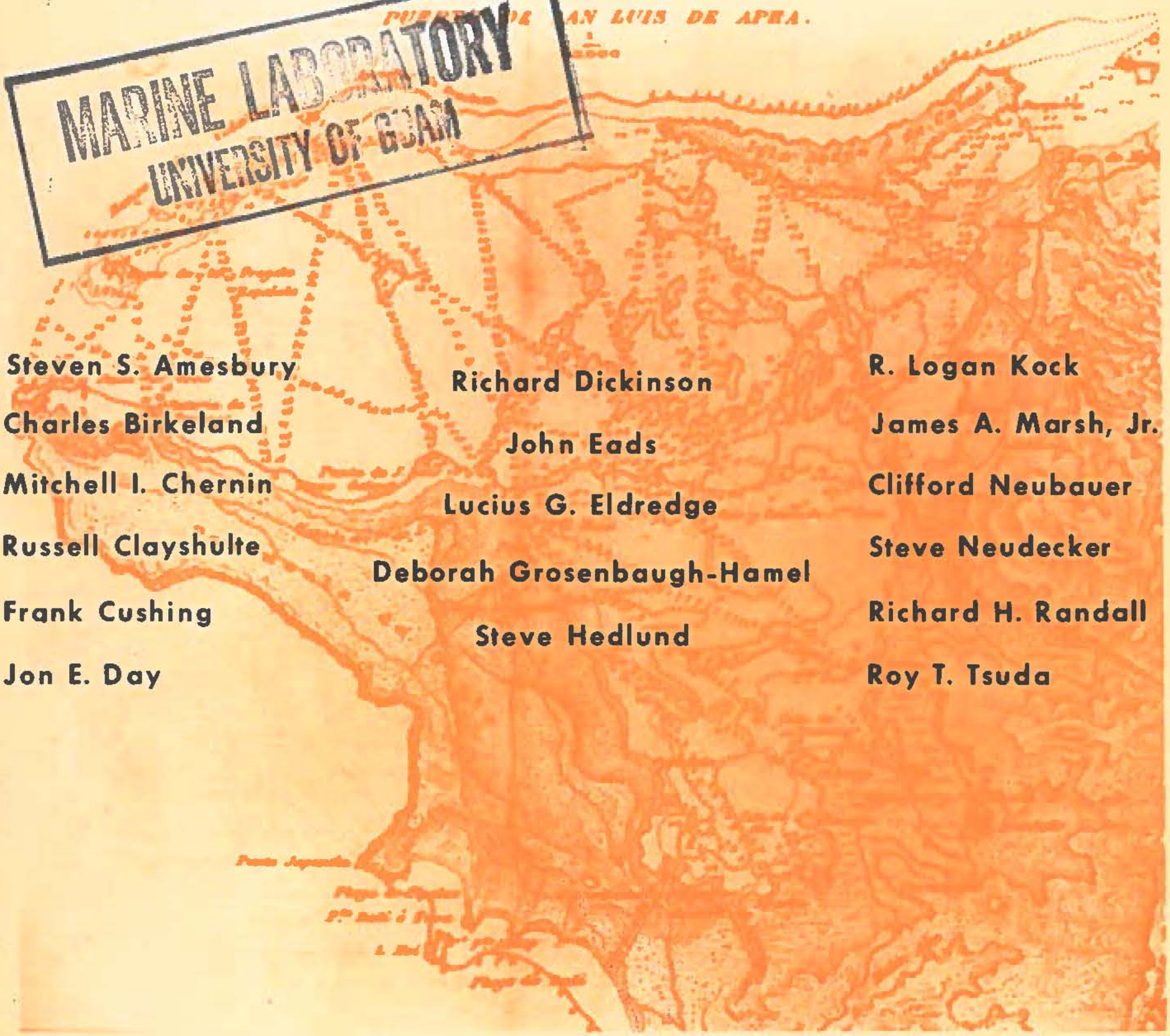
MARINE ENVIRONMENTAL BASELINE REPORT
COMMERCIAL PORT, APRA HARBOR, GUAM



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UNIVERSITY OF GUAM MARINE LABORATORY

Technical Report No. 34

April 1977

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APRA HARBOR, GUAM

The Marine Laboratory

University of Guam

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INTRODUCTION

This report presents the results of a marine environmental baseline study of Commercial Port, Apra Harbor, Guam for the U. S. Army Corps of Engineers. The purpose of this study is to provide data and general information on the local water current patterns, water chemistry, substratum composition, and the species composition, abundance and distribution of zooplankton, algae, corals, macroinvertebrates and fishes in the Commercial Port area of Apra Harbor. This information is planned for use by the Army Corps of Engineers in assessing the environmental impacts of each of several possible plans for improving the navigation and docking facilities of the Commercial Port area. Probable environmental effects will be one of the criteria used in the selection of the particular plan of improvement.

The University of Guam Marine Laboratory received the notice to proceed on this study on 9 December 1976. A rapid completion of a short-term project was called for and the field work was finished by 13 February 1977.

An extensive collection of data is available for the marine environment in Piti Channel through which a large portion of the water in the Commercial Port area enters. These data are presented in a series of five annual technical reports and summarized in Marsh and Doty (1976).

Scope of Work

In order to assess and compare the impact on the environment of alternative plans for improving on the navigation and docking facilities, the U. S. Army Corps of Engineers contracted the University of Guam Marine Laboratory to fulfill the following objectives:

1. Obtain baseline data on the marine environment in the Commercial Port area, Piti Channel, Jade Shoals and Sasa Bay at Apra Harbor; the data to include information on the current patterns, water chemistry, substratum sediment composition, zooplankton, benthic algae, corals, macroinvertebrates and fishes.

2. To identify the major marine ecosystems and any unique features of the local marine environment.

3. To evaluate and predict the environmental effects of increased sedimentation and other environmental modifications that may be caused by dredging, filling and land-clearing operations related to Commercial Port improvements.

More specifically, a comprehensive survey consisting of detailed current pattern studies, water chemistry analysis (including NO_2-N, NO_3-N, PO_4-P, O_2, salinity, turbidity, temperature and substratum composition studies and a quantitative sampling of the composition, abundance and distribution of zooplankton, benthic algae, corals, macroinvertebrates and fishes was to be conducted in Area A. A reconnaissance survey of substratum composition and qualitative information on species composition and distribution of the benthic algae, corals, macroinvertebrates and fishes was to be conducted in Area B.

Personnel

All personnel are from the Marine Laboratory of the University of Guam, either faculty, graduate students or marine technicians.

FACULTY

Steven S. Amesbury: Fishes, Plankton
Charles Birkeland: Macroinvertebrates
Lucius G. Eldredge: Gastropoda, Crustacea
James A. Marsh, Jr.: Study Coordinator
Richard H. Randall: Corals
Roy T. Tsuda: Algae

GRADUATE STUDENTS

Mitchell Chernin: Current studies
Russell Clayshulte: Sediment studies, current studies coordinator
Jon E. Day: Bivalvia
Richard "E" Dickinson: Mollusca
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Steven Hedlund: Current studies coordinator
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Steve Neudecker: Corals

MARINE TECHNICIANS

Frank A. Cushing: Boat operation
John E. Eads: Boat Operation

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DESCRIPTION OF THE SITES

Although the entire study area lies within the relatively protected environment of the barrier reef-lagoon system of Apra Harbor, considerable differences in benthic community structure and reef physiography are found from one part to another. Because of these differences, it is convenient to divide the study area into four regions (Fig. 1). The largest and most complex of these areas is Sasa Bay (referred to as Area B in the scopes of work) which is found at the east end of Apra Harbor between Dry Dock Point and POL Causeway to the north and Polaris Point to the south. The second and third areas consist of the much disturbed Piti Channel and Commercial Port areas which are situated between Dry Dock Point and Pol Causeway to the south and Cabras Island to the north. The fourth area is Jade Shoals which consists of two patch reefs that rise up from the deep lagoon floor west of Dry Dock Point. The latter three areas are referred to as Area A in the scope of work. All four of the study areas have been disturbed to varying degrees by dredging, land-filling, and construction activities. A causeway between Cabras Island and the main island of Guam separates Tepungan and Piti Channels which previously provided a natural pass from the northeast corner of Apra Harbor to the Philippine Sea. The only connection between these two bodies of water now is through the Cabras Island and Piti Power Plants which pump sea water from the Tepungan Channel and Piti Canal for condenser cooling and then discharge the heated water into Piti Channel. The effect of this thermal discharge into Piti Channel has been reported on and is currently being studied by a University of Guam, Marine Laboratory team (Marsh and Doty, 1976). The Commercial Port of Guam facilities and the U.S. Navy occupy the southwestern side of Cabras Island and the western end of Dry Dock Point. The remaining shoreline along the south side of Cabras Island has been greatly altered by dredging and filling. Both Dry Dock Point and connecting Pol Causeway and Polaris Point are artificially landfilled lagoon areas. Mangrove swamp occupies the eastern shoreline of Sasa Bay and scattered mangroves have become established on the artificial shorelines along Pol Causeway and the eastern side of Polaris Point. Distribution of mangroves and characterization of the shoreline along the three study areas are shown in Figure 1.

Sasa Bay

Sasa Bay (Area B) is the largest of the three study areas, forming an embayment 1.8 kilometers long in an east-west direction, 1.8 kilometers wide along the eastern end, and 0.8 kilometers wide at the western mouth. The depth is quite variable, ranging from about 20 or more meters at the western end where it adjoins the main part of Apra Harbor, to shallow reef-flat platforms which are partly exposed during low spring tides along the shorelines. The Sasa and Aguada Rivers empty into the east end of the bay, bringing fresh water and detrital sediments to the reefs from the adjacent alluvial lowlands and steep volcanic mountain slopes.

Reef structure is complex within the bay, consisting of isolated patch reefs which rise from the lagoon floor, to near the surface, and a lagoon fringing reef consisting of an irregular system of shallow anastomosing platforms which at places enclose a number of deeper secondary lagoons (Figs. 1 and 2). Based primarily upon their physiographic structure, the reefs in the bay can be divided into three distinct zones: the reef-flat platforms formed by the shallow upper surface of isolated patch reefs and fringing reefs, the peripheral lagoon slopes which extend downward into deeper water from the shallow reef-flat platforms, and the deep flat to undulatory lagoon floor.

The lagoon floor is principally a depositional environment where clay, silt, sand, and coral-algal-mollusk rubble accumulate. Examination of these lagoon floor deposits at most places revealed a soft plastic mud intermixed with lime sand and Halimeda and shell fragments, which give the mud a gritty texture. Near patch and fringing reefs the deposits become less muddy and contain a greater fraction of sand and coral-algal-mollusk rubble. The clay and mud fraction of the lagoon floor sediments consists mostly of detrital volcanic material brought to the bay by the two rivers at the east end. Sediments became conspicuously more muddy toward the mouths of these two rivers (Fig. 2). No corals were found on the lagoon floor except for an occasional colony that had slumped downward from a nearby patch or fringing reef lagoon slope. Because of their large size, these slumped corals survive and grow well in the deeper turbid water of the lagoon floor, but normally coral planulae cannot colonize the soft muddy substrates found there.

The shallow platforms forming the upper surface of patch and fringing reefs are relatively flat but are difficult to walk across because of irregular topography consisting mostly of large in situ dead coral colonies. Tracey (1964) mentions that many corals in the vicinity of this study area were probably killed during earlier dredging and land-filling activities in Apra Harbor. These large in situ dead colonies suggest that this area once supported a much more diverse and developed coral cummunity. Relief on these shallow platforms is generally less than 30-50 cm, but at places may be up to a meter where local holes and depressions occur. Living corals are small and scattered, being mostly found near the peripheral regions where the platforms are slightly deeper and grade downward to the lagoon slope.

Piti Channel and Commercial Port

Piti Channel and Commercial Port areas have been greatly altered by dredging, land-filling, and construction. A number of channelways, causeways, and islands have been dredged and constructed in much of the area (Fig. 1). Two power plants discharge heated water into Piti Channel at the east end, and nearby a series of submerged pipelines cross the shallow reef flats from Cabras Island to the main island. Except for the dredged channelways, much of the eastern end of the region exposes during low spring tides. Commercial Port, U.S. Navy and Gorco fueling docks occupy the western end of the region which has been dredged to allow the docking of ships and boats.

Sediments in the eastern end of Piti Channel consist of fine and coarse sand intermixed with variable amounts of coral-algal-mollusk rubble. Abundance of rubble consisting mostly of arborescent Acropora and ramose and massive Porites species indicate that a rich and diverse community of corals was previously developed here before being altered by dredging, land-filling, and construction activities. Dredging samples adjacent to the Commercial Port and fueling wharf facilities show the bottom to composed of mud and fine sand intermixed with some rubble. Between the dredged western end of Piti Channel and the shallow reef-flat platforms at the eastern end, a small relatively undisturbed region of patch reefs and mounds is found (Sta. 15, Fig. 1).

Jade Shoals

Jade Shoals is an elongate submarine ridge about 600 meters long that reaches to or near the surface, forming patch reefs at two locations which are separated by a short depressed region about six meters deep (Figs. 1 and 2). The patch reefs rise up from the lagoon floor about 35 meters deep on the northwest side and about 25 meters deep on the southeast side. Dredge samples from the lagoon floor reveal a substratum consisting mostly of mud intermixed with some sand and coral-algal-mollusk rubble. Toward the base of the patch reef the deposits become more sandy and rubbly. The lower patch reef slopes are rubbly with algal areas consisting predominantly of sand, rubble, and rocky outcrop. This type of substratum grades upward into a region with more rocky outcrops and, at places, forms cliffs and overhanging ledges at the upper margin.

The upper surface of the patch reefs forms shallow platforms which, on the southwest sides, have local areas that expose during low tides. In general these intertidal regions are composed of sand, gravel, and rubble which thinly veneer an underlying reef rock pavement. Corals are mostly absent in these rubbly areas. The remaining upper platform surface is somewhat undulatory, ranging in depth from one to two meters, and is predominantely composed of reef rock pavement studded here and there with knobs and knolls abundantly populated with Millepora dichotoma colonies.

METHODS

Current Pattern Studies

Detailed current studies were conducted in the Apra Harbor-Commercial Port area on 27, 28, and 29 December, 1976, and 4, 5, 10, 11, and 12 January, 1977. These dates were selected in order to ascertain the major circulation patterns during rising and falling spring tides and neap tides. The study area was divided into three major zones of study delimited as follows (Fig. 3): Zone I, extending from the eastern inner dredge line of Commercial Port to the western edge of Western Shoals, and including the northern edge of Jade Shoals; Zone II, extending from the eastern dredge line of Commercial Port approximately 300 m onto Tidal Flats C and D and including the western end of Piti Channel; and Zone III, subdivided into three natural areas including the inner portions of Flats C and D and the western end of Flat B, in the vicinity of the Gorco pipeline. All work was conducted during daylight hours to avoid potential shipping interference at night.

Three types of current studies were employed. Zone I was covered by using drift drogues suspended at three depths to indicate the movement of the surface water layer (top 2-3 m) and the subsurface water layer (extending from a depth of 6-7 m to 12-13 m). Additional information on the subsurface water layer and subsequent transport of the detrital sediments was obtained by utilizing SCUBA to track subsurface dye patches. The surface water layers in Zones II and III were studied by tracking fluorescein dye patches.

Drift drogues consisted of a 1-m tall aluminum vane with a cross shape (as seen in transverse section) suspended from a buoy by a length of line. The length of the line was varied to suspend the vane at three depths, in a surface water layer of 1-2 m, a subsurface layer of 6-7 m, and a deeper layer at 12-13 m in the outer portion of Zone I. The drogues were given sufficient weight to reduce the above-water exposure of the buoys to a height of 10-15 cm. Any additional weight resulted in negatively buoyant drogues.

Drogue tracking was accomplished by using two surveying transits placed 100 m apart on the Gorco Pier (Fig. 3). Paired readings from these transits allowed drogue positions to be plotted by triangulation. Establishment of semi-permanent tripod locations and backsights (prominent features found on orthographic maps of Apra Harbor) allowed for exact re-establishment of the tripods on different days, thus achieving a high degree of accuracy. The only difficulty with the method was in the late afternoon, when the glare of the sun on the water decreased visibility. Four drogues were released for each tracking set, one each at depths of 1 and 6 m in the inner portion of the Commercial Port area and one each at depths of 1 m and either 6 or 12 m in the outer portion of that area. Positions of the drogues were plotted every 30 min, and tracking sets usually continued 2 hrs between resets.

Surface fluorescein dye tracks were utilized to chart circulation patterns in Zones II and III. Dye track distances were measured with calibrated tapes or by stadia, with the use of a surveying leveling rod. Directions of movement were determined by employing surveying transits located at one of three semi-permanent tripod locations (Fig. 3). Dye patches were allowed to move fixed distances (25 m) and the direction determined; or, alternatively, they were allowed to move for a fixed time, with the direction of movement and distance (as determined by stadia) being recorded.

Dye studies at Jade Shoals and in Piti Channel, the Secondary Channel, and the Connecting Channel between Flats C and D were conducted by using an inflatable boat and a meter tape attached to the anchor line at the water surface. The boat was allowed to drift in front of a dye patch for 25 m in the channels and 50 m at Jade Shoals. The position of the bowline of the boat (centered on the dye patch) was then determined by triangulation with paired transits (in the case of Jade Shoals) or by using a hand-bearing compass and direct visual plotting on field maps (in the case of the channels).

A series of SCUBA dives at the eastern and western ends of the Commercial Port had a two-fold purpose: 1) to ascertain vertical and horizontal water movements at a depth of 12-17 m; and 2) to note turbidity in the lower portion of the water column and the effect of ship movements on subsurface circulation patterns and the resulting disturbance of the substratum. Subsurface dye tracking was accomplished by utilizing fluorescein dye, a meter tape, and an underwater hand-bearing compass. The dye was released 1 m above the substratum; and the direction of movement, elapsed time, and depth of the patch were recorded every 10 m. Because of rapid diffusion of the dye, it was necessary to locate the approximate center of the patch and renew it with more dye after 2-3 m of movement. Care was taken to avoid diver disturbance of the dye patch as much as possible. This method is not very precise, but it does give an indication of current direction and velocity at subsurface depths.

Wind direction and velocity were measured hourly with a hand-held anemometer. Tide readings were taken from a tide staff at intervals of 2-3 hrs and at the predicted times of tidal highs and lows. Since the interest was in tidal changes rather than absolute water levels, no attempt was made to correlate the tide-staff readings with the published tidal records.

Water Chemistry Analysis

Water samples for chemical analyses were collected at six different stations (Fig. 3) on three different days; two samples were collected on two of the days to bring the total number of sampling times to five. Two high tides, two low tides, and one falling tide were represented. Surface samples were dipped up in a plastic bucket and deeper samples were collected with a van Dorn bottle. Field temperature was measured with a mercury thermometer. Dissolved oxygen samples were siphoned into 300-ml BOD bottles and analyzed according to the azide modification of the standard Winkler procedure (APHA, 1971). Salinity was measured with a hand-held refractometer. Nitrogen and phosphorus samples were collected in plastic bottles and placed in an ice chest for transport to the laboratory, where they were frozen for later analysis. Nitrite nitrogen, nitrate nitrogen, and reactive phosphorus were analyzed according to the methods of Strickland and Parsons (1968). Turbidity samples were collected in plastic bottles and analyzed in the laboratory with a Hach turbidimeter (Model 2100A), using the nephelometric principle.

Substratum Characterization

General substratum descriptions were obtained from field observations. Further analysis of sediments from several sites in Study Area A were performed on samples returned to the laboratory. The samples were collected in the field by scooping a small amount (10-15 g) from the sediment interface into a plastic petri dish. Sediment collection was random within a collection area, with a minimum of two samples per area. Additional sediment samples were obtained from six sites in the outer portion of the study area by using a pipe dredge. See Fig. 3 for sample sites. Sediment samples were preserved in 70% ethanol.

Laboratory analyses of the samples were made for general composition, particle size, texture and relative sorting. An estimate of the amount of silt and clay present was obtained by washing ca. a 10-g portion through a 200 mesh sieve. The retained material was then examined under a sterescopic microscope (10-60 x) for the determinations.

Benthic Algae

Two methods were used to quantify the algae in the five habitats found in Study Area A. See Fig.1 for locations of habitats and stations. In those areas where algae were diverse and/or abundant (outfall lagoon, reef, and Jade Shoal), the point-quadrat technique was used to obtain values representing percent cover. A small gridded quadrat (25 cm x 25 cm), consisting of 25 squares and 16 interior points where the grid lines intersected, was tossed haphazardly 20 to 25 times in each sample site. Each algal species was recorded at every point at which it occurred. If no alga was found under the points, then whatever was present, e.g., sand, rubble, dead coral, live coral, was recorded. In a few cases, turfs of intermixed filamentous-like algae were present and were simply recorded as turf. These turfs were collected and later examined in the laboratory where species were determined. Percent cover was obtained by dividing the number of points at which the species was recorded as a percent of the total number of points per transect, i.e., 16 x Number of Tosses = Total Number of Points.

The other method used in areas where few algae occurred was to simply make a visual estimate of the dominant algae as was done for the channel area, where tows were made along the length of the main channel and portions of the secondary channel. This method provided a more meaningful estimate of algae over a greater area. All algae and sea-grasses observed in each of the five habitats were recorded.

In Area B, those algae which could be identified by sight were recorded from each of the stations. Coral rubble, shells and mud which possessed algal turf were collected and returned to the laboratory for further examination.

Corals

Scleractinian, coenothecalian, and hydrozoan coral communities were investigated qualitatively at Sasa Bay and both qualitatively and quantitatively at Jade Shoals and Piti Channel. At Sasa Bay, a 15 to 30 minute search was made at 20 stations (Fig. 1, Stations A-T) from which a checklist of corals was compiled (Table 10) and the physiographic reef structure and associated sediments were noted. At Piti Channel similar qualitative assessments were made at 15 stations and at Jade Shoals a general reconnaissance was made at both the northern and southern patch reefs on the upper shallow patch reef surface and steeply dipping lagoon slopes (Fig. 1, Stations 1-15 at Piti Channel and upper surface and slope stations at Jade Shoals).

Quantitative assessments were also made at Station 15 in Piti Channel and on the upper shallow surface of the northern patch reef at Jade Shoals by using the point-centered quarter or point-quarter technique (Cottam et al., 1953). Nineteen sample points at Jade Shoals and seventeen sample points in Piti Channel were selected by randomly throwing a geology hammer 3 to 5 meters ahead while swimming over the surface of the two stations. The axes of the quadrants were determined by the orientation of the handle of the hammer and the chisel blade of the hammer head.

The coral nearest the sample point in each quadrant was located and the specific name, diameter of the colony, and the distance from the center of the colony to the sample point was recorded. If no colony was observed within a maximum distance of 2 meters, the quadrant was recorded as having no colony with a diameter of zero and a sample point to colony distance of 2 meters.

The average dominance value for each species is defined as the average areal coverage of all individuals of the species encountered in the sampling. The following calculations were used to estimate the population and community parameters:

$$\text{total density of all species} = \frac{\text{unit area}}{(\text{mean point-to-point distance})^2}$$

$$\text{relative density} = \frac{\text{individuals of species}}{\text{total individuals of all species}} \times 100$$

$$\text{density} = \frac{\text{relative density of species}}{100} \times \text{total density of all species}$$

$$\text{percent coverage} = \text{density of species} \times \text{average dominance value for species}$$

$$\text{relative percent coverage} = \frac{\text{percent coverage for species}}{\text{total coverage for all species}}$$

$$\text{frequency} = \frac{\text{number of points at which species occurs}}{\text{total number of points}}$$

$$\text{relative frequency} = \frac{\text{frequency value for species}}{\text{total frequency values for all species}} \times 100$$

$$\text{importance value} = \text{relative density} + \text{relative percent coverage} + \text{relative frequency}$$

Additional qualitative data was also incorporated in the coral community, reef structure, and sediment analysis from previous field notes recorded from field observations made between the years 1966 and the present.

Macroinvertebrates

In Area B, thirteen study sites were examined qualitatively for the presence of species. In Area A, samples were taken with haphazard tosses of a 0.25 m^2 quadrat which was partitioned into 0.01 m^2 sections. The scale to which the counts were made depended upon the local abundance of the species.

Four different bivalve habitats were sampled in Sasa Bay: muddy intertidal areas, sandy intertidal areas, muddy bottom areas deeper than 1 m, and coral knolls. Bottom sediments from scattered areas in each habitat were sieved through a screen with 0.65 m^2 (¼") mesh openings. Population data for two of the most common bivalve species, *Saxostrea mordax* (Gould) and *Gafrarium tumidum* (Roeding), were collected. In muddy areas near *Rhizophora* communities, ten 0.1 m^2 quadrats were haphazardly selected, dug to a depth of approximately 5 to 7 cm and sieved. Members of the genus *Saxostrea* were found attached to any solid substrate in the upper 0.5 m of water. *Rhizophora* proproots, fallen trees, boulders, a metal pier, bivalve shells, and a WWII tank were found to be heavily encrusted by *S. mordax* individuals. On an oil barrel which provided a relatively even surface, we counted the number of oysters in ten 7.5 cm x 7.5 cm quadrats. Shell-free wet weights of the bivalves were determined in the laboratory.

Fishes

Two areas of Apra Harbor were visually censused for fishes: Jade Shoals and the area to the immediate east of the Commercial Port dredged area. Censusing was performed by swimming a measured transect line, enumerating the fishes seen within one meter of either side of the transect line. SCUBA was used for the deep transect at Jade Shoals (30 m in depth), while snorkeling equipment was used for the other transects.

Zooplankton

Zooplankton collections were made with a 0.5 m diameter, 0.35 mm mesh net. A series of tows made on December 6, 1976, were designed to test for tidal fluctuations in the plankton communities in the Piti Channel area, and to determine if outer harbor water could be identified, by its plankton constituents, in the Piti Channel area. Two tows were made in the Secondary Channel (Fig. 3) during ebb tide (10:20-10:45) and two more during flood tide (15:50-16:20). Another tow was taken in the region of Jade Shoals (Fig. 3) around 13:10.

A set of tows on December 17, 1976, were performed to evaluate day/night changes in the composition of the zooplankton communities. Nighttime tows (0500-0615) were made in Sasa Bay, the outer harbor, and Commercial Port area (Fig. 1). Daytime tows (1700-1750) were made in these same three areas, as well as in Lower Piti Channel and in the Secondary Cnannel (Fig. 3).

RESULTS AND DISCUSSION

Current and Sediment Movements

1. Zone I

Drogue observations in Zone 1 are plotted in Figs. 4-13, and additional information is given in Tables 1-4. Initial field observations indicated that the drogue paths were strongly influenced by the prevailing wind, which was from the east at 10-15 knots with gusts up to 25 knots. There was a definite external wind effect on both the 1-m and 6-m drogues because of the extension of their floats above the water surface. The attachment of weights to make the buoys ride lower in the water reduced this external wind effect but did not eliminate it entirely. Drift directions of the 1-m drogues followed the wind more closely than those of the 6-m drogues (Figs. 4, 5, 7, 9 and 12). The greatest wind effect was in more westerly regions of Zone I outside the narrow confines of the docking area; this effect was greater still west of Jade Shoals where there was greater wind fetch unobstructed by port structures. Despite the external wind effect, the drogues give a good indication of actual water movement in the first one to six meters of the water column.

Directions of the 1-m drogues were approximately the same as wind direction in most cases; the wind carried these drogues toward Western Shoals. Sometimes these drogues veered northward away from the shoals and curved at right angles to the direction of the wind (Figs. 3 and 6). Several large, barely submerged floating objects (e.g., a tire) were observed to followed this curving pathway also. There was no evidence for a tidal effect on the directions of movement of the 1-m drogues. The observations indicate a continuously strong outward (westward) flow of surface waters.

The 6-m drogues moved generally in the direction of the wind and the surface current, but patterns were more variable and complex than for the 1-m drogues. As the drogues passed from the confines of the narrow docking area into the wider stretch of water just east of the Gorco Pier, they tended to veer either north or south; movement was more uniform outside (west) of the pier. On one day several drogue sets started out in the general direction of the wind and then showed a strong turn northward at a right angle to the wind; this caused a dog-leg pathway in the plots of the drogues (Fig. 5). On another day (Fig. 12) there was a weaker curvature in the same direction. The zig-zag pattern in Fig. 11 shows another situation in which the 6-m drogue moved to the left of the wind for a period of time. These changes in the direction of drogue movement occurred primarily on rising tides and strongly suggest a reversal of subsurface flows or possibly a complex eddy system at the 6-m depth.

Drogues with vanes suspended at the 12-m depth were set at the outer release point (Point a) only, because the water depth at the more eastern release points (b and c) was not great enough to allow free movement of such vanes. The 12-m drogues moved outward directly toward Western Shoals and showed no changes in direction of movement with tidal changes.

Velocities of the drogues ranged from 0.03 to 0.33 m/sec for the 1-m sets, 0.03 - 0.10 m/sec for the 6-m sets, and 0.02 - 0.07 m/sec for the 12-m sets (Tables 1 and 2). The 1-m drogues showed no definite pattern of change with tidal changes. The 6-m and 12-m drogues moved significantly slower on rising tides than on falling tides.

Some observed movements of the 6-m drogues suggested flow reversal at that depth on rising tides, carrying water into the Commercial Port area from the west. If water volume in the area is to be maintained, there must be such a subsurface flow. Outflow of cooling water from the two power plants at the eastern end of Piti Channel totals no more than about 13.4 m per sec (slightly more than 180,000 gallons per min). Even with all the cooling water pumps operating, this is not sufficient to account for the total volume in the surface-water layer moving westward out of the Commercial Port area on rising and falling tides. The strong outward surface flow of water probably influenced the drogue floats strongly enough to prevent a total drogue reversal even if there was such a reversal at the level of the vane. Various drogue modifications were tried to see if a flow reversal could be observed, but none were observed.

In a further search for a subsurface inflow, several SCUBA dives were made in Zone I during strongly rising tides. One such dive in the western end of the zone (Fig. 14, Table 3) demonstrated some inward (eastward) flow of dye, but the movement was predominantly northward. Velocity was approximately 0.03 m/sec. There was considerable spiraling and diffuse streaming at divergent angles. There is a strong possibility that this area has low-velocity eddy currents and small, discontinuous inward-flowing currents. This is the region of the Commercial Port with the greatest complexity of water circulation patterns; these are probably affected by the bottom topography dropping off abruptly from a depth of about 18 m to about 30 m. A dive in the eastern end of the zone revealed inward and upward flow from a depth of 12 m to 9 m; continued inward flow was maintained at 9 m.

The dive at the western end of Commercial Port also revealed a strong effect of ship movements on subsurface current patterns. The effect of a large cargo carrier moving into the docking area was to cause a westward flow, and numerous small eddies were created.

A dive off the northeast corner of Jade Shoals (Fig. 14, Table 4) during a weakly dropping tide showed strong outward flow of water moving in the direction of Western Shoals. This outward flow was continuous from the surface to a depth of 33 m, and there was no noticeable change in velocity with depth.

It was noted at all three dive sites that when sediments, which consist of silt with low to high percentages of clay and fine sands, were disturbed they tended to slowly migrate upward in a large cloud-like mass. This colloidal suspension then moved with outflowing currents and possibly also moved inward at the site of ship disturbance. There was very slow settlement of suspended silts after even a small disturbance. Ship movements in the Commercial Port raised great quantities of silty sediments which rose into the surface waters and rapidly dispersed throughout the water mass in the shipping lane. Three to four hours after a ship had docked, there was little decrease of turbidity in the water column, as judged visually. It was also noted that the sediment cloud had moved toward Jade Shoals in the strong outward surface flow. This indicates that under present conditions the Jade Shoals area is being continually subjected to moderate-to-heavy siltation because of shipping. A dive on the northeastern side of Western Shoals revealed moderate-to-low siltation occurring shallower than 30 m and a marked increase at about 37-40 m. This indicates that presently the major portion of the outflowing silt load is deposited before it reaches Western Shoals. The greater siltation at about 37 m is probably a result of previous dredging activities, with the upper talus slopes having been partially swept clear of fine detrital materials by currents.

2. Zone II

All current patterns in this area were charted by tracking dye patches with transits. Results are shown in Figs. 15-17 and in Tables 5 and 6. The general trend for major current patterns is clear; however the detailed pattern for individual dye tracks is probably variable.

In general, on falling tides there is an outward movement towards the harbor of the water masses of Piti Channel, Flat C, and Flat D (Figs. 15, 16, 17). For the most part, there is not a flow reversal on a rising tide. The only dye tracts that showed such a reversal were those on Flat D (Fig. 15, H, L). The surface waters of Piti Channel continued moving outward towards the harbor on a rising tide, with a slightly lesser velocity than was recorded for a falling tide (Fig. 16, B'). However, Marsh and Gordon (1973) reported a slight reversal on a rising tide. On Flat C dye patches also showed slower velocity on a rising tide, but only Path G (Fig. 15) showed a reversal. On this flat, the velocity is greater further eastward on the flat, decreasing as the water mass approaches the point of land separating Flats C and D (Fig. 15, K and J; Fig. 17, M and N). There were not enough data recorded for the Secondary Channel to make a statement regarding velocity changes. However, the water mass in the channel moves at a slower velocity than the water mass on Flat C or in Piti Channel.

Water movement directly westward of the point between Flats C and D increases in velocity on its outward flow for a dropping tide (Fig. 17: I'', R, U, F'') but remains relatively constant on a rising tide (Fig. 15, F; Fig. 16, F'). There is a tendency for the water in the area to drift southward on its way out to the harbor (Fig. 17, I'', R), and in the case of Path I (Fig. 15) there is a near-reversal. This drifting effect is most likely due to wind, but Path I might reflect a more complex eddy situation.

As stated previously, Flat D was the only area of Zone II to show a flow reversal for a change in tide. On a falling tide, the velocity decreased as the water mass moved out toward the harbor (Fig. 15, L; Fig. 17, S). The opposite was the case on a rising tide, i.e., the velocity increased as the water moved eastward on the flat (Fig. 16, H'; Fig. 17, T). The change in direction of Path T could be attributed to a decrease in depth, along with wind influence.

Since Paths K and L (Fig. 15) were charted at the same time, we have reason to believe that on an ebb tide the velocity is approximately four times greater on Flat C than on Flat D. This phenomenon is probably due to the fact that Flat C receives a greater volume of water from the power plants via Upper Piti Channel than does Flat D.

In summary, on a falling tide the waters of Piti Channel on Flat C and Flat D all move at faster velocities at points further east and dissipate as they approach the point of the peninsula separating Flats C and D. As the waters of Flats C and D and the Secondary Channel move past the point there is convergence, with a tendency for waters from Flat C and the channel to drift toward Flat D. This probably reflects wind influence.

There appears to be no simple pattern of water movement in Zone II on rising tides. However, previous observations have indicated an eastward-moving subsurface flow in Lower Piti Channel on strongly rising tides. Such a subsurface inward flow probably occurs also in the Secondary Channel, as discussed in the next section.

Taking all things into account, for a falling tide the data indicate a strong and relatively direct outward flow of water from Piti Channel and Flat C. The waters of the Secondary Channel and Flat D also move westward on a falling tide. However, the flow is not as strong as that of Flat C and Piti Channel; and the major part of the water mass tends to be deflected toward the southern side of Flat D and Commercial Port. Any dredging in the northern two thirds of Zone II will result in sediments being swept out toward the harbor.

3. Zone III

All pathways in this zone, except those of Fig. 21, were charted by tracking dye pathes with transits. Results are shown in Figs. 18-20, 22A & B, 23, and in Table 6. As for Zone II, there is probably variability for individual pathways.

In order to obtain additional information for the area of the Gorco pipeline between Flats B and C and for the eastern portion of Flat C, a technique was employed that was different from the previously described tracing of dye patches with transits. This involved releasing large quantities (2-4 liters) of concentrated dye and yielded qualitative information about currents. The observations are presented in Fig. 21.

Water in Upper Piti Channel shows a continuous outward flow toward the harbor, whether the tide is rising or falling (Fig. 18, H,G; Fig. 19, A', G; Fig. 20, F). The water moves down the channel from the power plants and divides after passing the peninsula at the upper end of Flat C, with part of the water flowing into Lower Piti Channel and part being swept onto Flat C (Fig. 18, G, H; Fig. 19, A', G, C; Fig. 20, F). This latter movement is enhanced by wind. It appears that part of the water moves into the Connecting Channel as it moves out of Upper Piti Channel (Fig. 18, A'; Fig. 19, B'; Fig. 20, E). This occurs continuously, with no change in direction, in agreement with the observations of Marsh and Gordon (1973).

Water moves eastward in the Connecting Channel (Fig. 18, A', B', D; Fig. 19, B, H), rounds the bend and continues southward until it reaches the junction with the Secondary Channel.

Water on Flat C moves toward the harbor, with a tendency to drift south toward the Secondary Channel (Figs. 18, 19, 20). This movement toward the channel is probably the result of wind effect and the force of water moving away from the power plants and onto Flat C from Upper Piti Channel. Water on the eastern end of Flat C moves slowly westward and picks up speed as it approaches the point of the peninsula and converges with the water moving onto the flat from Piti Channel (Fig. 19, A, B, C, D.). This is true for both rising and falling tides.

Some of the water moving across Flat C enters the Secondary Channel, at which point an interesting phenomenon occurs (Figs. 18, 20, 21). It appears that in an area near the slight bend of the Secondary Channel there is a splitting effect. Part of the surface water moves west toward the harbor, and part reverses direction and flows eastward up the channel. This phenomenon was more distinct on a rising tide than a falling tide. In addition, Path C in Fig. 21 shows a depth pattern rather clearly. At this point, a large quantity of dye was released near the surface and also about 2 m below the surface. The surface patch moved westward, while the subsurface patch moved eastward up the channel. A vertical temperature difference was also noticeable to snorkelers.

Slow-moving water in the Connecting Channel (Fig. 20, C) converges with the slightly faster-moving water of the Secondary Channel (Fig. 18, F). The combined water mass then moves south in the extension of the Connecting Channel toward Flat D. As water moves around the bend and onto Flat D, it spreads out and shows an increase in velocity on falling tides but not on rising tides (Fig. 22A, 22B). As water moves down the flat it continues traveling at a relatively fast velocity on falling tides but shows a decreasing velocity and an eventual reversal on rising tides (Figs. 22B, 23). The reversal results when westward-flowing water meets water flowing eastward from the harbor.

In summary, there is a dominant westward outflow of water in Zone III on both ebb and flood tides. The only reversal occurs on Flat D, which corresponds with the data recorded for Zone II. Warm water from the power plants moves down Piti Channel, across Flat C and into the Secondary Channel, introducing a warm surface layer on top of a cooler subsurface layer. Water pumped from the power plants helps to flood Zone III during rising tides. However, there must be another source of flooding water also, and this source is apparently a subsurface inflow in Piti Channel and the Secondary Channel (Fig. 21, C) on strongly rising tides.

We conclude that any dredging in Zone II will have little effect on Zone III because of the predominantly westward movement of water currents.

Three detailed profiles were run in the vicinity of the Gorco pipelines between Flats B and C (Figs. 24 and 25). A semi-permanent benchmark was established on the peninsula near the eastern end of Flat C so that surveying methods could be used to plot bottom topography in relation to mean lower low water. Transect B skirted the edge of a shallow sand bar for about 80 m. It crossed the upper pipeline at 15-28 m from the peninsula and skirted the edge of a steep drop-off between 40 and 80 m. Transect A ran directly along one of the parallel pipelines, which was exposed for the first 90 m and buried from 90 to 160 m. Transect C ran south of the pipelines and is considered to be the boundary between Flat C and Lower Piti Channel. It crossed the northern edge of a shallow sand bar on Flat C between 40 and 65 m.

The topographic features seen in the profiles (Fig. 25) probably strongly influence observed current patterns in the area and in turn are shaped by the currents. The pipeline across the channel causes eddies in this area and leads to shifts in sediment deposits. Some water from these eddies moves toward Flat C, where the shallow sand bar partially deflects it into the Secondary Channel. On high tides more water can move directly across the sand bar onto the main portion of Flat C.

The profiles can be repeated at a later time to see if there are future changes in the area.

Water Chemistry Analysis

Table 7 presents results of chemical analyses of water samples (sampling locations are shown in Fig. 3). Temperatures are within the range of a large number of observations reported by Marsh and Gordon (1973, 1974) and Marsh and Doty (1975, 1976). Temperatures were higher at the stations on the tidal flats than the deeper-water stations in the afternoons but not in the mornings, again consistent with many previous observations. Turbidity values were somewhat variable, ranging from 0.12 to 2.2 NTU (nephelometric turbidity units) in the deeper waters and from 1.3 to 4.8 on the tidal flats. Salinity was relatively constant from station to station and from time to time, with no pattern to the small changes found; this is consistent with previous observations reported by Marsh and Gordon (1974) and Marsh and Doty (1976).

Dissolved oxygen values generally showed an increase between morning and afternoon sampling times on a given day, probably reflecting metabolic activity of the biological communities. The greatest changes between early morning and late afternoon samples occurred at the tidal flat stations. Observed values were generally equal to or higher than saturation values, except for early morning observations at the tidal flat stations. The lowest value observed at these stations was 85% of the saturation level. The oxygen data generally are similar to those of Marsh and Gordon (1973, 1974) and Marsh and Doty (1976) and reflect a healthy condition.

Observed nutrient levels were generally low and characteristic of what is found in unpolluted waters. Reactive phosphorus values were relatively constant with time and station and fell within the same range previously reported by Marsh and Gordon (1974) for the area. Nitrite nitrogen levels were low or indetectable; the occasional exceptions are inexplicable. Nitrate nitrogen values were more variable, with no obvious reason for the variability; however, the observations were consistent with those of Marsh and Gordon (1974).

Substratum Characterization

The substratum characteristics show extensive variation in the study area. The study area can be divided into five basic substratum or depositional types (see Fig. 3). The shallow inner channels (Piti Channel, Secondary Channel, Connecting Channel, and portions of Flat B) are a mixture of terrigenous and biogenous sediments of recent origin. The sediments show considerable variation in sorting size, texture, sorting and composition. The sediments are primarily of a depositional nature. The shallow inner flats (Flats B, C, and D) are predominantly biogenous sands and gravels. There is a noticeable introduction of terrigenous material at the eastern ends and adjacent land masses. There is a gradation of sorting size, with the finer material at the western end. There is a small isolated coral and limestone area at the western end of Flats C and D that extends to the eastern dredge line of Commercial Port. This area is a biogenous structural feature with coral and limestone as the major constituents. The sediments grade from silty sands to coarse gravel and rubble. The area has a very uneven topography, which permits increased faunal diversity. The Commercial Port and adjacent harbor floor is primarily a uniform silty ooze. The top 50-100 cm is a loosely packed accumulation of silty clay, fine sands, and medium to coarse sands. This area is a major depositional zone for fine detrital sediments washed in from adjacent land areas. It contains both terrigenous and biogenous sediments. The shoal reefs (Jade Shoals and Western Shoals) are biogenous features. Both shoals show heavy siltation on the talus slopes. The upper talus slopes of Western Shoals are mostly swept clean of fine detrital material, while Jade Shoals shows only moderate sweeping.

The adjacent sediments in the inner portion of the study area are pale brown to white, fine-, medium-, or coarse-grained limestones, referred to as Shioya soils. They contain some dark organic coloring and less than 10% fines in the top several cm. Since the inner portion is bounded by large amounts of artificial fill, there is a great deal of unidentified limestone and gravel, including large boulders, rubble, cobbles, earth, trash and scrap iron, occurring on the flats and in the channels. The fines introduced into the flats and channels are mostly a result of drainage from the Inarajan and Pago clay deposits found on adjacent land areas.

The inner channels contain fine sands and silts grading into coarse sands and gravel. The silty sands are usually in pockets or belts. There is a marked increase in the amount of *Halimeda* debris in the channels. The sediments vary from well to poorly sorted, with rounded to angular grains. The western ends of Secondary and Piti Channel contain higher percentages of fines. These sediments tend to be more biogenous in origin.

The sediments on Flat C (see Fig. 3) are characterized by an abundance of Mollusca shells, mostly bivalves. The sediments are well rounded to subangular with angular material becoming prominent toward adjacent land and fill areas. The sediments are mostly well sorted, with some isolated pockets of poorly sorted material, due to large coral and limestone rubble. The sediments get progressively finer toward the western end, where pockets and belts of packed silty sand are found.

The sediments on Flat D (see Fig. 3) are similar to those found on Flat C. The sediments are fine to medium grained sands, with high concentrations of silty sand on the southern edge. This silty sand contains a high organic content (20-50% decomposed organic matter). There is an extensive anaerobic layer beneath the surface along the entire southern edge. There is a definite introduction of terrigenous material on this flat that contains low percentages of volcanic material.

The sediments on Flats C and D integrate into the patch reef at the western end. There is a marked increase in the amount of coral and limestone rubble. There is a tendency for this area to be covered by a veneer of silty sands and silty clays, with the thickest veneer on the southern side. The stronger currents from Piti Channel and Flat C tend to remove a large portion of the fine detrital material. A more detailed discussion of this area is found in the biological sections.

Sediment samples for laboratory analyses were collected from Jade Shoals, the eastern and western ends of the Commercial Port shipping lane (by SCUBA), and at six dredge sites (Fig. 3). The dredge sites were as follows:

1 and 2 - Between Gorco Pier and the NE corner of Jade Shoals at 15 fathoms;

3 - The western end of the Commercial Port shipping lane at 9 fathoms;

4 - The eastern end of the Commercial Port shipping lane at 6 fathoms;

5 - 200-300 m north of the central portion of Jade Shoals at 18 fathoms;

6 - The talus slope of Jade Shoals at 17 fathoms.

Dredge samples 1-5 were uniform with respect to the sorting size, texture, sorting and general composition. These dredge samples were comparable to the dive samples, with one major difference. The dive samples showed a higher faunal diversity and concentration; this is a result of sampling method. Dredge sample 6 contained no sediments. This sample consisted of limestone secretion rock and coral. There were corals, foraminifera, polychaetes and sponges attached to rock. This is not a representative sample of area in regards to sediments. It was indicative of the faunal assemblage.

Dredge samples 1-6 and dive samples are characteristic of the general substratum. They contain high percentages of silty sands and fine sands. The substratum does contain some limestone blocks, boulders, cobbles, fine to coarse gravels and recent coral rubble. The predominant organisms on the substratum are sponges. The sediments contain sponge spicules, small Mollusca shells, coralline algae fragments, sparse Halimeda plates and foraminifera tests. The Foraminifera are as follows:

Marginopora vertebralis
Sorites marginalis
Heterostegina suborbicularis
Baculogypsina sphaerulata
Homotrema rubrum
Amphistegina madagascariensis
Rotalis sp.
Quinqueloculina spp.
Triloculina spp.
Elphidium sp.
Spirolina arietina
Globigerina sp.
Gypsina plana

The silty sands tend to become very packed beneath the silty ooze interface. This layer contains higher percentages of coarse rubble that is subrounded to angular. This material is a result of previous dredging. Visual observation and sediment samples show this substratum zone to be highly uniform.

The sediments from the talus slope of Jade Shoals are predominantly coralline material. They include coral fragments, coralline algae, Mollusca shells, Foraminifera, and limestone sands. The sediments are fine to coarse grained and show wide variation in texture (well rounded to very angular) and sorting (well to poorly sorted). The sediments are mostly white to buff with some iron staining toward the top of the shoal. The sediments get progressively finer toward the bottom of the talus slope and at 18-20 m are similar to harbor floor sediments.

The talus slopes of Western Shoals show a marked difference from those of Jade Shoals. There is considerably less detrital material on the upper slopes with the fine detrital sediments restricted to pockets and canyons. The sediments are fine to coarse sands with little or no silt deposition. Coral and limestone sands are the dominant constituents. The slope from 15-30 m appears to be mostly swept clean of fine detrital sediments. There are isolated pockets of silty sands to medium sands. Fine sands and silty sands were less than 20% of sediment deposit. Sponges are the dominant organisms in this zone and contribute greatly to the substratum characteristics. The slope from 30-40 m showed a marked increase in the percent of silty sand and fine detritus. The silty material formed large ooze pockets. The silty sands comprise 40-60% of the sediment deposit.

Biological Survey

The biota are divided into five groups: benthic algae, corals, macroinvertebrates, fishes, and zooplankton. Because different methods were used in the different study areas and because a different emphasis and approach was given to the different study areas, the three major areas of study (Sasa Bay, Piti Channel and Commercial Port) and Jade Shoals are each discussed separately under each taxonomic heading to allow for easy cross-referencing of different taxa in a given area or a given taxon in different areas.

1. Benthic Algae

Sasa Bay--Twenty-five species of benthic algae and one species of sea-grass were recorded from Sasa Bay. Of the 25 algal species (Table 8), only 16 species were collected or observed in the inner portion of the bay and an additional eight species were recorded on a reef (Station K) at the entrance of the bay. Station K represented a habitat unlike the other stations in that the substratum was composed of consolidated material which was ideal for algal attachment. The water was also much clearer than at the other stations.

Algae were absent in the mangrove zone (Stations A-D); none were found on the prop roots of Rhizophora. A thin crust of Microcoleus lyngbyaceus was the only alga found at the base of a Rhizophora stand at Station E where the substratum was solidified by the entangled mats of Rhizophora roots. A small stand of the seagrass Enhalus acoroides was found about 50 m from shore off Station A. Avrainillea obscura and Halimeda macroloba were growing in the compact sandy-silty substratum near shore at Station F and L, respectively.

The shallow reef flats of the bay consisted of consolidated calcareous material, i.e., dead coral and rubble, interspersed among loose silty substratum. Algae were again absent from the silty substratum but covered at least 60 per cent of the consolidated material. Halimeda opuntia seemed to comprise the greatest algal biomass on these reefs. The low matted "vaughaniella" stage of Padina tenuis, as well as Hypnea esperi and Laurencia sp., covered an extensive portion the reef. Caulerpa verticillata was present as isolated clumps on the reef and Polysiphonia upolensis was conspicuous on dead Acropora branches.

By far the richest area in terms of algal diversity was Station K which had 14 species. The dominant algae here were a mixed turf of Jania capillacea, Gelidiopsis intricata, and two species of Polysiphonia.

Piti Channel and Commercial Port--Twenty-one species of benthic algae and two species of sea-grasses were recorded from the Piti Channel and Commercial Port areas (Table 9). All of the algae are typical of lagoon situations adjacent to a large land mass with freshwater runoff. None of the algae or sea-grass can be considered as endangered or threatened species.

Twelve species of algae and one species of sea-grass were present in the outfall lagoon which is characterized by its warmer surface water caused by the effluent from both the Piti and Cabras thermal outfalls. The algal communities here were by no means homogeneous but rather reflected the thermal gradient from the outfalls to the channel. Station I, adjacent to the Piti outfall, is a sandy shallow area about 1 m deep which possessed (N=20) a luxuriant growth of Padina tenuis (71% cover) in association with Dictyota bartayresii (9% cover) and Gracilaria salicornia (1% cover).

Padina tenuis was present in two forms--the branching "vaughaniella" stage (36%) and the large foliose form (35%) with some individuals measuring up to 7 cm high and 10 cm broad. The "vaughaniella" stage was more prominent in water 2-3 m deep off the Cabras outfall (Sta. IV) where this alga was found in association with clumps of Halimeda opuntia, and stands of Halophila minor and scattered individuals of Avrainvillea obscura. The periphery of the outfall lagoon supported a different algal community. Spyridia filamentosa and Avrainvillea obscura were conspicuous along the northwest edge (Sta. II), whereas turfs of Polysiphonia were present on cobbles at the southeast edge (Sta. III) on the silty bottom. The blue-green alga Microcoleus lyngbyaceus was the only alga present on the concrete walls near the entrance (Sta. V) of the outfall lagoon.

Only four species of algae were seen in the channels. Large clumps of the green calcareous alga Halimeda opuntia covered approximately 20% of the channel bottom. Some clumps measured 6 m across and 0.5 m deep, and appeared as micro-islands on the silty bottom. Long hair-like strands of Microcoleus lyngbyaceus were prominent along the channel walls. Fewer clumps of Halimeda opuntia were present in the secondary channel (Sta. VII) than in the main channel (Sta. VI).

Algae covered less than 1% of the tidal sand flats at Station VIII. Polysiphonia sp. was present on the few isolated dead coral heads; Padina tenuis was present in small patches where coral rubble occurred. Sand-inhabiting algae, e.g., Avrainvillea obscura, Halimeda macroloba, and H. opuntia, and the sea-grasses Enhalus acoroides and Halophila minor were present but exceedingly rare on the tidal flat. This tidal flat is exposed during extreme low tides.

The reef area near the entrance of the channel seems to serve as a depository for the silt exiting the channels and, thus, is extremely murky at times. The algal communities at two sites (Stations IX and X) were quantified. In addition, two other species, i.e., Dictyota bartayresii (8%) and Caulerpa racemosa (4%) were found in Station IX, but not in Station X.

Species	Sta.IX (N=20)	Sta.X (N=20)
Turf comprising of Gelidiopsis intricata, Polysiphonia sp., Hypnea esperi, Jania capillacea	58%	79%
Padina tenuis (All "vaughaniella" stage)	14	4
Halimeda opuntia	13	5

Jade Shoals--Jade Shoals is a large patch reef where only 37% of the substratum (N=25) is covered by algae. Fine sand (31%) and coral rubble (31%) make up the remaining shoal. Dictyota bartayresii (14%), Padina tenuis (11%), algal turf (8%), and Lobophora variegata (4%) were the dominant algae on the shoal. The turf was comprised mostly of Laurencia sp. and the sporophyte generation of Asparagopsis taxiformis, with a few filaments of Jania capillacea, Polysiphonia sp., and Centroceras clavulatum intermixed. Tydemannia expeditionis was only present on the edge of the shoal. Dictoyota bartayresii was the only alga seen on the upper slopes in water 3 m deep.

2. Corals

Sasa Bay--In general, the shallow reef-flat platforms at the eastern end of the bay (Stations A-E, G, N and P) were barren of living corals where turbidity and sedimentation are greatest, although corals are absent on much of these platforms because of reef surface exposure during low tides. Stations located around the central part of the bay (Stations H-J, R, and S) support a poor to moderately diverse community of corals (5 to 32 species, Table 10), whereas the stations at the western end of the bay (Stations K and T) were most diverse (55-68 species, Table 10). It is interesting that the attenuation of coral diversity and dominance from eastern to western stations follows a similar gradient of high to low levels of sedimentation and turbidity from the eastern to western end of the Bay (Fig. 2). Visibility at Station R, the most eastern station where corals occurred, was less than one meter and a thin film of mud and silt covered the rocky substratum at most places, whereas at Station K, the most western station, visibility was 2-4 meters and thin patchy sediments on the rocky substratum consisted mostly of larger sand and rubble-sized bioclastic sediments instead of mud and silt. Fresh water discharge from the Sasa and Aguada Rivers during peak flows may also be inhibiting coral growth on some of the eastern stations but large in situ dead colonies suggests that corals grew there in the recent past. In order of abundance and tolerance to high levels of sedimentation and turbidity, the most common corals on the shallow platforms are Porites lutea, Pocillopora damicornis, Leptastrea purpurea, Montipora lobulata, and Montipora ehrenbergi.

Greatest coral diversity and dominance occurs on the slopes between the shallow patch and fringing reef-flat platforms and the lagoon floor. Surface relief on the slopes is irregular, consisting of large (up to a meter) dead and living colonies interspersed with smaller dead and living corals, coral-algal-mollusk rubble, sand, and mud. Downslope the mud and sand fraction becomes more abundant and living and dead coral colonies less abundant (Fig. 2). Slumping is evident at places, particularly at the western end of the bay where the slopes are longer and steeper, which accounts for the presence of some large disoriented colonies on the lower slopes and allows for the population of soft muddy substrates which would not otherwise be colonized. Most of the coral species commonly found on the shallow patch and fringing reef-flat platforms are also found on the deeper lagoon slopes, but here they reach a much greater size. Other common corals more or less restricted to the lagoon slopes are large ramose mounds of yellow and brown Porites andrewsi, yellow-brown columnar and explanate masses of Montipora spumosa, large columnar yellow to blue-grey-brown clumps of Porites (S.) iwayamaensis and Porites (S.) convexa, irregular twisted and contorted dark brown colonies of Porites (S.) horizontalata, and greyish brown knobby clumps of Galaxea clavus. Montipora spumosa is a unique coral to this habitat and to date has not been found elsewhere on Guam. Quite abundant but small in size and inconspicuous are the pea-sized colonies of Stylaraea punctata which grow on the underside of loose rubble at the upper part of the slope and Stylocoeniella armata patches which form small thumb-sized encrustations in shaded overhangs, holes, and projections. In general the diversity and dominance of the corals in this zone follows the same distribution pattern, in relation to sedimentation and turbidity levels, as that previously described for the shallow reef-flat platforms. Colony size, and diversity is somewhat reduced at places around Stations K and T where the natural slopes have been altered by dredging.

Jade Shoals--Because of considerable rubble areas lacking corals on the northernmost patch reef the overall percentage of coverage for the upper reef surface was only 4.6%, even though high dominance was found along the northwest side (Table 11A). Coral density was similarly quite variable with the overall value being 159 per 100 m . Although coral dominance and density were not measured on the southernmost patch reef, observations there revealed that these parameters are probably greater. In order of abundance, the most commonly occurring corals on the upper patch reef surface were Porites lutea in overall distribution, Porites (S.) iwayamaensis and Porites (S.) convexa which dominate the surface at the northwest end of the northernmost patch reef and in general along the peripheral margin of both patch reefs, Millipora dichotoma in dense clump on small knobs and knolls scattered over the surface of both patch reefs, and Porites andrewsi which is most predominant around the peripheral margin of both patch reefs. Psammocora contigua forms conspicuous grey-brown clumps locally on the south end of the northernmost patch reef and more widespread and scattered on the southernmost patch reef. Montipora species, except for a few scattered colonies of Montipora lobulata and Montipora sp. 1, were conspicuously uncommon on the northernmost patch reef and only slightly more abundant on the southernmost patch reef.

Coral distribution on the patch reef slopes is quite variable from place to place depending upon depth, topography, and degree of disturbance from previous dredging activities. In general greatest coral dominance and diversity were found on the upper part of the slopes where they grade into the shallow patch reef surface, and a general decrease was observed when measuring depth (Fig. 2). The southeast slope of the northernmost patch reef has been altered by dredging and coral diversity and dominance is reduced considerably. The upper slopes at the northwest side of both patch reefs are more diverse and have greater coral dominance than at other locations;arborescent Acropora thickets first start appearing here, and at the north patch reef this region is dominanted by Porites (S.) iwayamaensis and Porites (S.) convexa which form an almost unbroken expanse of even-topped columnar colonies. Down slope both coral diversity and dominance decrease as more surface area is occupied by finer grained sediments and turbidity increases (Fig. 2). Slumping is evident where slopes are steep and deeper water species such as Pavona praetorta, Pachyseris speciosa, Leptoseris incrustans, Leptoseris mycetoseriodes, Herpolitha limax, and Mycedium sp. 1 make their appearance. The deep slopes of Jade Shoals is the only location on the island where Pectinia lactuca has been found to date. Corals become widely scattered and patchy in occurrence where the slope flattens out to the lagoon floor. Porites (S.) horizontalata appears to tolerate high levels of sediment accumulation and is the most common coral on the deeper slopes. As the plastic mud of the lagoon floor is encountered corals are absent except on an occasional small patch of hard substratum here and there.

Piti Channel and Commercial Port--Fifteen stations were investigated for corals in this study area (Fig. 1). At Station 1 through 5, 8, and 14 no living corals were found; at Stations 6, 7, 9, 10, and 13 only one to four colonies of Porites lutea were observed; and at Stations 11 and 12 widely scattered colonies of Porites lutea and an occasional colony of Pocillopora damicornis were found. Corals are scattered to locally very abundant on the upper surface and sides of patch reefs at Station 15 where eleven species were recorded.

At the eastern end of Piti Channel water temperatures are elevated because of thermal discharge from power plants, which except for a few tolerant species probably prevents recolonization of corals. Local areas downstream from the thermal discharge areas would probably be favorable for a few coral species except that strong currents and some kind of burrowing organisms keep the bottom sediments from becoming stabilized in the main part of the channel and competition from dense algal growth prevents successful larval settlement and development in more stable adjacent regions. Several Porites lutea colonies transplanted to a sunken wooden barge in this area by J. E. Doty are growing successfully and becoming attached to the hull by basal growth. Previous field investigations (unpublished records, RHR, 1967) made in the vicinity of Station 9 on the submerged structure of a submarine railway revealed the presence of greater coral development than now. A few living colonies of Porites lutea were found on the deepest part of the railway during this study, but a number of larger dead Porites colonies up to 30 cm dia. were also observed which were presumably those observed earlier in 1967. Possibly these colonies were killed during the land-filling activities and construction of the Cabras Island Power Plant, but no documentation to this effect was noted.

At Station 15 a number of mounds and patch reefs support a community of corals composed of 11 species (Table 10). Coral distribution is quite irregular, with some mounds scarcely populated at all while others are dominated almost completely by living corals. Porites lutea is the most widespread species in the area, but Pavona frondifera is the most dominant (Table 11B). The upper surface and slopes of some mounds were completely covered by this folicaeous Pavona species which to date is the only record of its occurrence on Guam. Even though the lagoon floor between these patch reefs and mounds is composed of soft plastic mud and lacks corals, the overall dominance was higher here (20.6% coverage) because of the presence of extensive beds of Pavona frondifera than at Jade Shoals (4. 6% coverage) where the diversity of corals was an order of magnitude higher.

In summary, Jade Shoals was the most diverse area in this study with 94 species and 39 genera of corals recorded (Table 10). Twenty species of corals were recorded there that were not found at either Sasa Bay or Piti Channel. Although Jade Shoals has the smallest area of the three study areas, the overall levels of sedimentation and turbidity are lower and conditions for coral settlement, growth, and development greater than at the other two areas. Pectinia lactuca is a unique species found on the lower slopes of Jade Shoals, in that it has not been recorded elsewhere on Guam.

Sasa Bay is the largest of the three study areas with 88 species and 31 genera of corals recorded (Table 10). Thirteen species of corals were found in this area that were not recorded at either Jade Shoals or Piti Channel. Montipora spumosa has not been recorded from any other locality on Guam, although it was fairly widespread and common at stations located in the western part of the bay (Table 11). Because of the rivers emptying into the eastern end of the bay the levels of sedimentation and turbidity were greater here than at either Jade Shoals or Piti Channel. Before the land-filling of Dry Dock Point, Pol Causeway, and Polaris Point and the dredging at the west end of the bay, this area probably supported one of the most diverse coral communities on Guam. The presence of numerous patch reefs, submarine mounds, and a fringing mesh reef enclosing a number of secondary lagoons in this region also indicates a previous period of reef development that is not so evident today.

Piti Channel has been altered more by dredging, land-filling, and construction than any other part of the study area. This region was once a natural channel or pass that connected the eastern end of Apra Lagoon with the Philippine Sea and examination of sediments and dredge material indicates the presence of a previous coral community that was quite diverse and well developed. The small area of patch reefs located at Station 15 (Fig. 1) is responsible for over 80 percent of the 11 species recorded from this area. Greater dominance of corals was measured at this transect than at Jade Shoals. Although only the upper reef surface was quantitatively sampled at Jade Shoals, time did not permit the sampling of the upper slopes which qualitatively appear to have a greater surface of corals than the patch reefs at Station 15 in Piti Channel. The unique feature of Piti Channel is the presence of Pavona frondifera at Station 15 which has not been recorded elsewhere on Guam, but here is the dominant species present. The relative richness of the coral community at Station 15 is best explained as a local region which hasn't been disturbed to the same degree as other parts of the channel and the corals present represent a relict community from an area that once supported a considerably more diverse and developed community.

In general, corals are absent on the lagoon floor habitats where soft plastic mud and the presence of burrowing organisms that are responsible for developing the widespread cone-and-funnel topography are found. Successful coral settlement on soft sediments is unlikely, but even if some do become established on small intermixed larger sized fragments of rubble the rapid turnover of sediments from burrowing organisms would rapidly bury the newly settled coral planulae.

Corals are best developed on the steep upper slopes of patch and fringing reefs where sediments are least likely to accumulate. A distinct gradient of decreased coral diversity and dominance was found with increased depth on these slopes which correlates well with increasing rates of sedimentation and decreased available light. Light can not be the limiting factor completely, though, because in habitats where turbidity levels were high, specific corals could be found if stable hard substrates were available. Coral diversity and dominance also increases in a horizontal gradient from the habitats near river mouths where high levels of sedimentation and turbidity occur, to more distant habitats away from such an influence.

Within the entire study area a total of 110 species representing 40 genera were recorded. Although this is a remarkably high number of species considering the high levels of sedimentation and turbidity and degree of prior disturbance by land-filling, dredging, and construction, the total number of species could probably be increased by 15 percent with a more thorough investigation.

3. Macroinvertebrates

Sasa Bay--There is a noticeable zonation of invertebrates in Sasa Bay from the mangrove shore (Stations A, A', B, C, G) seaward to Station K (Fig. 1). Along the shore at the north, east and south sides, the mangrove community dominates, salinity is lower than normal seawater, and the water is more turbid. Stations I, J, and K had the clearest water and the most normal salinity. The fauna associated with these changes are typical of the areas. The mangrove area had a typical crustacean and mollusk association. Stations I, J. and K had the most diverse fauna (Table 12), consisting primarily of large sponges and shallow-water crustaceans. Station L was most atypical because of its disturbed (oil-covered) nature; however, several intertidal crabs were collected.

Stations A-E were all in mangrove communities; Stations A-C were very similar (Fig. 1). Mangrove growth tended to be dense at A and becoming more sparse towards Station C. The substratum at all three stations was composed of thick mud and silt and the water visibility was poor. At Stations A and B at the Sasa River mouth area and just north of the river the salinity was 31°/oo. At Station C (Fig. 1), the salinity was 34°/oo. The only gastropod noted at all three stations was the high intertidal littorine <u>Littorina scabra.</u> It was found attached to the mangal prop roots and on mangrove leaves above the high tide level. The oyster <u>Saxostrea</u>

mordax was also found attached to the prop roots, though below the high tide level and in decreasing abundance from Station A to C. Other species present in abundance were fiddler crabs (Uca sp.), grapsid and portunid crabs, cerithiid gastropods (only at Stations A and B), and the mud-skipper fish (Periophthalmus koelreuteri). The substratum was covered and composed of sediments with sand, mollusk rubble, and volcanic rock. At Station C, there were numerous crab burrows, fewer oysters on roots than at A or B, but with Periophtalmus koelreuteri and with sediments with lime below the surface layer.

Many freshly broken fragments from the oyster and from the bivalve Gafrarium tumidum were found at Station B which may indicate predation by the mangrove crab Scylla serrata (this crab has been traditionally caught in this area, though none were seen during this study). Station B had many thick, black, tar-like deposits covering the substratum (cf. GEPA 1976:93). Some of these deposits were as large as 4 m^2. Also noted at Station B were the gastropod Cerithium sp. (numerous) and the burrows of the land crab Cardisoma sp.

Stations D and E had a more consolidated substratum, mostly sand, and the water was less turbid. The plant community on shore at Station D was composed predominantly of Avicennia at the shore and Rhizophora further inland. Station E was near the attenuated end of the mangrove community. The salinity was 30°/oo at Station D and 34°/oo at Station E. Only one root branch was found with oysters. A few individuals of Littorina scabra were found on Avicennia leaves at Station D and Cerithium sp. were noted on the prop roots of Rhizophora at Station E. The bivalve Gafrarium tumidum was found in this zone and sampled as will be discussed below. Other invertebrates noted were the portunid crab (Thalamita crenata) and an unidentified grapsid crab found to be eating a small fish in a mangrove tree.

Stations F, H, and I were all part of patch reefs within the bay. A layer of silt covered the substratum at all three stations, though siltation at Station I was less and was probably due to its more seaward location. The salinities at Stations F, H, and I were 31°/oo, 34°/oo and 35°/oo, respectively. Station F had some isolated live coral patches and a few mollusks including Chicoreus penchinati, Morula (Cronia) margariticola, and Septifer bilocularis. None of these were common. Other invertebrates included the purple sponge, the black didemnid ascidian, and the shrimp associated with gobies.

Station H had a loose rubble substratum and was heavily silted. The bivalves Malleus malleus and Arca ventricosa were very common as was the gastropod Cymatium gutturnium. This station had two other notable occurrences. One of these was the presence of the coral Porites sp. with fresh scars characteristic of parrot fish grazing. The other was the collection of the oyster Pinctada martensii; the species used in the cultured pearl industry of Japan. A number of sponges and ascidians were present on the undersides of a few loose flat-topped boulders.

Station I was in a more exposed location and had many live corals and fishes. The soft coral Sinularia polydactyla and a number of sponges were common. Malleus malleus was common though not as abundant as at Station H. The gastropod Morula (Cronia) margariticola was found amongst the loose coral rubble and the sponge Cinachyra australiensis was also common. Pholadid bivalves were common in the substratum (20-30/0.2m^2 for 5 samples).

Station G was located in the shallow water that forms the mouth of a small tributary (the Aguada River) emptying into the bay. Avicennia and Rhizophora occupied the shore. The substratum was a thick, black, anaerobic mud composed of decaying organic litter and various molluscan fragments. The salinity was 32°/₀₀. Littorina scabra was noted on the Rhizophora and Avicennia and a small black grapsid crab was observed also on the mangrove trees. A few oysters were present on the mangrove roots.

Station J (salinity 35°/₀₀) was located in a sandy area with some isolated coral patches. Porites microatolls had much evidence of fish grazing. Soft corals, Sinularia polydactyla, were very common. Sponges, bivalves, and the hermit crab Dardanus megistos were observed.

Station K had greater exposure to the ocean than any other station sampled. The salinity was 35°/₀₀. This was where the greatest variety of gastropods was found. These included the strombid Lambis lambis (common) and the muricids Drupella cornus, and Chicoreus penchinati. The sea cucumbers Holothuria bivittata and H. argus, were noted only at this station. Numerous sponges, soft corals (Sinularia polydactyla), and solitary ascidians were also present.

Station L (salinity 34°/₀₀) was a shore collection. Invertebrates were mainly planaxid gastropods and xanthid and grapsid crabs. A small portunid crab was also collected. The only bivalve observed was Malleus malleus. Nerita nor Littorina were found.

Station M was at the innermost part of a small cove. The substratum was a fine silt with a lower anaerobic ooze.

Invertebrates included abundant *Cerithium* sp. and numerous ghost crab burrows. A small portunid crab was also collected.

Bivalve mollusks are usually the prevalent invertebrates in sheltered soft substratum bays and so a special effort was made to sample the Bivalvia in Sasa Bay. *Gafrarium tumidum* occurred only in patchy areas. Where individuals of *G. tumidum* were fairly abundant, the mean density was 14 m^2; s=1.0 (n=10, 0.1 m^2 quadrats). The shell-free wet weight biomass was 8.0 gm/m^2. *Saxostrea mordax* was more abundant and was found profusely covering most solid surfaces in the upper 0.5 m of water in Sasa Bay. On one such flat surface we counted these oysters in ten 56.3m^2 quadrats and got a mean of 14.2 ± 3.74. This number per 56.3 cm^2 implies a population density of 2,500 per m^2 ± 665 per m^2. The average shell-free wet weight (meat) biomass is therefore about 636 g per m^2 ± 426 g (roughly 1.5 pounds shell-free wet weight per square meter).

Scattered among the clumps of *S. mordax* were numerous small *Septifer bilocularis* which numbered approximately 8,670 per square meter. The biomass of *Septifer bilocularis* was not determined since these bivalves were too small (<1 cm) to be of economic value.

The bivalve species that appeared most successful in Sasa Bay were attached to solid surface above the muddy bottom. Of the common bivalve species, only *Gafrarium tumidum* was infaunal.

Crustaceans were also sampled quantitatively. Among mangrove communities *Uca* sp. was locally abundant. A mean density of one patch was 22 crabs per m^2 ± 14 crabs (n=20). We also found one isolated clump of about 5,000 hermit crabs *Clibanarius striolatus*. Nowhere else did we find these hermit crabs in our 2-1/2 hours of searching. This implies a significantly clumped distribution. Barnacles were limited to the solid substrata above the sea floor. Approximately 760 *Chthamalus* sp. per square meter were found on an oil barrel.

In general, the inner part of the bay, A-H, are characterized by heavy siltation and turbid water. In many areas the substratum is composed solely of thick silty muds which are often anaerobic. The molluscan fauna is sparse except for *Littorina scabra* found attached to vegetation above the high tide line at Stations A-E and G; *Malleus malleus* and *Cymatium gutturnium* at Station H; and the occurrence of *Gafrarium tumidum* at Stations D and E.

The outer stations, I-K, are much less silty and have a more diverse assemblage of gastropods as well as corals and associated fishes. There were also more different species of gastropods noted at the outer stations. It is believed the disparity between the molluscan fauna of the inner and outer areas is greater but due to time limitations the inner area was more intensively sampled (8 stations) than the outer (3 stations).

The fine sediments of Sasa Bay appear to be a likely habitat for infaunal and semi-infaunal bivalves. However, very few infaunal bivalves are found. Rhoads and Young (1970) found a similar occurrence in areas of heavy sediment deposition. If sediments accumulate rapidly, then bivalve larvae may have difficulty settling. An abundance of attached bivalves indicates the productivity of Sasa Bay.

Piti Channel and Commercial Port--Macroinvertebrates showed very clumped distributions in Piti Channel and Commercial Port as already emphasized in the distribution of crustaceans in Sasa Bay. Although quantitative samples were taken, the great abundances of species in some areas and their absence from most other areas makes it a great waste of space to present data in tabular form. Therefore, information on macroinvertebrates taken at stations in Piti Channel and Commercial Port areas (Fig. 1) will be given in paragraph form.

At Station 2 (Fig. 1) the substratum was composed of compacted sand and silt, vertical down to the low tide level. Twenty-eight 0.01 m^2 quadrats were taken to count <u>Macropthalmus</u> sp. (crab) burrows in a colony of 65 m^2 in area and the number of burrows per quadrat was found to be 3.14 ± 2.24. This implies the colony to be composed of 20,400 ± 14,600 crabs. The burrows of <u>Cardisoma</u> sp. (crabs) and <u>Periophtalmus koelreuteri</u> (fish) were also present. <u>Littorina scabra</u> (a gastropod) was also present in Station 2.

Station 3 was in an area of gravel and rubble substratum. Thirty-two 0.1 m^2 quadrats were taken to help calculate the number of <u>Planaxis sulcatus</u> (a snail) in a 20 m^2 patch of snails. The number of snails per quadrat was found to be 2.53 ± 1.81. This implies that a total of about 5,000 ± 3,600 <u>Planaxis</u> were present in the patch. The snail <u>Nerita plicata</u> was also present, but it was rare.

Station 6 was along a seawall. <u>Cassiopea</u> sp. (a scyphozoan medusa), <u>Actinopyga</u> sp. (a holothurian), <u>Trochus niloticus</u> (a gastropod), <u>Sabellastarte indica</u> (a sabellid worm), chitons, and limpets were present at the bottom of the seawall or on sediments at the base of the seawall. A large form of

Littorina scabra was common. A $5m^2$ quadrat contained 74 individuals, a $1m^2$ quadrat contained 14 and a $10m^2$ quadrat contained 44. This implied an average of 8.25 Littorina scabra m^{-2}.

Station 7 was near a seawall by the Cabras Power Plant outfall. Littorina scabra were sampled on the seawall with thre $5m^2$ quadrats and found to be in an abundance of 41 ± $17m^{-2}$.

Station 8 was in an area of gravel with scattered rubble. Thirty-two $0.01m^2$ quadrats were taken in a $100m^2$ patch of Planaxis sulcatus which were found to have a mean abundance of 6.28 ± $5.13m^{-2}$. This implies that 63,000 ± 51,000 Planaxis were present in the patch.

Two species were sampled separately at Station 9. On the hard-packed supratidal sand area, a $210m^2$ colony of Uca (Amphiuca) chlorophthalmus crassipes (Adams and White) was sampled with 32 samples ($0.25m^2$ each). The mean abundance was found to be 5.28 ± 2.90. This implies a total population of 4400 ± 2400 fiddler crabs in this single colony. On a sand, gravel, and rubble substratum at Station 9, thirty-two $0.01m^2$ quadrats were taken in a $16m^2$ patch of Planaxis sulcatus. The mean abundance was found to be 3.53 ± 2.11 which implies that the population constituting the patch was 5,600 ± 3,400.

On a substratum of gravel and rubble at Station 10, two large patches of Planaxis sulcatus were each sampled with thirty-two $0.01m^2$ quadrats. The larger patch ($100m^2$) contained an average of 6.81 ± 3.77 Planaxis per quadrat for a total of about 14,600 ± 8,500 Planaxis in the patch. Nerita polita were also present in the area but scarce. In deeper areas at this station, the prevalent organisms included the holothurians Bohadschia bivittata and Euapta sp., an aggregation of urchin Diadema sp., stomatopods, and the gastropod Lambis lambis.

Another patch of Planaxis sulcatus was found at Station 11 and thirty-two $0.01m^2$ quadrats were taken. The mean abundance per quadrat was 5.38 ± 4.20.

In an area of small boulders, rubble, and gravel at Station 12, we found Nerita reticulata, a species which is usually rare. We also found a $20m^2$ patch of Cerithium moras and took thirty-two $0.01m^2$ quadrats. The average abundance was 8.0 ± 4.4 per quadrat suggesting a total population of about 16,000 ± 8,800. On the north side of the steep-sided fill islet at Station 12, Planaxis sulcatus was rare. On the rubble substratum of the south side of the islet, a

12m patch of Planaxis sulcatus contained a population with an average density of 11.0 ± 5.2 Planaxis per $0.01m^2$ quadrat (n = 32). The population must have contained about 13,000 ± 6,200 Planaxis.

A $10m^2$ area of Uca (Thalassuca) vocans burrows were found in the supratidal sand substratum at Station 14. Seventeen $0.25m^2$ quadrats were taken and a mean density of burrows was found to be 3.29 ± 2.42 burrows per quadrat. If we assume one crab per burrow, the population must contain about 130 ± 97 crabs.

Station 15 was a patch reef with a remarkably extensive coral cover. The coral community was not diverse, but large monospecific clumps of coral covered extensive areas. As mentioned above in the section on corals, one of the patches is composed of a coral species found nowhere else on Guam. This area is particularly interesting for ecological studies because of the extent to which the coral community exists in monoculture patches.

One hundred $0.25m^2$ quadrats were taken at Station 15. Most of the quadrats that did not land on coral contained only rubble, Halimeda, Padina, Dictyota, and other algae. Six of the quadrats contained the sponge Cinachyra australiensis with 2.5 ± 1.4 sponges per quadrat that contained any. The sponge Terpios sp., the holothurian Holothuria atra, and a social corallimorpharian anemone were each found in three quadrats. The gastropod Lambis lambis and the feather-duster worm Sabellastarte indica were each found in two quadrats and the bivalve Malleus malleus, the soft coral Sinularia polydactyla, and a hermit crab were found in only one quadrat each. Two individual Diadema and one large aggregation of Diadema were also observed but this species never occurred in any of the one hundred quadrats.

Jade Shoals--Fifty $0.25m^2$ quadrats were taken for macro-invertebrates on the upper surface of Jade Shoals at $1.3m^2$ depth. The black sponge Terpios sp. was present in eight of the quadrats, and the soft coral Sinularia polydactyla, the gastropod Trochus nilotica, the gastropod Conus sp., and the holuthurian Holothuria atra were found in only one quadrat each. Also observed on the upper surface of Jade Shoals, but not occurring in the quadrats were: the sponges Cinachyra australiensis and Sponge sp. 2, the urchin Diadema sp., the holothurian Bohadschia argus, the asteroid Linckia laevigata, a large black-and-blue predatory opisthobranch and the gastropod Cerithium sp. Most of the horizontal surface was covered by rubble and algae.

Twenty-five 0.25m quadrats were taken for macroinvertebrates along the vertical walls and undersides of overhangs at 2m depth on Jade Shoals. The bright yellow solitary tunicate Ascidia gemmata was prevalent and found in ten of the 25 quadrats with a mean abundance of 4.8 ± 2.8 in those ten quadrats in which it was found. Sponge sp. 2 was found in two of the quadrats. A light blue tubular sponge, the black sponge Terpios sp., a yellow, red and blue zoanthid anemone, the soft coral Sinularia polydactyla, a bright yellow didemnid tunicate, and the gastropod Lambis lambis (on a shelf), were each found in only one of the 25 quadrats. Ophiothrix was abundant along the vertical walls. These ophiuroids are suspension feeders that reach their arms out of crevices in the walls.

The vertical wall at Jade Shoals gives way to a sloping substratum of living corals, coral rubble and sediment between the depths of 8 and 14m. Many suspension feeders are prevalent in this area including the light blue tubular sponge Sponge sp. 2, Terpios sp., Sinularia polydactyla, Ophiothrix sp., Ascidia gemmata, a clear social tunicate,and a bright yellow didemnid. A very large (28 cm diameter) cushion star Culcita novaeguiniensis was also observed at this depth.

The soft coral Lobophyton sp. was observed below 15m and Sinularia and Lobophyton were both found to 30m. Several gigantic zoanthid polyps (probably Palythoa sp.) were found at a depth of 21m and were measured to be 50 cm in diameter. Ophiothrix extended arms for 30 cm from crevices which implies that they were at least 60 cm in diameter (arm-to-arm-tip. Ascidia gemmata was abundant on scattered rubble clear to 30m where the soft sediment bottom was predominantly occupied by burrows from the shrimp-goby association.

4. Fishes

Sasa Bay--A brief survey of the fishes of Sasa Bay was made on November 20, 1976. Visual cenusing was used on the coral-dominated reef areas near the mouth of Sasa Bay. Further to the east in the bay, the silt suspended in the water reduced visibility to a few inches and no fishes could be observed. Several fish traps are being operated in Sasa Bay, and the catch of two of these traps was examined and the species listed.

A beach seine was used to sample fishes adjacent to two beaches near the mouth of the bay.

The following species of fish were observed associated with coral reef structures in Sasa Bay.

Acanthuridae
- _Acanthurus xanthopterus_ Cuvier and Valenciennes
- _Ctenochaetus striatus_ (Quoy and Gaimard)

Apogonidae
- _Paramia quinquelineata_ (Cuvier and Valenciennes)
- other unidentified cardinal fishes

Blenniidae
- _Meiacanthus atrodosalis_ (Gunther)
- other unidentified blennies

Chaetodontidae
- _Chaetodon auriga_ Forskal
- _C. bennetti_ Cuvier
- _C. ulietensis_ Cuvier

Gobiidae
- _Amblygobius albimaculatus_ (Ruppell)

Labridae
- _Hemigymnus fasciatus_ (Bloch)
- _H. melapterus_ (Bloch)
- _Stethojulis bandanensis_ Bleeker
- juvenile labrids

Lutjanidae
- _Lutjanus vaigiensis_ (Quoy and Gaimard)
- _Scolopsis cancellatus_ (Cuvier and Valenciennes)

Pomacentridae
- _Abudefduf coelestinus_ (Cuvier)
- _Amblygliphidodon curacao_ (Bloch)
- _Dascyllus aruanus_ (Linnaeus)
- _Eupomacentrus albifasciatus_ (Schlegel and Muller)
- _E. lividus_ (Bloch and Schneider)
- _Glyphidodontops leucopomus_ (Lesson)

Scaridae
- _Scarus sordidus_ Forskal

Siganidae
- _Siganus spinus_ (Linnaeus)

Synodontidae
- unidentified lizard fish

Zanclidae
- _Zanclus cornutus_ (Linnaeus)

Many unidentified lavae and juvenile fishes

These reef areas were not especially rich in fishes, although there are probably considerably more species of fishes present in these areas than were observed during this brief survey.

In the two fish traps examined the following fish species were seen:

Acanthuridae
    Acanthurus xanthopterus Cuvier and Valenciennes
Carangidae
    Scomberoides santi-petri (Cuvier)
    Caranx melampygus Cuvier
Diodontidae
    Diodon hystrix Linnaeus
Holocentridae
    Flammeo sammara (Forskal)
Leiognathidae
    Gerres argyreus (Block and Schneider)
Siganidae
    Siganus spinus (Linnaeus)

It was not known for how long the trap had been operating since the catch was last removed so no rate of catch could be calculated for the fish traps.

A few species were collected by beach seining:

Gerres argyreus (Bloch & Schneider)
Hyporhamphus dussumieri (Valenciennes)
Kuhlia represtris (Lacepede)

Mullets of an undetermined species were seen leaping out of the net as the net was brought on to the beach.

Preliminary observation revealed a rather small number of fish species. However, observation was hampered by the poor underwater visibility, and a considerably larger number of species may have been present. The presence of five fish traps in this bay indicates the presence of a moderate number of food fishes in this area. There appeared to be a rather large number of juvenile fishes of various species in Sasa Bay. It might be well to direct studies to determine whether Sasa Bay is a nursery area for developing fishes.

Piti Channel Commercial Port--Three parallel transects, totalling 190m, were censused in the area just inside the zone dredged for Commercial Port (Table 13). The substratum showed a zonation which, proceeding from the Commercial Port end, consisted of a Padina zone, a Dictyota zone, a Halimeda zone, a Pavona zone, and a zone of scattered coral heads, dead coral, and silt. The Padina, Dictyota, and Halimeda zones had few fishes. The Pavona zone had considerably more species, and large numbers of some forms, particularly Chromis caerulea, Dascyllus aruanus, Apogon compressus, and juvenile cardinal fishes (Apogonidae). The zone of scattered coral heads and silt had a moderate number of species in relatively low abundance, except for a large concentration of young cardinal fishes among the spines of the urchin Diadema. The Piti backwaters may provide refuge for these juvenile fishes until they mature and recruit to other communities.

Jade Shoals--The fish fauna at Jade Shoals is fairly diverse (Table 13). Many of the fish species found here are plankton feeders, especially the more abundant ones. Schools of the plankton feeding fusilier Caesio caerulaureus were observed feeding in the waters at the edge of Jade Shoals. The fish community at 10 meters appears to be more abundant than the community along the top of the reef.

5. Zooplankton

The tows taken on different phases of the tide cycle in the Piti secondary channel show no clear indication of tide-related differences in the zooplankton community (Table 14). The greatest variation is caused by the unusually high abundance of crab zoeae on the first ebb-tide collection which was not observed on the replicate tow made some 15 minutes later. The major difference between the ebb-and flood-tide collections appears to be the relatively high abundance of gastropods in the latter collections. The largest concentration of gastropods, based on the December 17 sampling, is in the Commercial Port area (Table 15), and these may be exported into the secondary channel during flood tide. As the Piti secondary channel appears to the area of most marked tide-related fluctuations in current direction, the general lack of tidal variation in the plankton communities here can probably be generalized to the whole Piti area.

Night-time catches in the outer harbor and in the Commercial Port area are significantly greater than daytime catches, while daytime zooplankton abundance appears somewhat greater in Sasa Bay (Table 15). Ostracods, copepods, and Lucifer are consistently more abundant at night, while pteropods and fish eggs are more abundant during the day. Other groups show variability in their day/night abundance in different areas.

Certain groups appear to be restricted to, or at least notably more abundant in, the outer harbor area (including Jade Shoals), particularly ostracods and chaetognaths. The zooplankton communities of the Piti area are typically dominated by crab zoeae. The Commercial Port area has high abundances of gastropods, Lucifer, copepods, pteropods, and larvaceans. Sasa Bay is characterized by abundant ostracods and chaetognaths, apparently derived from outer harbor waters, as well as crab zoeae, pteropods, and "shrimp" zoeae, more characteristic of the Commercial Port-Piti Channel area (a variety of decapod and anomuran zoeae are combined in the category "shrimp" zoeae). The ichthyoplankton shows an interesting distribution with fish eggs being restricted to the Sasa Bay, Commercial Port, and Piti areas, while fish larvae are most abundant in the outer harbor. This probably reflects the life history patterns of a number of marine fishes in which the eggs are spawned in inshore areas, and the lavae subsequently migrate to offshore waters for their growth and development. The relatively high abundance of fish eggs in the Sasa Bay, Commercial Port, and Piti areas suggest that these may be spawning areas for a number of marine fishes.

ANTICIPATED IMPACTS OF INCREASED DREDGING OPERATIONS

The circulation patterns observed in this study strongly suggest that increased dredging operations will profoundly affect the biological communities on Jade Shoals and Western Shoals. Jade Shoals may receive as much, or more, additional siltation than Western Shoals in the event of more dredging activity, but the biota of Western Shoals may be more greatly distressed. This is because the biota presently existing on Jade Shoals are already accommodated to a heavy stress from siltation and may be able to handle an increased load. (On the other hand, they may be nearing their threshold of tolerance.) The biotic community at Western Shoals is not presently as well adjusted to receiving a stress from sediments and therefore may not be able to adjust to increased sedimentation.

The faunal communities in the Commercial Port shipping lane will probably remain in much the same state as at present. If disruption occurs from increased dredging, it is probable that a faunal community similar to the present one will become reestablished. It is anticipated that the silty ooze in this area will be greatly increased, thereby providing a long term source of disruptable sediments. The full impact of dredging cannot be completely ascertained, due to the limited study period.

A coral species, Pectinia lactuca, found on the lower slopes of Jade Shoals, has not been found elsewhere on Guam. At Station 15 (Fig. 1), at the boundary of the Piti Channel and the Commercial Port area, the patch reefs are richly covered by Pavona frondifera. This species is known only from this location on Guam. These statements on the absence of these species from other locations around Guam is based on over 450 field trips to areas all around Guam dating back from the present to 1965.

In addition to siltation, dredging will cause an increase in water turbidity which will easily be an increase of an order of magnitude and is commonly as great an increase as two orders of magnitude over the present levels of turbidity (Marsh and Gordon,1974). Turbidity, like siltation, is especially detrimental to corals. A distinct gradient of species occurs from the muddy substrates and turbid water environments of the eastern part of Sasa Bay, where rivers empty into the reefs, to the western part of the bay where the water is less turbid and substrates are less muddy with a greater fraction of the sediments being composed of biogenous materials of reef origin. The number of species attenuates toward the east end of the bay with an accompanying general deterioration of ecological conditions for the growth of reef corals and reef development. The coral communities are probably adjusted quite closely to the range of environmental conditions along this gradient and would be quite vulnerable to additional stress, particularly in the form of increased turbidity in the water column and rate of sedimentation. Dredging operations produce considerable dredge spoil, which depending upon the current patterns present, would be carried to various surrounding areas. Sediments suspended in the spoil would be selectively deposited according to their size along the path of movement. The finer fractions of sediment would remain in suspension longer than the coarser fractions and thus would be carried further by the currents present and would have an effect at a greater distance from the site of dredging operations. Based upon observations of community structure in the study site, sediment accumulation of finer sized sediment fractions has a greater inhibiting effect on the recruitment and growth of corals than does the larger sized fractions. Increased turbidity levels and sedimentation rates caused by dredging would probably affect any part of the study area because of close adjustment to present stress from these two environmental factors. Greatest effect from dredge spoil would be found in areas well out into Apra Harbor, providing that current patterns were present to carry the dredge spoil there, such as the southernmost Jade Shoal patch reef and Western Shoals. These regions have lagoon coral communities which are quite diverse and have developed with relatively little influence from the effects of sedimentation and turbid water in Sasa Bay.

Further dredging in the vicinity of Commercial Port at Piti Channel would probably not have a great effect on the coral communities lying farther up the channel because the net movement of water would most likely be toward the lagoon. The principal effect here would be in dredging up a channel eastward from the present port area which would remove the rich coral located at Station 15 (Fig. 1).

The Jade Shoals area is the richest in fish species of the areas surveyed. Many of these fishes, and especially the more abundant species, are plankton feeders. This fish fauna is particularly liable to adverse impact due to increasing suspended silt in the water and the diversity of this fish community can be expected to decline if dredge-caused siltation occurs in this area.

Dredging operations are not expected to cause significant changes in salinity, temperature, NO_3-N or PO_4-N. Dissolved oxygen levels are not expected to be greatly affected because water in the area has good circulation. Ship propellors mix the water in the channel all the way from the surface to the bottom.

Siltation is a major problem for demersal species and turbidity is a major problem for plants and for animals which are symbiotic with plants. However, heterotrophic suspension feeders attached to substrata above the sediment are not adversely affected to such a great degree. Because the oyster S. mordax was found attached to most any surface in the upper 0.5m of the bay, the raft culture of oysters should be considered for Sasa Bay as an alternative economic use of this region. If we calculate that about 1-1/2 pounds of oyster meat is produced on a square meter of substrate, then using local retail store prices, the value of these oysters ranges from \$4.50 to \$7.50 per square meter. A raft 3m x 3m with sixteen 3m x 0.3m collecting surfaces suspended into the water would provide $288m^2$ of surface. Theoretically this could collect 432 pounds of shell-free oysters which if priced at a rate comparable to local prices would be equivalent to about \$1700 per raft. The area of this raft is only $9m^2$ compared to the total surface area of the bay which is about $2200,000m^2$.

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Table 1. Paths and velocities of drift drogues in outer part of Zone I, released from Point a (see Fig. 3). The directions for drogue movements represent a straight line from the starting point to the end point, even if the actual path traveled was curved. Directions indicated for drogue paths are those toward which the drogue is moving; wind directions are those from which the wind is blowing.

Date	Start Time	Outer Drift Drogue Depth-Path	Δ Time (hrs.)	Dist. (m)	Velocity m/sec.	Velocity m/hr.	Direction	Wind Dir.	Wind Vel. (knots)	Δ Tide (ft.)	Fig.
28 Dec	0755	1M-C	1.5	572	0.11	381	255	90°	7.5-9	+.63	4
		6M-D	1.5	343	0.06	229	290*				4
28 Dec	0955	1M-A	2.0	1680	0.23	840	276*	90°	10	+.52	5
		6M-B	2.0	663	0.09	331	285**				5
28 Dec	1215	1M-C	.5	535	0.30	1070	278	90°	10	+.12	5
		6M-D	1.0	274	0.08	274	264			+.25	5
29 Dec	0700	1M-A	2.75	887	0.09	323	250*	60°	10-14	+1.47	8
		6M-B	2.75	530	0.05	193	235*				3
4 Jan	1525	1M-C	2.0	1130	0.16	565	257	90°	9-13	+.30	12
28 Dec	1322	1M-E	1.5	1705	0.32	1137	282*	90°	10-14	-.25	5
								to			
		6M-F	2.0	759	0.11	379	290**	60°			5
29 Dec	1000	1M-A	1.5	1797	0.33	1200	259	60°	10-16	-.13	9
								to			
		6M-B	2.5	1728	0.19	691	269	90°		-.16	9
4 Jan	0825	1M-C	1.5	978	0.18	652	247*	90°	4-8.5	-.30	10
		12M-D	1.5	366	0.07	244	238*				10
4 Jan	1135	1M-C	1.5	1189	0.22	792	253	90°	5-10	-.20	11
		12M-D	3.42	617	0.05	180	248	90°	5-13	-.20→+.27	11
		d-d'	1.5	320	0.06	213	238	90°	5-10	-.20	11
		d'-d"	1.92	297	0.04	155	248	90°	5-13	+.27	11

*Indicates a curved path.

**Indicates a dog-leg path.

Table 2. Paths and velocities of drift drogues in inner part of Zone I, released from Points b and c (see Fig. 3). The directions for drogue movements represent a straight line from the starting point to the end point, even if the actual path traveled was curved. Directions indicated for drogue paths are those toward which the drogue is moving; wind directions are those from which the wind is blowing.

Date	Start Time	Outer Drift Drogue Depth-Path	Δ Time (hrs.)	Dist. (m)	Velocity m/sec.	Velocity m/hr.	Direction	Wind Dir.	Wind Vel. (knots)	Δ Tide (ft.)	Fig.
28 Dec	1308	1M-C	2.0	1097	0.15	549	272*	60° to 90°	10-14	-.19	6
		6M-D	2.37	343	0.04	145	262			-.22	6
28 Dec	1530	1M-A	2.5	1564	0.17	625	255	60-90°	8-12	-.76	7
		6M-B	2.5	457	0.05	183	271*				7
29 Dec	1005	1M-C	2.0	1287	0.18	643	266*	60-90°	10-18	-.13	9
		6M-D	3.17	663	0.06	209	266			-.20	9
4 Jan	0830	1M-A	.53	150	0.08	285	235	90°	5-8.5	-.11	10
		6M-B	1.08	110	0.03	102	218			-.12	10
4 Jan	1020	1M-E	.5	147	0.08	293	240	90°	5-10	-.05	10
		6M-F	.5	115	0.06	230	270				10
4 Jan	1140	1M-A	1.5	1273	0.24	848	264	90°	5-13	-.20	11
		6M-B	2.33	805	0.10	346	251*			-.20→+.13	11
		b-b'	1.5	503	0.09	335	271			-.20	11
		b'-b"	.83	302	0.10	364	251			+.13	11
28 Dec	0800	1M-A	1.67	585	0.10	350	282	90°	7.5-9	+.63	4
		6M-B	1.5	210	0.04	140	272				4
28 Dec	1000	1M-A	3.0	1554	0.14	517	271	90°	10-16	+.77	6
		6M-B	3.0	457	0.04	152	271				6
29 Dec	0655	1M-C	2.92	1125	0.11	385	259*	60°	10-14	+1.47	8
		6M-D	2.92	306	0.03	105	257*				8
4 Jan	1530	1M-A	2.0	882	0.12	441	277	90°	9-13	+.30	12
		6M-B	2.0	192	0.03	96	303*				12
12 Jan	0836	12M-A	4.40	310	0.02	70	229	90°	3-10	+.75	13
		7-8M-B	4.40	385	0.02	88	238				13

*Indicates curved path.

Indicates curved path.

Table 3. Subsurface circulation patterns in the eastern and western ends of Commercial Port shipping lane. See Fig.14 for locations of paths.

Date	Time	Path	Depth (m)	Δ Time (min.)	Dist. (m)	Velocity m/sec.	Velocity m/hr.	Path Dir.	Tide
10 Jan	0850	C-1	15.2-9.1	39	60	0.03	92	18°	Strong Rise
10 Jan	0930	C-2	17	1	1.5	0.03	90	ca. 80°	Strong Rise
12 Jan	0753	A	12.2-9.1	17	32	0.03	118	140°	Strong Rise
5 Jan	1120	B-1	15	1	ca. 3	ca. 0.05	ca. 180	ca. 260°	Drop
5 Jan	1128	B-2	24	1	ca. 2	ca. 0.03	ca. 120	ca. 260°	Drop

Table 4. Surface dye path movements on Jade Shoals 29 December 76. See Figs. 8 and 9 for locations.

Time	Path, Dye	Δ Time (min.)	Dist. (m)	Velocity m/sec.	Velocity m/hr.	Direction	Wind Dir.	Wind Vel. (knots)	Tide	Fig.
0835	E	8.5	50	0.10	354	240	60°	10-17	Strong Rise	8
0908	F	17.5	50	0.05	174	271	60°	8-18	Strong Rise	8
1040	E	9.83	50	0.08	305	278	60°	10-15	Drop	9
115	F	9.58	50	0.09	313	279	60°	15-18	Drop	9

Table 5. Dye patch directions and velocities in Zone II, Flats C and D. See Figs. 15-17 for locations. The tide change was calculated from the tide curve for runs longer than 15 minutes; for shorter runs a falling tide is indicated by (-) and a rising tide by (+).

Date	Start Time	Figure	Dye Patch	Time (min.)	Dist. (m)	Velocity (m/sec.)	Direction	Wind Dir.	Wind Vel (knots)	Tide Change
12/28/76	1400	15	A	2.40	25	.16	270°	60°	10-12	-
	1410		A	2.50	25	.15	270°	60°	10-12	-
	1415		B	2.10	25	.19	270°	60°	10-12	-
	1420		B	2.15	25	.19	270°	60°	10-12	-
	1405		C	1.00	25	.42	270°	60°	10-12	-
	1425		C	1.10	25	.36	270°	60°	10-12	-
	1030		F	75.00	113	.03	252°	90°	10	+.36
	0900		G	21.40	100	.08	117°-270°	90°	10	+.1
	0900		H	23.30	44	.03	87°	90°	10	+.1
	1600		I	30.00	56	.03	209°	60°-90°	8-12	-.1
	1650		J	20.00	28	.02	280°	60°-90°	8-12	-.09
	1410		K	10.00	161	.27	265°	60°	10-14	-
	1400		L	8.30	37	.07	270°	60°	10-14	-
1/ 4/77	1200	16	A'	4.30	25	.09	270°	90°	5-13	-
	1600		A'	5.30	30	.09	270°	90°	9-13	+
	1211		B'	3.00	25	.14	270°	90°	5-13	-
	1610		B'	4.30	25	.09	270°	90°	9-13	+
	1130		C'	17.00	50	.05	270°	90°	5-13	-.05
12/29/76	0945		D	12.00	75	.10	270°	90°	10-18	+
	1154		D	9.00	50	.09	270°	90°	15-18	+
1/ 4/77	0928		E	17.00	37	.04	240°	90°	5-10	-.05
12/29/76	1020		F'	17.00	75	.07	254°	90°	10-18	+.09
	1255		F'	10.00	25	.04	254°	90°	12-16	+
	0915		H'	16.00	25	.03	86°	90°	10-14	+.09
	1120		H'	17.00	25	.02	86°	90°	10-18	+.09
1/ 4/77	1102		I'	10.00	50	.08	244°	90°	5-13	-
1/11/77	1518	17	C"	1.15	25	.33	270°	50°	6-10	-
	1522		C"	1.55	25	.22	270°	50°	6-10	-
	1526		C"	2.15	25	.19	270°	50°	6-10	-

Table 5. (continued)

Date	Start Time	Figure	Dye Patch	Time (min.)	Dist. (m)	Velocity (m/sec.)	Direction	Wind Dir.	Wind Vel (knots)	Tide Change
	1457	17	F"	2.15	25	.19	222°	50°	6-10	-
	1505		I"	7.20	50	.08	255°	50°	6-10	-
	1504		M	3.00	50	.28	272°	50°	6-10	-
1/11/77	1500		N	1.30	25	.28	270°	50°	6-10	-
	1422		O	8.15	75	.15	263°	50°	5-8	-
	1355		P	8.30	25	.05	270°	50°	8-10	-
	1422		Q	5.15	25	.56	276°	50°	6-10	-
	1513		R	3.15	25	.13	245°	50°	6-10	-
	1351		S	12.15	25	.03	269°	50°	8-10	-
	1408		S	5.10	25	.08	269°	50°	8-10	-
	1057		T	28.08	25	.07	94°	50°	5-8	+.04
	1520		U	3.25	25	.12	270°	50°	6-10	-
12/27/76	1515		V	1.45	25	.24	267°	50°	4-6	-
	1520		V	2.00	25	.21	267°	50°	4-6	-
	1525		V	2.03	25	.20	267°	50°	4-6	-

Table 6. Dye patch directions and velocities in Zone III, Flats C and D. See Figs. 18-23 for locations. The tide change was calculated from the tide curve for runs longer than 15 minutes; for shorter runs a falling tide is indicated by (-) and a rising tide by (+).

Date	Start Time	Figure	Dye Patch	Time (min.)	Dist. (m)	Velocity (m/sec.)	Direction	Wind Dir.	Wind Vel (knots)	Tide Change
1/10/77	1200	18	A	6.15	20	.05	270°	30°	9-12	-
	1700		A'	3.00	10	.06	91°	50°	4-8	-
	1222		B	5.30	20	.06	209°	30°	9-12	-
	1710		B'	6.00	20	.05	90°	50°	4-8	-
	1240		C	5.00	20	.07	208°	30°	9-12	-
	1730		C'	6.00	10	.03	270°	50°	4-8	+
	1300		D	7.30	10	.02	105°	30°	9-12	-
	1740		D'	3.15	10	.05	63°	50°	4-8	+
	1753		E	4.00	15	.06	62°	50°	4-8	+
	1800		F	5.00	20	.07	90°	50°	4-8	+
12/27/76	1100		G	5.00	20	.067	90°	30°	4-6	+
	1110		H	5.00	20	.067	248°	30°	4-6	+
1/10/77	1600	19	A	5.30	20	.06	271°	30°	4-8	-
1/ 4/77	1223		A'	6.00	30	.08	257°	90°	5-13	-
	1626		A'	5.00	25	.08	257°	90°	9-13	+
1/10/77	1620		B	4.00	20	.08	233°	50°	4-8	-
1/ 4/77	1315		B'	5.00	5	.02	97°	90°	5-13	+
	1655		B'	10.00	10	.02	97°	90°	9-13	+
1/10/77	1631		C	2.00	20	.17	242°	50°	4-8	-
	1641		D	2.00	20	.17	253°	50°	4-8	-
12/27/76	1540		E	2.02	25	.20	252°	50°	4-6	-
	1545		E	1.55	25	.22	252°	50°	4-6	-
	1625		F	6.15	25	.07	61°	50°	4-6	-
	1635		F	6.35	25	.07	61°	50°	4-6	-
1/10/77	1056		G	6.00	31	.08	243°	30°	4-6	+
	1143		H	6.00	20	.056	90°	30°	4-6	-
12/27/76	0900	20	A	70.00	165	.04	235°	30°	4-6	+.25
	0900		B	105.00	210	.03	238°	30°	4-6	+.38
	1100		C	30.00	80	.04	160°	30°	4-8	+.12

Table 6. (continued)

Date	Start Time	Figure	Dye Patch	Time (min.)	Dist. (m)	Velocity (m/sec.)	Direction	Wind Dir.	Wind Vel (knots)	Tide Change
	1200	20	D	30.00	55	.03	266°	60°	2-6	+.10
	1300		E	45.00	120	.04	90°	60°	2-6	±.0
	1530		F	15.00	155	.17	209°	50°	4-6	-.03
12/27/76	0715	22A	D	84.00	200	.04	253°	30°	4-6	+.31
	0907		E	53.10	100	.03	290°	30°	4-6	+.28
	1043		F	10.00	25	.042	256°	30°	4-6	+
	1140	22B	A'	45.00	100	.037	283°	60°	2-6	+.1
	1230		B'	37.00	60	.027	105°	60°	2-6	+.1
	1021		C'	53.00	160	.05	174°	30°	4-6	+
	1442		D'	29.00	100	.057	288°	50°	4-6	-.1
	1518		E'	15.00	50	.056	259°	50°	4-6	-.05
	1550		F'	5.45	50	.145	304°	50°	4-6	-
1/10/77	1452	23	A'	8.00	20	.042	190°	50°	9-12	-
	1600		B'	21.00	100	.079	269°	50°	4-8	-.1
	1225		C	19.00	100	.088	305°	30°	9-12	-.1
	1631		C'	44.00	125	.047	275°	50°	4-8	-.15
	1320		D	4.00	25	.104	260°	30°	9-12	-
	1326		D	4.00	25	.104	260°	30°	9-12	-
	1719		D'	13.00	25	.032	266°	50°	4-8	-
	1311		E	4.00	25	.104	263°	30°	9-12	-
	1339		F	10.00	25	.042	262°	30°	9-12	-
	1355		F	4.00	25	.104	262°	30°	9-12	-
	1405		F	3.00	25	.139	262°	30°	9-12	-

Table 7. Results of water chemistry analyses. Sampling station locations are shown in Fig.

Station	Temp. (°C)	Turbidity (NTU)	Salinity (ppt)	Oxygen (mg/l)	Reactive Phosphorus (μg-at/l)	NO_2-N (μg-at/l)	NO_3-N (μg-at/l)
29 Dec 76, 0630-0730 hrs, low tide							
1	27.9	0.6	31.1	6.30	0.21	-0-	5.1
2	27.3	0.8	33.3	6.09	0.21	-0-	6.8
3	28.5	2.3	33.9	5.98	0.19	-0-	0.80
4	28.9	1.7	34.4	5.60	0.17	0.07	1.1
5	29.0	1.3	33.9	5.90	0.19	-0-	0.68
6	27.7	2.8	33.9	5.69	0.11	-0-	1.4
29 Dec 76, 1700-1800 hrs, falling tide							
1	28.0	2.1	34.4	6.49	0.16	-0-	0.58
2	28.5	1.6	33.9	6.57	0.12	0.23	0.31
3	29.0	2.2	33.9	7.23	0.17	-0-	0.64
4	30.9	2.1	34.4	7.14	0.10	-0-	0.66
5	30.8	1.3	31.6	7.10	0.13	0.14	8.4
6	30.3	4.8	32.2	7.04	0.06	-0-	7.1
4 Jan 77, 0630-0700 hrs, high tide							
1 surface	27.7	0.36	33.9	6.19	0.21	-0-	1.8
1 10 m	27.0	0.39	33.9	6.53	0.10	-0-	0.07
2 surface	27.7	0.77	33.9	6.28	0.14	0.09	0.60
2 10 m	27.6	0.79	33.9	6.28	0.10	-0-	0.70
3	27.8	1.2	33.9	6.11	0.12	-0-	2.3
5	28.5	1.8	33.9	5.52	-0-	0.09	1.0
6	27.9	2.4	33.9	5.73	0.18	0.11	0.71
4 Jan 77, ca. 1800 hrs, high tide							
1 surface	27.9	0.17	35.0	7.11	0.12	-0-	8.7
1 10 m	27.6	0.21	27.2	6.95	0.10	0.02	0.51
2 surface	28.4	0.18	33.9	7.08	0.09	-0-	5.75
2 10 m	27.2	0.12	18.3	6.81	0.08	-0-	0.37
3	30.3	0.37	32.8	7.10	0.07	-0-	6.4
5	31.0	-	-	7.26	0.11	-0-	0.44
6	30.3	-	-	7.75	0.07	-	0.50
12 Jan 77, 0630-0730, low tide							
1	27.5	0.46	33.9	6.74	0.12	-0-	0.51
2	28.0	0.98	33.9	6.19	0.22	-0-	5.7
3	28.6	1.0	33.9	5.77	0.12	-0-	1.5
5	28.3	3.3	33.9	5.90	0.18	-0-	2.6
6	27.5	4.8	33.9	5.52	0.18	-0-	0.28

Table 8. Checklist of marine benthic algae and sea-grass observed in Sasa Bay.

Species	Stations												
	A	B	C	D	E	F	G	H	I	J	K	L	M
Cyanophyta													
Schizothrix calcicola (Ag.) Gomont								X			X		
Schizothrix mexicana Gomont											X		
Microcoleus lyngbyaceus (Kutz.) Crouan					X						X	X	
Chlorophyta													
Avrainvillea obscura J. Ag.						X							
Boodlea composita (Harv.) Brand											X		
Caulerpa serrulata (Forsskal) J. Ag.											X		
Caulerpa verticillata J. Ag.						X		X	X				
Dictyosphaeria versluysii W. v. Bosse						X		X					
Halimeda gigas Taylor											X		
Halimeda macroloba Decaisne												X	
Halimeda opuntia (L.) Lamx.						X		X	X		X	X	
Valonia aegagropila C. Ag.								X					
Rhodophyta													
Acanthophora spicifera (Vahl) Boerg.								X					
Gelidiopsis intricata (Ag.) Vickers								X			X		
Gracilaria arcuata Zanard.						X		X	X				
Hypnea esperi Bory						X		X	X				
Jania capillacea Harvey											X		
Laurencia sp.						X		X	X				
Polysiphonia upolensis (Grunow) Hollenberg						X			X	X			
Polysiphonia spp.									X		X	X	
Spyridia filamentos (Wulf.) Harvey						X						X	
Wurdemannia miniata (Lmk. & DC) Feldm. & Hamel											X		
Anthophyta													
Enhalus acoroides (L.f.) Royle	(one clump observed off Station A)												

Table 9. Checklist of marine benthic algae and sea-grasses observed in Study Area A, Apra Harbor, December, 1976 and January, 1977.

Species	Outfall Lagoon (I-V)	Channel (VI-VII)	Tidal Flat (VIII)	Reef (IX-X)	Jade Shoal (XI)
Cyanophyta					
Calothrix pilosa Harvey					X
Hormothamnion enteromorphoides B. and Fl.	X				X
Microcoleus lyngbyaceus (Kütz.) Crouan	X	X	X	X	X
Schizothrix calcicola (Ag.) Gomont					X
Schizothrix mexicana Gomont	X				X
Chlorophyta					
Avrainvillea obscura J. Ag.	X	X	X		
Caulerpa racemosa (Forssk.) J. Ag.				X	
Caulerpa serrulata (Forssk.) J. Ag.				X	
Enteromorpha clathrata (Roth) J. Ag.			X		
Halimeda macroloba Decaisne			X	X	
Halimeda opuntia (L.) Lamx.	X	X	X	X	
Tydemannia expeditionis W. v. Bosse					X
Phaeophyta					
Dictyota bartayresii Lamx.	X			X	X
Feldmannia indica (Sonder) Womersley and Bailey					X
Hydroclathrus clathratus (C. Ag.) Howe					X
Lobophora variegata (Lamx.) Womersley					X
Padina tenuis Bory	X	X	X	X	X
Sargassum polycystum C. Ag.	X				
Sphacelaria tribuloides Meneghini				X	X
Turbinaria ornata (Turner) J. Ag.					X

Table 9. (continued)

Species	Outfall Lagoon (I-V)	Channel (VI-VII)	Tidal Flat (VIII)	Reef (IX-X)	Jade Shoal (XI)
Rhodophyta					
Amphiroa foliacea Lamx.					X
Asparagopsis taxiformis (Delile) Collins and Harvey [sporophyte stage]					X
Centroceras clavulatum (C. Ag) Montagne					X
Galaxaura filamentosa Chou					X
Galaxaura oblongata (E. and S.) Lamx.					X
Gelidiella cf. *myriocladia* (Boerg.) Feldm. and Hamel	X				
Gelidiopsis intricata (Ag.) Vickers				X	
Gracilaria salicornia (Mert.) Grev.	X			X	
Hypnea esperi Bory				X	
Jania capillacea Harvey				X	X
Laurencia sp.					X
Leveillea jungermannioides Harvey				X	
Polysiphonia sp.	X		X	X	X
Spyridia filamentosa (Wulf.) Harvey	X				
Anthophyta					
Enhalus acoroides (L. f.) Royle			X		
Halophila minor (Zool.) Hartog	X		X		
NUMBER OF SPECIES	13	4	9	13	21

Table 10. List of corals observed within the study areas. See Figure 1 for station locations.

CORALS	SASA BAY (No Corals at Sta. A-E, G and M-Q)									JADE SHOALS		PITI CHANNEL (No Corals at Sta. 1-5,8 and 14)							
	F	H	I	J	K	L	R	S	T	Upper Platforms	Slopes	6	7	9	10	11	12	13	15
CLASS-ANTHOZOA																			
ORDER-SCLERACTINIIA																			
SUBORDER-ASTROCOENIINA																			
FAMILY-ASTROCOENIIDAE																			
Stylocoeniella armata (Ehrenberg)					+			+	+	+	+								
Stylocoeniella guentheri (Bassett-Smith)			+	+	+						+								
FAMILY-THAMNASTERIIDAE																			
Psammocora contigua (Esper)					+				+	+	+								
Psammocora nierstrazi Van der Horst											+								
Psammocora samoensis Hoffmeister											+								
Psammocora (Plesioseris) haimeana Milne Edwards Haime									+		+								
Psammocora (Stephanaria) togianensis Umbgrove				+					+		+								
FAMILY-POCILLOPORIDAE																			
Stylophora mordax (Dana)										+									
Seriatopora hystrix Dana					+				+		+								
Pocillopora damicornis (Linnaeus)	+	+	+	+	+	+	+	+	+	+	+					+	+		+
Pocillopora danae Verrill					+				+	+									
Pocillopora elegans Dana											+								
Pocillopora eydouxi Milne Edwards Haime											+								
Pocillopora meandrina Dana					+				+		+								
Pocillopora verrucosa (Ellis and Solander)					+						+								
FAMILY-ACROPORIDAE																			
Acropora aspera (Dana)				+															
Acropora brueggemanni (Brook)					+						+								
Acropora delicatula (Brook)					+					+									
Acropora formosa (Dana)				+	+				+		+								

Table 10. (continued)

CORALS	SASA BAY (No Corals at Sta. A-E, G, and M-Q) F	H	I	J	K	L	R	S	T	JADE SHOALS Upper Platform	Slopes	PITI CHANNEL (No Corals at Sta. 1-5, 8, and14) 6	7	9	10	11	12	13	15
Acropora humilis (Dana)					+				+	+									
Acropora kenti (Brook)					+														
Acropora nasuta (Dana)											+								
Acropora palifera (Lamarck)					+				+	+	+								
Acropora rambleri (Bassett-Smith)					+														
Acropora rayneri (Brook)					+						+								
Acropora surculosa (Dana)					+				+	+	+								
Acropora teres (Verrill)											+								
Acropora virgata (Dana)					+				+		+								
Astreopora myriophthalma (Lamarck)										+									
Montipora ehrenbergi Verrill	+	+	+	+	+	+	+	+	+										
Montipora foveolata (Dana)					+				+		+								
Montipora granulosa Bernard				+															
Montipora hoffmeisteri Wells					+				+	+	+								
Montipora lobulata Bernard				+	+	+		+	+	+	+								
Montipora monasteriata (Forskaal)											+								
Montipora patula Verrill			+		+				+										
Montipora tuberculosa (Lamarck)									+		+								
Montipora verrilli Vaughan				+	+		+	+	+	+	+								
Montipora verrucosa (Lamarck)					+				+		+								
Montipora spumosa ?			+	+	+			+	+										
Montipora sp. 1 (Papillate)			+							+									
Montipora sp. 2 (Glabrous)				+						+									
SUBORDER-FUNGIINA																			
FAMILY-AGARICIIDAE																			
Pavona decussata Dana					+					+	+								+
Pavona frondifera (Lamarck)																			+
Pavona minuta Wells					+						+								
Pavona praetorta (Dana)					+						+								
Pavona varians Verrill					+				+		+								

Table 10. (continued)

CORALS	SASA BAY (No Corals at Sta. A-E, G, and M-Q) F	H	I	J	K	L	R	S	T	JADE SHOALS Upper Platforms	JADE SHOALS Slopes	PITI CHANNEL (No Corals at Sta. 1-5,8 and 14) 6	7	9	10	11	12	13	15
Pavona (Polyastra) obtusata (Quelch)				+	+			+	+	+	+								
Pavona (Polyastra) venosa Ehrenberg					+				+	+									
Pavona (Polyastra) sp. 1					+					+	+								
Leptoseris incrustans (Quelch)					+				+		+								
Leptoseris mycetoseroides Wells					+						+								
Pachyseris speciosa (Dana)											+								
FAMILY-FUNGIIDAE																			
Cycloseris sp. 1											+								
Fungia (Fungia) fungites (Linnaeus)					+					+	+								
Fungia (Pleractis) scutaria Lamarck										+									
Herpolitha limax (Esper)											+								
FAMILY-PORITIDAE																			
Goniopora lobata Milne Edwards and Haime									+		+								
Goniopora tenuidens (Quelch)									+		+								
Stylaraea punctata Klunzinger			+	+				+		+									
Porites andrewsi Vaughan	+	+	+	+	+	+	+	+	+	+	+								+
Porites australiensis Vaughan				+	+			+	+	+	+								+
Porites cocosensis Wells				+	+			+	+	+	+								+
Porites lichen Dana				+						+	+								
Porites Lobata Dana				+					+	+	+								
Porites lutea Milne Edwards and Haime	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Porites murrayensis Vaughan				+	+			+			+								
Porites fragosa Dana					+														
Porites sp. 1 (massive)									+										
Porites (Synaraea) convexa Verrill		+		+	+			+	+	+	+								+
Porites (Synaraea) hawaiiensis Vaughan					+				+		+								
Porites (Synaraea) horizontalata Hoffmeister			+	+	+			+	+		+								
Porites (Synaraea) iwayamaensis Eguchi			+	+	+	+		+	+	+	+								+
Alveopora allingi Hoffmeister											+								

Table 10. (continued)

CORALS	SASA BAY (No Corals at Sta. A-E, G, and M-Q) F	H	I	J	K	L	R	S	T	JADE SHOALS Upper Platform	Slopes	PITI CHANNEL (No Corals at Sta. 1-5,8 and 14) 6	7	9	10	11	12	13	15
SUBORDER-FAVIINA																			
FAMILY-FAVIIDAE																			
<u>Favia favus</u> (Forskaal)					+														
<u>Favia pallida</u> (Dana)					+				+	+									
<u>Favia speciosa</u> (Dana)											+								
<u>Favia stelligera</u> (Dana)									+										
<u>Favites flexuosa</u> (Dana)					+														
<u>Goniastrea australiensis</u> (Milne Edwards and Haime)											+								
<u>Goniastrea parvistella</u> (Dana)									+		+								
<u>Goniastrea pectinata</u> (Ehrenberg)					+				+		+								
<u>Goniastrea retiformis</u> (Lamarck)										+									
<u>Platygyra daedalea</u> (Ellis and Solander)				+	+					+	+								
<u>Platygyra rustica</u> (Dana)					+					+	+								
<u>Leptoria phrygia</u> (Ellis and Solander)									+		+								
<u>Hydnophora microconos</u> (Lamarck)					+						+								
<u>Diploastrea heliopora</u> (Lamarck)					+						+								
<u>Leptastrea bottae</u> (Milne Edwards and Haime)					+				+	+									
<u>Leptastrea purpurea</u> (Dana)	+	+	+	+	+	+	+	+	+	+	+								+
<u>Cyphastrea microphthalma</u> (Lamarck)								+			+								
<u>Cyphastrea chalcidicum</u> (Forskaal)									+		+								
<u>Echinopora lamellosa</u> (Esper)					+				+		+								
<u>Plesiastrea versipora</u> (Lamarck)					+						+								
FAMILY-OCULINIDAE																			
<u>Galaxea clavus</u> (Dana)			+	+	+			+	+	+	+								+
<u>Galaxea fascicularis</u> (Linnaeus)					+					+	+								
<u>Acrhelia horrescens</u> (Dana)					+				+		+								
FAMILY-MUSSIDAE																			
<u>Lobophyllia corymbosa</u> (Forskaal)				+	+				+	+									
<u>Lobophyllia costata</u> (Dana)				+	+						+								

Table 10. (continued)

CORALS	SASA BAY (No Corals at Sta. A-E, G, and M-Q) F	H	I	J	K	L	R	S	T	JADE SHOALS Upper Platform	JADE SHOALS Slopes	PITI CHANNEL (No Corals at Sta. 1-5,8 and 14) 6	7	9	10	11	12	13	15
<u>Lobophyllia</u> <u>hemprichii</u> (Ehrenberg)				+	+														
<u>Acanthastrea</u> <u>echinata</u> (Dana)									+		+								
FAMILY-PECTINATA																			
<u>Echinophyllia</u> <u>aspera</u> (Ellis and Solander)											+								
<u>Mycedium</u> sp. 1											+								
<u>Pectinia</u> <u>lactuca</u> (Pallas)											+								
SUBORDER-CARYOPHYLLIINA																			
FAMILY-CARYOPHYLLIIDAE																			
<u>Euphyllia</u> <u>glabrescens</u> Chamisso and Eysenhardt				+	+						+								
SUBORDER-DENDROPHYLLIINA																			
FAMILY-DENDROPHYLLIIDAE																			
<u>Tubastraea</u> <u>aurea</u> (Quoy and Gaimard)										+									
ORDER-COENOTHECALIA																			
<u>Heliopora</u> <u>coerulea</u> (Pallas)				+	+			+	+		+								
CLASS-HYDROZOA																			
ORDER-MILLEPORINA																			
FAMILY-MILLEPORIDAE																			
<u>Millepora</u> <u>exaesa</u> Forskaal					+				+	+	+								
<u>Millepora</u> <u>dichotoma</u> Forskaal				+					+	+	+								
<u>Millepora</u> <u>platyphylla</u> Hemprich and Ehrenberg					+				+	+	+								
TOTAL SPECIES	5	6	13	32	68	7	6	20	55	42	81	1	1	1	1	2	2	1	11
TOTAL GENERA	4	4	7	15	25	4	4	10	24	19	35	1	1	1	1	2	2	1	5

	Entire Study Area	Sasa Bay	Jade Shoals	Piti Channel
TOTAL SPECIES	110	88	94	11
TOTAL GENERA	40	31	39	5

Table 11. Size distribution, frequency, density, and percent of substratum covered by stony corals on the upper patch reef platform at Jade Shoals (Transect I) and the coral zone at Piti Channel (Transect II). Relative values of frequency, density, and percent of substratum covered are also given and an importance value is calculated from the sum of these three relative values. The procedures for calculating the statistics in the colums from data obtained by the point-quarter sampling technique are explained in the coral section. The standard symbols are used for the number of data (n), arithmetic mean ($\bar{y}$), standard deviation (s), and range (w). See Figure 1 for transect locations.

Transect 1 Jade Shoals Corals	Size Distribution of Colonies-Diameters in cm				Frequency	Relative Frequency	Density Per 100 m^2	Relative Density	Percent of Cover	Relative Percent of Cover	Importance Value
	n	$\bar{y}$	s	w							
Porites lutea	29	13.4	7.8	3-36	.50	31.8	73	46.8	1.4	30.2	108.8
Porites (Synaraea) convexa	9	12.0	13.5	2-46	.23	14.7	22	14.5	.5	10.8	40.0
Porites (Synaraea) iwayamensis	5	25.2	17.3	3-40	.14	8.9	13	8.1	.9	19.7	36.7
Millepora dichotoma	5	17.0	23.5	5-59	.09	5.7	13	8.1	.8	17.4	31.2
Porites andrewsi	5	14.6	19.9	3-50	.18	11.5	13	8.1	.5	10.8	30.4
Pocillopora damicornis	2	11.0	1.4	10-12	.09	5.7	5	3.2	.1	2.2	11.1
Millepora platyphylla	1	21.0	-	-	.09	5.7	3	1.6	.1	2.2	9.5
Porites australiensis	2	11.0	2.8	9-13	.05	3.2	5	3.2	.1	2.2	8.6
Montipora sp. 1 (papillate)	1	17.0	-	-	.05	3.2	3	1.6	.1	2.2	7.0
Pavona decussata	1	15.0	-	-	.05	3.2	3	1.6	.1	2.2	7.0
Leptastrea purpurea	1	3.0	-	-	.05	3.2	3	1.6	*	*	4.8
Psammocora contigua	1	3.0	-	-	.05	3.2	3	1.6	*	*	4.8

* = Less Than .1
Overall Density 159 Corals per 100 m^2
Percent of Substratum Coverage 4.6%
Total Species - 12
Total Genera - 7

Table 11. Transect II

Piti Channel Corals	Size Distribution of Colonies-Diameters in cm				Frequency	Relative Frequency	Density Per 100 m^2	Relative Density	Percent of Cover	Relative Percent of Cover	Importance Value
	n	$\bar{y}$	s	w							
Pavona frondifera	15	59.5	87.8	4-200	.29	19.5	23	30.7	19.3	95.0	145.2
Porites lutea	19	16.5	13.5	2- 45	.54	36.2	29	38.8	1.0	4.0	79.0
Porites australiensis	3	9.7	4.7	6- 15	.18	12.1	5	6.1	.1	.3	18.5
Porites andrewsi	4	11.0	10.0	2- 22	.12	8.1	6	8.2	.1	.3	16.6
Pocillopora damicornis	2	15.9	6.4	12- 21	.12	8.1	3	4.1	.1	.3	12.5
Pavona decussata	3	4.3	1.5	3- 6	.06	4.0	5	6.1	*	*	10.1
Galaxea clavus	1	12.0	-	-	.06	4.0	1	2.0	*	*	6.0
Leptastrea purpurea	1	3.0	-	-	.06	4.0	1	2.0	*	*	6.0
Porites (Synaraea) iwayamaensis	1	5.0	-	-	.06	4.0	1	2.0	*	*	6.0

* = Less Than .1

Overall Density 74 Corals per 100 m^2

Percent of Substratum Coverage 20.6%

Total Species - 9

Total Genera - 5

Table 12 . List of Sasa Bay invertebrates.

Species	Stations A	B	C	D	E	F	G	H	I	J	K	L	M
Porifera													
Cinachyra australiensis (Carter)								X	X	X	X		
Spirastrella vagabunda Ridley											X		
Stylotella agminata (Ridley)											X		
Terpios sp.											X		
Tetilla sp.											X		
Sponge sp. 1 (purple, encrusting)						X							
Sponge sp. 2 (orange, fibrous, encrusting)								X			X		
Sponge sp. 3 (green, yellow interior)								X			X		
Sponge sp. 4 (brilliant green)								X					
Sponge sp. 5 (brown, astrorhizae)								X					
Sponge sp. 6 (green, astrorhizae)								X			X	X	
Sponge sp. 7 (black, upright)											X		
Cnidaria													
Hydrozoa									X		X		
Hydroid													
Scyphozoa													
Cassieopea sp.						X							
Anthozoa													
Sinularia sp.									X	X	X		
Mollusca													
Gastropoda													
Cantharus fumosus (Dillwyn)								X			X		
Cerithium sp.	X	X			X						X	X	
Chicoreus penchinati (Crosse)						X			X		X		
Conus sp.											X		
Cymatium gutturnium (Roding)								X					

Table 12. (continued)

Species	A	B	C	D	E	F	G	H	I	J	K	L	M
Cypraea mappa (Linn.)										X			
Drupella cornus (Roding)											X		
Lambis lambis (Linn.)											X		
Littorina scabra (Linn.)	X	X	X	X	X		X						
Morula (Cronia) margariticola (Broderip)								X	X				
Vasum turbinellus (Linn.)											X		
Bivalvia													
Arca ventricosa Lamarck									X	X	X		
Barbatia bicolorata (Dillwyn)						X							
B. lima (Reeve)						X		X					
Chama reflexa jukesi (Reeve)										X			
Gafrarium tumidum (Roding)		X			X	X						X	
Malleus malleus (Linn.)								X	X	X			
Periglypta puerpera (Linn.)								X					
Pinctada martensii (Dunker)								X					
Saxostrea mordax (Gould	X	X	X										
Septifer bilocularis (Linn.)						X		X	X				
Spondylus nicobaricus Schreibers								X					
Annelida													
Polychaeta													
Eurythoe complanata (Pallas)												X	
Sebellastarte indica (Savigny)					X				X		X		
Arthropoda													
Crustacea													
Homaridae													
*Eneplomatopu_* sp.											X		

Stations: A–M

Table 12. (continued)

Species	A	B	C	D	E	F	G	H	I	J	K	L	M
Diogenidae													
Clibinarius striolatus Dana					X								
Dardanus lagopodes (Forskal)											X		
Portunidae													
Thalamita crenata (Latreille)					X								
Thalamita danae Stimpson												X	
Thalamitoides tridens A. Milne Edwards												X	
Ocypodidae													
Uca chlorophthalmus crassipes Adams and White	X	X	X										
Uca vocans (Linnaeus)	X												
Grapsidae													
Metapograpsus oceanicus (Jacquinot)												X	
Pachygrapsus minutus A. Milne Edwards												X	
Pachygrapsus planifrons deMan	X												
Pachygrapsus plicatus H. Milne Edwards		X											
Gecarcinidae													
Cardisoma sp. (burrows)		X	X	X									
Xanthidae													
Ozius guttatus H. Milne Edwards												X	
Gonodactylidae													
Gonodactylus falcatus (Forskal)										X			

Table 12. (continued)

Species	A	B	C	D	E	F	G	H	I	J	K	L	M
							Stations						
Echinodermata													
Holothuroidea													
Bohadschia argus Jaegar										X			
Bohadschia bivitatta Mitsukuri										X			
Holothuria atra Jaeger										X			
Chordata													
Ascidiacea													
Herdmania momas (Savigny)								X					
Microcosmus exasperatus Heller										X			
Didemnid (Unident. spp.)						X				X			

Table 13. Fishes observed at survey sites in Apra Harbor on December 6, 1976. + = present, ++ = abundant

Species	Jade Shoals 1 Meter	Jade Shoals 10 Meters	Mouth of Piti Channel
ACANTHURIDAE			
Acanthurus mata Cuvier and Valenciennes			1
A. nigroris Cuvier and Valenciennes	1		
A. xanthopterus Cuvier and Valenciennes	+		
Ctenochaetus striatus (Quoy & Gaimard)	1	3	2
Zebrasoma flavescens (Bennett)	+	1	
Z. veliferum (Bloch)		3	
APOGONIDAE			
Apogon compressus (Smith & Radchffe)			100
Apogon juveniles			765
Paramia quinquelineata (Cuvier and Valenciennes)	1		
BALISTIDAE			
Sufflamen chrysoptera (Bloch & Schneider)	+	1	
BLENNIIDAE			
Meiacanthus atrodorsalis (Gunther)	4		
CHAETODONTIDAE			
Chaetodon auriga Forskal	1		
C. bennetti Cuvier	1		
C. citrinellus Cuvier	+		
C. ephippium Cuvier	+		3
C. trifasciatus Mungo Park	5	1	21
C. ulietensis Cuvier	1	1	2
Heniochus chrysostomus Cuvier	+		
GOBIIDAE			
Amblygobius albimaculatus (Ruppell)	+	1	3
HEMIRAMPHIDAE			
unidentified half-beaks		+	
HOLOCENTRIDAE			
Adioryx spinifer (Forskal)		1	
Flammeo sp.	+		

Table 13. (continued)

Species	Jade Shoals 1 Meter	10 Meters	Mouth of Piti Channel
LABRIDAE			
Epibulus insidiator (Pallas)	+	1	
Gomphosus varius Lacepede	1		
Halichoeres trimaculatus (Quoy & Gaimard)	1		
Hemigymnus melapterus (Bloch)			1
Labroides dimidiatus (Cuvier and Valenciennes)	+	1	
Stethojulis bandanensis Bleeker	1		
LUTJANIDAE			
Aphareus furcatus (Lacepede)	+		
Caesio caerulaureus Lacepede	++		
Lutjanus vaigiensis (Quoy & Gaimard)	+	1	1
Scolopsis cancellatus (Cuvier and Valenciennes)			+
POMACENTRIDAE			
Abudefduf coelestinus (Cuvier)	1		
Amblyglyphidodon curacao (Bloch)	34	65	
Amphiprion melanopus Bleeker	+		
A. perideraion Bleeker		+	
Chromis caerulea (Cuvier)	1	46	233
Dascyllus aruanus (Linnaeus)	+	35	70
D. trimaculatus (Ruppell)	+	3	
Eupomacentrus albifasciatus (Schlegel and Muller)	1		
E. lividus (Bloch and Schneider)			36
E. nigricans (Lacepede)	6		
Glyphidodontops leucopomus (Lesson)	+		
Plectroglyphidodon leucozona (Bleeker)			7
unidentified sp. A	5		
unidentified sp. B		7	
SCARIDAE			
Scarus sordidus Forskal	+		5

Table 13. (continued)

Species	Jade Shoals 1 Meter	Jade Shoals 10 Meters	Mouth of Piti Channel
ZANCLIDAE			
Zanclus cornutus (Linnaeus)	+	1	
Transect length (m)	40	75	190
Number of species censused	17	17	15
Total species observed	36	19	15
Number of individuals/m^2	.94	1.14	3.29

Table 14. Zooplankton abundance in Piti secondary channel and around Jade Shoals, December 6, 1976. Abundance in number of organisms per m^3 of water filtered.

Organisms	Piti Secondary Channel: Ebb Tide 1	Ebb Tide 2	Flood Tide 3	Flood Tide 4	Jade Shoals 5
foraminiferans	0.08	0.11	0.03	0.02	0.08
medusae	0.10	0.05	-	-	-
pteropods	0.79	0.07	0.07	0.03	6.37
gastropods	-	-	0.41	1.46	-
polychaete larvae	-	-	-	-	-
ostracods	-	-	-	-	8.82
copepods	2.07	0.18	-	0.03	0.33
mysids	-	-	-	-	-
Lucifer	-	-	0.01	-	-
stomatopod larvae	-	-	0.03	0.03	-
crab zoea larvae	23.61	1.25	1.52	0.54	-
"shrimp" zoea larvae	1.18	0.08	0.01	0.17	0.41
chaetognaths	0.01	-	-	-	12.17
larvaceans	0.15	0.07	0.05	0.11	11.52
fish eggs	0.20	0.62	0.01	0.02	-
fish larvae	0.48	0.17	0.14	0.66	0.24
miscellaneous	0.05	0.03	-	-	-
TOTAL	28.72	3.63	2.28	3.10	39.95

Table 15. Zooplankton abundance at several sampling sites in Apra Harbor, December 17, 1976. Abundance in number of organisms per m^3 of water filtered.

Organisms	Piti Secondary Channel	Lower Piti Channel	Commercial Port (Day)	Commercial Port (Night)	Sasa Bay (Day)	Sasa Bay (Night)	Outer Harbor (Day)	Outer Harbor (Night)
foraminiferans	1.17	-	-	-	-	-	-	-
medusae	0.04	0.62	2.56	5.43	1.33	-	5.03	0.90
pteropods	2.07	98.61	102.52	12.14	47.10	9.62	17.61	14.82
gastropods	0.04	8.40	0.96	48.54	-	1.33	3.14	0.45
polychaete larvae	-	-	0.32	0.32	0.22	0.17	-	0.45
ostracods	.09	0.93	3.19	7.98	2.21	16.25	96.83	1402.16
copepods	-	363.34	9.26	175.66	6.85	57.88	27.67	72.76
mysids	-	-	-	-	0.22	1.00	-	0.45
Lucifer	0.09	32.97	13.73	60.68	1.33	18.41	-	0.45
stomatopod larvae	-	-	-	-	0.22	0.66	0.63	-
crab zoea larvae	5.66	66.26	18.52	61.64	56.16	31.84	1.89	0.90
"shrimp" zoea larvae	0.22	58.17	24.92	17.25	9.06	18.07	3.14	6.29
chaetognaths	-	12.75	7.98	21.08	63.68	17.91	152.16	83.54
larvaceans	0.04	5.60	1.60	8.30	3.54	1.99	6.92	-
fish eggs	4.63	19.29	3.83	1.28	3.54	1.33	-	-
fish larvae	0.85	0.93	0.32	1.60	0.88	0.66	2.52	2.25
miscellaneous	-	2.18	1.28	2.88	-	1.33	-	-
TOTAL	14.91	670.07	190.99	424.77	196.34	178.43	317.53	1585.40

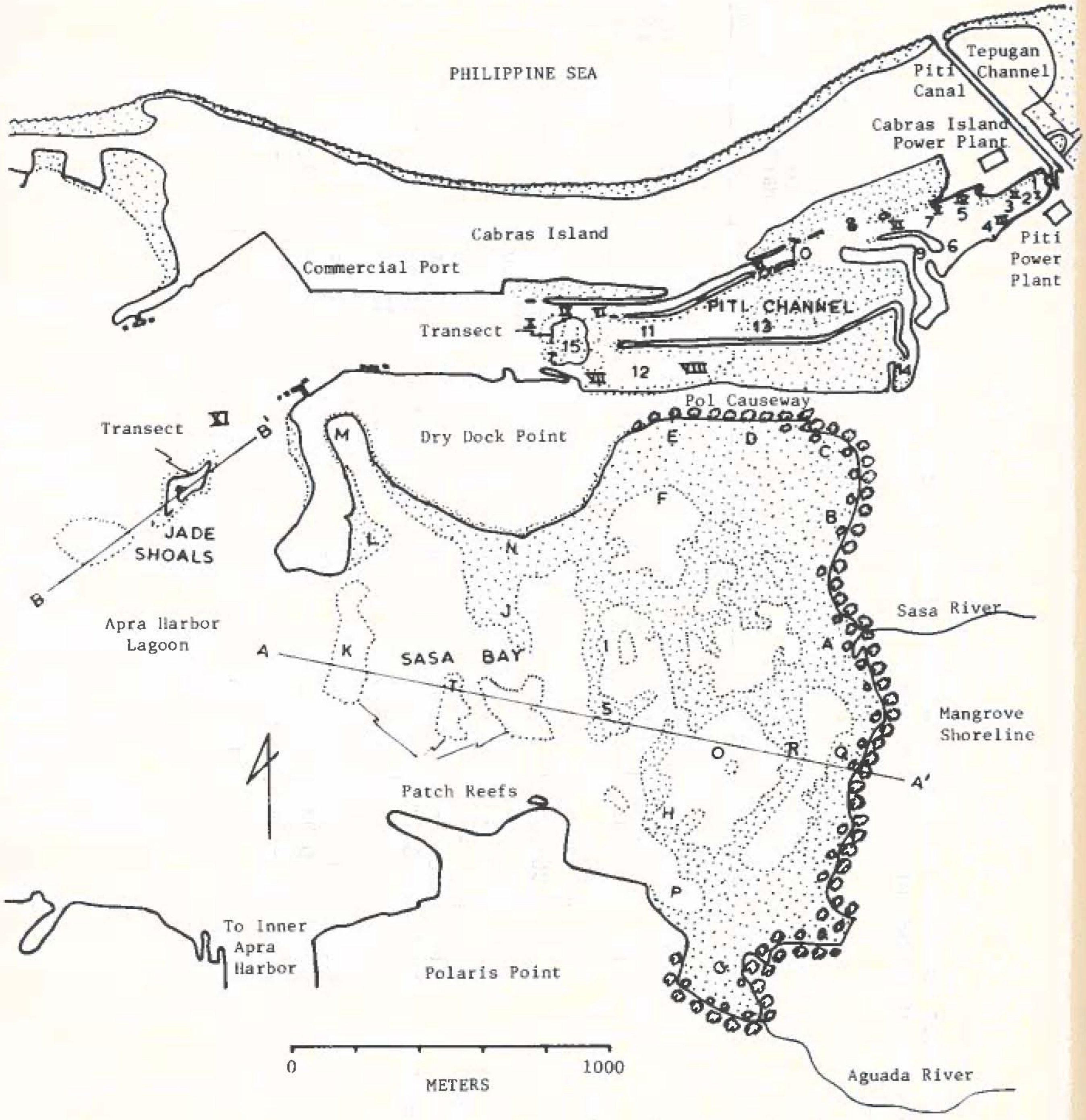

Figure 1. Map of study area showing coral station and transect locations. Stations A-T are located in Sasa Bay and 1-15 in Piti Channel. Arrows show the locations of the point-centered transects at Jade Shoals and Piti Channel. Patch reefs are enclosed by dotted lines and fringing reefs are stippled. Profiles A-A' and B-B' are shown in vertical profile on Figure 2. Stations for the survey of benthic algae are given in roman numerals.

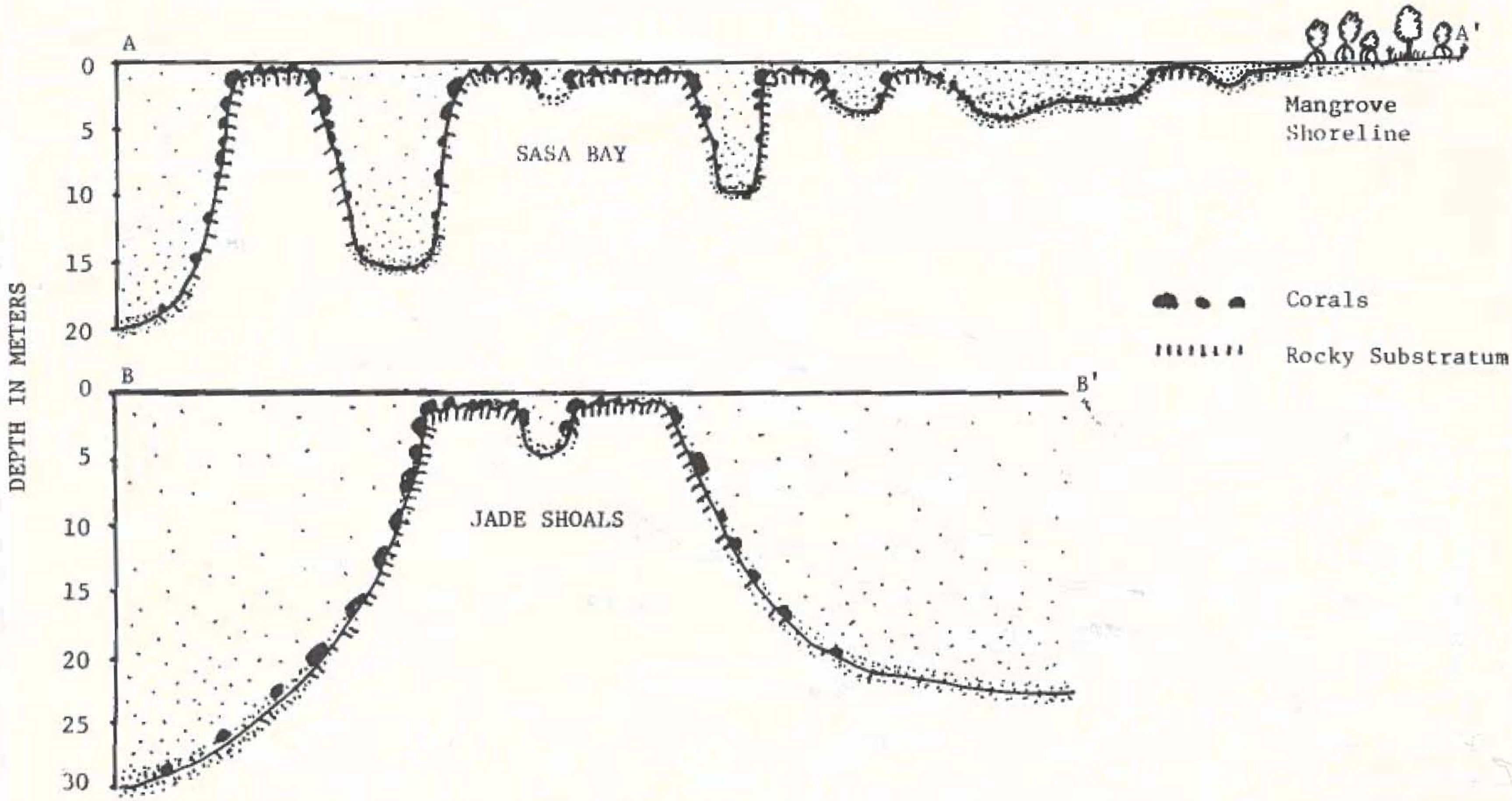

Figure 2. Vertical profiles A-A' at Sasa Bay and B-B' at Jade Shoals showing relative turbidity and distribution of corals, sediments, and rocky substratum. Density of stippling indicates the level of turbidity in the water column and the amount of sediment accumulation on the patch reef surface and slopes and lagoon floor. See Figure 1 for profile location. Vertical exaggeration X20.

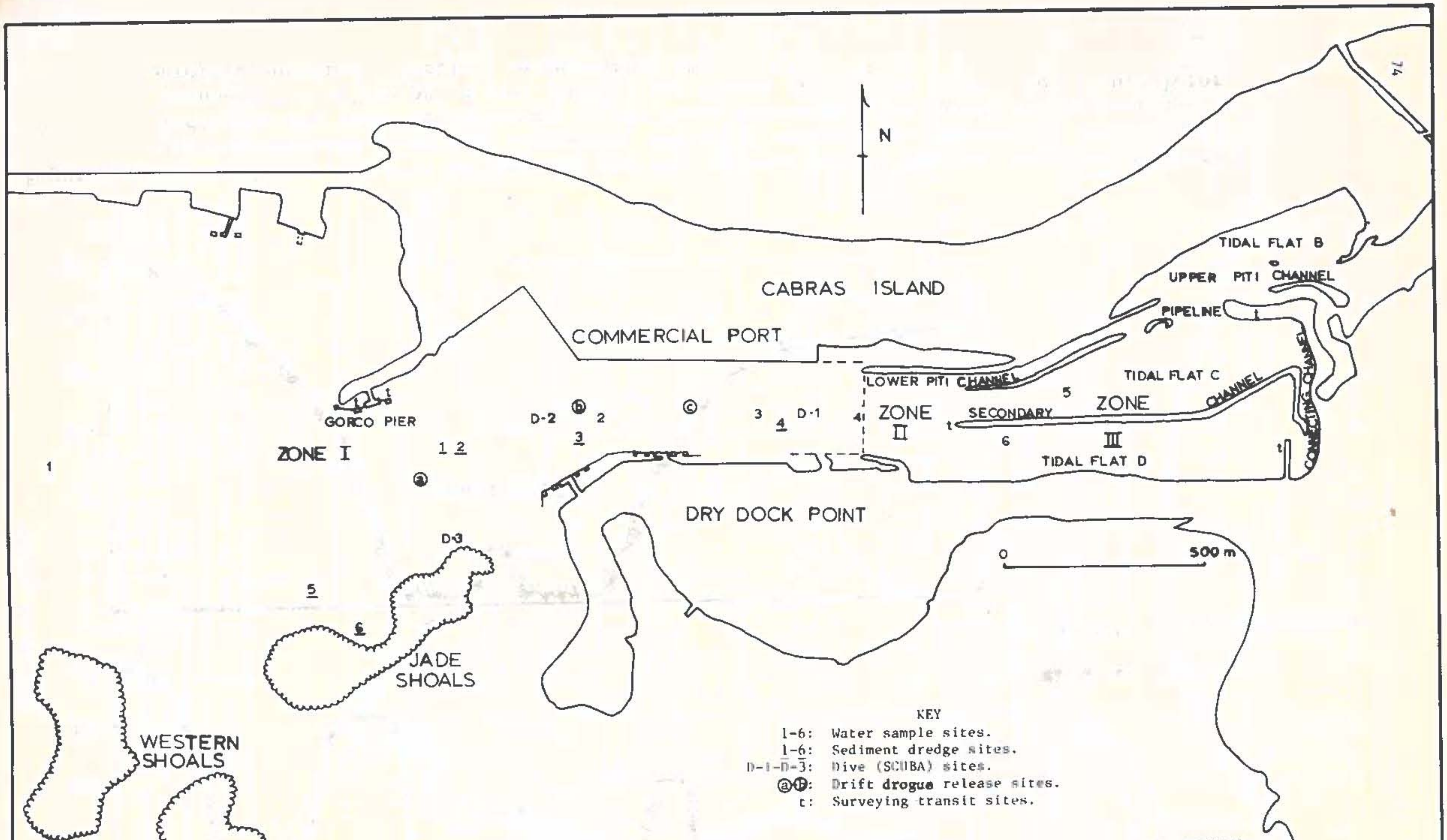

Figure 3. Location map for current studies including water sample sites, sediment dredge sites, and dive (SCUBA) sites.

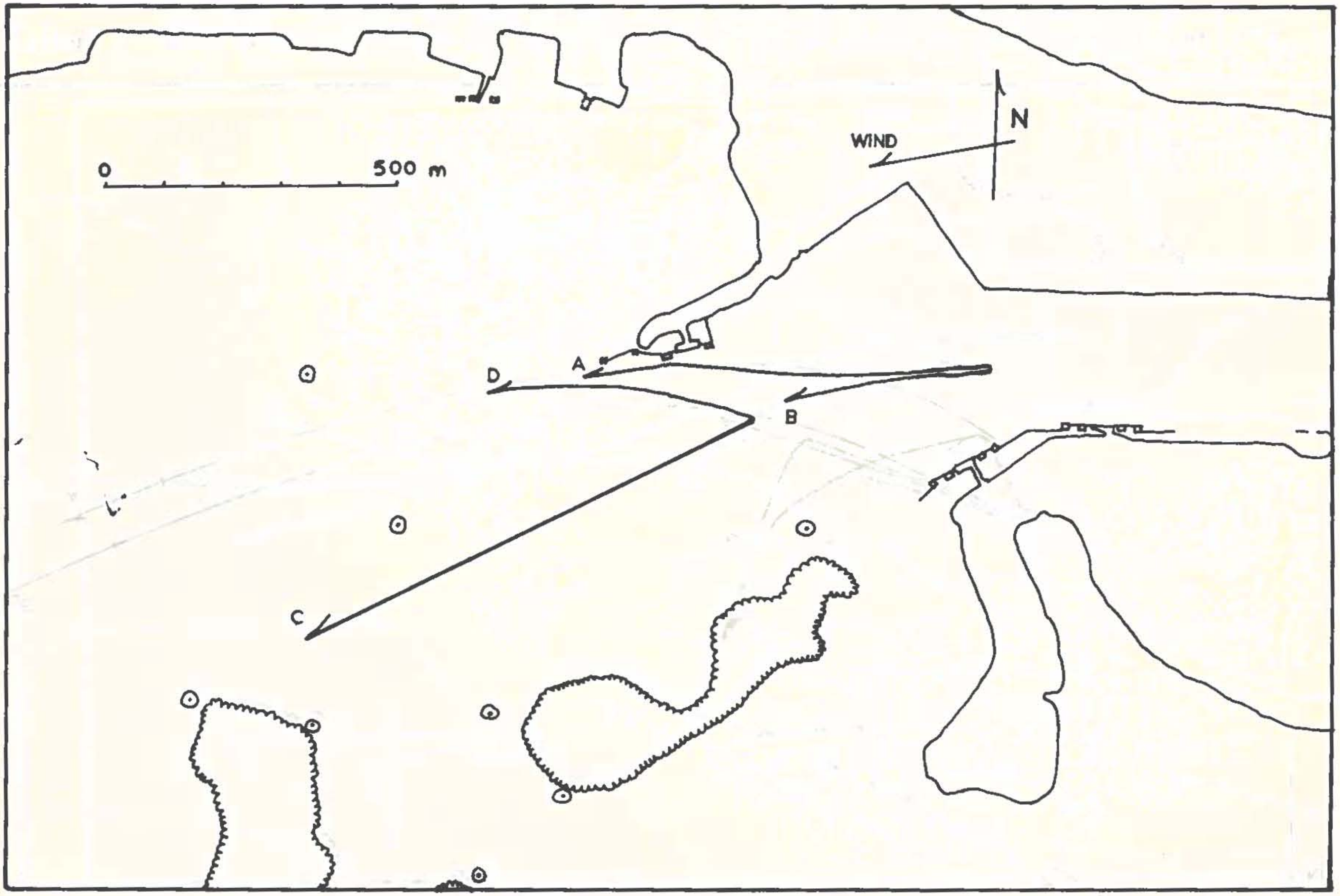

Figure 4. Inner and outer drift paths for 28 December, 1976, strong rising tide, 0800-0930. The wind was from the east at 7-9 knots. A and C, 1 -m drogue; B and D, 6 -m drogue.

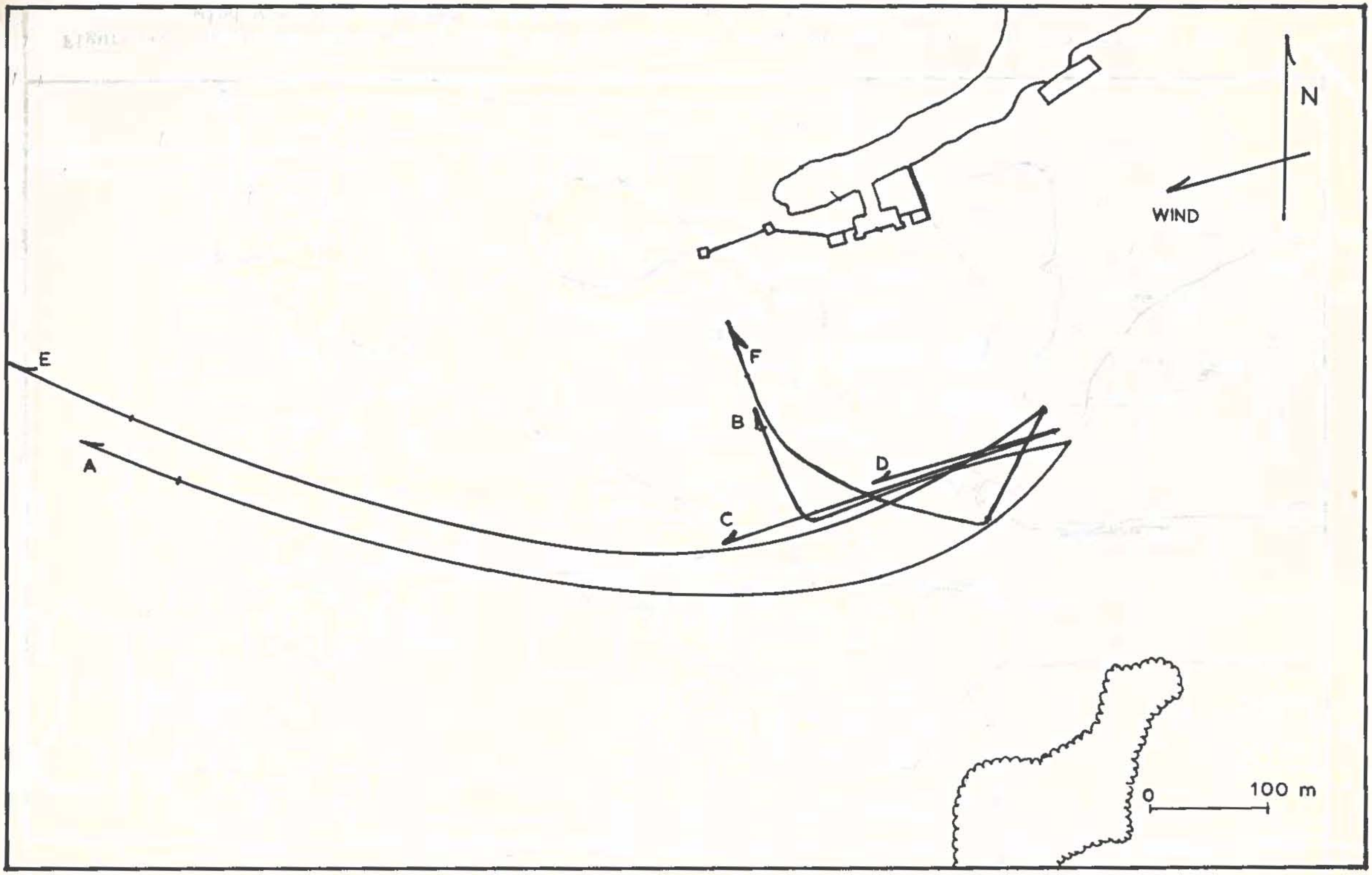

Figure 5. Outer drift drogue paths for 28 December, 1976, strong rising and weak falling tides, 0955-1522. The wind was from the east at 10 knots. E, A and C, 1 -m drogue; F, B and D, 6 -m drogue.

Figure 5. Outer drift drogue paths for ... E, A and C, 1 -m drogue; F, B
0955-1522. The wind was from the east at 10 knots.
and D, 6 -m drogue.

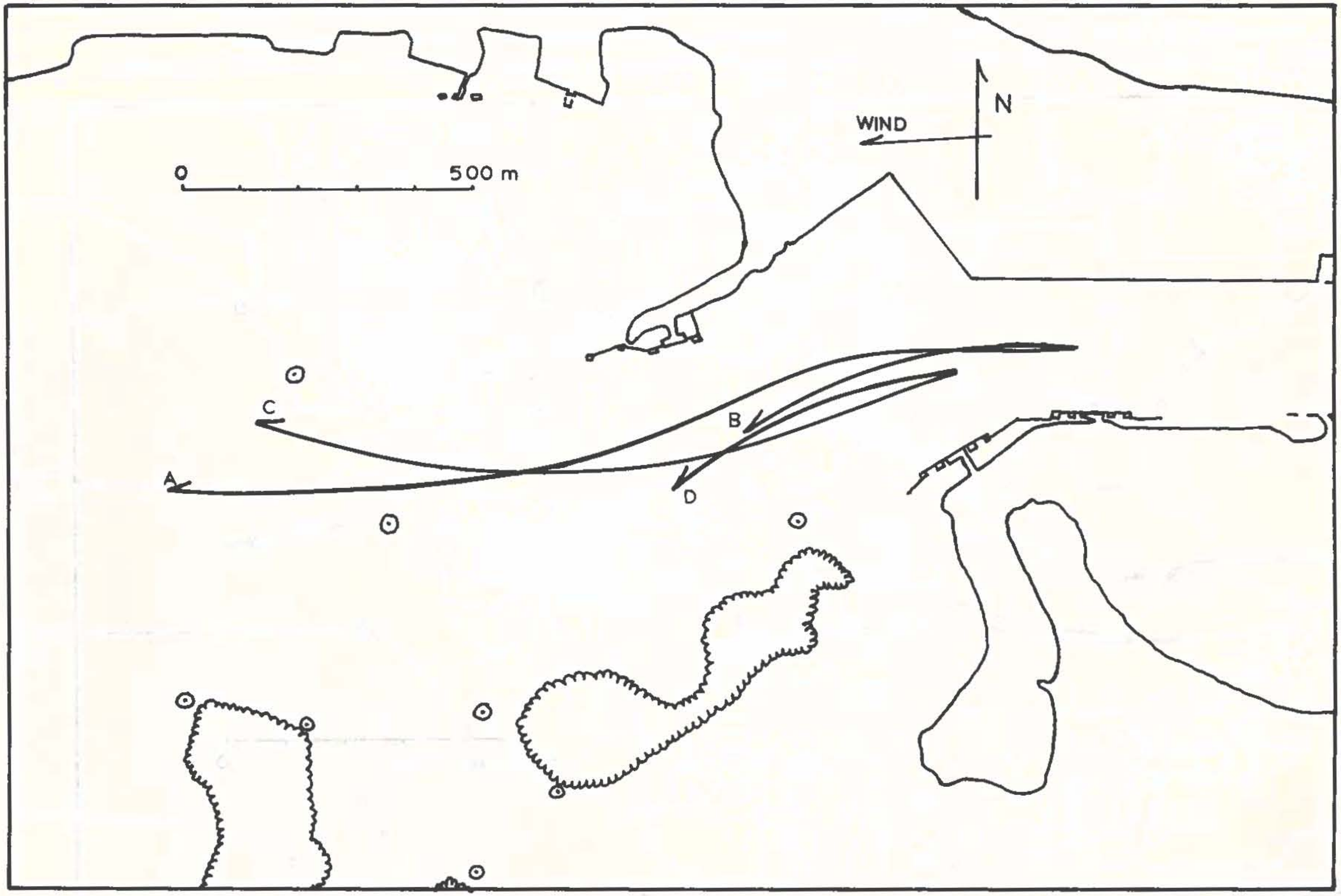

Figure 6. Inner drift drogue paths for 28 December, 1976, strong rising and weak falling tides, 1000-1530. The wind was predominantly from the east at 10-14 knots. A and C, 1 -m drogue; B and D, 6 -m drogue.

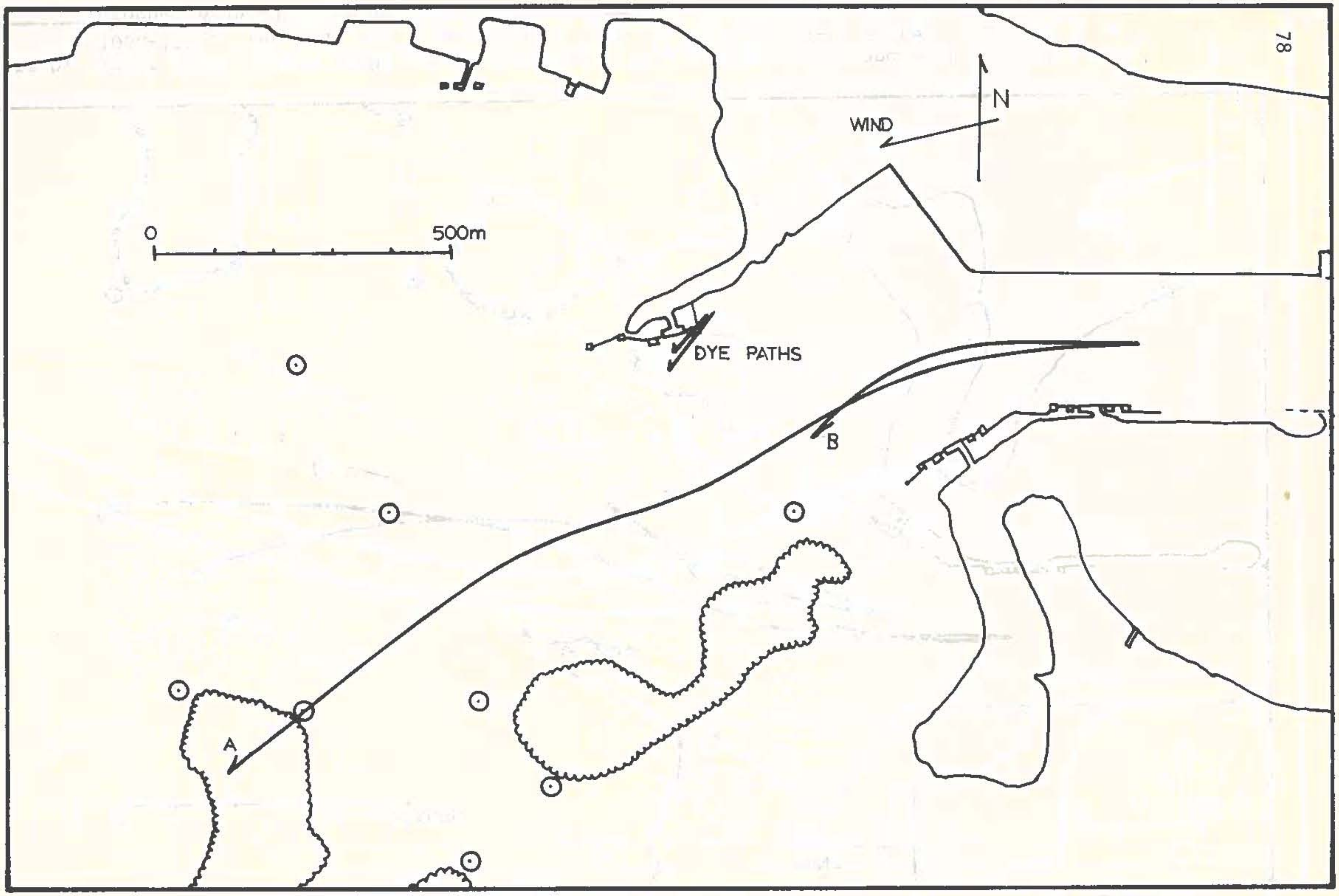

Figure 7. Inner drift drogue paths for 28 December, 1976, strong falling tide, 1530-1800. The wind was from the east and northeast at 8-12 knots. Dye paths under Gorco Pier at 1675-1730 had a velocity of .10-.08 m/sec and a direction of 245°. A, 1 -m drogue; B, 6 -m drogue.

was from the east and northeast at 8-12 knots. Dye paths under Gorco Pier at 1675-1730 had a velocity of .10-.08 m/sec and a direction of 245°. A, 1 -m drogue; B, 6 -m drogue.

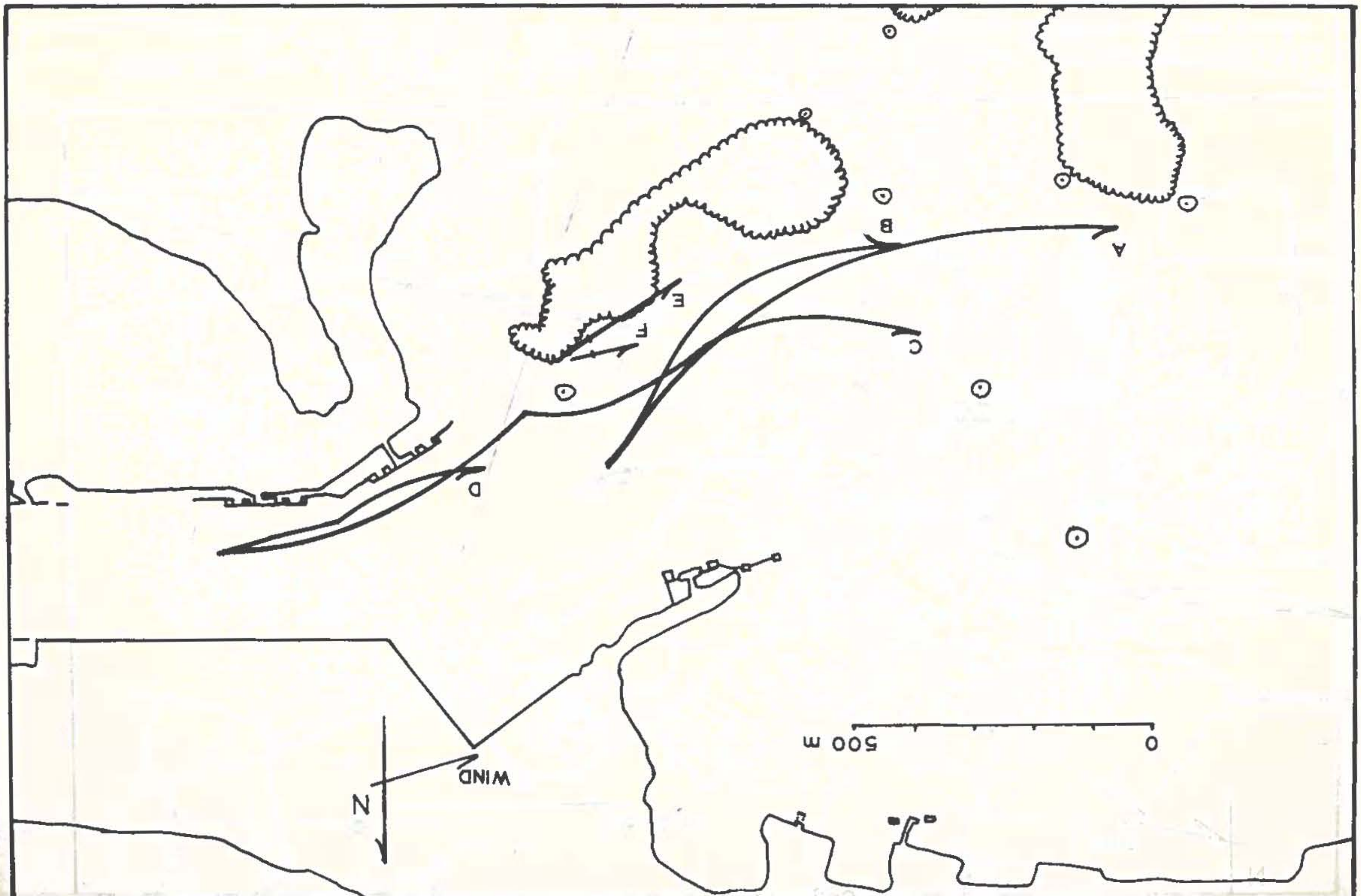

Figure 8. Inner and outer drift drogue paths for 29 December, 1976, strong rising tide, 0700-0945. The wind was from the northeast at 8-18 knots. Dye releases at Jade Shoals were at 0835 and 0908. A and C, 1 -m drogue; B and D, 6 -m drogue; E and F, Jade Shoals.

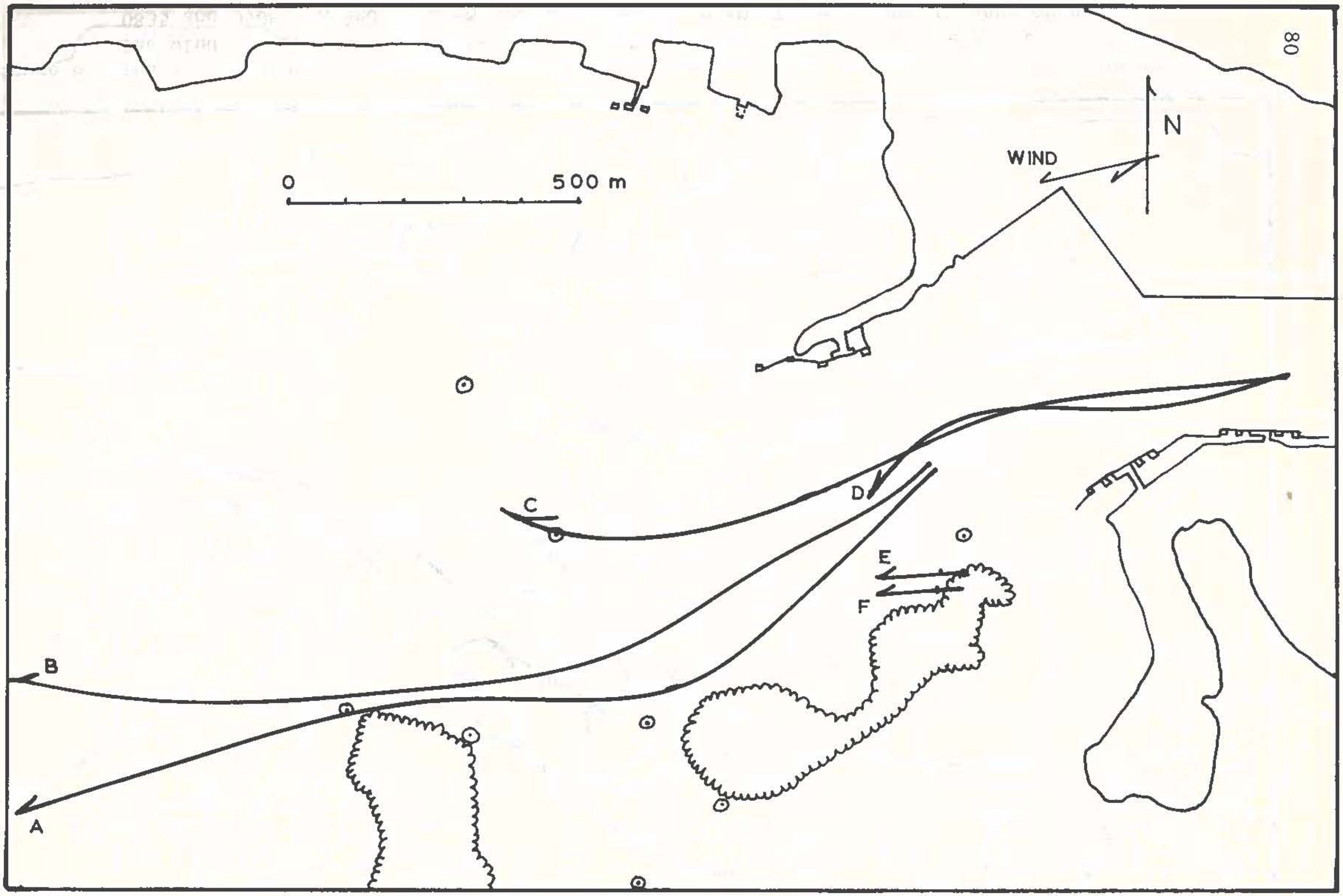

Figure 9. Inner and outer drift drogue paths for 29 December, 1976, weak falling tide, 1000-1315. The wind was from the east and northeast at 10-18 knots. Dye releases on Jade Shoals were at 1040 and 1115. A and C, 1 -m drogue; B and D, 6 -m drogue; E and F, Jade Shoals.

The wind was from the east and northeast at 10-18 knots. Dye releases on Jade Shoals were at 1040 and 1115. A and C, 1 -m drogue; B and D, 6 -m drogue; E and F, Jade Shoals.

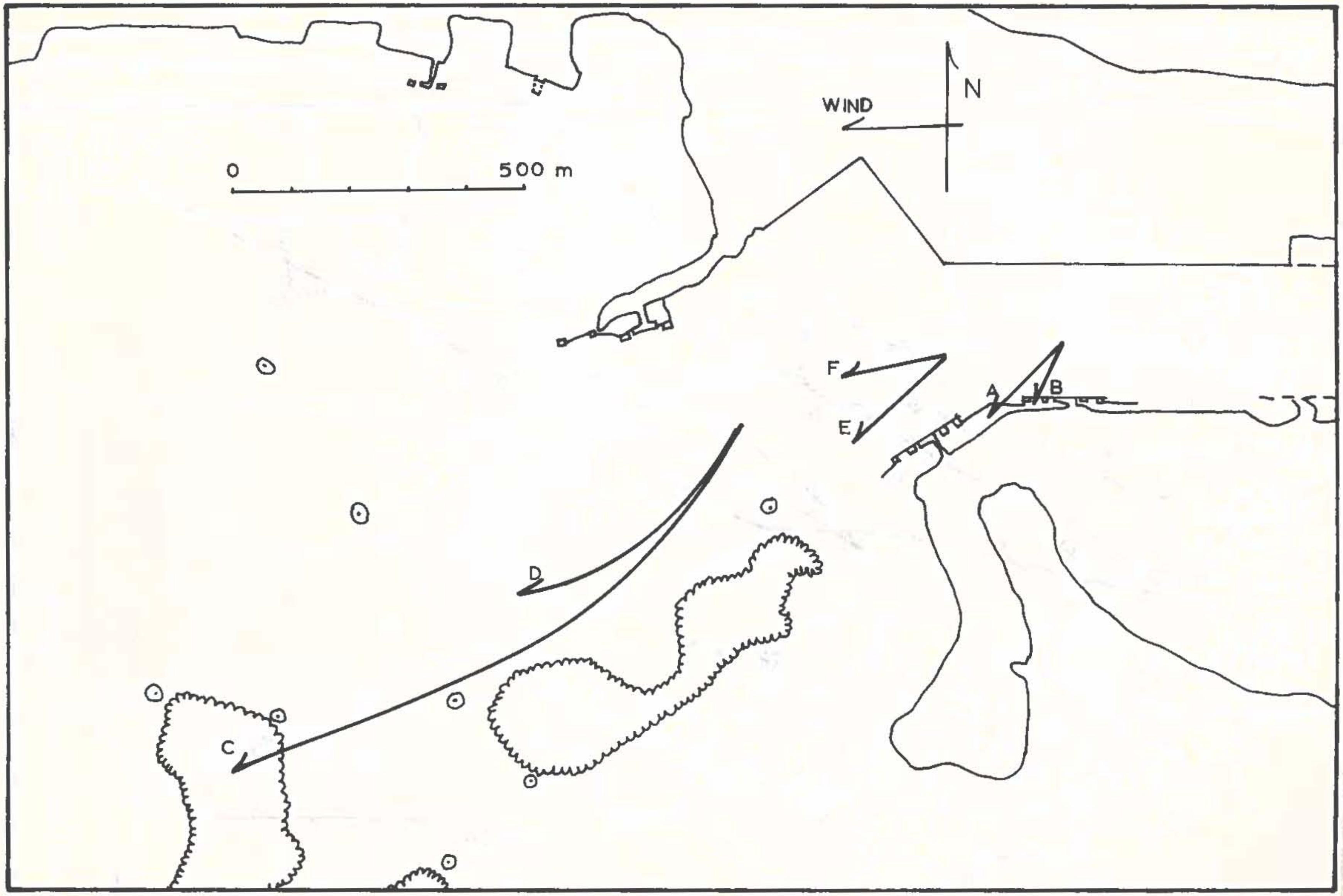

Figure 10. Inner and outer drift drogue paths for 4 January, 1977, weak falling tide, 0830-1055. The wind was from the east at 5-10 knots. A, C, E, 1 -m drogue; B and F, 6 -m drogue; D, 12 -m drogue.

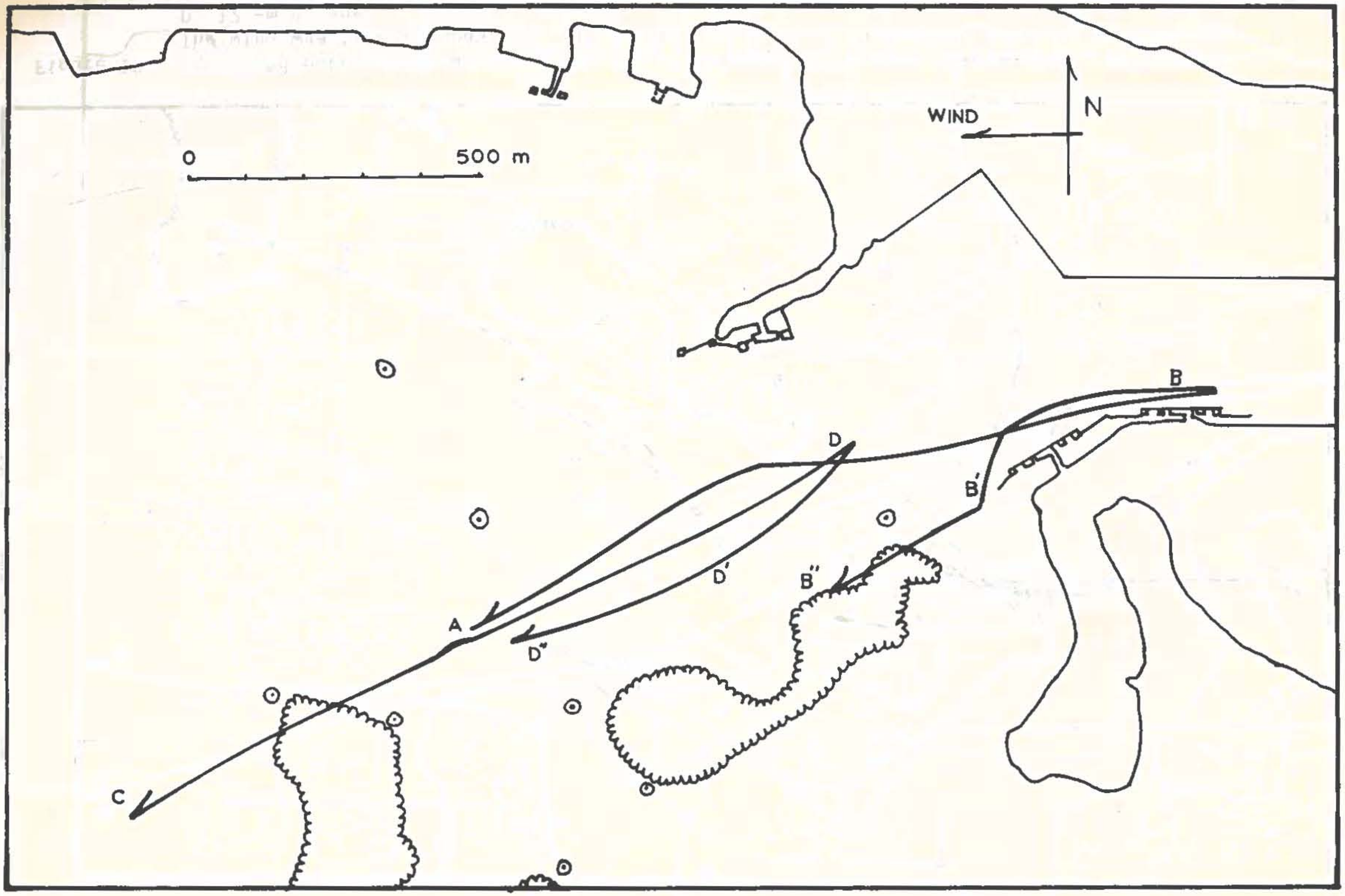

Figure 11. Inner and outer drift drogue paths for 4 January, 1977, weak rising and falling tides, 1140-1500. The wind was from the east at 5-13 knots. A and C, 1 - m drogue; B, 6 -m drogue; D, 12 -m drogue.

1140-1500. The wind was from the east at 5-13 knots. A and C, 1 - m drogue; B, 6 -m drogue; D, 12 -m drogue.

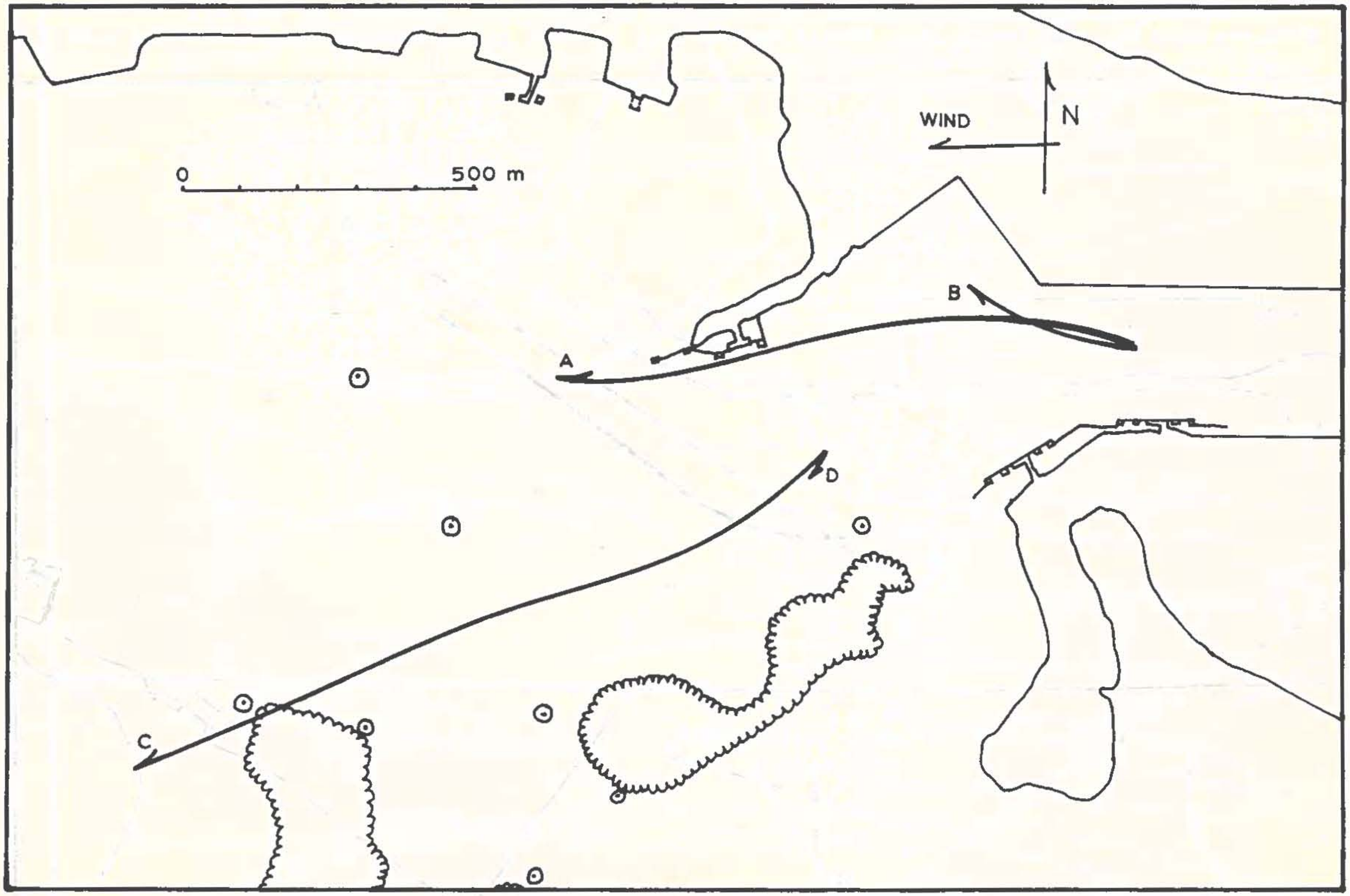

Figure 12. Inner and outer drift drogues for 4 January, 1977, weak rising tide, 1530-1730. The wind was from the east at 9-13 knots. A and C, 1 -m drogue; B, 6 -m drogue; D, sank.

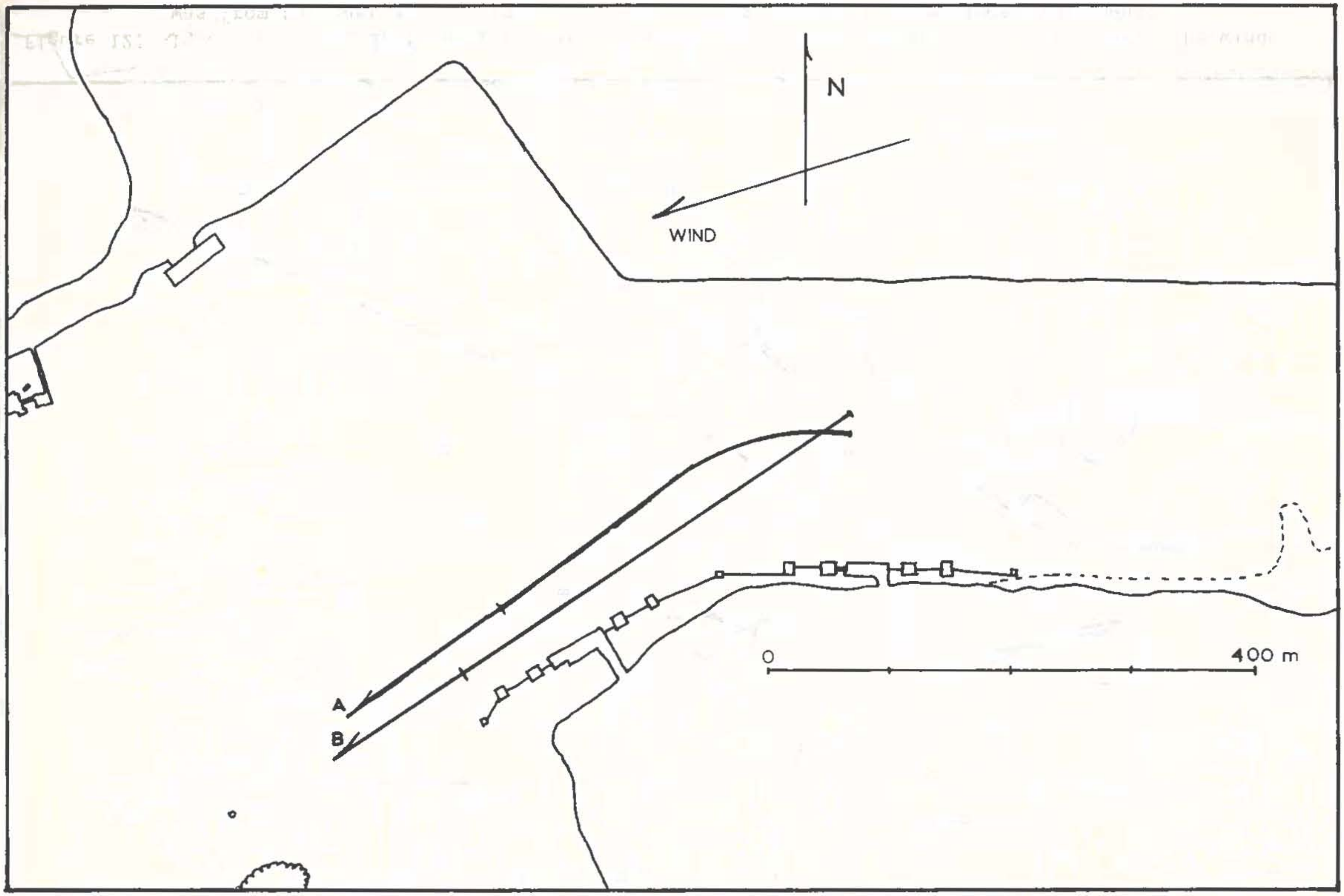

Figure 13. Inner drift drogues for 12 January, 1977, strong rising tide, 0836-1320. The wind was from the east at 3-4 knots, with gusts to 10 knots. A, 12 -m drogue; B, 6 and 7 -m drogue.

the east at 3-4 knots, with gusts to 10 knots. A, 12 -m drogue; B, 6 and 7 -m drogue.

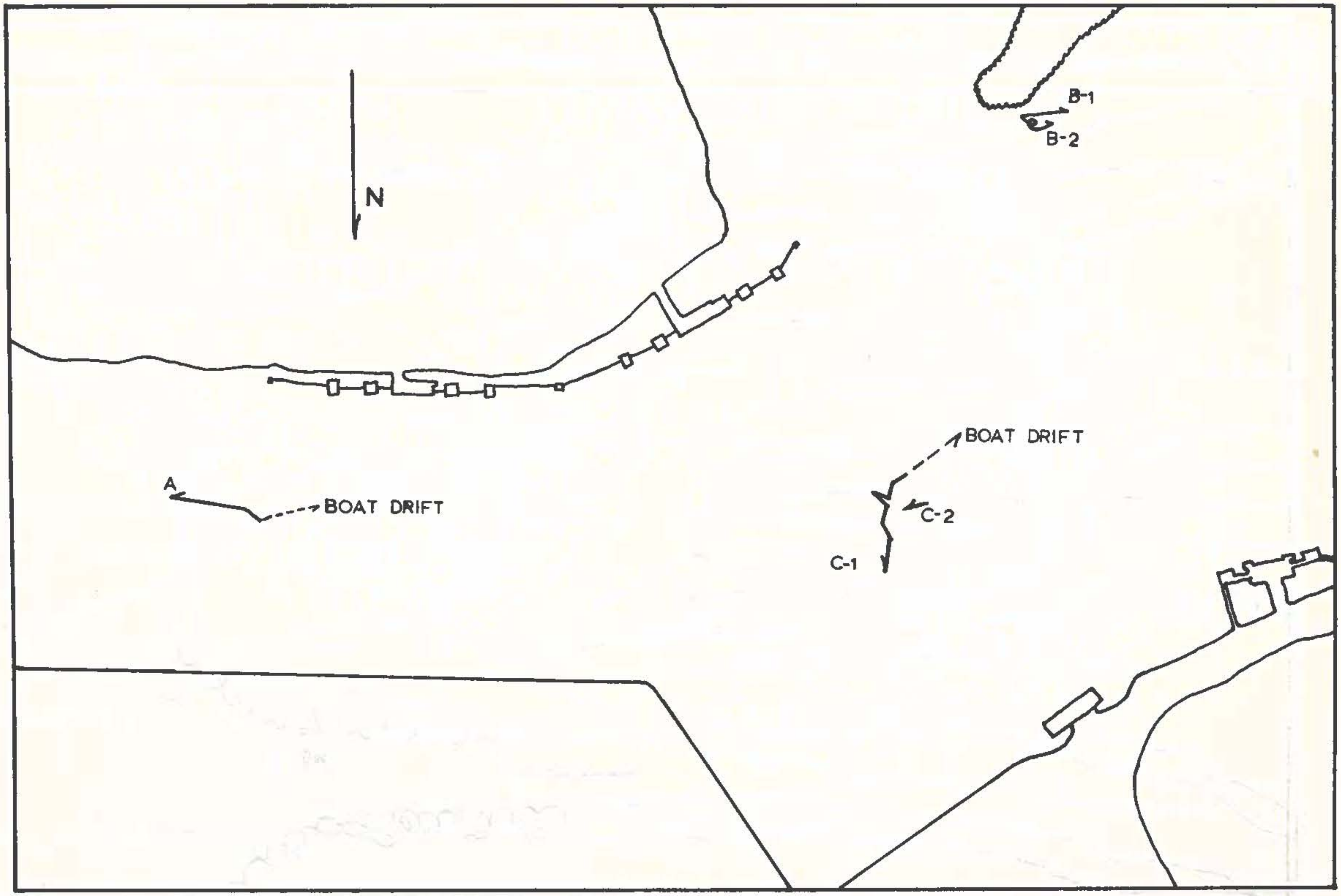

Figure 14. Subsurface dye studies 5, 10 and 12 January, 1977, strong rising and weak falling tides. See Table 3.

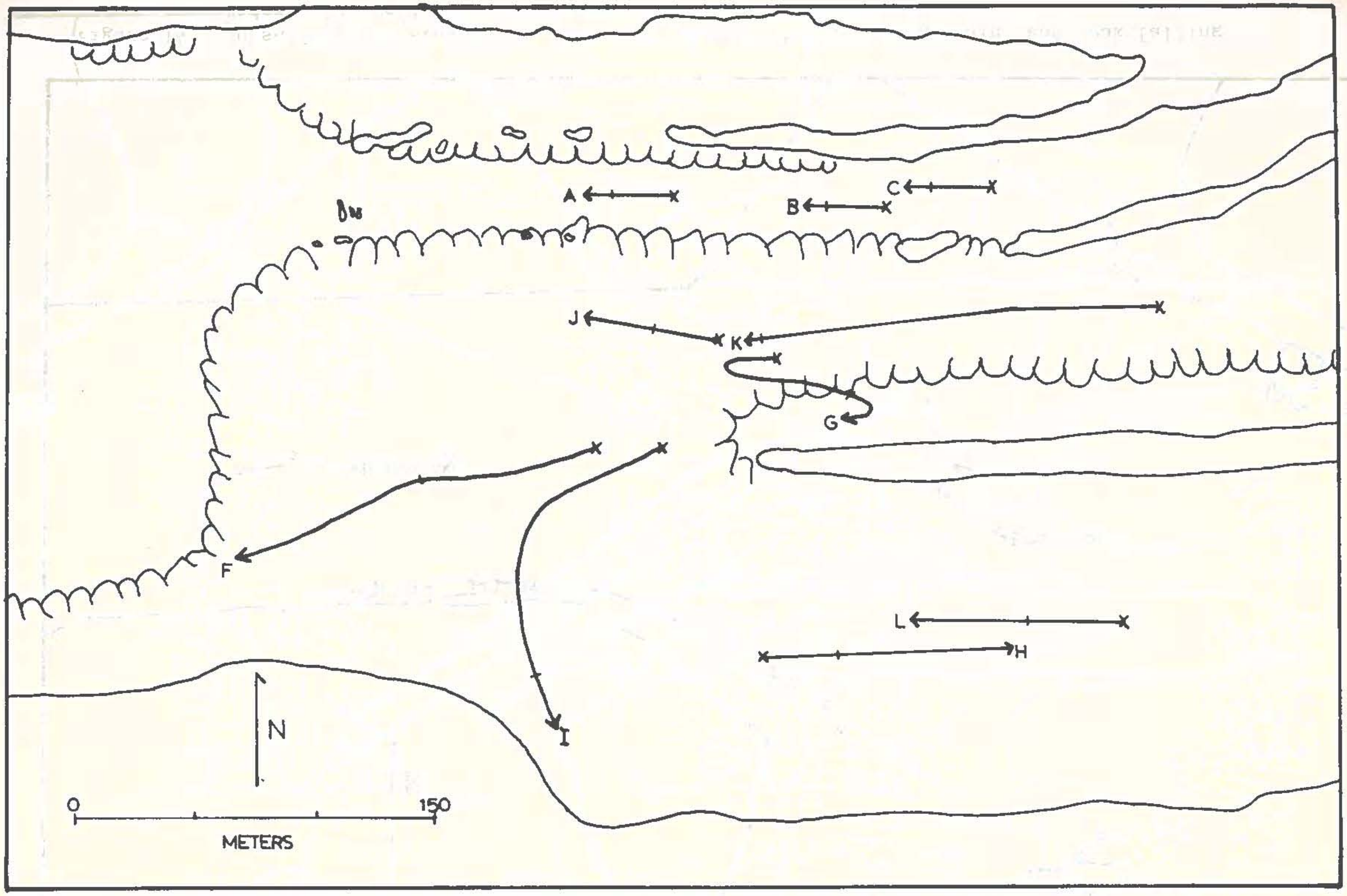

Figure 15. Dye paths in Lower Piti and Secondary Channels, Flat C and Flat D; Zone II. See Table 5 for detailed information.

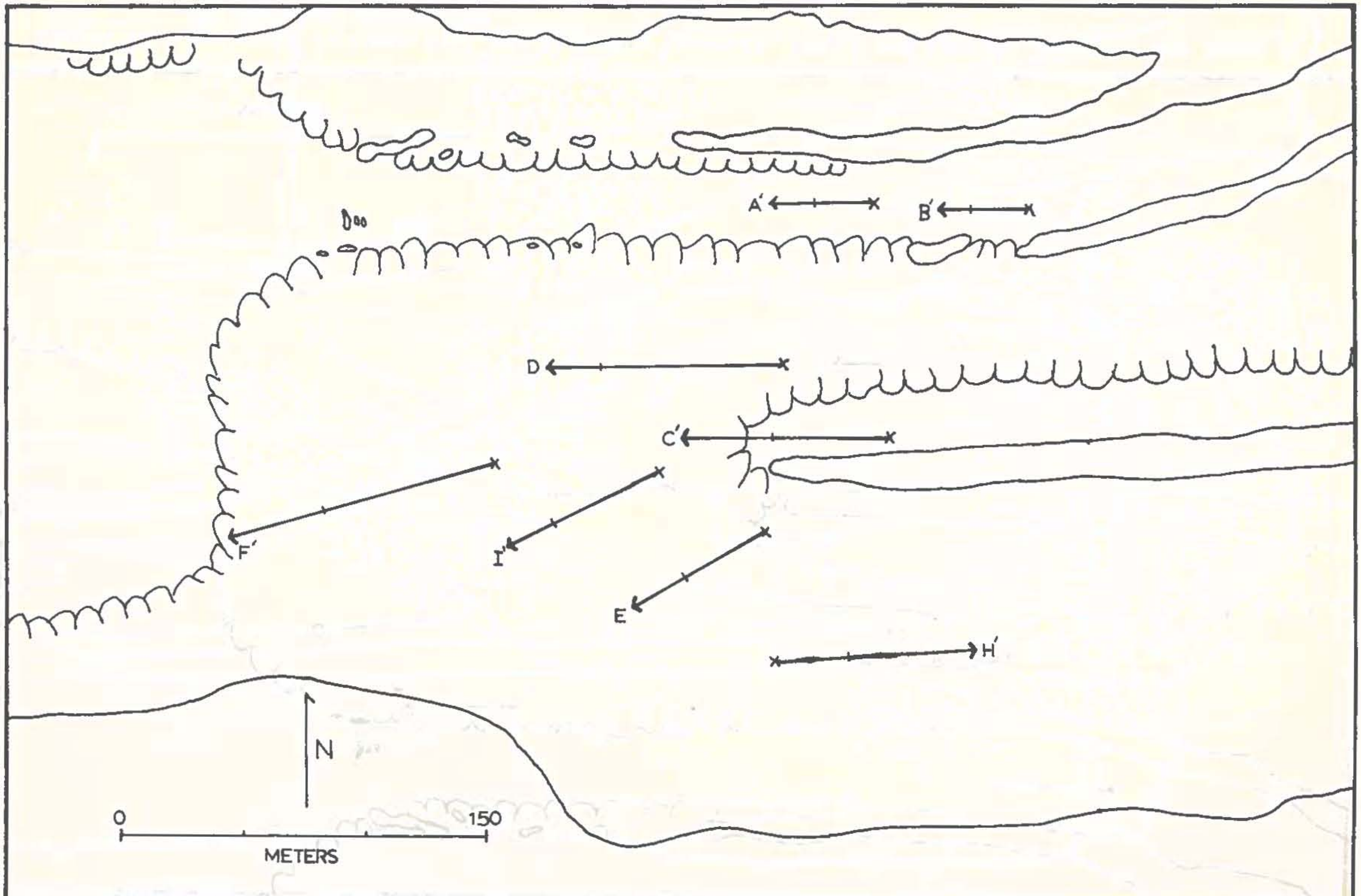

Figure 16. Dye paths in Lower Piti and Secondary Channels, Flat C and Flat D; Zone II. See Table 5 for detailed information.

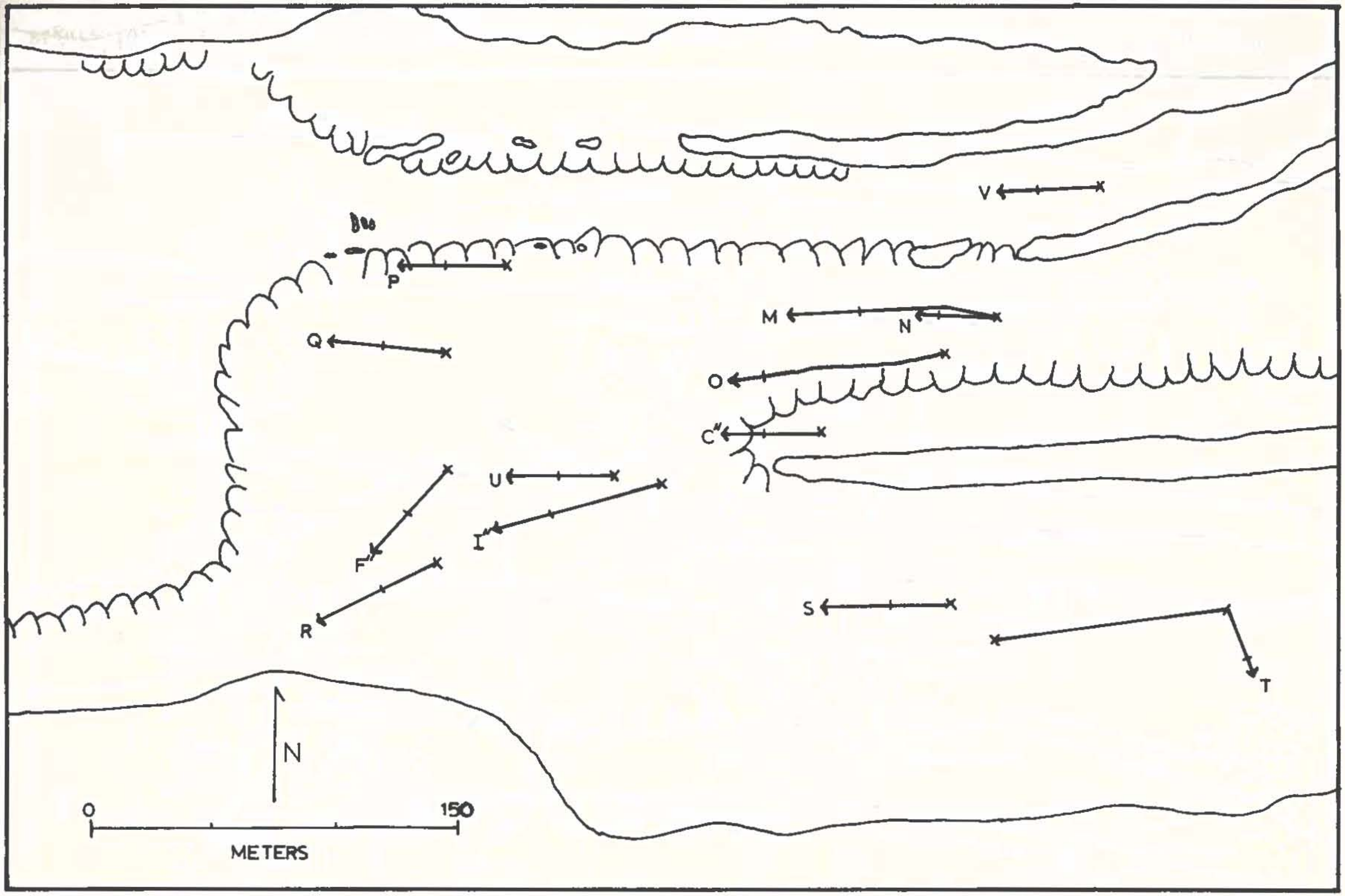

Figure 17. Dye paths in Lower Piti and Secondary Channels, Flat C and Flat D; Zone II. See Table 5 for detailed information.

for detailed information.

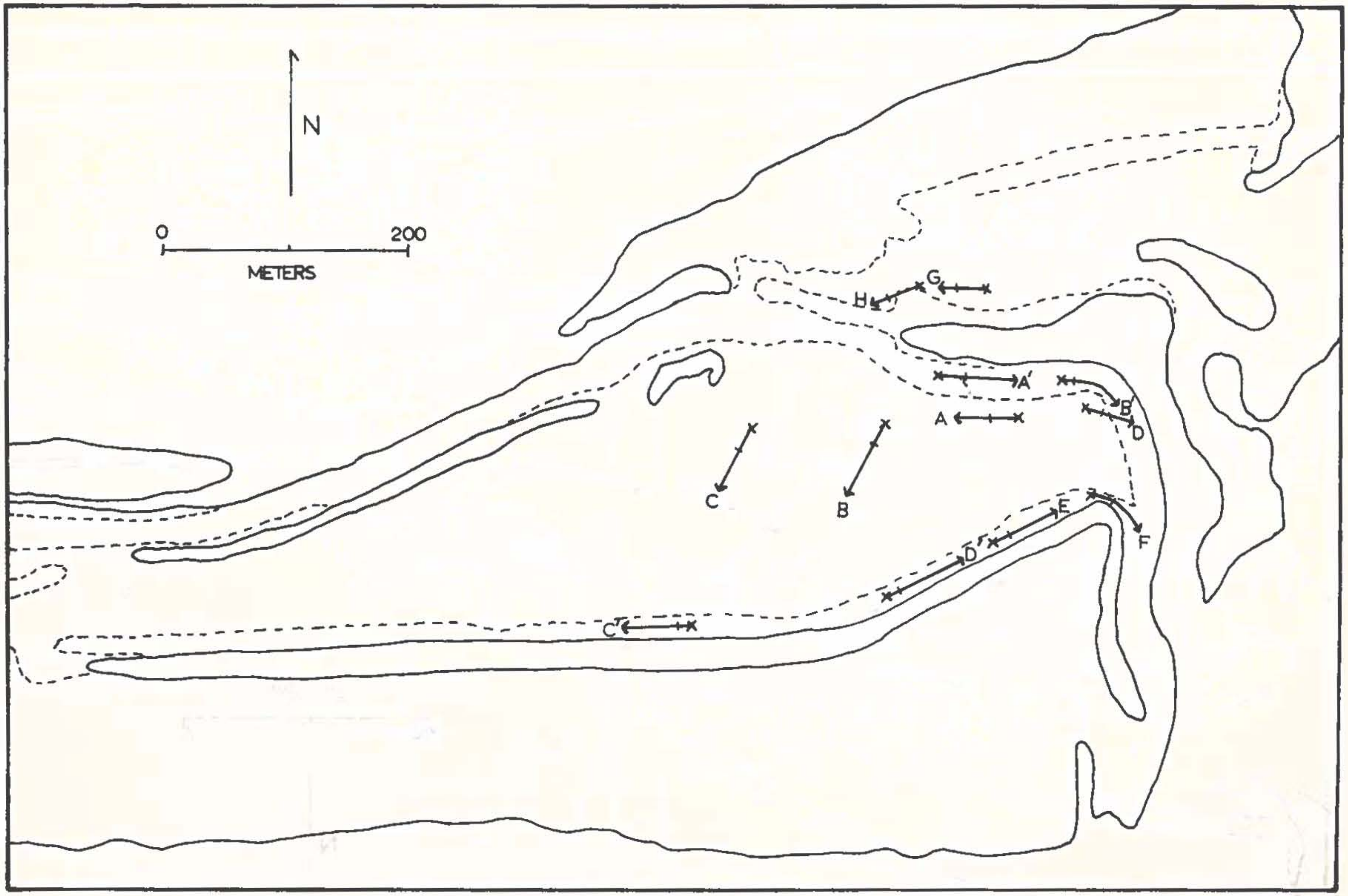

Figure 18. Dye paths of Upper Piti and Secondary Channels and Flat C; Zone III. See Table 6 for detailed information.

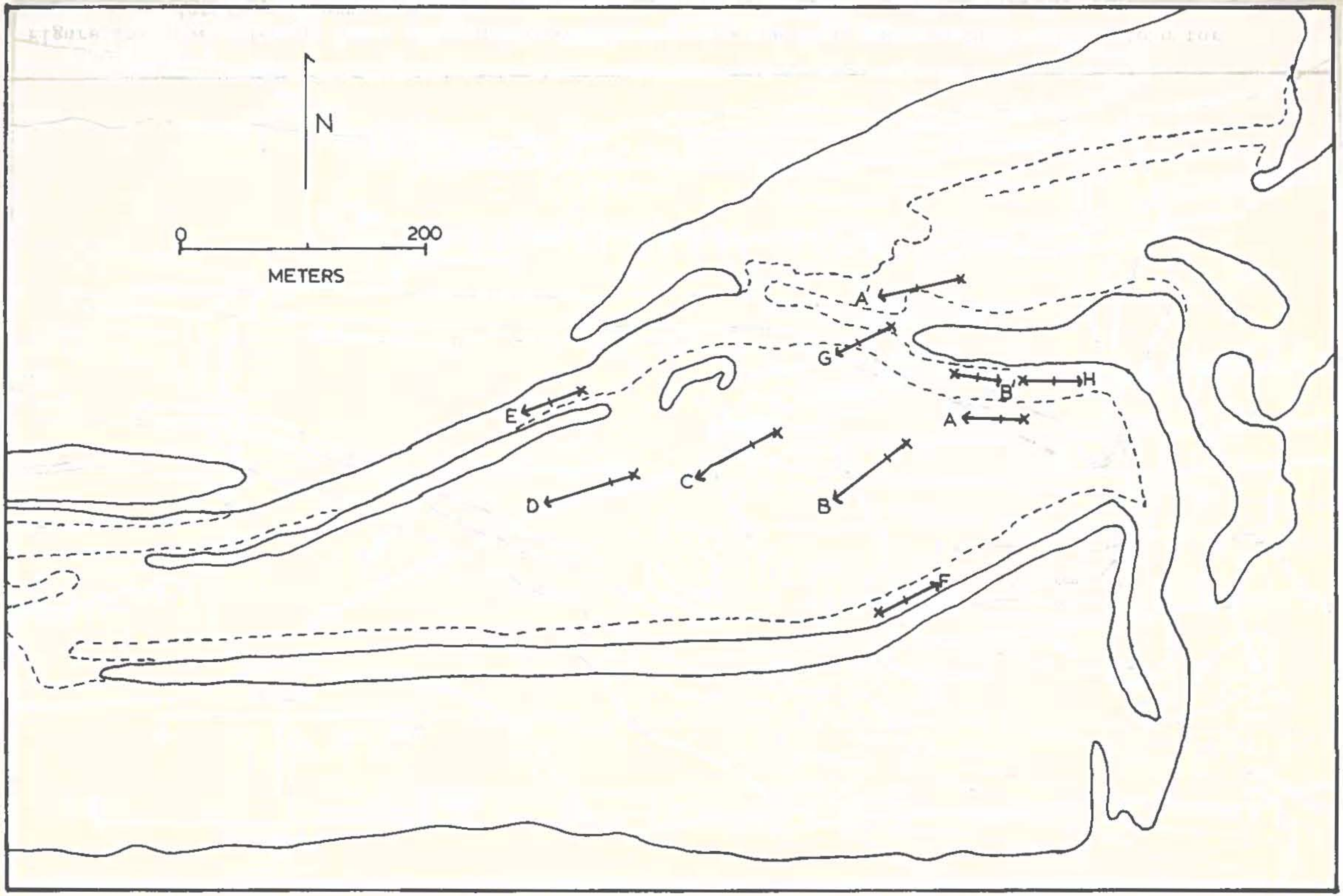

Figure 19. Dye paths of Upper Piti and Secondary Channels and Flat C; Zone III. See Table 6 for detailed information.

detailed information.

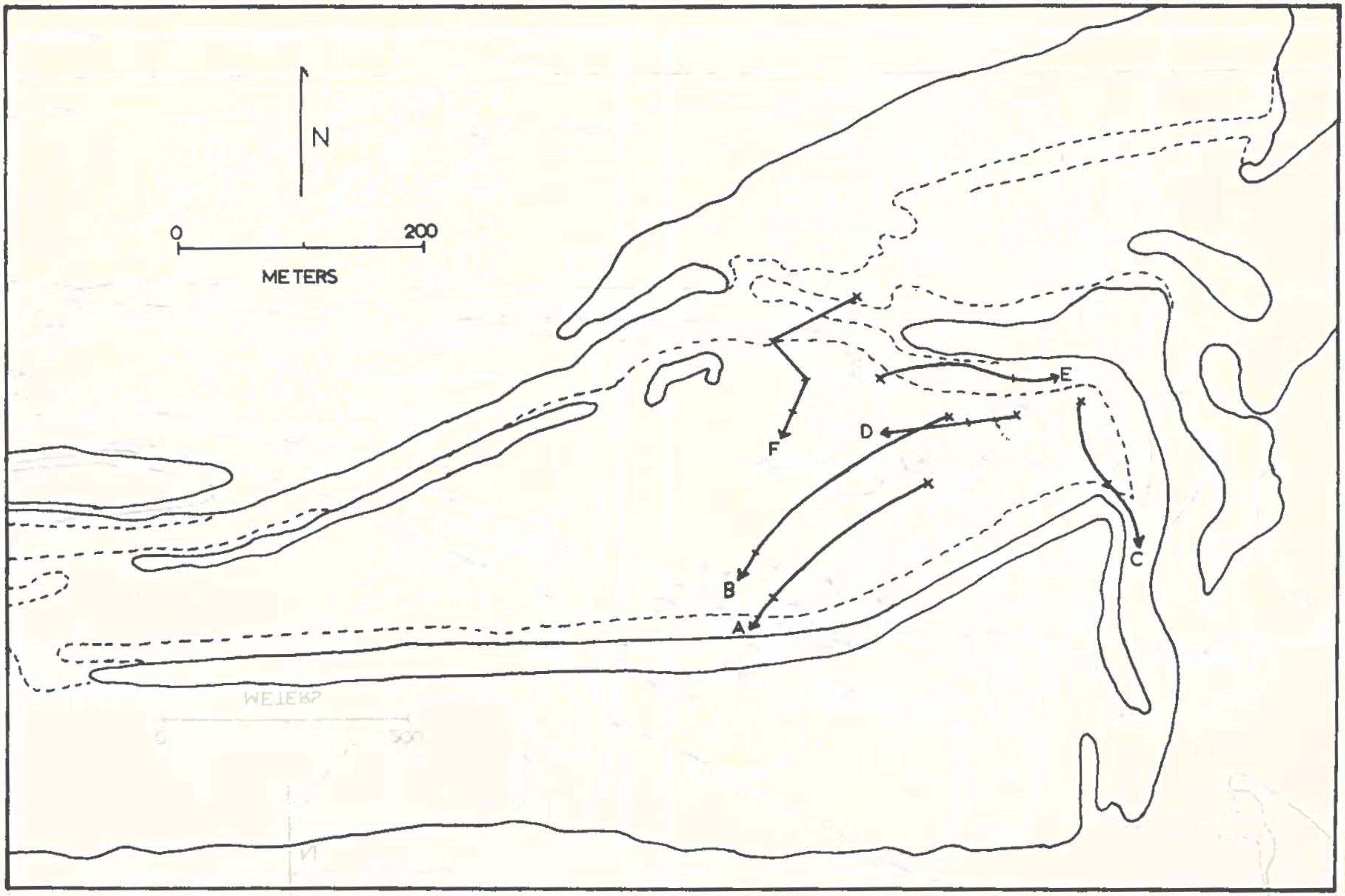

Figure 20. Dye paths of Upper Piti and Secondary Channels and Flat C; Zone III. See Table 6 for detailed information.

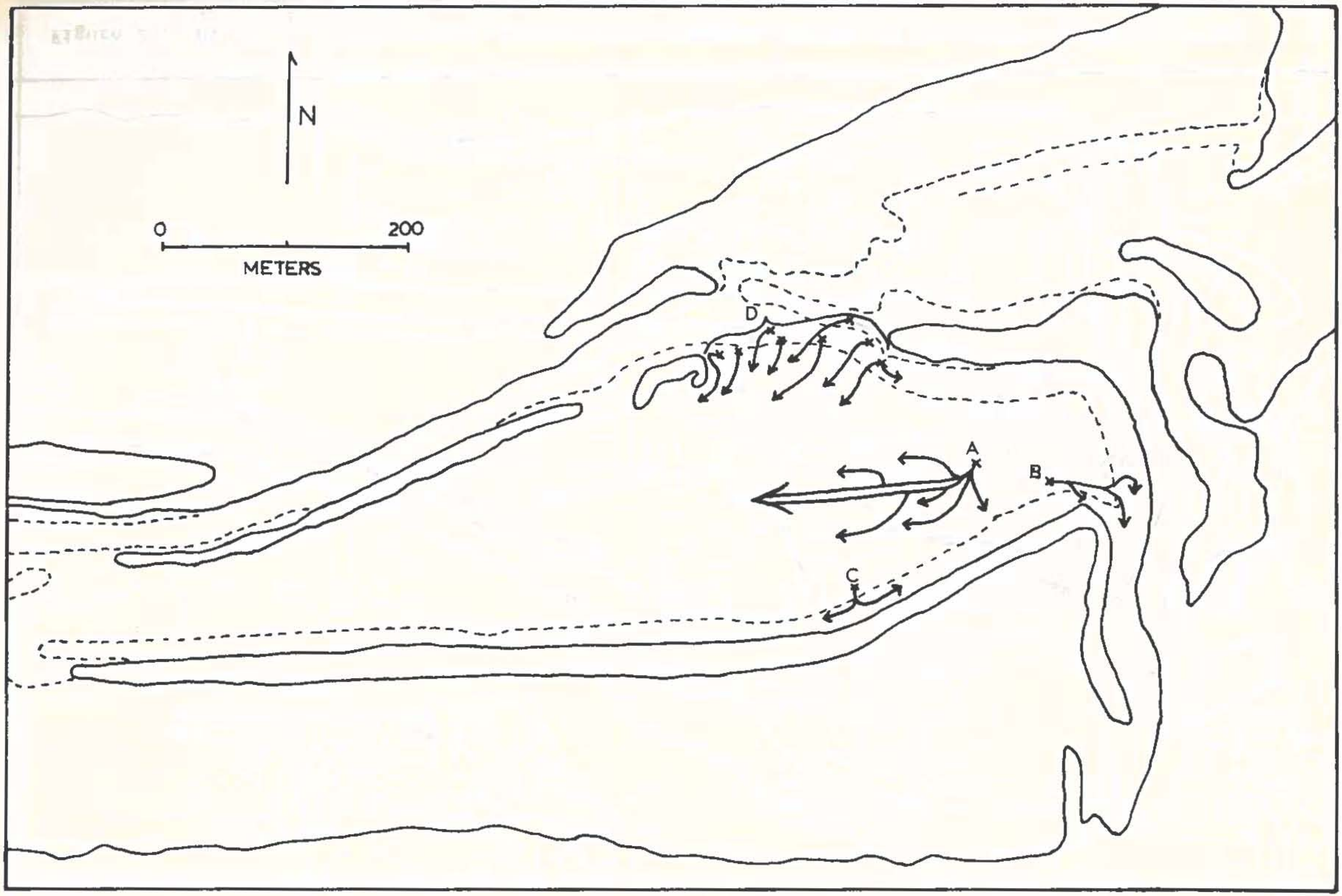

Figure 21. Qualitative study of dye patch movement for Flat C and Upper Secondary Channel; Zone III.

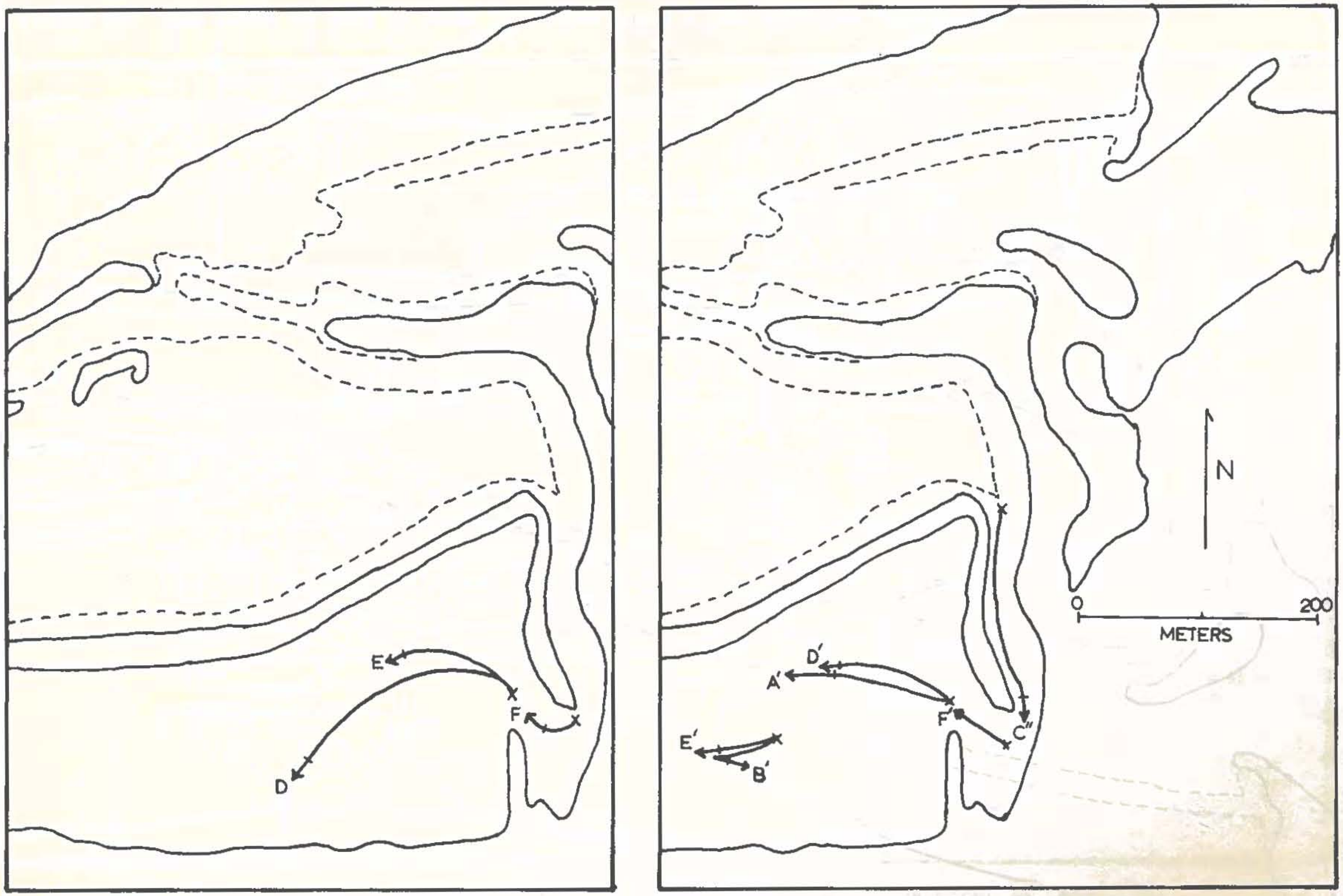

Figure 22. Dye paths of Flat D; Zone III. See Table 6 for detailed information. A, left; B, right.

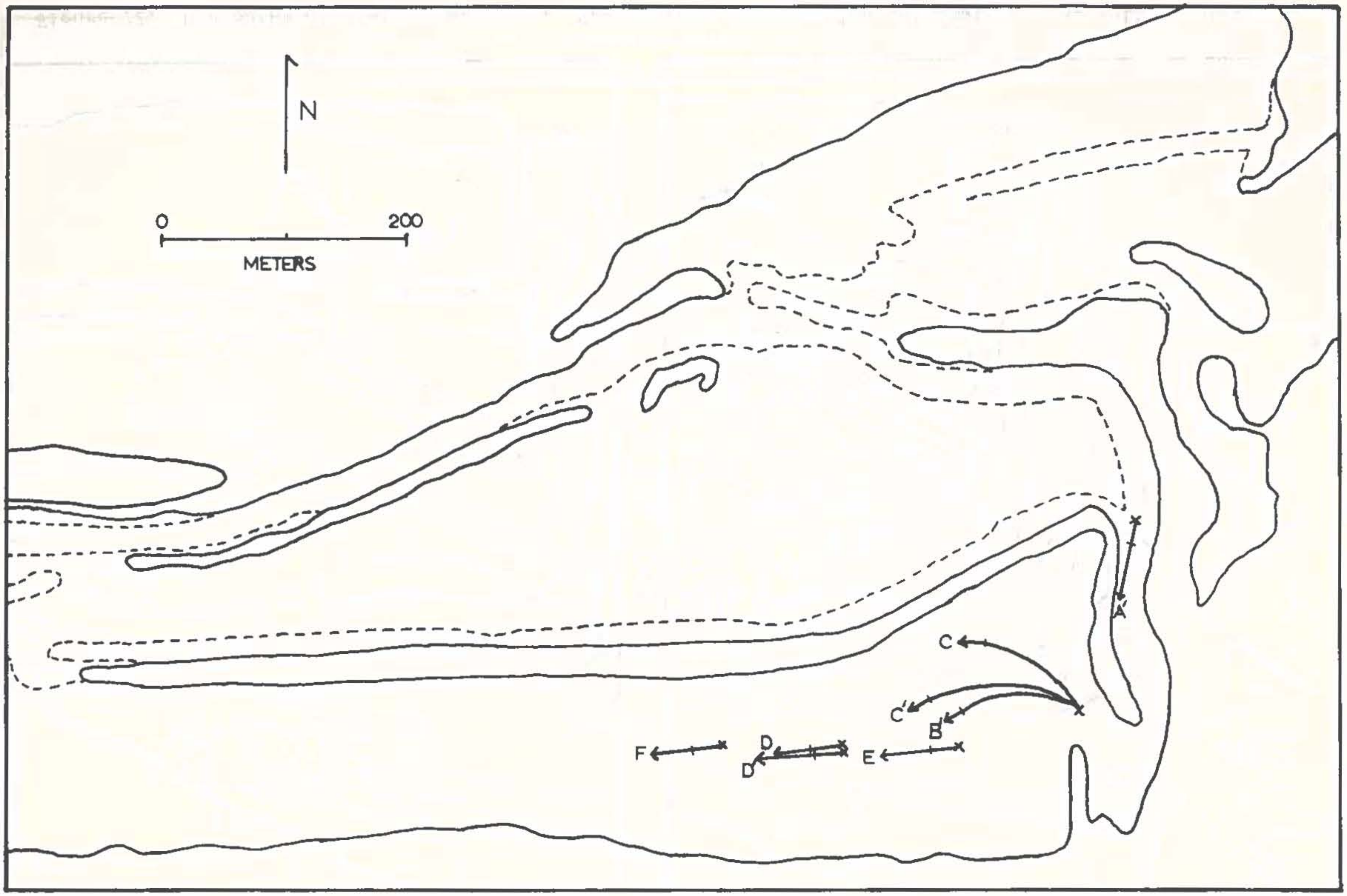

Figure 23. Dye paths of Flat D; Zone III. See Table 6 for detailed information.

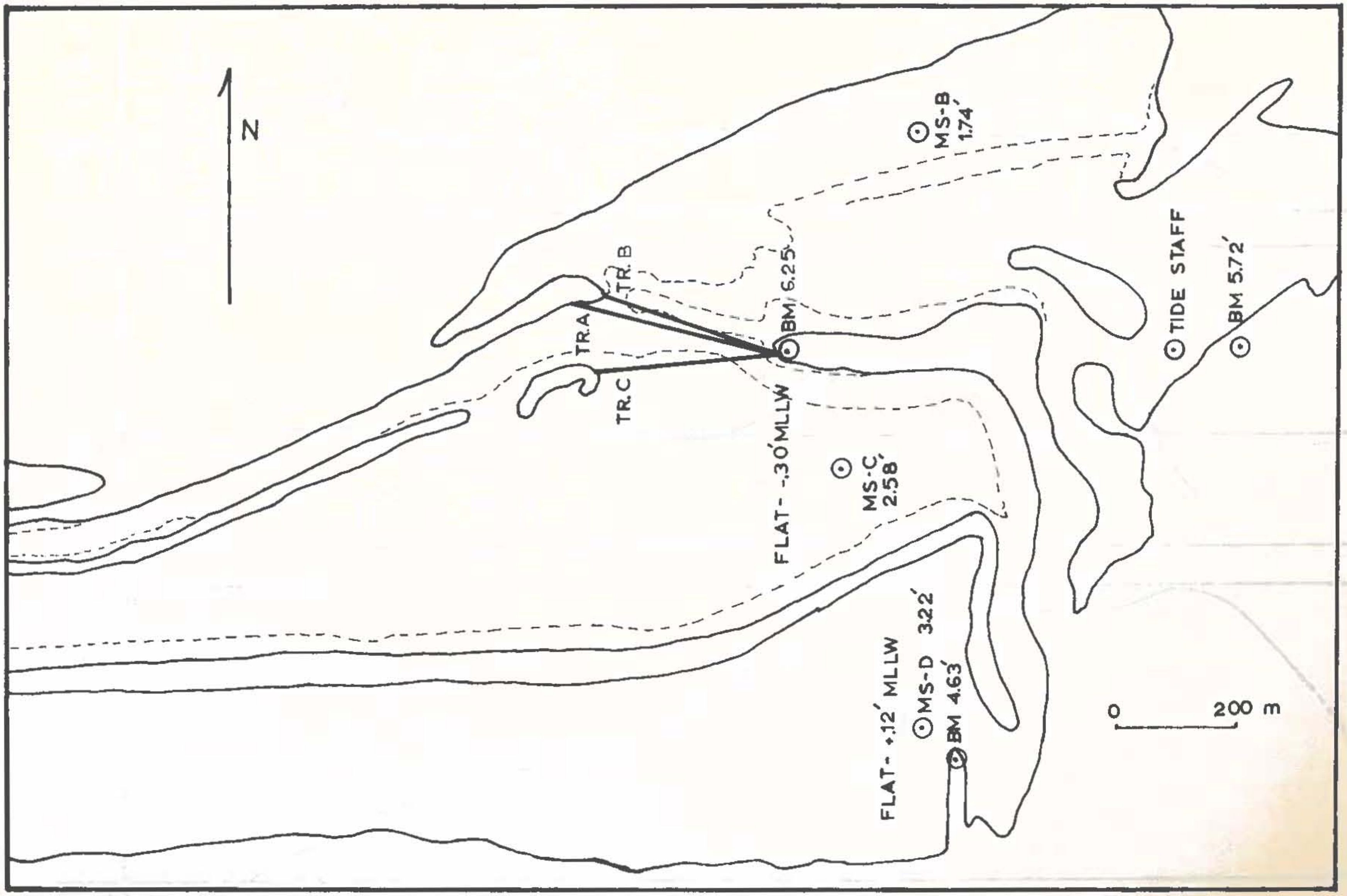

Figure 24. Gorco pipe line transects for 12 February, 1977. BM, bench mark; MS, reef flat bench marks.

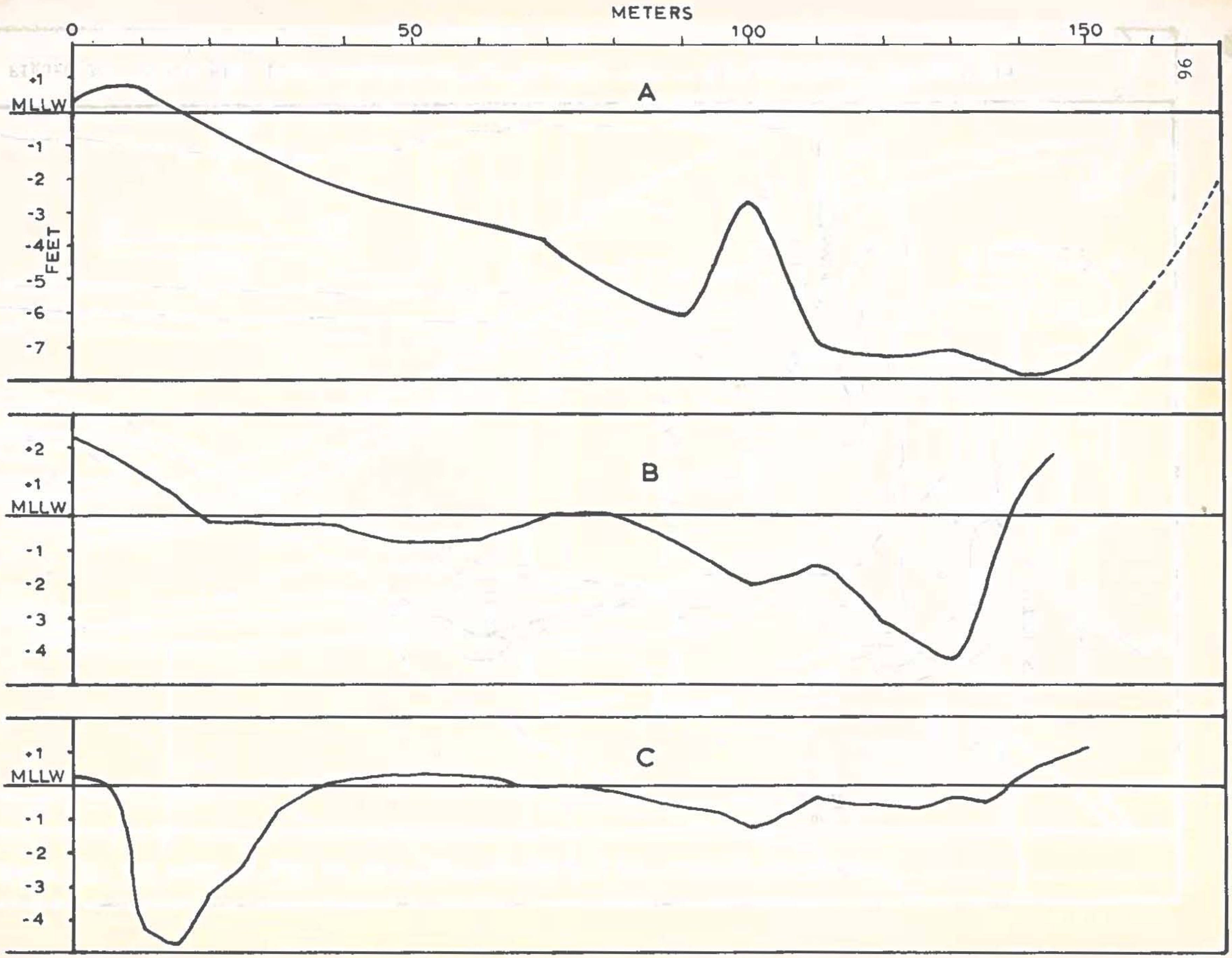

Figure 25. Profiles of Gorco pipe line transects. See Figure 24 for transect locations.