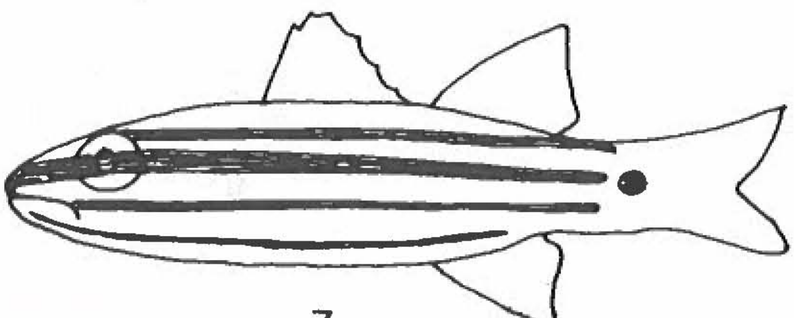

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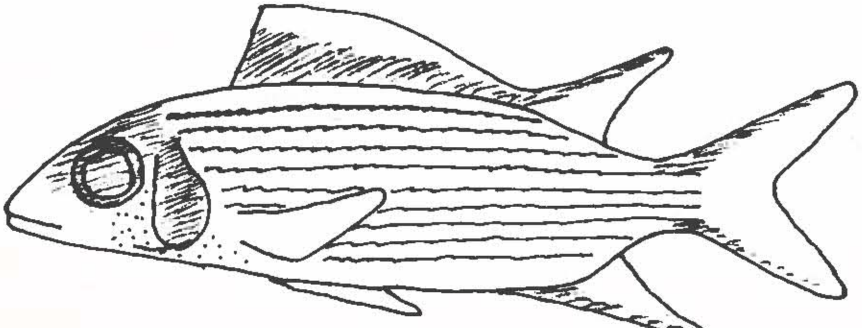

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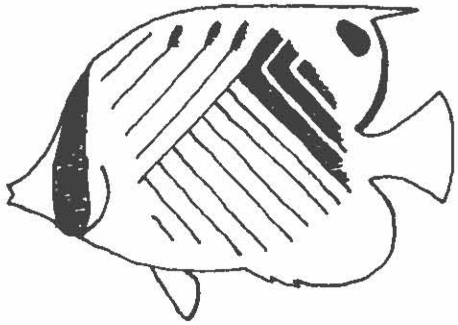

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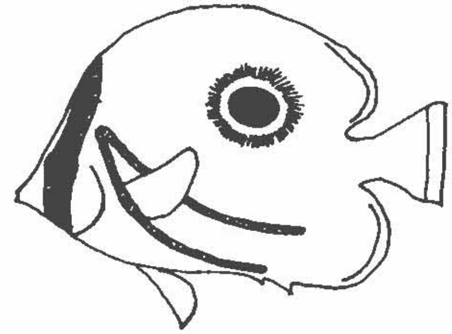

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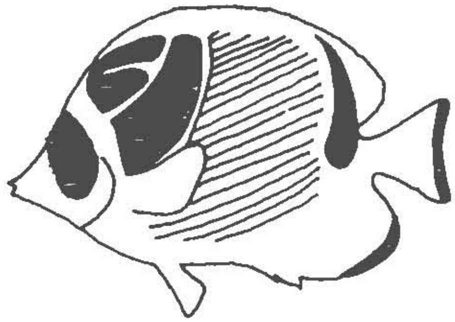

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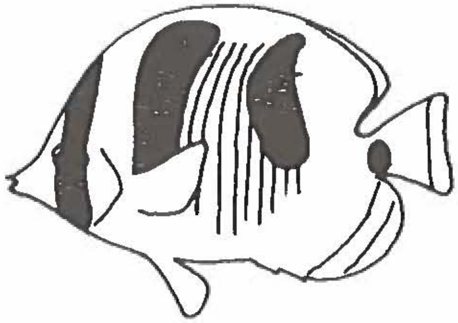

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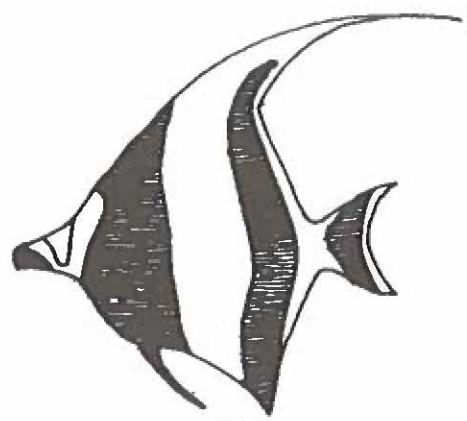

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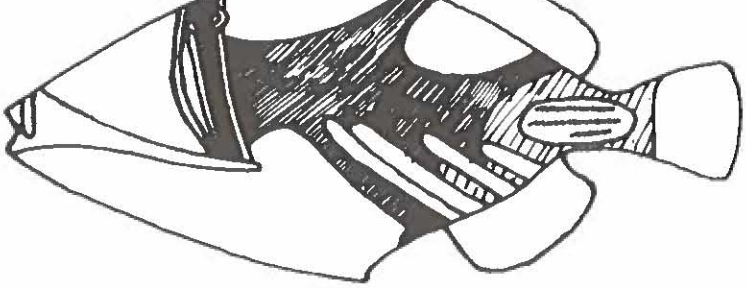

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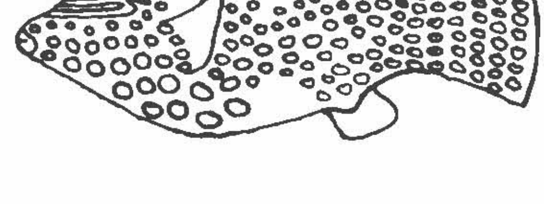

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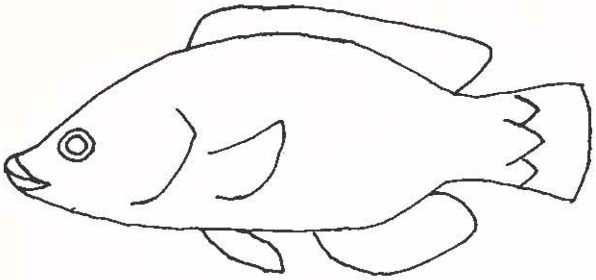

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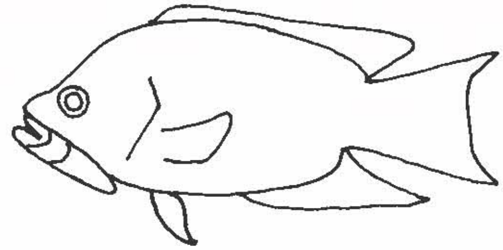

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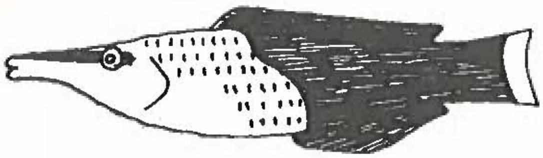

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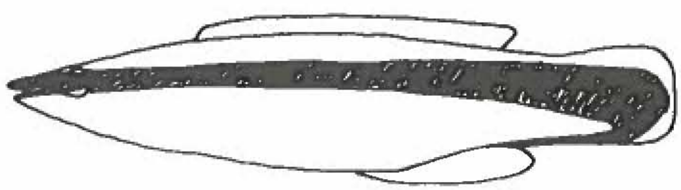

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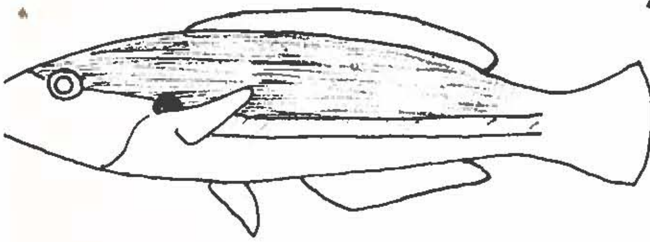

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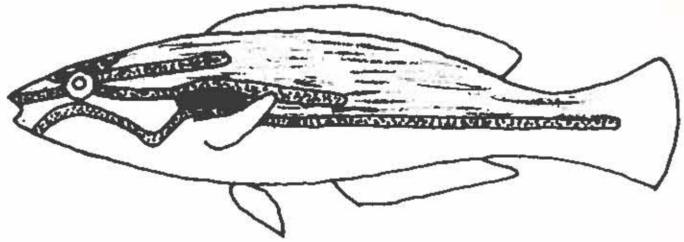

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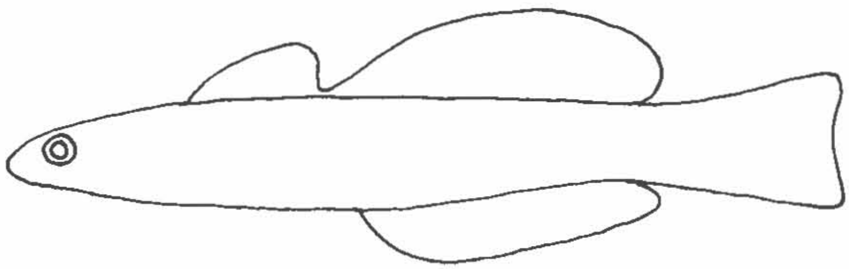

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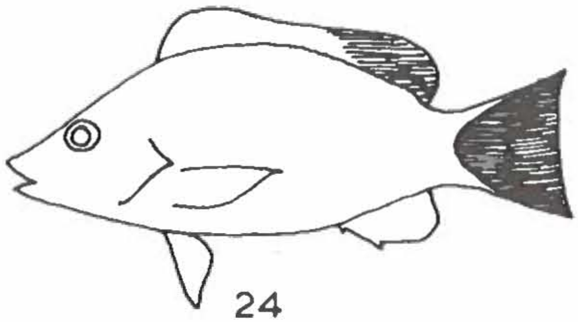

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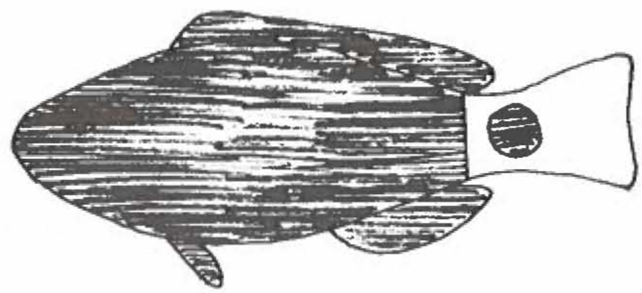

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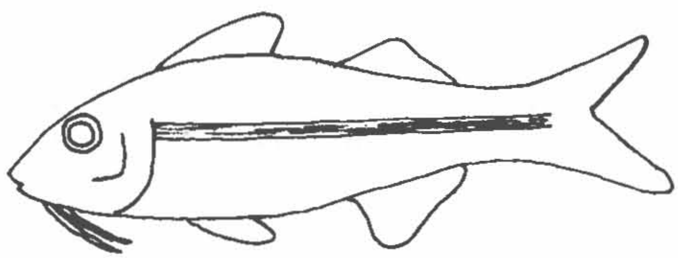

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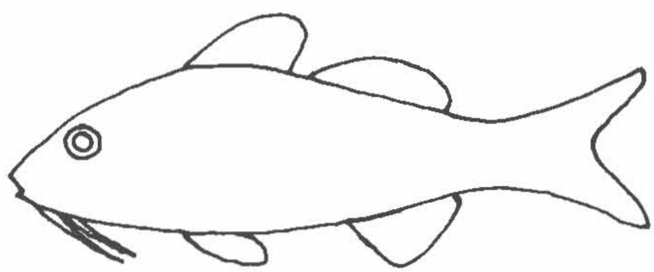

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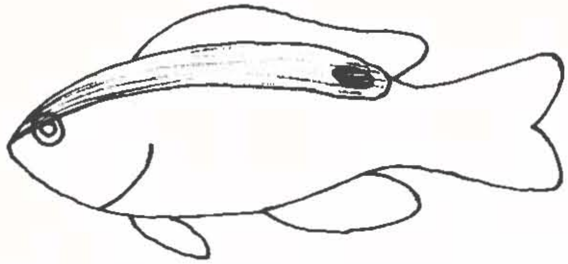
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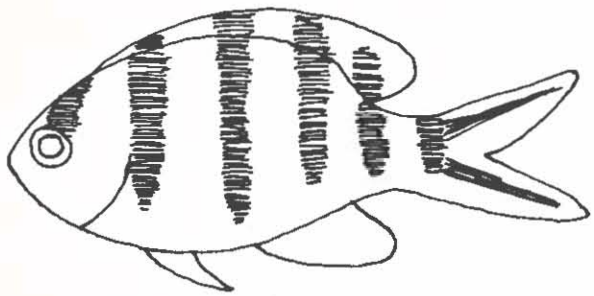
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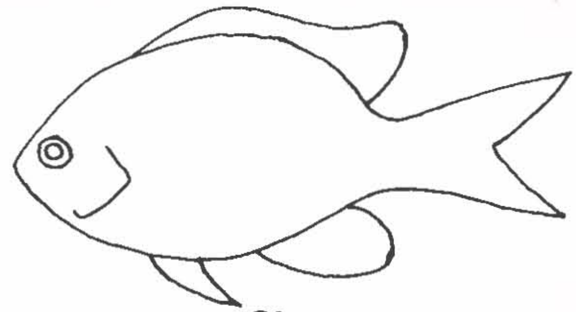
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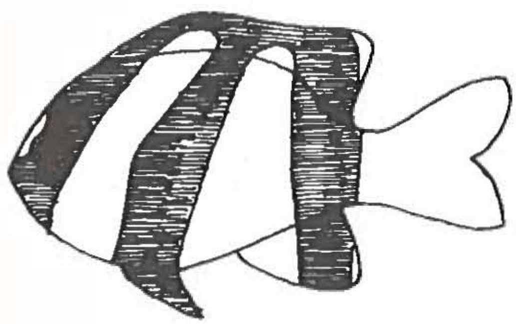
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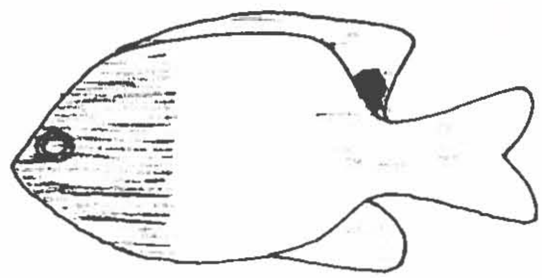
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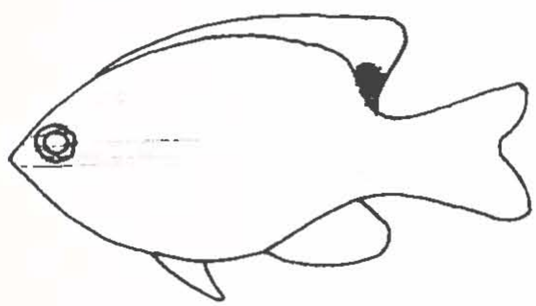
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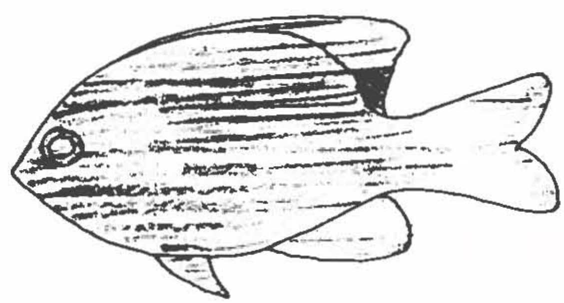
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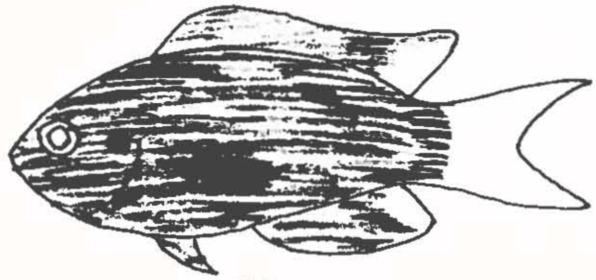
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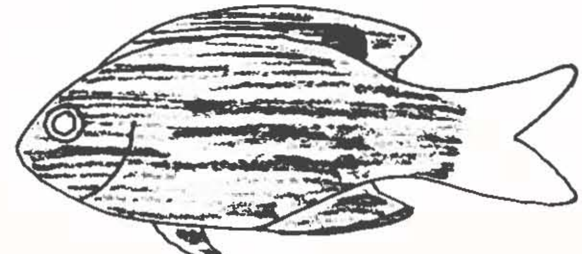
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