CCOP/SOPAC Technical Report 23

COASTAL ZONE SURVEYS ON SEDIMENTATION, EROSION AND POLLUTION PROBLEMS IN KIRBATI. CCOP-SOPAC CONSULTANT'S REPORT.

THE MARINE ECOLOGY OF BETIO ISLAND, TARAWA ATOLL, REPUBLIC OF KIRIBATI

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CONTENTS

Preface

This study was conducted for the Economic and Social Commission for Asia and the Pacific (United Nations Development Programme), to "plan and initiate a marine baseline data collection at Tarawa Atoll, Kiribati" (terms of contract 638930 EPT 01).

In this initial survey the ecology of the site of the proposed Bairiki-Betio causeway was established to enable the monitoring of any environmental changes caused by the construction. The reefs around Betio were also investigated to determine the effects of urbanization and development.

This study was conducted in close co-operation with the University of the South Pacific's Atoll Research Unit (A.R.U.) based on Tarawa, and the U.N. Committee for the Co-ordination of Joint Prospecting for Mineral Resources in the South Pacific (CCOP-SOPAC).

Ecology, pollution and fisheries are included in this report; hydrology and productivity are presented in a Uni. South Pacific/Uni. Hawaii SEAGRANTS report by Dr. W. Kimmerer.

Acknowledgements

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1. INTRODUCTION: BACKGROUND

1.1 KIRIBATI: GEOGRAPHY, DEMOGRAPHY, ECONOMY

The Republic of Kiribati, part of the former British Gilbert and Ellice Islands Colony, comprises three atoll groups (The Gilberts, Phoenix and Line Groups) on the equator of the Central Pacific.

The population, of Micronesian origin, is about 56,000 almost all of which live in the Gilberts, 16 atolls with a combined area of only 280 sq. km.

The islands are mostly dry and infertile; agriculture is difficult. Traditional staples are coconut (meat and "toddy") and fish, with pandanus, breadfruit and, rarely, babai (a taro). Today flour, rice and canned fish are widely consumed, particularly in urban Tarawa.

The economy remains a subsistence fishing one, with copra, the sole cash crop, suffering a depressed market. Handicrafts, remittances from overseas workers (Nauru phosphate and merchant crewmen) and postage stamps are the main revenue earners but balance of payments are adverse (approx. A$15 million imports, A$3 million exports, 1979). Proposed economic developments include fisheries and tourism on Christmas (Kiri-mati) Island.

Possibly the most serious problems facing the newly independent nation are related to the rapid urbanization of South Tarawa - unemployment, overcrowding, health problems, civil disruption and environmental problems.

1.2 TARAWA GEOGRAPHY DEVELOPMENT ECOLOGY

1.2.1 Geography

Tarawa atoll (01° 20'N; 173, 00'E) is a V-shaped chain of islets enclosing a wide, shallow lagoon, open to the west. It is 93.4 km in circumferance with a lagoon area of 375 sq. km, but a land area of only 21 sq. km. (Fig. 1).

Rural North Tarawa comprises 12 major islets or motus, with a land area of 14.7 sq. m. and a population of about 2,200. Urban South Tarawa comprises 5 elongated islets (most linked by causeway) with an area of 7.2 sq. km. and a population of nearly 20,000. Half this population lives on one islet, Betio (1.3 sq. km.).

1.2.2 Formation

Tarawa atoll is a limestone cap covering a peak of an undersea mountain range several thousand metres high. Little is known of its geology, but it is probably similar to the well-studied Bikini and Eniwetok atolls in the Marshalls to the north (e.g. Ladd, 1973). These seamounts, of volcanic origin, probably once rose above sea level in pre-tertiary times but were later eroded or truncated to sea level by wave action. During the Eocene period corals grew around the edges and over the plateaus during periods of subsidence or higher sea levels. During periods of emmergence, they were exposed as high, flat-topped islands.

Coral growth was extensive around the islands during the Pleistocene when the sea stood over 100m lower than the present. The gradual rise in level over the past 20,000 years covered the islands but coral growth continued upwards at a similar rate, to create a rim of coral in the manner postulated by Darwin.

The present islands were formed in recent times as the reef top was eroded and sediments were deposited by waves and currents. The land building processes are continuing; deposition and erosion is evident today and areas of beach rock on the reef platform indicate the positions of former islets.

1.2.3 Climate, Oceanography

The climate is an oceanic-equatorial one. Mean air temperature range is 25°C (at night) to 32°C (at day). The climate is governed by the ocean; for most of the year (March-October) prevailing light E to SE trades bring settled weather while the stormy season is characterized by W. winds. The rainfall is variable and the Gilberts are subject to droughts (average 1520 mm; 380 mm to 3000 mm).

Ocean surface temperatures range from 27°C to 29°C (28.5°C to 30°C in this study). Ocean surface salinities in this study were 35.10% to 35.55%. Prevailing Ocean currents (S. equational currents) are E to W, with an E set around Tarawa. Tarawa lies in an equatorial upwelling region.

1.2.4 Ecology

Little is known of Tarawa's marine ecology. Banner and Randall (1953), Cloud (1953), Catala (1957) have published on Tarawa or other Gilbert atolls. Weins (1962) reviewed literature to that period. Johannes et. al. (1979) included some ecological data in their report on pollution. Studies of currents, the biology of the cockle *Anadara (te bun)* and corals of Tarawa are underway at the Atoll Research Unit (Groves and Bolton).

1.3 BETIO ISLET

Betio lies at the extreme western point of Tarawa (Fig 2 & 3). Like other atoll islets it is formed of sand and rubble of diverse origins:

coral, molluscan, echinoderm, algae, foraminifera etc. (see Weber and Woodhead, 1972).

The terrestrial vegetation has been greatly disturbed. Prior to the arrival of man it was probably dominated by a low, windshorn scrub of *Messerschmidia argentea (te ren), Premphis acidula, Scaevola sericea (te mao)* and *Pandanus*, with a cover of coarse grasses such as *Lepturus repens* and sedges such as *Cyperus polystachyos* (Doran, 1960).

The ancestors of the I-Kiribati brought a range of plants - coconut palms, breadfruit, taro, pandanus varieties - and cleared much of the land; much more was cleared for the copra trade which began a century ago.

Betio was the administrative capital of the British Colony but the population remained low until the invasion by Japan in 1942 when it was in excess of 5,000. During the occupation the middle of the island was levelled for an airstrip and the shores were heavily fortified. The island was totally devasted in the U.S. landing of 1943, reputed to have been amongst the bloodiest fighting of WWII. The population remained low under the post-war British government but urbanization accelerated in the 1970's. Today Betio is overcrowded.

Health problems are serious. A cholera epidemic in the late 1970's was responsible for many deaths and illnesses. Today diabetis is a major problem. The small islets also face severe environmental problems resulting from development and urbanization: wastes and rubbish disposal, erosion following dredging and port works, destruction of coral reefs, localized pollution, and over-exploitation of fisheries.

1.4 BAIRIKI-BETIO CAUSEWAY

All the South Tarawa islets, with the exception of Betio, are now linked by causeway, greatly facilitated modern urban life in the capital. Because the airport lies at Bonriki islet, the hospital, some administration and residences on Bikenibeu, the government on Bairiki and the light industries and high density housing on Betio, it is often necesary to travel between centres. Travel to the linked islets is fast and efficient, but it is necessary to take a motor barge (bi-hourly, daytime service) or launch to Betio. Communications with Betio are therefore costly in fuel, fares and lost working time. The construction of the causeway is therefore essential in the development of the capital.

Work on the causeway began in 1977 but was suspended the following year because of engineering problems. It is anticipated that it will recommence in 1982-1983. There are also suggestions that the airport be included in the causeway development as the present Bonriki strip is considered unsafe.

Because of environmental problems arising from the construction of the previous, much smaller causeways, there is considerable concern on the impact of such a large-scale project on the ecology and fisheries of

Tarawa. This study was therefore initiated to establish as baseline by which any changes may be gauged, and may assist in the planning of any future works of this type.

1.5 SURVEY & METHODOLOGY

Between November 7 and 18, 1981, at total of 134 stations and transects were examined on the Bairiki-Betio platform, on Betio reef and in the adjoining open sea and lagoon (Fig. 4: and APPENDIX 1). Aerial observations and D.O.S. photographs, maps and charts were also used in interpretation and location of ground sites.

Sea stations were visited by A.R.U. motor boat. Underwater observations (approx. 20 min. duration) were conducted by skindiving in shallows (to 5m), and SCUBA (to 25m). Transects were conducted on reef platforms during very low spring tides (0.0m). Positions offshore were fixed by compass or horizontal sextant angles, both of limited accuracy because of lack of landmarks.

Temperature-salinity profiles were established using a 'Hammon' type ST meter with 100m cable; depths were estimated by lead line; turbidity by 0.5m scechi-disc. These hydrographic data (Appendix II) were supplied to Kimmerer for interpretation. Plankton samples were taken at several stations and held for further studies.

The primary objective was the ecological mapping of the proposed causeway area and Betio reefs. Gross quantitative methods as used by Done *et.al.* (1981) and others in Australia, were used. At each station the situation, depth and water characteristics were noted. The bottom type (substrate) was noted and the % of different sediments (sand, limestone, dead coral etc.) were estimated. The biota was classified according to dominants and % coverage of major benthic organisms estimated by eye. Because of time limitations, most organisms could only placed into genera or higher taxa. Some dominants were collected for specific identifications. Benthic organisms (bottom dwelling corals etc.) were emphasised as these are key organisms in the community.

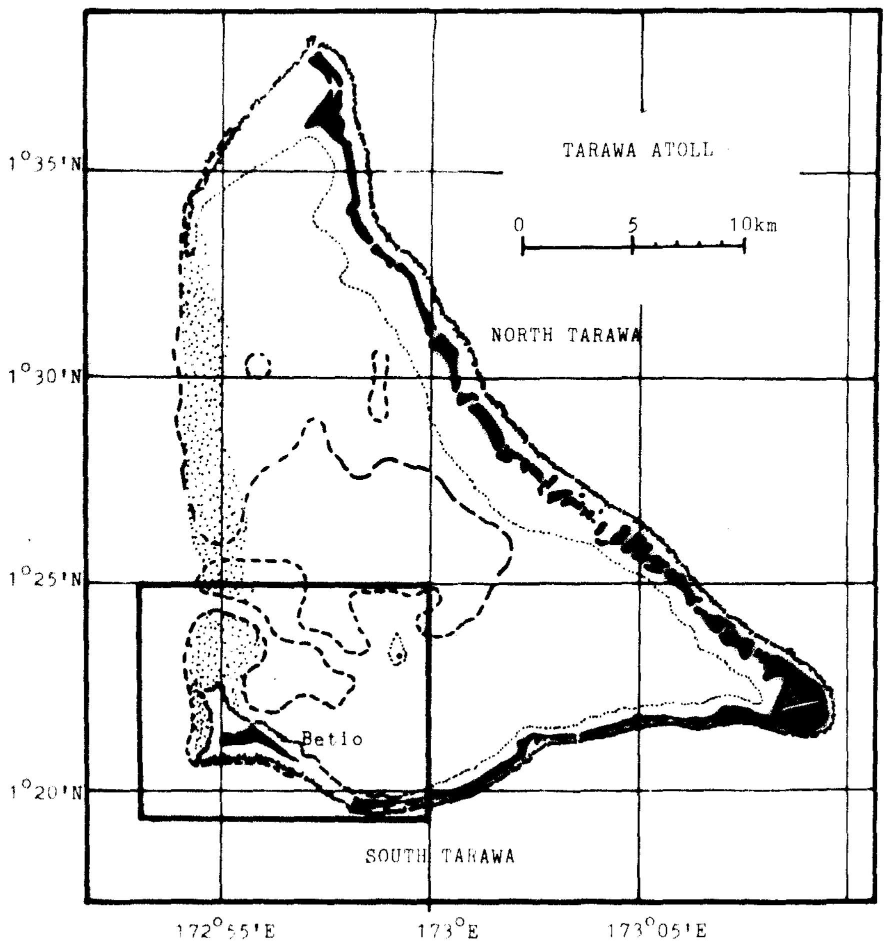

FIG. 1 TARAWA ATOLL, REPUBLIC OF KIRIBATI.

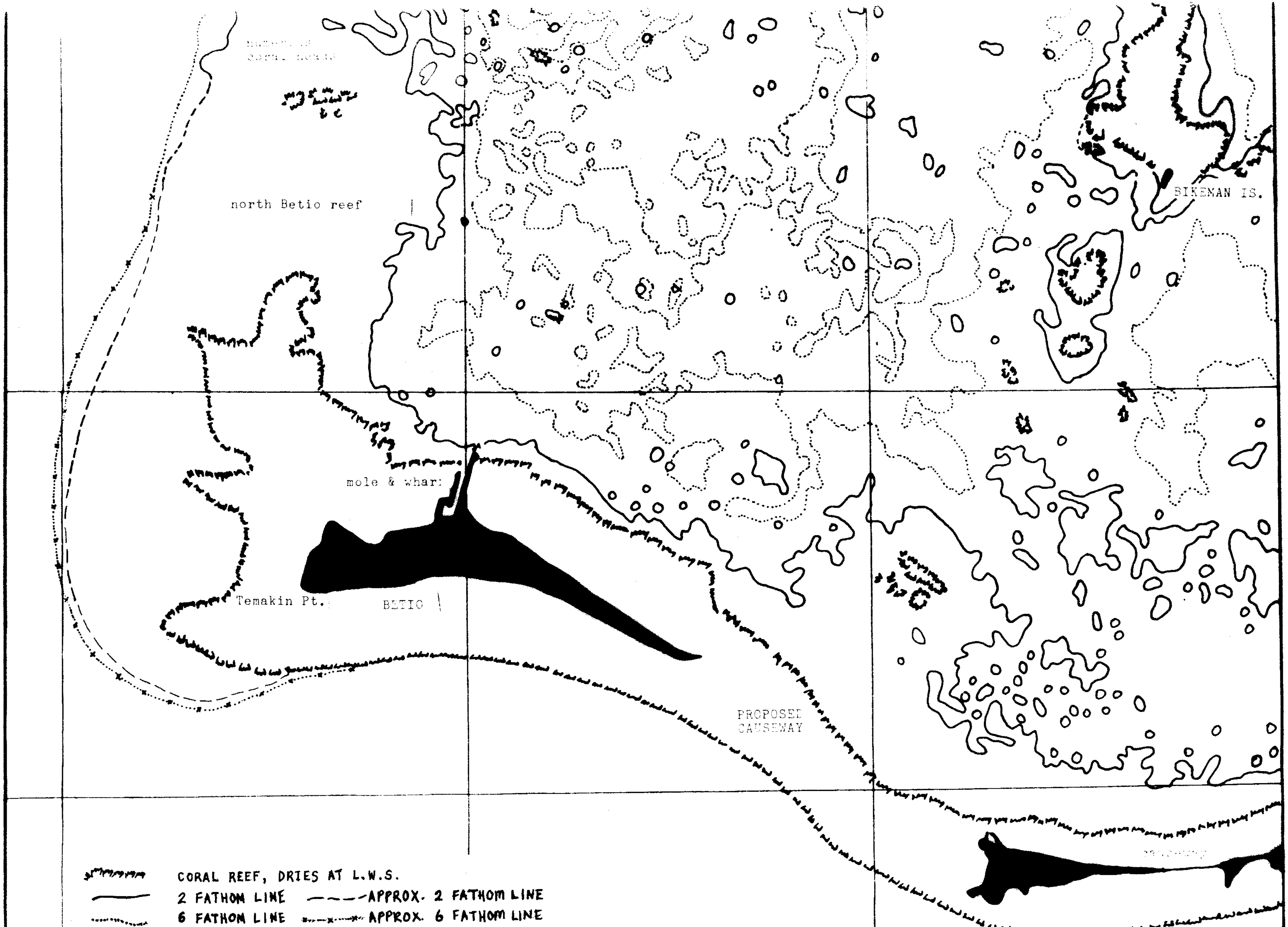

FIG. 2 BAIRIKI-BETIO AREA, BOTTOM TOPOGRAPHY (FROM ADMIRALTY CHART)

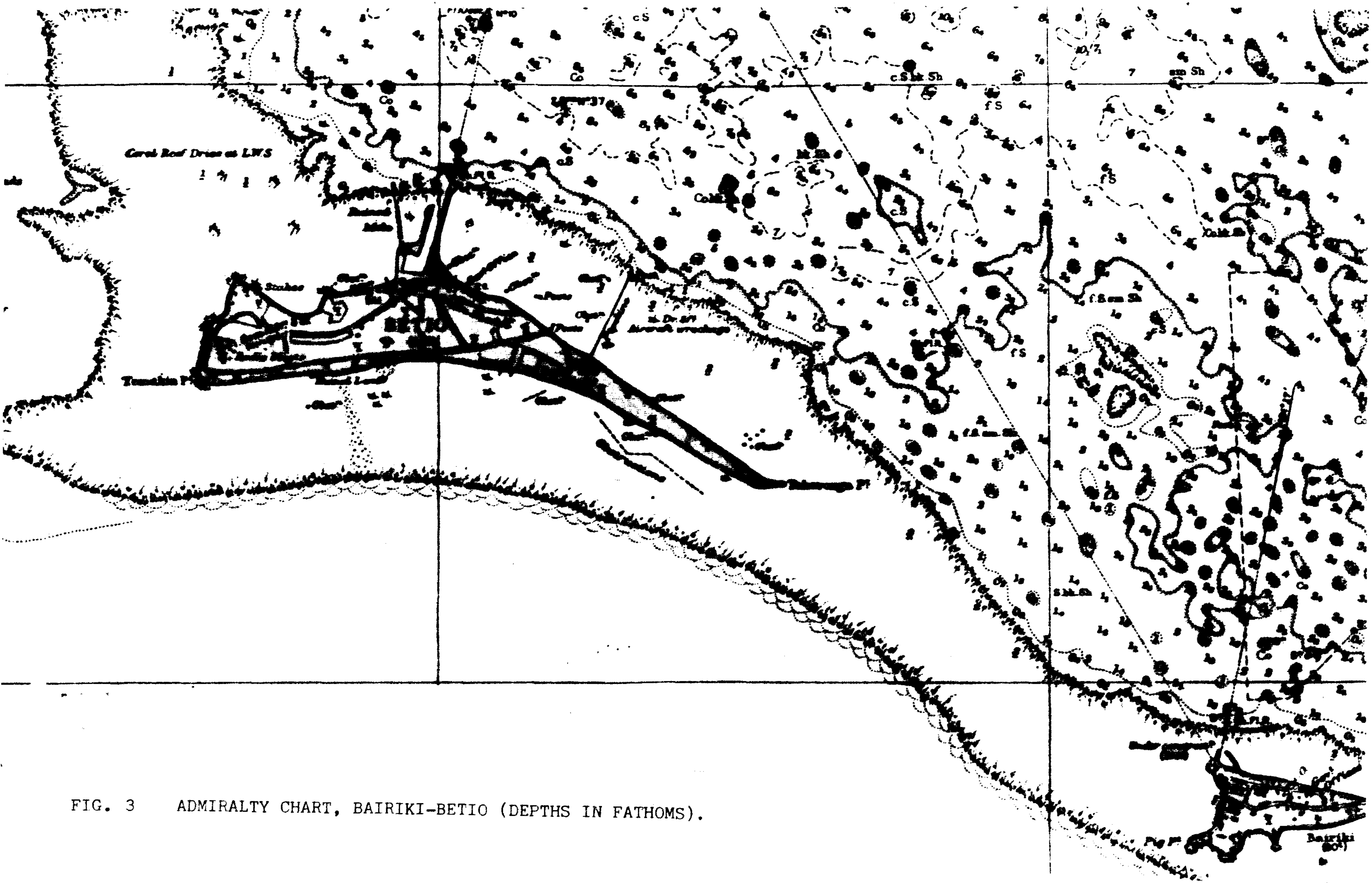

FIG. 3 ADMIRALTY CHART, BAIRIKI-BETIO (DEPTHS IN FATHOMS).

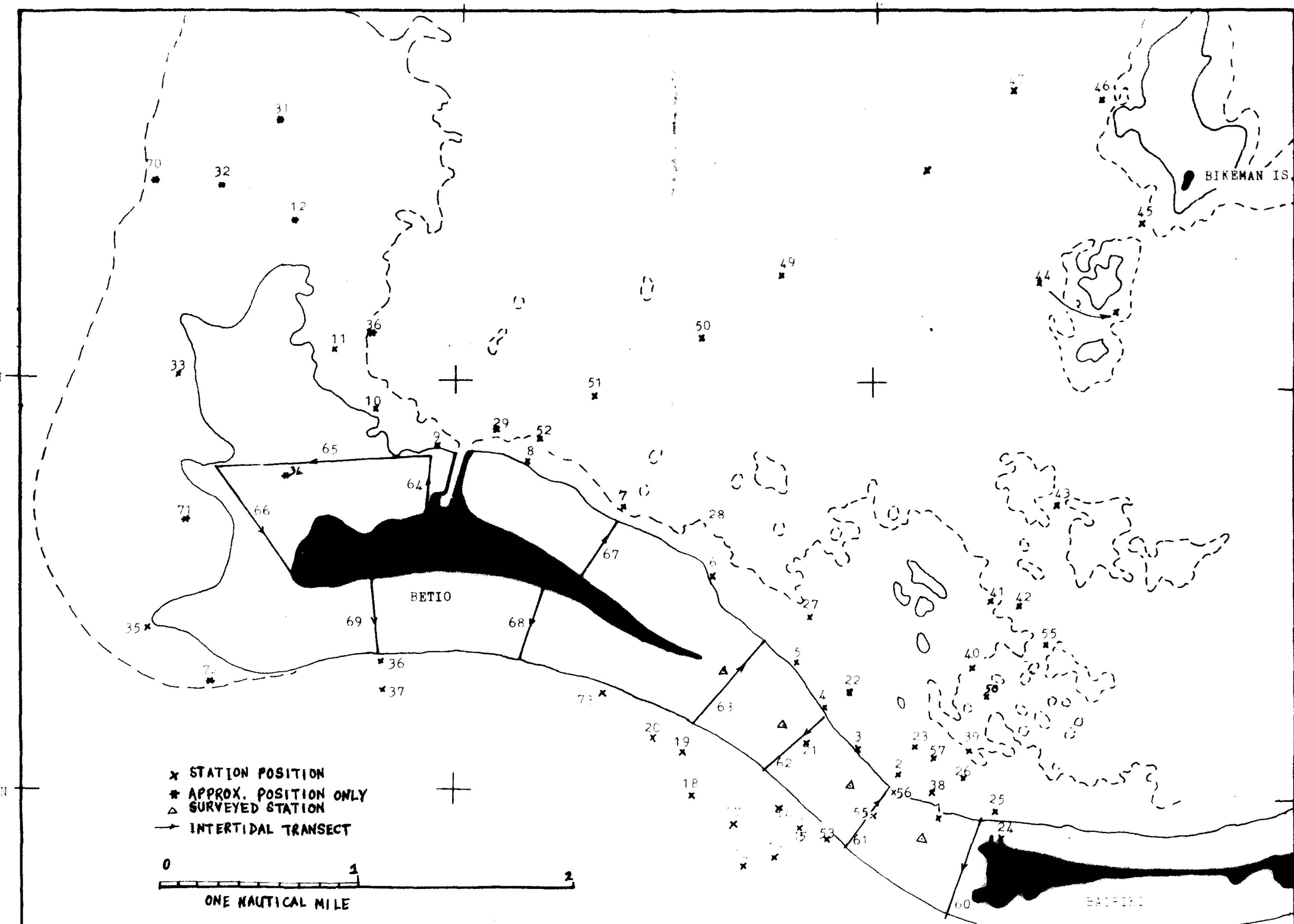

FIG. 4 BAIRIKI-BETIO AREA SHOWING POSITION OF STUDY SITES AND STATIONS. (* indicates position approximate).

2. ECOLOGY OF BAIRIKI-BETIO PLATFORM AND ADJACENT WATERS

Betio and Bairiki islets are separated by a 2.4 km wide passage, most of which is exposed at low water. The platform or reef-flat is 680m to 950m in width, and consists of exposed limestone, coral and other calcareous sediments, rubble tracts, a long sandbank or spit, and wide lagoonal sandflats (Fig. 5).

Four transects were examined at low water while 10 adjacent underwater sites were examined by diving. Transects differed slightly in detail but several distinct physical and biological zones (biotypes) and sub-zones (faces) could be differentiated. These reflected differences in depth or elevation, topography and substratum, wave and air exposure, temperature, light etc. Major biotypes and depths, from ocean to lagoon, were:

UPPER SEAWARD SLOPES (- 40m to - 15m)
REEF FRONT OR TERRACE (- 15m to - 4m)
REEF MARGIN (-4m to 0m)
REEF PLATFORM (0m to + 1m)
SAND BEACHES: ISLAND OR SPIT (+ 1m to + 2.5m)
LAGOON SAND FLATS (+ 1m to + 0.5m)
LAGOON SAND POOLS (+ 0.5m to 0m)
LAGOON MARGIN REEF (+ 0.2m to - 4m)
LAGOON (0m to - 10m)

These are described in general terms below, and in detail in Appendix III.

2.1 SEAWARD REEF SLOPE

The Gilbert chain of atolls rise from deepwater (4,000m - 6,000m). The angle of the outer reef slopes probably ranges from 30° to 60° (Emery *et al* 1954 found the average slope of the 400m level in the Marshalls was 37.5° and up to 68° in parts). Nothing is known of the biota of the slope below 40m, although CCOP-SOPAC tangle-dredged for precious coral *(Corallium)* off Phoenix atolls in 1980 (Gauss).

In the Marshalls sedimentary materials grade downward along the reef slope from coarse to find (Jones, 1973). Coral and *Halimeda* debris is the main component of the upper slope with finer *Halimeda* silt at 1200m. Limestone outcrops were exposed in steeper slopes, to 170m.

The biota between 200m and 500m probably resembles Fiji's: carid shrimps (King, 1981), a range of potentially commercial snappers (Raj *et. al.* 1981), sponges, ahermatypic corals, gorgonians and crustaceans (Zann, unpubl.).

The upper reef slope (-40m to -15m) is relatively steep (to about 45°) and covered by a skree of fine to coarse calcareous sediments with outercrops of living and dead coral outcrops and knolls. The coverage of living coral increases as one approaches the surface as reef-forming or hermatypic corals require sunlight for the photosynthesis of their symbiotic zooxanthellae; reef-forming corals are confined to the top 40m to 50m of the slope.

Communities at 30m, 20m and 10m depths at station 36 were:

a) 30m: mainly fine sediment and sand (60%) with exposed dead coral and limestone (30%), and living corals (10%). Corals include: *Lobophyllia, Tubastrea, Favites, Heliopora,* seawhips *(Cirripathes)* and gorgonians. Encrusting sponges, actinians and soft corals (cf *Dendronephthya)* present. Slope subjected to strong currents (1 knot to 2 knots).

b) 20m: sediments (50%), dead coral and rubble (30%) and living corals (15% - 20%). Dominant coral *Heliopora* and *Pocillopora; Acropora, Montipora, Favia, Porites* common; many other genera present. Encrusting colonial actinians (10%) on dead coral. Sponges.

c) 15m: sand and rubble (50%), dead coral knolls (20%), living corals (20%). Dominant *Heliopora* (5%); community as above.

2.2 SEAWARD REEF FRONT

The reef front consisted mainly of a gently sloping terrace at about 10m to 15m with elongate coral patches or butresses 10m to 50m long and 2m to 4m high, separated by sandy channels or gutters 3m to 6m wide. In some cases these were extensions of the grooves of the reef margin; in others they were separated by sand, rubble or coral. The buttresses and terrace ranged from 50m in width off the exposed W. reefs and wider in the more sheltered N.W. exposure. (Fig. 6).

A terrace between 14m and 18m depth was characteristic of Marshall reefs, but at Bikiri was widest off the more exposed reefs, to 380m in width (Emery *et al*, 1954). The terrace is generally supposed to be an erosional feature.

The buttresses comprised approximately 70% - 80% algal-encrusted eroded coral and 20% - 30% living coral: *Heliopora* (5% - 10%), *Pocillopora eydouxi* (3%), *P. verrucosa* (2%), *Acropora* spp. (5% - 10%), *Montipora* (5%), with *Distichopora, Fungia, Pavona, Hydnophora* and other genera present. The dead coral was encrusted by coralline algae (lithothamnions), over-grown by zoanthids *Polythoa* (2%) and colonial actinians (10%). Coral reef fish - acanthurids, scarids, chaetodons, pomacentrids, labrids, etc. - abounded. The sand/rubble sediment in the channels was highly mobile, precluding encrusting organisms.

In deeper water the elongate buttresses broke into more isolated coral knolls and patches, separated by wider expanses of sand and rubble. Living coral coverage was about 10% - 15%. Dominants included: *Heliopora, Porites* (massives), branching *Acropora, Pocillopora* and *Seriatopota,* with *Fungia, Herpolitha, Turbinaria, Millepora,* etc.

The coral buttresses of the terrace were interrupted in two areas off the platform by flows of sand (Fig. 5 inset). These were probably formed adjacent channels which cross the platform from the lagoon. Sediment-laden lagoonal waters flowing into oceanic waters deposit fine silt over the reef slope, smothering corals and reefs of the terrace. Thus lagoonal sediments are continually being lost to the seaward slopes via the Bairiki-Betio platform.

The reef front and terrace are areas of great coral growth, and high algae productivity, fish diversity and biomass. It is an important fishing ground for canoe fishermen in Tarawa.

2.3 REEF MARGIN

The terrace stepped up to the jagged spur-and-groove systems characteristic of high energy or wave-exposed reef edges. The jutting spurs (10m to 20m long) were of highly eroded, algae-encrusted, coral rock. Small,mainly encrusting corals *(Porites, Montipora, Pocillopora)* had about 5% coverage.

The open surge channels or grooves and numerous eroded holes and overhanges tended to have a greater coral coverage (5% - 10%) dominated by branching *Pocillopora* spp., *Acropora* and *Heliopora,* with stands of fragile *Distichopora* in more protected areas.

The dead corals and eroded rock was completely encrusted by 1cm - 3cm mat of coralline and brown algae, overgrown by green *Caulerpa racemorpha* (5% - 10%) and the zoanthid *Polythoa* (5% - 10%).

2.4 REEF PLATFORM

The wide, flat reef platform consisted of a limestone basement partially covered by sand, and coral rubble and boulder tracts. At the centre was a wondering sandbank extending from Bairiki to Betio and broken only by a system of channels.

The limestone platform is probably also an erosional feature, cut to the present low water level by waves following a land emergence or slight fall in sea level. The platform was notably lacking in living corals and other organisms, unlike those of the Marshall atolls, probably because of a higher platform which completely dries during most low tides, the absence of permanent tidal pools and surge channels, and the greater radiation and desiccating effect of the equatorial sun. Temperatures of 35^{o}C to 38^{o}C were recorded in shallow pools by the author in 1979.

Several geomorphological zones ran parallel to the reef margin: spur-and-grooves (20m - 30m wide); eroded pools (0m - 20m); raised algal ridge (60m - 100m); boulder zone or rubble tract (20m - 30m); moated pools (0 - 20m); sand and coral rubble flat (60m - 100m); ranging into a sand flat with tidal pools (60m - 100m); sand beach and sand spit (30m - 100m); lagoon sand flat (100m - 180m); sand flat tidal pools

(50m); lagoon coral-knoll and/or *Halimeda* zone (0 - 50m); lagoon proper. (Note: 0 indicates that this zone was not present in a transect).

Zones are represented in perspective scheme (Fig. 6)and plan (Fig. 5) based on D.O.S. aerial photographs.

Most zones result from the physical sorting of different sediments (sand to boulders) by regular wave action and currents, and high energy waves produced in seasonal westerly gales. Zones included:

a) Algal ridge

This is a characteristic zone of high energy reefs where the edge of the platform is kept permanently moist by wave surges and spray, and light for photosynthesis is intense. The upper part of the spur-and-grooves was encrusted (90% coverage) by a thick algae mat of coralline lithothamnians, *Lithophyllum* and nodular *Hydrolithon, Amphiroa* and filamentous green and brown algae. *Caulerpa, Dictyota, Paddina* and *Halimeda* formed a canopy over 20% of the mat. Encrusting zoathids *Palythoa* covered 5% to 10%, and branching corals such as *Pocillopora verrucosa, P. damicornis, Acropora* and encrusting *Montipora Porites* and *Favia* covered about 5%.

This community continues into an area of permanent pools in eroded coral where the canopy of *Caulerpa* and other higher algae was better developed, covering about 50% to 70% of the algae mat. Small actinians, ascidians, zoanthids, sponges and branching corals (above) were present in the pools. Other organisms included gastropods (*Cypraea annulus, Drupa*), polychaete nereid worms, polyclads, octopuses, and many long-armed brittle stars, *Ophiocoma scolopendrina* (1 to 3/sqm). A slightly elevated ridge of algal-cemented rubble lay behind this zone.

With a great biomass of algae, the algae ridge is also a very productive zone. Although few grazing animals were evident at low water, many grazing fish (scarids, pomacentrids, acanthurids) move over the reef top at high water to feed on algae.

b) Rubble tracts

Lines of coral boulders and rubble lay immediately behind the algal ridge in two transects. Rocks closer to the sea were covered by green and blue-green algae, while browns and other algae were present in shaded interstices. The brittlestar *Ophiocoma* was abundant and was seen feeding on nutrient-rich reef "scum" on the surface of the rising tide. Black sea cucumbers, *Holothuria atra,* were common on sandy patches between rocks.

c) Moated pools

The rubble tracts moated shallow pools of limestone, sand and rubble. Again biota was notably sparse, possible because of abrasion by moving sediment from breaking waves at ebb and flood tide. Filamentous green algae encrusted rocks while sea cucumbers *H. atra* and *Stichopus chloronotus* were common (0.5 to 2/sq. m) in sandy pools.

d) Sand/rubble flats and pools

The moated pools gave way to broad sand/rubble flats, dry during most low tides. Rubble was partially covered by coralline and filamentous algae. The sand component gradually increased from about 40% adjoining the pools, to 90% closer to the sand bank. A rippled sand surface indicated strong currents and a highly mobile substratum, preventing the development of a benthic community.

Patches of red or green, probably microscopic diatoms or phytoflagellates, were present on the surface of the sand. Small burrows, possibly of *Alpheus* shrimps, were present in pools. A small sand-dwelling actinian or zoanthid was abundant in areas (to 10/sq. cm).

Few sand-dwelling molluscs were present. No bivalves were seen, although careful seiving of sand might have revealed some as the trails of predatory sand snails (Naticidae) were noted. Sand dwelling *Conus pulcarius* and crabs *Calappa hepatica* and *Ocypode* were present but not common, while many small, bright red synaptid holothurians were present in drier sand.

e) Sand spit

A long sand spit was present about half-way across the platform. The height was approximately 1m to 1.5m above low water and it is awash at all high tides. The bank was higher near Betio where the 1978 dredging built it up to a higher level, and parts are newly vegetated. The width varied from zero (where cut by channels) to over 100m. Widths at the transects were 25m, 122m, 35m and 110m. The sediments of the bank were well sorted, fine to coarse sand (80% to 90%), with small pieces of coral rubble and mollusc shells.

Four deeper channels transected the middle of the sandspit. At a time of theorectically zero tide (1010 hrs, 12 November 1981) the channels were 10 cm to 30 cm deep, and 6m to 20m wide. A strong current estimated at 2 knots to 3 knots flowed from ocean to lagoon.

Biota of the sand was limited: a few red synaptids and tufts of filamentous green algae on fragments of rubble. The slope of the ocean "beach" was steeper (10^{o} to 20^{o}) than that of the lagoon "beach" (2^{o} to 5^{o}), as noted by Wells (1951) at Arno.

f) Lagoon sand flats and pools

A wide (av. 250m) sand flat lay between the sand spit and edge of the lagoon. The coral rubble component gradually declined from about 10% adjoining the sand spit, to 0% at the lagoon edge. The origin of sediments was mainly lagoonal.

This area was again biologically impoverished. Macroscopic animals included the gastropod *Oliva* and crab *Calappa* in upper reaches, but lower areas including sand in pools was heavily bioturbated (turned-over by burrowing animals) mainly the worm *Sipunculus indicus*.

Filamentous algae "turf" was embedded in the sand while holothurians *H. atra* and *S. chloronotus* and snails *Strombus luhuanus* and *S. gibberulus* were present.

Women were seen collecting *S. indicus ("te ibo")* on one sand bank. The method of capture is unusual: A stick is used to plug one entrance to the U-shaped tube while another is used to transfix the worm through the mouth and extract it. It is then everted and cleaned of sand, to be later eaten raw, dried or cooked.

The sandflat gradually shelved below zero tide level to form deeper pools (to 30cm) bounded by a line of living and dead coral heads along the lagoon edge. The coral rubble component increased closer to this reef and beds of green algae *Caulerpa racemorpha* and *C. speciosa* appeared. The sea cucumbers *H. atra* and *S. chloronotus* were abundant (to 2/sq. m) while the edible sea urchin *Tripneustes gratillus* was common in rocky areas.

The barren lagoon flats of the Bairiki-Betio platform are to be contrasted with those of most of South Tarawa (Nanikai to Bonriki) which are dominated by sea grasses and are productive fishing grounds for shellfish *(Anadara or "te bun"; Gafrarium; Atrina; Strombus* spp.): crustaceans *(Leptosquilla)*, and finned fish. The greater wave energy of the Bairiki-Betio flats has possibly prevented the development of the productive seagrass community.

g) <u>Lagoon reef margin</u>

The discontinuous line of small patch reefs and micro-atolls (flat-topped coral heads often with eroded centres) lay in depths from +0.2m to -3m. They were clearly discernable in aerial photographs.

Underwater studies (stations 1 to 5) along the lagoon edge at high water indicated that most of the coral was dead *Porites*, covered by the algae *Caulupa racemorpha* and *Halimeda* c.f. *macrolobata*. The proportion of dead coral was greatest nearer Bairiki:

<u>Stn. 1</u>: Coral rubble reef; 0.1% living coral (one small *P. damicornis* colony in 200m transect). 100% algae cover *(Dictyora, Padina, Caulerpa racemorpha, C. speciosa)*. Small anemones; sponges in sand. Fish: juvenile scarids and labrids abundant.

<u>Stn. 2</u>: Coral rubble reef, dead *Porites* heads *in situ*. Coral cover approx. 0.1%. (Several small lobes of *Porites lobata* and *P. damicornis)*. Algae and fish as above.

<u>Stn. 3</u>: Living and dead coral reef; 20% living coral *(Porites* heads, *Acropora* spp.) *Montipora* common; *Heliopora* present only). Fish: pomacentrids abundant, juv. scarids and labrids common.

<u>Stn. 4</u>: Mainly living coral on coral gravel. 20% - 40% living coral *(Pocillopora eydouxi, Porites, Montipora, Acropora* dominant; *Heliopora* present). Fish: as above, chaetodons and pomacenthids common.

Stn. 5: Mainly dead *Porites* heads covered by *Halimeda*. 10% - 20% living coral *(Acropora, Porites lobata, P. lutea, P. andrewsi, Montipora)*. *Halimeda* 60%, *Caulerpa* 20%.

Station 4 was adjacent the channels in the sand spit and coral growth was probably enhanced by the regular flushing by oceanic waters and currents. The coral *P. eydouxi* dominant here is characteristic of moderate-energy reef fronts, while *Heliopora* was not seen elsewhere in the lagoon.

The large % of dead massive *Porites lobata* and *P. lutea* , and rubble from branching corals indicate some relatively recent environmental perturbations in the lagoon, possible an increase in sedimentation (see section 4).

h) <u>Lagoon</u>

Lack of time and equipment (grabs, dredges, air lifts) prevented detailed sampling of the lagoon sediments. Physical data were collected from 15 stations along two transects (Bairiki - Bikeman; Bikeman - Betio) and 12 dive stations on lagoon patch reefs.

Tarawa's lagoon is shallow (averaging about 10m - 15m) with many sand shoals scattered between Bikeman and the main islets, and with numerous coral patch reefs (dead and living) towards the open W. side of the atoll. The sediments, of diverse origins, were described by Wever and Woodhead (1972). Weins (195) noted that in atolls with similar shallow lagoons, excessive sedimentation has killed off and buried former coral growths.

Organisms present on and in lagoon sediments include the gastropods *Rhinoclavis, Natica, Polinices, Strombus, Oliva, Tonna, Mitra, Terebra* and others; the bivalves *Fragum, Lucina, Venus*; the sea cucumbers *H. atra* and *S. chloronotus*, and sea urchins c.f. *Clypeaster*. Several boats were seen gillnetting milkfish *(Chanos)* and bonefish *(Albula)* in the lagoon near Bikeman.

i) <u>Lagoon patch reefs</u>

Corals reef "patches" were scattered in the lagoon. Most were small a few metres in diameter, but three larger reefs were situated towards the centre of the lagoon. On one reef a vegetated cay, Bikemaan Islet, has developed.

The patch reefs closer to the atoll motus were similar to those along the lagoon reef edge i.e., consisting of dead algal-covered heads of *Porites lobata* and *P. lutea* with smaller living corals attached.

Coral diversity and coverage increased further from shore e.g. patch reefs one nautical mile off Bairiki (Stn. 42) consisted of 5% living coral *(Porites* 3%, *P. andrewsi* 2%, with *Montipora, Fungia Pocillopora* present). A large patch reef 2.5 n. miles N. Bairiki consisted mainly of dead *Porites* heads (20% cover) with 5% living *Porites*. Two sites on Bikeman Reef edge (3 n. miles off Bairiki) had a more diverse coral community with 30% living coral coverage, dominated by *Montipora* (15%), *Pocillopora verrucosa* (7%), *P. damicornis* (2%), *P. eydouxi* (1%), *Acropora* spp. (2%) with *Favia, Turbinaria, Fungia, Herpolitha* and others present. Algae (dominated by *Turbinaria turbinata* (20%)) encrusted the dead coral substrata.

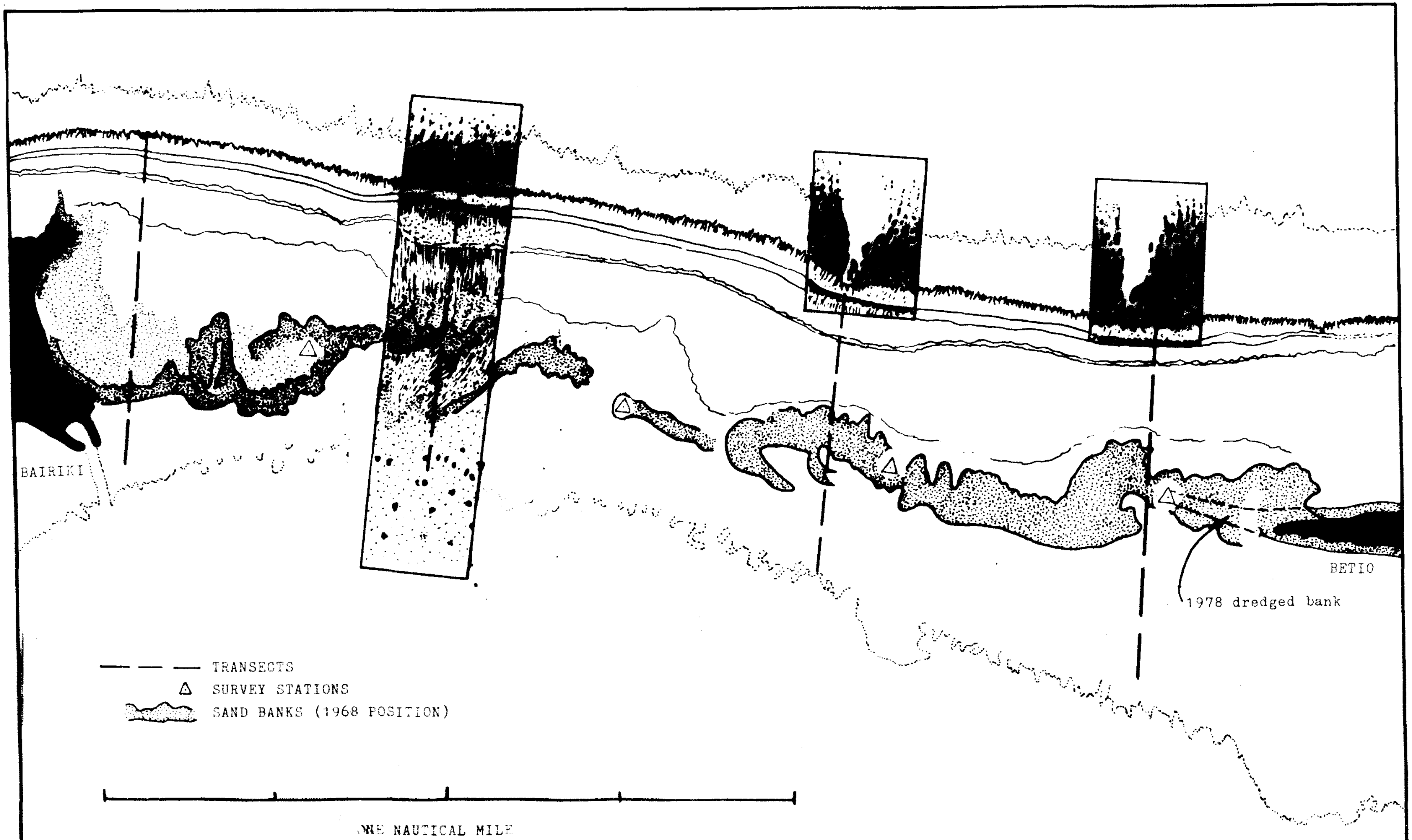

FIG. 5 BAIRIKI-BETIO PLATFROM (FROM D.O.S. AERIAL PHOTOGRAPHS, 1968). The sand spit (stippled) has since changed shape and position. Insets show detail of prominent features. Dashed lines show positions of transects. Triangles show present survey marks.

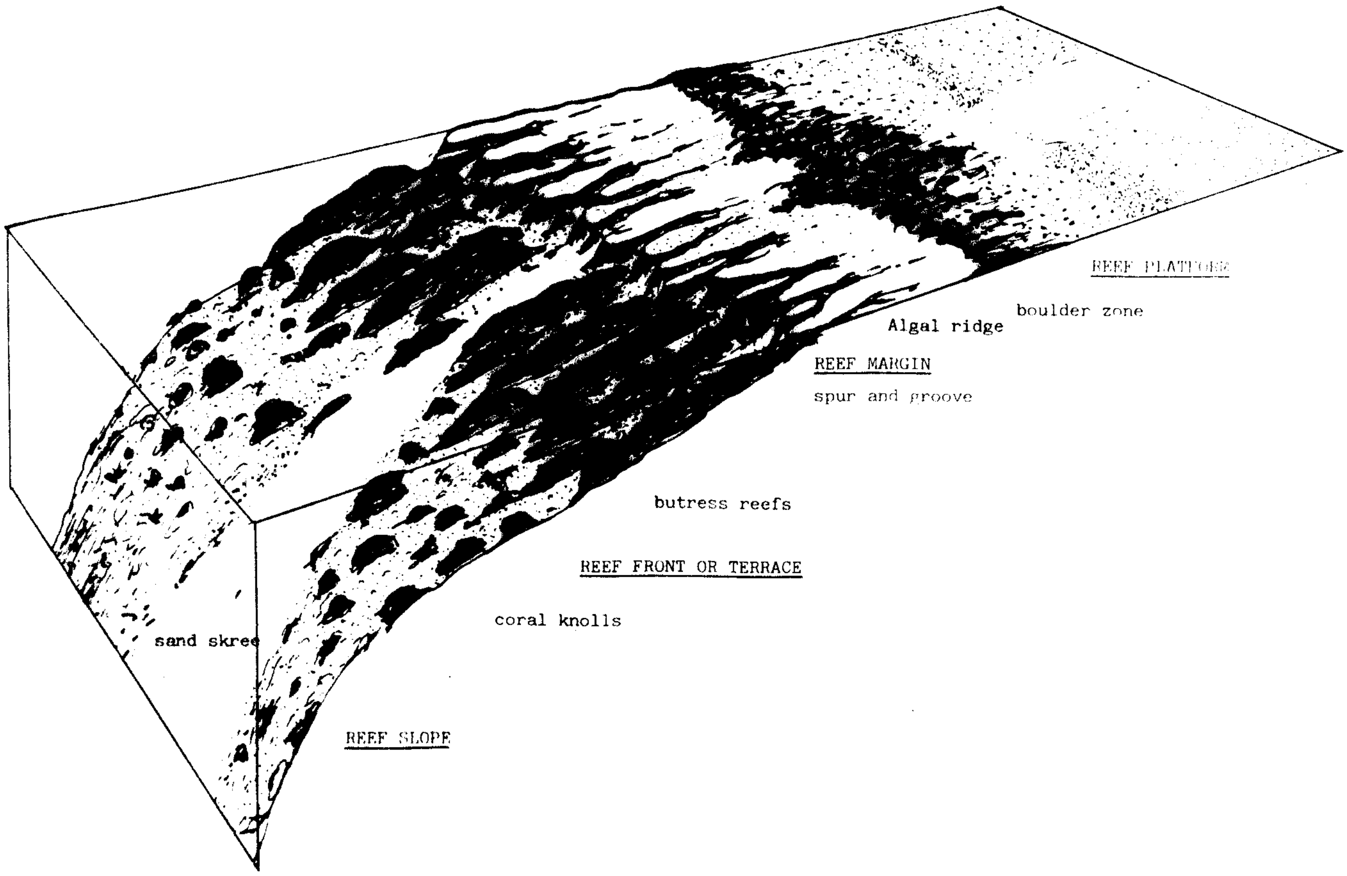

FIG. 6 SEAWARD REEF FRONT, BAIRIKI-BETIO PLATFORM (PERSPECTIVE VIEW). Note spur-and-grooves and elongated butress reefs on the reef front terrace.

3. ECOLOGY OF BETIO REEFS

Betio reefs were also surveyed to assess previous environmental disturbances (port development, dredging, moles, small boat channels, war wrecks, sewerage disposal, fishing pressure), and to provide a baseline against which the effects of future disturbances (expansion of Betio Port, causeway and airstrip) might be judged.

The study included 17 dive stations along the reef edges and submerged reefs and 6 walk transects across reef platforms during spring low tides. Four areas were investigated: seaward S. platform, edge and slope; lagoon N. platform and edge; reef platform N. Betio, lagoon to seaward; submerged coral reef W. and N. of Betio (Fig. 2). From these data biotypes and bottom types were mapped (Fig. 7).

3.1 SEAWARD PLATFORM TO UPPER REEF SLOPE

Two transects (68 & 69) were investigated. Both were similar to the seaward reef platforms of the Bairiki-Betio platform.

The outer reef slope at 15m - 20m comprised dead corals *in situ*, rubble and eroded limestone faces (50%), finer sediments overlying this substratum (30%) and living corals (10% - 20%) dominated by *Heliopora* (5%), with *Acropora, Montipora, Lobophyllia, Euphyllia, Platygyra, Tubastrea* etc., and seawhips *Cirripathes* and gorgonians, sponges and actinians present.

The reef front was similarly terraced between 6m and 10m, but narrow (50m - 90m) than that off the Bairiki-Betio platform (90m to 250m). Buttress reefs consisted of coral limestone and dead-standing corals (80%), and living corals (20%) dominated by branching *Heliopora* with *Pocillopora, Acropora, Porites, Platygra* and many other genera present. The dead corals were encrusted by algae (coralline lithothamnians, a mat of filamentous browns, greens).

The spur-and-grooves also consisted mainly of limestone and dead coral (95%) encrusted by a mat of algae and a secondary canopy of *Caulupa*. Corals comprised 5% *(Pocillopora verrucosa, P. eydouxi Porites)*.

A wide boulder tract (90m) was followed by moated pools (250m) grading into sandflats (180m), and finally a sleeply sloping beach. Biota of the outer platform included: algae (filamentous greens, *Caulerpa, Padina)*, urchins *Tripneustes gratilla* (1/sq. m), the brittlestar *Ophiocoma scolopendrina* (to 15/sq. m), and sea cucumbers *Holothuria atra* (to 1/sq. m). Biota of the sand flats included crabs, *Ocypode* and *Calappa*, sipunculid worms *Sipunculus indica*, echiuroid worms, small colonial actinians (to 20/sq. cm). Many war wrecks (aircraft motors and bodies, live and dead ordnance, barges, tank traps, 6" cannon etc) littered the inner platform.

Of note was a large aggregation of the urchin *T. gratilla* in an area between transects 68 and 69. These large echinoderms were present in densities of up to 20/sq. m on and behind the algal ridge, and covered an area of at least 300m along the reef x 50 m wide. The total population probably exceeded 100,000. It is suggested that this aggregation may have been caused by wastes from a nearby sewerage outfall enriching filamentous algae, the urchin's food. This is further discussed in 4.4.

3.2 LAGOON REEF PLATFORM

Two transects (64 & 67) were examined. The zones included: a steep beach of coarse to fine graded sand and graded coral rubble (12m and 20m wide); moated pools with exposed limestone bed rock, sand and rubble (70m and 80m wide); rubble tract on eroded limestone (100m and 45m); and the lagoon ie. sand, living and dead coral etc.

The biota was impoverished. *Ocypode* crabs, small isopod and amphipod crustaceans and matricid bivalves were present in sand of the beach. Snails (*Nerita signata)* and hermit crabs *(Pagurus)* were abundant on rocks on the upper reef flat of transect 64. These rocks were probably the remains to the demolished Burns Philp pier.

The gastropods *Oliva, Polinices, Natica,* and *Cypraea annulus* and *Rhinoclavis* were present in and on the sandy reef flats. The ubiquitous sand actinians were abundant (to 15/sq. cm) in patches, and filamentous algae and *Padina* were attached to coral rubble. Many burrows, possibly of sipunculid, echinoid and balanogalossid worms, were present on intertidal sand banks.

The above, plus *Caulupa* and *Halimeda* algae, penaeid prawns, crabs *(Callappa* and Portunids), and sea cucumbers *(H. atra* and *S. chloronotus)* were present in moated sand and rubble pools.

The lagoon margin comprised of coral rubble (fragments of branching corals e.g. *Acropora* and *Pocillopora),* dead heads of *Porites* with, rarely, small living *Porites* heads, and large (to 10m diameter), thick (to 20cm deep) beds of the calcareous algae *Halimeda.*

3.3 CROSS SECTION, NORTH BETIO REEF PLATFORM

The intertidal reef platform north of Betio (transects 65 & 66) was district from the other sides. The platform was lower (approx. 1m to -0.5m above L.W. zero) and was therefore mostly covered by shallow water at low tide. Notable were vast beds of *Halimeda,* indicating a high primary productivity and intense calcification.

Zones, from seaward to lagoon, were: a wide (1200m) subtidal reef terrace of buttresses and patches (described in 3.4); a low-energy or protected reef margin; a sand bank; rubble tracts; *Halimeda* reef flats and pools; eroded limestone bank; further *Halimeda* flats; lagoon coral margin; lagoon.

The reef margin, instead of spurs-and-grooves, rose gradually from the wide terrace into an area of coral rubble and sand. Two long sand ridges (approx. 100m long and about 30m wide) ran from N. Betio and Temakin Point to the reef margin. These were relatively high above the tide flats (+0.3m to 0.6m) and were formed mainly from *Halimeda* fragments from the reef top, deposited by currents. They contained many burrows and sand casts; about 12 I-Kiribat men were seen collecting the worm *te ibo (Sipunculus indicus)* here. The lagoon edge of the sand bank gradually sloped into a highly rippled sand flat (approx. 600m wide) apparently swept by strong currents at high water. The mobile sand flat was inhabited only by small, tube-forming errant polychaetes and snails (*Rhinoclavis, Cerithium, Natica)*. A narrow (20m - 40m) rubble tract at the edge of the sand flat supported encrusting green algae and *Padina,* as well as small colonies of the branching coral *Porites andrewsi.*

Halimeda spp. *(H. macroloba; H.* cf. *discoidea; H.* cf. *tuna)* comprised 20% - 75% of the reef platform surface. Other algae such as *Caulerpa* spp. *(C. sertularoides, C. serrulata, C. racemorpha* var. *clavifera), Dictyota, Padina* etc. were also abundant. Corals (mainly massive *Porites lobata* and branching *P. andrewsi; Pocillopora damicornis)* were present in pools. Crabs *(Calappa),* mantis shrimps (cf. *Lysiosquilla*) and small reef fish (pomacentraids, scarids, ballistids etc) were common in pools.

The *Halimeda* flats graded into a reef margin of eroded limestone, boulders and sandy pools. *Halimeda* dominated (80% cover); small coral colonies *(Porites; Pocillopora)* were present. This continued in a gradual slope into the lagoon proper. Dive stations (9 and 10) in 2m to 3m of water off here showed a sand-gravel bottom, heads of dead algal covered *Porites* and *Halimeda* patches (20% - 30%) and scattered small living *Porites lobata* nodules (10cm to 30cm diameter). Reef fish were abundant around wrecked WWII landing craft.

3.4 NORTH BETIO SUBMERGED REEF

A wide submerged reef follows the western reef platform northwards to join the large submerged reef which runs about 15 to 20 km across the open western side of the atoll. Eleven dive stations were examined around Betio and one mid-way between Betio and Buariki in North Tarawa (Oct, 1979). Station positions (Fig. 4) are approximate because of the low elevation of the islets and lack of marks; at the mid-reef station no land was visible.

Reef structure (or morphology) and biota varied greatly depending on exposure, currents depth etc. The elongate buttress reefs were well developed on the sheltered, western side despite the low wave-energy. The orientation of buttresses (from D.O.S. photos) was perpendicular to the wave train generated by the prevailing trades.

Three distinct areas were studied:

a) Exposed Western Reef Edge (Stn. 35 & 72).

Stn. 72 was situated on the reef terrace in 10m of water. The reef margin was exposed to moderate wave action and strong currents rounding the westernmost part of the atoll, and was extensively spur-and-grooved. The substrate was sand and coral rubble (45%), dead standing corals (mainly *(Pocillopora* and *Porites)* (30%), and living corals (15%) dominated by *Pocillopora eydouxi* (5%), *P. verrucosa* (3%) and *Heliopora* (3%), with *Acropora, Porites, Montipora* and others. Reef fish were common. A strong current (2 knots E) parted the dive boat's anchor cable, preventing detailed studies.

Stn. 35 was similarly exposed and extensively spare-and-grooved. Substratum was as above but with fewer dead-standing corals. Living coral coverage was 30% - 40% (dominated by *Heliopora* 10% - 15%, *P.eydouxi* 5%, *P. verrucosa* 5%, with *Acropora* spp. *Montipora, Turbinaria* and others). Reef fish (pomacentrids, acanthurids, mullids, chaetodontids etc) were abundant.

b) <u>Protected Western edge</u> (Stn. 71 & 33)

Both sites were sheltered from the prevailing swells. The reef margin adjoined the two intertidal sand spits. Spur-and-grooves were absent. The substratum was sand (60%) and rubble(10%), with coral pinnacles or pillars, rising towards the low water level. The pinnacles were mainly of old, eroded dead coral with about 20% - 30% of more recent dead-standing corals (mainly *P. verrucosa, P. eydouxi* and *Heliopora)*. Living corals (15% - 20%) included *Pocillopora* spp. (10%), *Heliopora* (3%) and *Porites, Montipora* and others. Algal coverage *(Halimeda* and *Caulerpa)* was extensive (eg. 15% at stn. 33) Acanthurids (surgeonfish) were abundant.

c) <u>Northern Reef</u> (stn. 70, 31, 32 & 12)

Stn. 70, in 4m water near the reef edge, was predominantly dead coral patches and elongate reefs or buttresses, separated by sand channels 3m - 5m wide. Dead-standing corals, mainly branching *Pocillopora* and *Porites*, were extensive (20%); living corals coverage was less (10%), dominated by *P. verrucosa* (3%), *P. eydouxi* (3%), *Acropora* (3%). Again *Halimeda* was dominant (20%).

Stn. 32, in 4m of water on the inner part of the reef, was similar. Dead standing coral comprised 20% of patches; living coral was also 20% (as above, but with *Heliopora, Fungia, Hydrophora, Pavona,* etc.). *Halimeda* coverage was 10%.

Stn. 31, in 2m near a WWII tank, was in shallow water on the reef top. The substratum was sand and rubble (40%) with dead coral heads (20%), and living corals (5%: *Porites* 3%, with *P. andrewsi, Pocillopora* spp. *Montipora* and *Fungia* present). *Halimeda* covered 30% and *Caulerpa* 5%.

Stn. 12 lay nearer to the lagoon edge in 3 - 5m. The substratum comprised sand and rubble (50%) with dead standing *Acropora* (30%) and living *P. eydouxi* (10%), *P. verrucosa* (2%), *P. damicornis* (1%), *Acropora* (3%), *Montipora* (3%) and *Dendrophyllia, Platygyra* and others. Two giant clams (70 cm and 90 cm) were present in the study area.

d) Lagoon margin (stns. 10 & 11)

Both stations were in shallow water (2m - 3m) in the lagoon. The substratum was gravel and sand with a large proportion of *Acropora* rubble. Living coral coverage was $<$ 1%, mainly small *Porites* nodules. *Halimeda* beds dominated 40% - 50% of the seafloor.

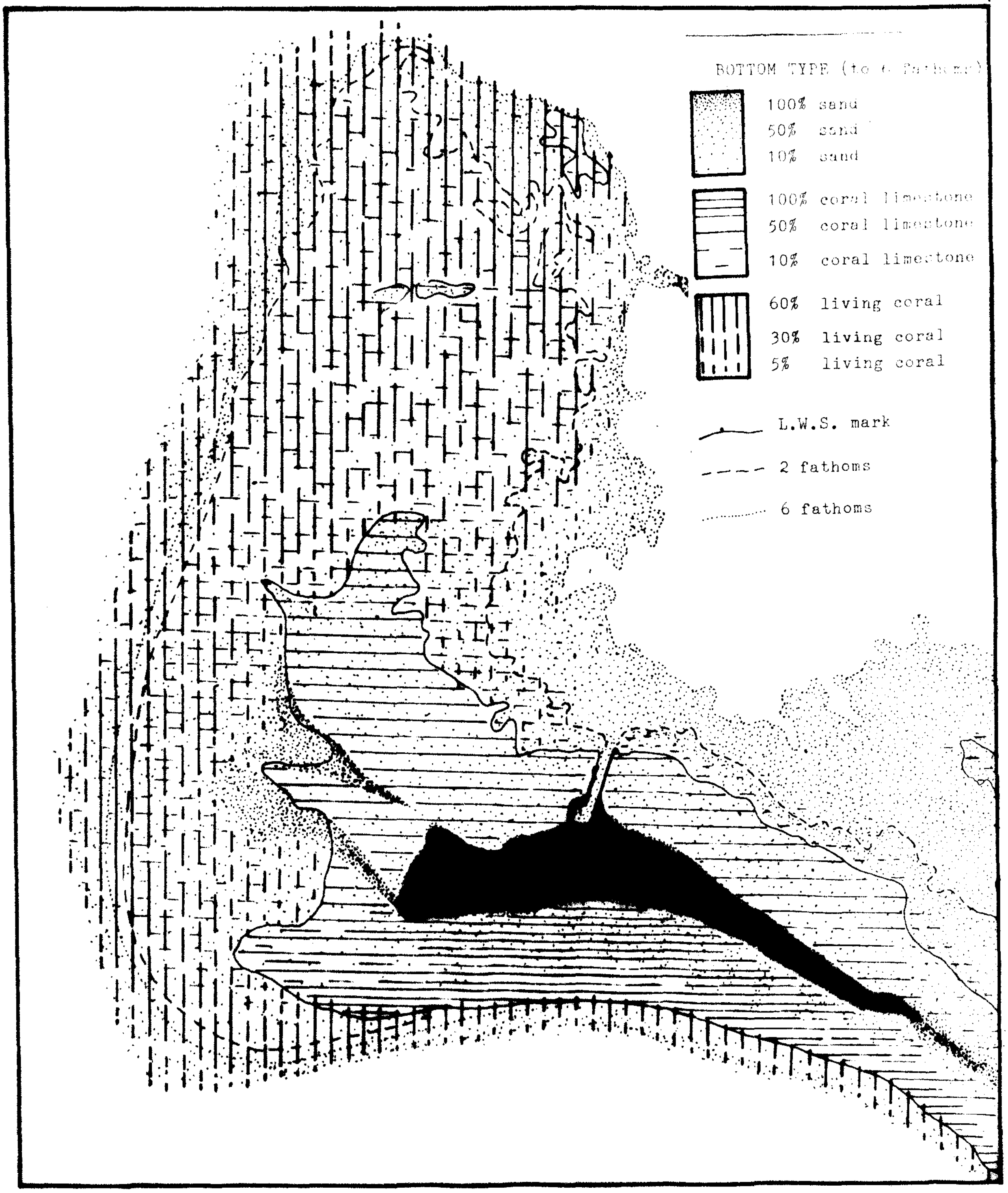

FIG. 7 BOTTOM-TYPE AND BIOTIC DOMINANTS OF BETIO REEFS TO SIX FATHOM MARK.

4. HUMAN IMPACT

Small islands and coral reefs are both extremely vulnerable to disturbances. Tarawa has been inhabited for many hundreds of years and although the original vegetation was disturbed by introductions and cultivation, and the islets pitted by *babai* pits, this was minimal compared with that of the past century. Extensive land clearing for copra, the colonial settlement at Betio, the Japanese occupation, the devastation in the recapture by the U.S., postwar urbanization, reef blasting, dredging, construction of moles, land reclamation, the urban growth of the 1980's, the problems of wastes disposal etc. have placed new and very intense pressures on the terrestrial and marine environments. Today nearly 15,000 people live and work on the small islets of Betio and Bairiki which formerly supported only 1% of this number. Some of the problems and pollution are outlined:

4.1 PASSAGES, PORT WORKS AND LAND RECLAMATION

Several channels (Fig. 8 A) have been blasted, excavated and dredged through the lagoonal reef platforms to allow small boats access to land. Largest port-works are at Betio where a long channel and basin have been excavated in the reef and island. The port is to be considerably enlarged in the near future. A smaller harbour has been constructed at Bairiki for the Betio-Bairiki shipping. Small boat channels have also been cut for access to the Marine Training School at Betio, at Teaoraeriki and Bikenibeu.

Locally, lagoon foreshores have been extensively reclaimed as there is a lack of land for housing on Tarawa and many dwellings have now been erected on land claimed from the lagoon. Coral boulders (mainly *Porites,* living and dead) are collected from the lagoon reefs and rafted to shore for the erection of retaining walls. Fill is gleaned from beaches, the lagoon, or stolen from neighbour's land. "Land hunger" is a common term on Tarawa.

The greatest land reclamation has been at Bonriki where Temaiku Gulf has been reclaimed to construct the airstrip approaches, a proposed copra plantation, tuna baitfish ponds, and access roads.

The local effects of these have been the removal or covering of the original marine communities (to the great disadvantage of Bonriki village), but more seriously, the disturbed silt may have drifted further to smother corals (very susceptable to siltation) and other organisms. The effects of dredge spoil on coral communities, often kilometres from the work site, is very well documented from around the world.

4.2 CAUSEWAYS AND MOLES

Groves (ARU) is currently investigating the physical effects of causeways on currents and sediment transport. The obvious local effects include erosion of shores and even the disappearance of small islands, sedimentation elsewhere, interference with the migration and spawning runs of fish (eg. milkfish); destruction of fishing grounds, and an inconvenience for those canoe fishermen operating from the sheltered lagoons.

The construction of the Bairiki - Betio causeway, blocking the largest and last remaining passage in South Tarawa, would therefore be expected to have an even greater effect on the environment. (see 5. for discussion of effects).

4.3 LITTER, REFUSE, WRECKS

Visitors to Betio often remark on the squalor - the litter in the streets, beer cans, improvised housing, war debris - which is so out of place on a beautiful, remote, equatorial atoll. War debris (landing craft, ships, aircraft, bunkers, guns, ordnance) and more recent refuse (aluminium beer and soft drink cans and bottles, plastics containers, domestic refuse etc) lie scattered all over Betio's beaches and reefs.

The aesthetics and the visual pollution is a less concrete, but no less serious problem. New settlers from other islands do not seem to take the same care of their new home as they do of their old one. Villages in outer islands are spotless and even newly fallen leaves are collected each morning for compost. Perhaps a general cleaning up of Betio would encourage a new pride in their surroundings.

A health problem is posed by broken glass cutting feet and disease-carrying mosquitoes breeding in empty containers, etc. In addition it has been suggested that outbreaks of ciguetera fish poisoning and coral-eating crown-of-thorns starfish are associated with wrecks, debris and environmental disturbances.

War wreckage beneath the sea, out of sight, has a more beneficial effect, for it attracts fish life. It was noted that wrecked U.S. landing craft near the port and a large Japanese ship to the north were favoured by local fishermen. The fish-attracting effects of "artificial reefs" are very well documented and wrecks are often dumped to form reefs.

4.4 HUMAN WASTES

Johannes *et. al.* (1979) and Kimmerer and Walsh (in press) discuss in detail the health and environmental effects of human wastes on Tarawa.

It was suspected that contamination of ground water and shellfish such *te bun (Anadara,* the staple shellfish of Tarawa) caused the disastrous cholera epidemic of 1977. Over-water latrines were therefore removed from lagoons and the traditional beach defaecation habit was banned in Tarawa. A sewage scheme is being constructed in South Tarawa, and has been operating on Betio for two years. The sewerage is now pumped via an outfall off Temakin Point, into the ocean.

The environmental effects of this are unknown but might have been better considered at the time of construction. During this survey an enormous aggregation of sea urchins, *Tripneustes gratilla,* were observed 800m to 1000m,E of the sewage outfall. Densities of up to 20/sq. m were seen over an area of several hundred metres along the algal crest. This may have represented an unusually high but natural breeding aggregation, but it is suspected that it is related to the outfall. Strong E currents noted off Temakin on several occasions may be sweeping the nitrogen-and phospherous-rich sewerage along the reef edge, enriching benthic algae, the food of the urchin. Although eaten elsewhere in the Pacific, as *Tripneustes* is not esteemed in Kiribati it does not pose an imminent health problem. However it does indicate the vulnerability of the coral reef ecosystum to disturbance. The devastating "plague" of coral-eating crown-of-thorns starfish *Acanthaster,* is thought to have been similarly related to subtle, man-made changes in the environment.

Edible octopuses, morays and some gastropods which are often collected by reef-gleaners in the immediate vicinity of the outfall may represent a more imminent health hazard.

It should be noted that the outfall may also have a beneficial environmental effect by providing nutrients for the food chain, thus benefitting fisheries.

4.5 FISHERIES

Use of the reef and platform by fishermen was also recorded during the surveys. The I-Kiribati are traditionally subsistence fishermen and many urban dwellers fish around Betio, commercially, for subsistence, and for recreation.

Local fishermen (per field assistant Tekabwere) indicated that the Bairiki-Betio platform and adjacent lagoon were not very good fishing grounds. This was substantiated by the survey: this area was biologically impoverished.

Fishing activity is included in Fig. 8 (noted 1 - 6 to indicate each fishermen seen and the catch). Thus several pole and line fishermen (No. 1) were seen along the seaward spur-and-groove margin; two women were seen collecting worms (*Sipunculis indicus, "te ibo"*) on a sand bank on the platform; etc. In addition to those noted, a dozen or so people were seen walking along the sand spit, probably walking to the other islet.

The most important fishing seen on the platform was gillnetting for half-beaks (cf. *Euleptorhamphus, "te anaororo"*) in which pairs of fishermen surrounded or seined shallow lagoon waters with nylon monofilament gill nets (Fig. 8, 4). Several men were also seen cast netting small fish (misc. species of herrings, anchovies) in shallows.

The eastern or lagoon platform off Betio was likewise impoverished and only a few bait gleaners were noted.

The large North Betio reef was more productive and greater fishing activity was noted. Wrecked WWII barges off the port were fished by small boys pole-and-lining and a dozen men, women and children were pole-and-lining and gill netting on a large Japanese wreck (stn. 10). Many cast netters were seen along the lagoon reef edge. Underwater diving off this reef indicated a great diversity and biomass of reef fish and even giant clams (*Tridacna*) - unexpected off an island so densely inhabited. This suggests that reef fishing has probably not exceeded the maximum sustainable yield.

It should be noted that these observations were conducted over a period of 10 days only, with only a few hours in each locality. Clearly a more detailed knowledge of nocturnal fishing activites, landings etc. over a long period of time is necessary for a detailed and accurate assessment of the level of fisheries exploitation.

4.6 THE CAUSES OF CORAL MORTALITIES

Coral death is a continuing process in the coral reef ecosystem and is fundamental in the growth of reefs. Environmental stresses (temperature extremes, desiccation, siltation, anoxia, etc), mechanical damage in storms, biological predation (by crown-of-thorns starfish, certain snails and nudibranchs, grazing by parrotfish, etc), and bio-erosion (by boring sponges and bivalves) are natural agents and a certain amount of dead coral can be seen on any thriving reef.

Abnormally large amounts of dead-standing coral (ie. "recently" dead coral not yet broken down) were present in Tarawa lagoon and on Betio reef. Johannes *et. al.* (1979) also reported much dead coral in the lagoon and attributed it to natural sedimentation following westerly gales. However the author had the opportunity to examine many more areas and feels that the causes are more complicated

Large amounts of dead corals (mainly *Porites lobata* heads and micro atolls) were seen around the edge of the lagoon between Ambo and Betio, and on patch reefs between the islets and Bikemaan (Fig. 9).

Living corals were common only on a few lagoonal patch reefs off Betio-Bairiki platform which were regularly flushed by oceanic water.

Large areas of dead standing corals were also seen on the lagoonal patch reefs off N. Betio, mid-way towards Bikemaan, off Bikemaan, and on the terrace buttress reefs off W. Betio.

The causes probably vary. Those in the lagoon are mainly due to siltation. Some flat encrusting and foliose corals seen off Bikemaan (250m NNW) in 1979 were being smothered at the time. Polyps underneath parts heavily covered by silt were dead, while those partially covered were shedding their zooxanthellae (i.e. were white), indicating stress. Other corals had been dead a considerable period as they were extensively overgrown and bored by sponges (*Cliona*) and bivalves (*Lithophaga*). The mortalities are therefore a continuing process and not the result of a strong gale as suggested by Johannes.

No evidence of sedimentation was seen on a site 7 n. miles N. Betio where large strands (20% - 50% coverage) of dead-standing *Acropora* and *Millipora* were seen by the author in 1979. Likewise extensive areas of dead *Acropora* and *Porites* seen in this study off N. and W. Betio were in oceanic areas not affected by silt.

The causes are unknown but crown-of-thorns *(Acanthaster)* should be considered. Weber and Woodhead (1972) noted that "plagues" of these starfish were present in the early 1970's.

Whether the siltation or starfish can be attributed to human influence is debatable. It is suggested that siltation from port-works and land reclamation is at least partially responsible for lagoonal mortalities; scientific opinion is divided on the starfish question (e.g. Kenchington, (1978).

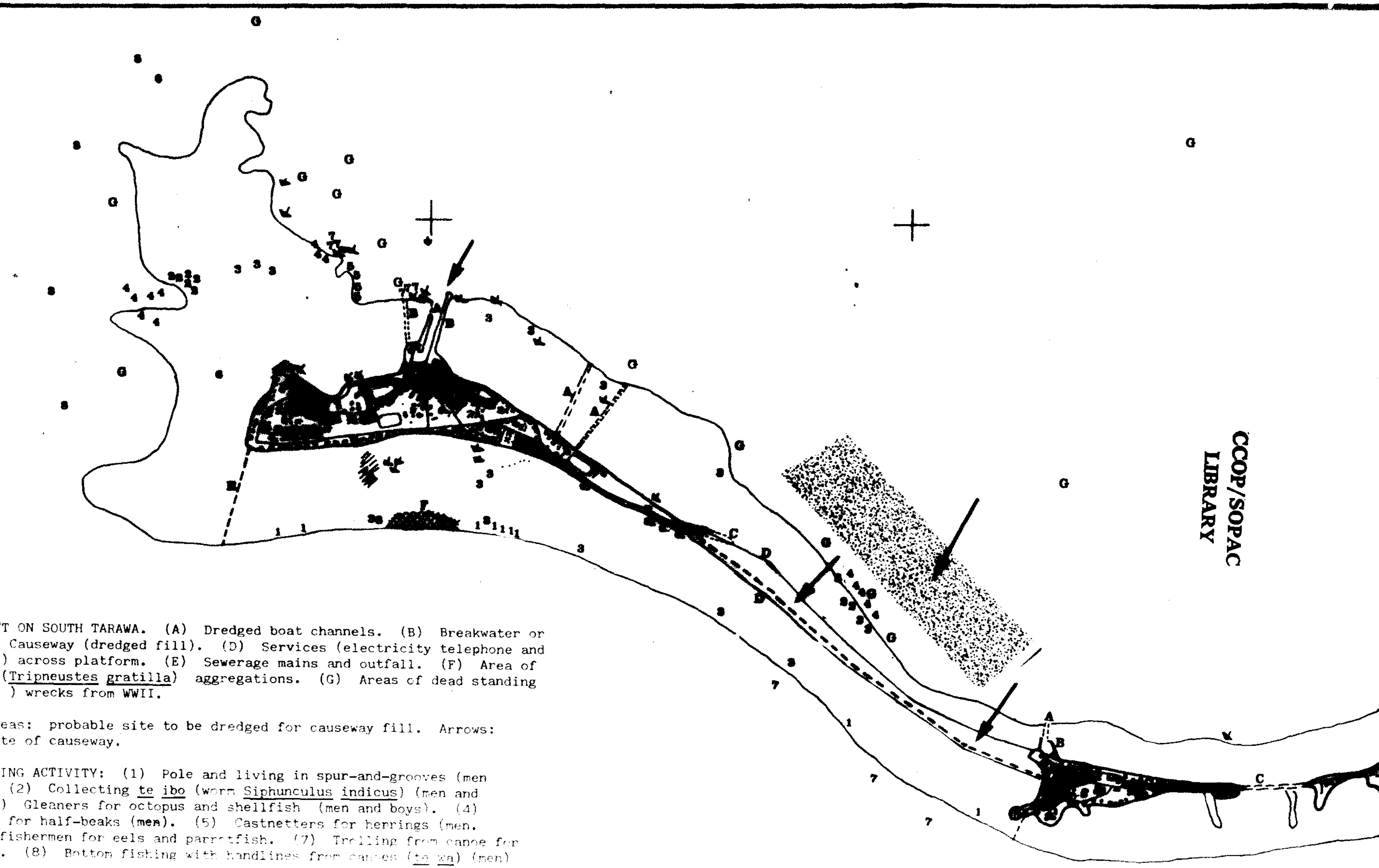

FIG. 8

HUMAN IMPACT ON SOUTH TARAWA. (A) Dredged boat channels. (B) Breakwater or mole. (C) Causeway (dredged fill). (D) Services (electricity telephone and water mains) across platform. (E) Sewerage mains and outfall. (F) Area of seaurchine (Tripneustes gratilla) aggregations. (G) Areas of dead standing coral (   ) wrecks from WWII.

Stippled areas: probable site to be dredged for causeway fill. Arrows: proposed site of causeway.

1 - 8 FISHING ACTIVITY: (1) Pole and living in spur-and-grooves (men and boys). (2) Collecting te ibo (worm Siphunculus indicus) (men and women). (3) Gleaners for octopus and shellfish (men and boys). (4) Gillnetters for half-beaks (men). (5) Castnetters for herrings (men. (6) Spear fishermen for eels and parrotfish. (7) Trolling from canoe for tunas (men). (8) Bottom fishing with handlines from canoes (te wa) (men)

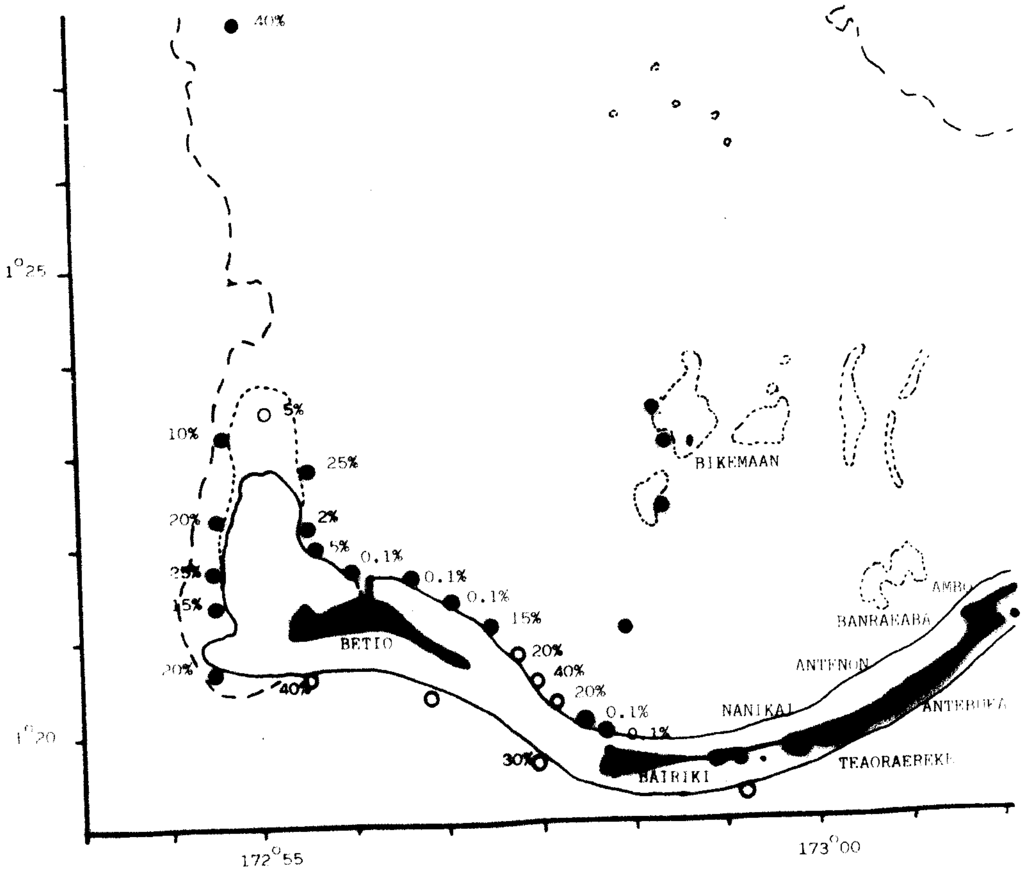

FIG. 9 LIVING CORAL COVER (%) IN S.W. TARAWA. Dark circles indicate large proportions of dead-standing corals in study area.

5. POSSIBLE EFFECTS OF CAUSEWAY PROJECT

Although the exact long-term repercussions of the dredging of the causeway and blockage of the passage cannot be predicted with any certainty, some effects may be anticipated:

5.1 ON THE SITE

The platform area is the least productive and most impoverished area seen on Tarawa. If a road is constructed, only a small strip of the platform will be affected. A far greater area would be buried if an airstrip is also constructed, but the burial of the site itself would have a negligible effect on the overall ecology, productivity and fisheries of Tarawa.

5.2 EFFECTS OF DREDGE SPOIL

The effects of the dredge spoil on more productive communities in the vicinity might be great. Corals are very susceptable to siltation (see 4.6), and spoil might be carried considerable distances by currents. Current studies conducted by Kimmerer and Groves would be useful in assessing the danger.

From this study there appears to be a considerable movement of lagoon water by the E to SE trades through the causeway area into the open sea, where lagoonal sediments are deposited down a scree on the reef slope. Much of the spoil would therefore be carried into the open sea, but may damage the productive seaward reef edge.

5.3 EFFECTS OF PASSAGE BLOCKAGE

The blockage of the passage would halt this water drift and the net loss of lagoon sediments down the reef slope.

Sand would build-up on the lagoon side of the causeway, smothering the few remaining corals along the platform edge. However, this would aid the engineering and reduce the amount of sand to be dredged for fill.

The blockage would interrupt the spawning runs of many fish (eg. milkfish). Fishermen say that the number of milkfish *(Chanos)* and other important lagoon fish have declined since the construction of other causeways, but one informant (Bita pers. comm) says that the fish "have now learnt new routes into the sea". Further work is necessary in this field.

The blockage will also inconvenience those fishermen who go through the pass at high water to reach the open sea. The trip from Bairiki harbour around North Betio would increase the distance from the present 1 nautical mile to 12 nautical miles (22 km). However boats must now take the longer route at low water when the passage dries.

A more subtle effect would be a decline in the productivity of the ocean reef adjacent the platform. Considerable fishing activity was noted in this area and many fish were noted in underwater surveys. Several mantarays *(Manta alfredi)* were seen feeding at the interface of the lagoon and oceanic water bodies, an area of plankton enrichment. Clouds of baitfish and feeding tunas were also associated with the interface and canoes regularly sailed along it while trolling for tunas.

6. CONCLUSION AND RECOMMENDATIONS

This study was initiated to provide a baseline from which environmental changes following causeway construction might be judged. The project will continue irrespective of any findings of this report.

As stated, the platform is neither a unique nor very productive area, nor of great importance to Tarawa's fishery. Its loss would therefore not produce an environmental castrophe.

However the long-term effects of dredge spoil on nearby (and possibly more distant) coral communities will be more serious. The corals of the lagoon have suffered severe damage in the recent past, probably largely due to man's influence. Further damage is inevitable, but would be reduced by more careful planning.

Other possible effects have been discussed, none of them individually very severe, but the overall effect on the atoll of man's distrubances will be no doubt be great. Hopefully the I-Kiribati decision makers will be more careful of their environment than their former colonial masters.

RECOMMENDATIONS

6.1 That the insertion of a bridge or culvert in the causeway be considered. The engineering problems, great financial cost, problems with siltation, etc. might be great, but so might the permanent ecological effects.

6.2 That the area be monitored during the construction and after completion of the project. The initiators of this survey might therefore fund two or three further studies eg. one in the year of construction, one in the year following completion and one about 3 years to 5 years later. The author, personnel at A.R.U. or the University of the South Pacific would be available for successive studies.

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APPENDIX I ITINERARY AND WORK DIARY

Period of Consultancy: 6/11/81 - 18/11/81

Date	Activity (approx. hours indicated)
6.11.81 Fri.	Depart Suva residence 0630. Arrive Tarawa 1700.
7.11.81 Sat.	Skindive surveys by boat, Bairiki-Betio lagoon. 12 stations. 0830 - 0530*
8.11.81 Sun	Skindive, Scuba, hydrographic surveys. Boat, ocean side of causeway. 11 stations. 1200 - 1800*
9.11.81 Mon	Completion of lagoon dive station, Bairiki-Betio. Boat, seaward stations, Berio reef. 14 stations. 0900 - 1700.
10.11.81 Tues.	Lagoon hydrographic and dive stations. Boat: Bairiki - Bikuman-Betio. 22 stations. 0900 - 1730,
11.11.81 Wed.	Aerial photography. 0900 - 1200. Bonriki - Betio seaward and lagoon. ARU laboratory 1300 - 1600 examining aerial photographs, charts, etc.
12.11.81 Thurs.	Low water transects of Bairiki-Betio causeway, inter-tidal by foot. 0830 - 1400. 4 transects, 24 stations. p.m. compile data.
13.11.81 Fri	Low water transects, N.W. Betio reef. Intertidal, by foot. 0800 - 1600. 3 transects, 20 stations.
14.11.81 Sat.	Low water transect, E and W Betio reef. Intertidal, by foot 1000 - 1600. Three transects, 28 stations
15.11.81 Sun.	Skindives, ocean reef, W. Betio, 3 sites. 10300 - 1400
16.11.81 Mon.	Dept. surveys (mappings) 900 - 1200. ARU 1400 - 1800 (preparing coral specimen)
17.11.81 Tues.	Preparation of specimen. Identification of specimens, ARU. 100 - 1700.
18.11.81 Wed.	Packing. Visiting officials. Depart Bonriki 1000, arrive home, Suva 1000.

APPENDIX II HYDROGRAPHIC STATIONS

APPENDIX III TRANSECT DATA

These are included only in the master copies of this report.

APPENDIX VI

CORAL SPECIES OF KIRIBATI FROM COLLECTION BY DR. ZANN, LESLEY BOULTON AND DR. RAJ IDENTIFIED BY PROFFSSOR M. PICHON

($01^{o}20$N - 173.00E)

FAMILY: ACROPORIDAE	1.	Acropora formosa
		" cf divaricata
		" hyacinthus
		" humilis
		" variabilis
		" digitifera
		" tenuis
	2.	Asteropora myriophthalma
		" cf listeri
	3.	Montipora sp cf patula
		" foveolata
		" cf tuberculosa
		" sp. 1
		" sp. 2
		" verrucosa
		" cf hispida
FAMILY: POCILLOPORIDAE	4.	Pocillopora damicornis
		" verrucosa
		Pocillopora eydouxi
	5.	Stylophora pistillata
	6.	Seriatopora hystrix
FAMILY: THAMNASTERIIDAE	7.	Psamonocora haimeana
		Psamonocora profundacella
FAMILY: SIDERASTREIDAE	8.	Coscinaraea columna
FAMILY: AGARICIIDAE	9.	Pavona maldivensis
		" varians
		" clavus
	10.	Pachyseris speciosa
	11.	Leptoseris mycetoseroides
FAMILY: FUNGIIDAE	12.	Fungia (Ctenactis) scutaria
		" (Fungia) fungites
		" (Donafungia) horrida
		" (juv.)
	13.	Herpolitha limax
	14.	Podabacia crustacea

FAMILY:	PORITIDAE	15.	Porites lichen
			Porites lobata
			" lutea
			" andrewsi
FAMILY:	FAVIIDAE	16.	Favia pallida
			" malthai
			" stelligera
			" rotumana
		17.	Favites chinensis
			" pentagona
		18.	Goniastrea pectinata
			" edwardsi
		19.	Platygyra eloedalea
			" sinensis
		20	Leptoria phrygia
		21.	Montastrea magnistellata
		22.	Hydnophora microconos
			" rigida
			" exesa
		23	Leptastrea purpurea
		24.	Cyphastrea serailia
		25.	Echinopora lamellosa
FAMILY:	MERULINIDAE	26.	Merulina ampliata
FAMILY:	MUSSIDAE	27.	Lobophyllid hemprichi
			" corymbosa
		28.	Acanthastrea echinata
		29.	Symphyllia radians
FAMILY:	PECTINIIDAE	30	Echinophyllia echinata
			" sp.
		31.	Oxypora lacera
FAMILY:	DENDROPHYLLIIDAE	32.	Turbinaria frondens
			" mesenterina
			" sp.
			Dendrophyllia micrantha
			" sp.

NON-SCLERACTINIAN

- Distichopora violacea
- Stylosteridae indet
- MillePepora sp.
- Millepora platyphylla
- Heliopora coerulea

(ADDENDA) BY M. PICHON

Mycedium elephantatum

Favites russelli

Janolalilitha robusta

Halonutra pileus

Pterogyra simplex

Favites Flexuosa

Echinopora horrida

Leptoseris sp.

Gardineroseris planulata

Pavona cactus

Favia favus

Ganiopora stutchburyi

Pavona explanulata

Oulophyllia sp.