ATOLL RESEARCH BULLETIN

NO. 419

DESCRIPTION OF REEFS AND CORALS FOR THE 1988 PROTECTED AREA SURVEY OF THE NORTHERN MARSHALL ISLANDS

BY

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ISSUED BY
NATIONAL MUSEUM OF NATURAL HISTORY
SMITHSONIAN INSTITUTION
WASHINGTON, D.C., U.S.A.
AUGUST 1994

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Abstract

The Republic of the Marshall Islands requested a natural and cultural biodiversity survey of 6 northern atolls (Bok-ak, Pikaar, Tōke, Wōtto, Ron̄dik, Ādkup) and one reef island (Jemo̧) which was accomplished over 17 days in September 1988. This report covers the results of the survey of the reefs and corals during the expedition. Ninety-five marine sites were snorkeled and the shorelines of all island were surveyed during the expedition. A total of 168 species and 55 genera and subgenera of stony corals were reported including several new species and one new genus recorded (Polyphyllia) for the Marshalls.

Bok-ak Atoll, the northernmost atoll, supports large giant clam populations, a completely native flora, and the largest seabird populations in the Marshalls. Pikaar Atoll also supports large giant clam populations and the largest sea turtle nesting populations in the Marshalls. Both Bok-ak and Pikaar are isolated from other atolls and have shallow lagoons elevated slightly above sea level due to their geomorphological configuration. Tōke Atoll is located about 10 km from inhabited Utrōk Atoll, and supports healthy coral reef habitats and giant clams. Jemo̧ Island supports large seabird populations and is the second most important sea turtle nesting site in the Marshalls. Boat access to Jemo̧, Pikaar and Bok-ak is hazardous due to wave exposure or strong currents. Ron̄dik Atoll supports healthy coral reefs, blue coral habitats, pink foraminiferan sand beaches, and large coconut crab populations. Ādkup supports abundant seabird populations, sea turtle nesting populations, and healthy coral reefs. Inhabited Wōtto also supports healthy coral, coconut crab, sea turtle and giant clam habitats and has beautiful beach, reef and lagoon habitats.

On the basis of the surveys, Bok-ak, Pikaar and Jemo̧ are recommended for designation as limited entry ecological preserves. Tōke is recommended as a national park accessible to both tourists and residents. Limited sport diving and beach-going is also suitable for Ron̄dik and Ādkup. Assistance should be provided to the people of Wōtto Atoll to fulfill their desire for small scale adventure tourism.

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Manuscript received 8 March 1990; revised 30 August 1994

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES - cont'd

I. INTRODUCTION

Oceania represents one of the last frontiers for the assessment of biological diversity, especially for shallow water marine ecosystems. Coral reefs are among the most widely distributed ecosystems on the face of the earth, and within Micronesia they dominate in terms of area. They also provide critical physical and ecological support to most other ecosystems including those of low coral islands. Because of remote access, geographic isolation, and the physical limitations of underwater surveying techniques, most marine areas in Micronesia remain unstudied. Yet assessment of the ecological and biological importance of reef areas for conservation, subsistence, recreation, visitor and commercial uses must require on-site surveys to some extent. With many thousands of reefs and islands yet to be evaluated, new techniques must be employed to allow a rapid but technically adequate evaluation of reef sites. Existing regional evaluations (IUCN, 1989; 1988; Dahl, 1980) provided valuable information on many areas with respect to park and reserve potential, but the emphasis has been placed on terrestrial (island) ecosystems which are easier to visit and survey. The Marshall Islands study of September 1988 offered a unique opportunity to accomplish a marine oriented regional survey of reefs using a non-conventional rapid field assessment technique relying on a combination of field observations, teamwork, aerial photographs, underwater photographs, available maps, and interviews with knowledgeable islanders.

The study is primarily based on the results of a three week expedition to six atolls and one table reef in the northern Marshalls during September 1988. The areas surveyed were the atolls of Bok-ak, (Taongi, Bokak, Pokak), Pikaar (Bikar), Tōke (Taka), Ādkup (Erikub), Roñdik (Rongerik), and Wōtto (Wotho) and the table reef of Jemo̧ (Table 1, Fig. 1). The name spellings used above reflect the most current official RMI linguistical determinations. Those in parentheses above reflect spellings commonly used in the past.

The field expedition concentrated on evaluating the following categories of resources with respect to potential justification and interest in protected area designation; names in parentheses refer to the expedition team members responsible for collecting information about the resources:

* island vegetation (Derral Herbst),
* seabird nesting, resting and feeding (James Juvik),
* other terrestrial animals (James Juvik, Peter Thomas),
* turtle nesting and feeding habits (John Naughton, James Maragos, Peter Thomas),
* nearshore reef fishes (John Naughton, R. Virgil Alfred and Paul Maddison),
* giant clams and other edible shellfish (John Naughton, R. Virgil Alfred, James Maragos),
* coral and reef features (James Maragos),
* pelagic fisheries and marine mammals (Paul Maddison, R. Virgil Alfred, and John Naughton),

* cultural historical and archaeological resources (Charles Streck Jr.), and
* tourism, park and reserve feasibility (Peter Thomas)

The present report describes the results of the surveys of reefs and corals with emphasis on ecology and related oceanographic and geological characteristics. It is meant to serve as a technical supplement to the report prepared by Thomas et al (1989), a summary of all survey results.

Table 1. Physiographic data on the atolls and table reef visited during the September 1988 expedition to the northern Marshall Islands.

NAME	TOTAL ISLAND AREA (km^2)	NO. OF ISLANDS	LAGOON AREA (km^2)	LATITUDE (N)	LONGITUDE (E)	DIMENSIONS (km^2) (L X W)	POPULATION (1989)
Ādkup	0.91	14	231.32	9°08’	170°02’	27 X 24	0
Bok-ak	3.77	11	78.38	14°43’	168°57’	18 X 8	0
Jemo̧	0.18	1	0	10°06’	169°30’	8 X 2	0
Pikaar	0.49	6	37.57	12°15’	170°07’	12 X 7	0
Rońdik	2.11	17	144.59	11°21’	167°26’	18 X 18	0
Tōke	0.57	5	93.52	11°07’	169°46’	14.5 X 14.5	0
Wōtto	4.16	13	95.34	10°06’	165°59’	18 X 14.5	103

II. MATERIALS AND METHODS

Limited field time required that maps, aerial photographs, underwater photographs, and other sources of valuable information be consulted before the design and execution of field observations. For one, the time available to cover such a large number of reef areas was too short to warrant quantitative sampling surveys. Field work concentrated on collecting qualitative information on several subjects for a broad number of sites. During the 17 days of the expedition (7-24 September 1988), four days were spent in transit between atolls leaving 13 days field time on station at the study sites, or an average of about two days per atoll. Three days were spent on Bok-ak allowing 20 marine sites there to be surveyed. Elsewhere 12-13 sites were surveyed at the remaining atolls and table reef. Only one day was spent at Jemo̧ due to the small size of the reef and lack of safe overnight anchorage. Field time at Roñdik was cut short due to a medical emergency. Thus the western half of Roñdik could not be investigated. A total of 95 marine sites were surveyed at the seven areas during the September 1988 expedition. Additional observations were also made on land, along sandy beaches (especially for evidence of turtle nesting) and during small boat travel.

Most observations were made underwater using snorkeling equipment. SCUBA diving was not possible. Notes and reef profiles were recorded in situ on waterproof paper attached to clipboards, (See Appendix A). Underwater photographs of each site were obtained using Nikonos cameras. Most coral species and all coral genera were identified in situ by visual observation. A few specimens were collected to clarify or confirm species identification. Major reference books on the taxonomy of reef corals were brought on the expedition and include Veron (1986), Veron and Wallace (1984), Veron and Pichon (1976, 1979, 1982), Veron et al (1977), Randall (1984), and Wells (1954). At the end of each day's field work, these reference guides were consulted to finalize species assignments and to compile lists of corals for each station. Master coral lists for the expedition and for each atoll were compiled (Tables 2 and 3).

Corals

Relative abundance of each coral species was visually estimated in the field and assigned to one of the five following abundance categories:

D = dominant
A = abundant
C = common
O = occasional
R = rare

Definitions of each of these categories are provided in Appendix B. Previous coral records from the region include 35 species reported in Wells (1954) based upon collections and observations at Bok-ak and Roñdik (Table 4). There are no published records of corals from the five other reefs visited in 1988. Thus, most compiled species constitute new atoll records. Other important coral surveys in the Marshalls were reviewed and include Wells (1951), Hiatt (1951), Titgen et al (1988), Devaney and Lang (1987), Maragos and Lamberts (1989), Lamberts and Maragos (1989), Scanland (1977), and Maragos, in preparation.

Reef Geomorphology

Previous geological studies of the Marshalls were consulted, including Wells (1954), Fosberg (1988), MacNeil (1969), Fosberg et al (1956), Tracey et al (1948), Nugent (1946), MacNeil (1954), Ladd et all (1953), and Emory (1948). A few of these included descriptions of the atolls visited in September 1988. Observations on reef features concentrated on confirming earlier evaluations, identifying trends or changes, and describing features not previously reported (particularly underwater features).

Map Sources

The U.S. Army Mapping Service (AMS) compiled topographic maps at a scale of 1:25,000 for all of the seven visited areas, except Wōtto whose maps were compiled at a scale of 1:50,000. The AMS maps were based upon limited ground truthing and aerial photo-interpretation of low altitude black and white imagery flown by the U.S. Army in 1944. Later the Defense Mapping Agency reviewed, updated, and corrected many of the AMS maps and published navigation charts of all atolls at a smaller scale. A listing of all maps of the seven areas within the DMA and AMS catalogues is found in Appendix C.

Aerial Photographs

Copies of 1944 black and white Army aerial photographs were available for inspection at the Bernice P. Bishop Museum Map Collection, Honolulu. In addition, the U.S. Department of Energy sponsored complete coverage of 15 northern Marshall atolls and collection of color aerial photographs at a scale of 1:30,000. A few additional photographs were flown at a scale of 1:8,000 for the northern Marshall Atolls in 1978 (E G & G, 1978). Unfortunately, Bok-ak was not surveyed. The 1978 photographs include outstanding detail of all islands and most reef areas to depths of 15m or more. The 1978 photographs allowed photo interpretation and comparison to the earlier 1944 photographs and maps to determine the extent of geomorphological changes to reefs and islands for five of the seven visited areas (all except Bok-ak and Ādkup). Appendix D provides a listing of the 1944 and 1978 aerial photographs reported for the seven visited reef areas.

Marine Protected Area Evaluative Criteria

A number of criteria were used during evaluation of the marine sites surveyed during the 1988 expedition (Table 5). These criteria were not assigned ranks or numerical weights so that each site could be "quantitatively" evaluated. Such approaches are highly subjective, and given the lack of quantitative data collected during field surveys, quantitative comparisons are not justified. However, the gross number of positive criteria identified for each site gave a good approximation of the value it serves a candidate protected area. Most importantly, the criteria provide a useful checklist from which to identify truly significant or substantial resource values and attributes.

Ship Itinerary

Figure 1 consists of a map of the northern Marshalls which shows the atolls visited during the 1988 field expedition. The RMI government kindly made available their fisheries patrol vessel Ionmeto I to provide transportation and lodging during the expedition. With a top speed of 22 knots and modern navigation equipment, use of the ship reduced travel time and increased survey time at each of the target study areas. The maximum distance between Majuro (Mājro) (port of departure) and the most outlying atoll (Bok-ak) was nearly 500 miles. The 17 day expedition covered approximately 2,000 miles, including two unscheduled (medical and supply) stops at Kuwajleen (Kwajalein) Atoll.

Digitizing of Maps

Original maps were prepared by CORIAL for presentation in this report. The maps were digitized using Intergraph ® MGE and MapInfo ® software. Maps of all atolls are being digitized as part of a geographic information system now being developed for the Marshall Islands termed the Marshall Atoll Resource Information System (MARIS).

Table 2. Check list of corals observed in the Northern Marshall Islands, September 1988.

P = Pikaar Atoll, B = Bok-ak Atoll, T = Tōke Atoll, J = Jemo̧ Island, W = Wōtto Atoll, R = Rōn̄dik Atoll, and A = Ādkup Atoll. Letters in parenthesis are additional records reported in Wells (1954) at the same atolls.

Stony Corals (Scleractinia, calcified octocorals, calcified hydroids)

FAMILY ACROPORIDAE

Acropora abrotanoides (Lamarck) - P, B
A. aculeus (Dana) - P, B
A. acuminata Verrill - P, B, T, W, (R)
A. austera (Dana) - B, W, A
A. cerealis (Dana) - P, B
A. cytherea (Dana) - T, J, W, R, A
A. danai (Edwards and Haime) - B, (R)
A. digitifera (Dana) - P, B, T, J, W
A. diversa (Brook) - P
A. echinata (Dana) - (R)
A. formosa (Dana) - P, B, T, W, R, A
A. florida (Dana) - W, R, A
A. gemmifera (Brook) - P, B, W, A
A. grandis (Brook) - W
A. granulosa (Bernard) - B, W
A. glauca (Brook) - B, T, W
A. horrida (Dana) - W
A. humilis (Dana) - P, B, T, W, R, A
A. hyacinthus (Dana) - P, T, W
A. irregularis (Brook) - P, B, T, W
A. loripes - (R)
A. lovelli Veron and Wallace - P, B, W, A
A. microphthalma Verrill - B
A. millepora (Ehrenberg) - W
A. nasuta (Dana) - P, B, T, W, R, A
A. robusta (Dana) - A
A. nobilis (Dana) - B, W
A. polystoma (Brook) - P, B, T, W
A. selago (Studer) - P, B, T, W
A. striata - (R)
A. surculosa (Dana) - P, B, T, W, R, A
A. syringodes (Brook) - W
A. squarrosa (Ehrenberg) - P
A. tenuis (Dana) - B
A. vaughani Wells - P, B, T, W
A. yongei Veron and Wallace - P, B, W
A. spp (6) - P, R, A
Acropora (Isopora) palifera (Lamarck) - P, B, J, R, A
A. (I) brueggemanni (Brook) - P
A. (I) cuneata (Dana) - W, R
Anacropora forbesi Ridley - B
Astreopora explanata Veron - B, T, R, A
A. gracilis Bernard - P, B, T, J, W, A
A. listeri Bernard - B, T, R

A. myriophthalma (Lamarck) - P, B, T, J, W, R, A
A. sp. (1) - T, R, A
Montipora aequituberculata Bernard - P, B, J, W, R, A
M. caliculata (Dana) - B
M. foliosa (Pallas) - P, B, T, J
M. foveolata (Dana) - P, B, T, J, W, R, A
M. hoffmeisteri Wells - P, B, T, W, R
M. informis (Bernard) - T, W, R
M. marshallensis Wells - P, B
M. monasteriata (Forskål) - P
M. tuberculosa (Lamarck) - P, B, T, J, R, A
M. venosa (Ehrenberg) - B, T, W
M. verrucosa (Lamarck) - P, B, T, W, R, A
M. spp (3) - B, T, R, A

FAMILY ASTROCOENIIDAE

Stylocoeniella armata (Ehrenberg) - P, B, T

FAMILY POCILLOPORIDAE

Pocillopora damicornis (Linnaeus) - P, B, W, R, A
P. brevicornis Lamarck - B
P. eydouxi Edwards and Haime - P, B, R
P. meandrina Dana - P, B, T, J, W, R, A
P. verrucosa (Ellis and Solander) - P, B, T, J, W, R, A
Seriatopora hystrix Dana - P, B, T, W, R, A
S. angulata Klunzinger - P, B, T, W, R, A
Stylophora pistillata (Esper) - P, B, T, W, R, A

FAMILY PORITIDAE

Goniopora lobata Edward & Haime - B, A
G. columna Dana - T, W
Porites australiensis Vaughan - P, B, T, J, R, A
P. cylindrica Dana - P, B, T, W, R, A
P. lichen Dana - P, B, T, J, W, R, A
P. lobata Dana - P, B, T, J, W, R, A
P. lutea Edwards & Haime - P, B, T, W, R, A
P. murrayensis Vaughan - P, B, W
P. solida (Forskål) - P
P. superfusa Gardiner - B, R
P. vaughani Wells - T, W, A
P. spp (2) - R
Porites (Synaraea) rus (Forskål) - T, W

FAMILY SIDERASTREIDAE

Coscinaraea columna (Dana) - P, T, W, R, A
Psammocora haimeana Edwards & Haime - T
P. nierstraszi Van der Horst - B
P. profundacella Gardiner - P, B, T, A

FAMILY AGARICIIDAE

Pavona clavus (Dana) - P, B, T
P. minuta Wells - P, B, J, W, R, A
P. varians Verrill - P, B, T, W, R, A
P. venosa Ehrenberg - P
P. maldivensis (Gardiner) - B, T
Leptoseris mycetoseroides Wells - P, B, T, A

FAMILY FUNGIIDAE

Fungia fungites (Linnaeus) - P, B, W, A
F. (Danafungia) valida Verrill - P, B, T, W, A
F. (D) horrida Dana - A
F. (Pleuractis) paumotensis Stutchhbury - T, W, R, A
F. (P) scutaria Lamarck - P, B, T, R, A
F. (Verrillofungia) concinna Verrill - P, W, R
F. (V) repanda Dana - B, W, R, A
Cycloseris sp - W
Halomitra pileus (Linnaeus) - W
Herpolitha limax (Houttyun) - P, B, T, W, A
Polyphyllia talpina Lamarck - W
Sandalolitha robusta (Quelch) - T, W

FAMILY MUSSIDAE

Acanthastrea echinata (Dana) - P
Lobophyllia hemprichii (Ehrenberg) - P, B, T
L. hataii Yabe, Sugiyama and Eguchi - P
L. corymbosa (Forskål) - B, T, R
Symphyllia radians Edwards & Haime - P, B, W, R, A
S. recta (Dana) - P, B, J, (R)

FAMILY MERULINIDAE

Hydnophora microconos (Lamarck) - P, B, J, A
Scapophyllia cylindrica Edwards & Haime - P, B, T, W, R, A

FAMILY FAVIIDAE

Favia spp (2) - P, T, J, W, R, A
F. matthaii Vaughan - P, B, T, W, R, A
F. pallida (Dana) - P, B, T, W, R, A
F. rotundata (Veron, Pichon, & Best) - P, T
F. speciosa (Dana) - P, B, T, W, R, A
F. stelligera (Dana) - P, B, T, W, A
Favites flexuosa (Dana) - P, B, T, W, R
F. halicora (Ehrenberg) - P, B, T, R
F. spp (2) - P, B, J, W, R
Goniastrea edwardsi Chevalier - P, B, T, W
G. pectinata (Ehrenberg) - P, B, T, R
G. retiformis (Lamarck) - P, B, T, W, R, A

Leptoria phrygia (Ellis & Solander) - P, B, W
Plesiastrea versipora (Lamarck) - R
Oulophyllia crispa (Lamarck) - B, T, W, R
Platygyra daedalea (Ellis & Solander) - P, B, T, J, W, R, A
P. pini Chevalier - B, W
P. sinensis (Edwards & Haime) - B
P. lamellina (Ehrenberg) - B
P. sp (1) - A
Leptastrea purpurea (Dana) - P, B, T, J, W, R, A
L. transversa (Klunzinger) - P, R, A
L. sp (1) - P, T
Cyphastrea serailea (Forskål) - P, R
C. microphthalma (Lamarck) - P, B, T, W, R, A
Echinopora lamellosa (Esper) - P, B, T, R, A
E. sp (1) - R, A
Montastrea curta (Dana) - P, B, T, W, R, A
M. valenciennesii (Edwards & Haime) - (R)

FAMILY PECTINIIDAE

Pectinia lactuca (Pallas) - P

FAMILY DENDROPHYLLIDAE

Turbinaria frondens (Dana) - P
T. stellulata Lamarck - P, B, T, W, R, A
T. sp (1) - R, J

FAMILY CARYOPHYLLIDAE

Euphyllia glabrescens Chamisso & Eysenhardt - A, (R)

FAMILY TUBIPORIDAE

Tubipora musica (Linnaeus) - B, W, R, A

FAMILY HELIOPORIDAE

Heliopora coerulea (Pallas) - P, B, T, J, W, R, A

FAMILY STYLASTERIDAE

Stylaster sp (1) - B, A
Distichopora violacea (Pallas) - P

FAMILY MILLEPORIDAE

Millepora platyphylla Hemprich & Ehrenberg - B, T, J, W, R, A
M. exaesa (Forskål) - B, T, W, R, A
M. dichotoma (Forskål) - P, B, R, A

SOFT CORALS

Sinularia sp (1) - P, B, T, J, W, R, A
Sarcophytum sp (1) - P, B, T, W, A
Xenia sp (1) - P, W
colonial clownfish anemones - A
Palythoa sp (1) - R
unidentified alcyonacean - A

TOTALS genera and (subgenera): 50 + 5 = 55
species: 164 (1988 surveys) + 4 (from Wells, 1954) = 168

Table 3. Relative diversity and distribution of major stony coral genera (and subgenera) and species observed in shallow water at seven northern Marshall atolls in Sep 1988.

	NUMBER OF SPECIES AT EACH ATOLL							
NAME OF GENUS (OR) SUBGENUS	BOK-AK ATOLL	PIKAAR ATOLL	TŌKE ATOLL	JEMO ISLAND	WŌTTO ATOLL	RONDIK ATOLL	ĀDKUP ATOLL	TOTALS
Acropora	22	21	17	10	26	11	12	40
(Isopora)	1	2	1	1	2	2	1	3
Anacropora	1							1
Astreopora	4	2	5	2	2	4	4	5
Montipora	8	8	8	4	6	7	6	15
Stylocoeniella	1	1	1					1
Pocillopora	5	4	2	2	3	4	3	5
Seriatopora	2	2	2		2	2	2	2
Stylophora	1	1	1		1	1	1	1
Goniopora	1		1		1		1	2
Porites	7	7	6	3	7	7	7	11
(Synaraea)			1		1			1
Coscinaraea		1	1		1	1	1	1
Psammocora	1		2				1	3
Pavona	3	4	3	1	2	2	2	5
Leptoseris	1	1	1	?			1	1
Fungia	1	1	1		1		1	1
(Danafungia)	1	1	1		1		2	2
(Pleuractis)	1	1	2		1	2	2	2
(Verrillofungia)	1		1		2	2	1	2
Cycloseris					1			1
Halomitra					1			1
Herpolitha	1	1	1		1		1	1
Polyphyllia					1			1
Sandalolitha			1		1			1
Acanthastrea		1						1
Lobophyllia	2	2	2			1		3
Symphyllia	2	2	?	1	1	1	1	2
Hydnophora	1	1	?	1			1	1
Scapophyllia	1	1	1		1	1	1	1
Favia	4	5	5	3	4	4	5	7
Favites	2	3	2	1	3	3	1	4
Goniastrea	2	3	3	?	2	2	1	3
Leptoria	1	1	?		1			1
Plesiastrea						1		1
Oulophyllia	1		1		1	1		1
Platygyra	3	3	1	1	3	1	2	4
Leptastrea	1	3	2	1	1	2	2	3
Cyphastrea	1	1	1		1	2	1	2
Echinopora	1	1	1			2	2	2
Montastrea	1	1	1		1	1	1	1
Heliopora	1	1	1	1	1	1	1	1
Millepora	3	2	2	1	2	3	3	3
Pectinia		1						1
Tubipora	1				1	1	1	1
Turbinaria	1	2	1	1	1	2	1	3
Stylaster	1		?		?		1	1
Distichopora		1	?		?			1
Euphyllia							1	1
TOTALS: GENERA	38	35	35	16	36	29	35	
& SPECIES PER ATOLL	93	93	93	33	88	74	75	158

TABLE 4. Previous coral records from the atolls studied during the September 1988 expedition to the Northern Marshall Islands. Compiled from Wells (1954). R = Roñdik, B = Bok-ak

PREFERRED NAME	NAMES OF SAME SPECIES (NOW JUNIOR SYNONYMS) LISTED IN WELLS (1954)	LOCATION
Stylophora pistillata	Stylophora mordax	R, B
Seriatopora hystrix		R, B
Pocillopora damicornis		R
P. verrucosa	Pocillopora elegans	R, B
P. eydouxi		R
Acropora acuminata		R
A. cytherea	Acropora corymbosa	R
A. (I.) cuneata		R
A. nasuta	A. cymbicyathus	R
A. echinata		R
A. humilis		R
A. (I.) palifera		R
A. danai	A. rotumana	R
A. loripes	A. squarrosa	R
A. striata		R
Astreopora myriophthalma		R, B
Fungia (P) scutaria		R, B
Porites cylindrica	Porites andrewsi	R
P. lichen		R
P. lobata		R
Favia pallida		R
F. speciosa		B
Montastrea valenciennesii	Favites valenciennesii	R
Favites flexuosa	Favites virens	R
Goniastrea retiformis		R
Platygyra daedalea	Platygyra rustica	R
Leptoria phrygia	Leptoria gracilis	B
Hydnophora microconus		B
Echinopora lamellosa		B
Lobophyllia hemprichii	Lobophyllia costata	B
Symphyllia recta	Symphyllia nobilis	R, B
Euphyllia glabrescens		R
Tubipora musica		R
Heliopora coerulea		R
Millepora platyphylla		R

TOTALS 21 GENERA AND 35 SPECIES, 30 SPECIES OF WHICH WERE REPORTED FROM ROÑDIK AND 11 SPECIES OF WHICH WERE REPORTED FROM BOK-AK

Table 5. Criteria for evaluating candidate reef areas as marine protected areas and parks in the RMI.

1. high diversity of stony corals
2. high abundance of stony corals
3. high bathymetric relief for reef habitat
4. high abundance of reef fish
5. high diversity of reef fish
6. high abundance of giant clams
7. high diversity of giant clams
8. presence of Tridacna gigas (the rarest & largest giant clam)
9. high abundance of large sand dwelling mollusks
10. high abundance of top shell and other reef dwelling mollusks
11. black coral and other precious corals
12. aesthetic stony corals (e.g. Stylasteridae)
13. aesthetic soft corals (e.g. Alcyonaria)
14. high abundance of sharks, skates, rays
15. absence of crown-of-thorns starfish infestations
16. absence of pollution or human damage
17. swimming or feeding sea turtles
18. resting sea turtles
19. nesting habitat for sea turtles
20. large populations of coconut crabs
21. coral and algal encrusted ship & plane wrecks
22. flourishing lagoon reef pinnacles
23. well developed patch reef system
24. overhanging ribbon reef formations
25. lagoon or ocean reef fingers and extensions
26. deep lagoon reef holes or sublagoons
27. unusual reef geomorphological features
    a. perched lagoons
    b. blue coral moats
    c. coral-algae dams
    d. restricted meandering passes
    e. ocean reef pinnacles
28. wide reef flat with micro atoll zone
29. wide reef flat with coral moats
30. wide reef flat with room and pillar formations
31. wide reef flats with productive algal turf zones
32. seagrass beds or meadows
33. mangrove associations
34. tidal lagunas and inlets
35. complex emergent reef rock formations
36. marine mammal aggregation sites
37. sea snakes and crocodiles
38. back reef coral heads & blue coral zones
39. unique marine species or new records for the region (RMI)
40. safe ocean reef slope snorkeling sites
41. safe atoll reef pass snorkeling sites
42. accessible spur-and-groove formations
43. narrow reef isthmuses and indentations
44. sites of historic or cultural significance

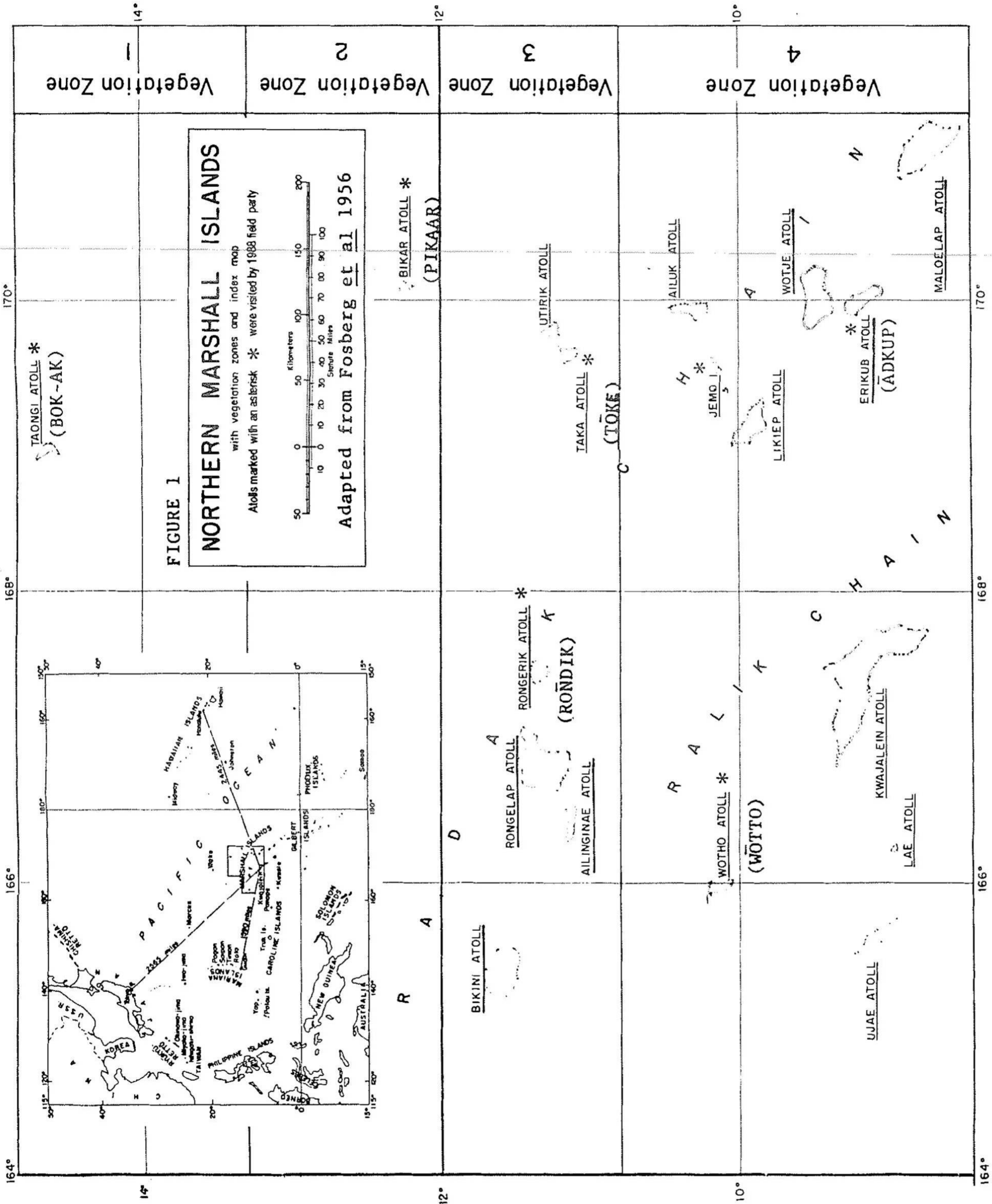


FIGURE 1

NORTHERN MARSHALL ISLANDS

with vegetation zones and index map

Atolls marked with an asterisk * were visited by 1988 field party

Adapted from Fosberg et al 1956

III. RESULTS

General descriptions of the reef and island systems of the seven areas are found in Fosberg (1988) and Fosberg et al (1956). Maps and additional geological information are reported in MacNeil (1969). The six atolls (Bok-ak, Pikaar, Wōtto, Tōke, Rondik, and Ādkup) are generally small compared to the average size of atolls in the rest of the Marshalls, in terms of island land area and lagoon area (Table 1). The island of Jemo is also smaller than the average size of islands on the other four table reefs in the Marshalls (Mejit, Kili, Lib, Jabat). All areas visited are not permanently inhabited except Wōtto. Jemo, Tōke, and Ādkup are occupied for brief periods during seasonal harvesting of fish, turtles and their eggs, coconut crabs, or other resources. The other areas (Rondik, Pikaar, and Bok-ak) appear to be visited less frequently based upon our 1988 field observations. A combination of factors discourages permanent occupation of the uninhabited areas, including limited fresh water supplies and rainfall, poor soil conditions for cultivation, remoteness from nearby population centers, difficult or hazardous boat access to main islands, and perhaps greater vulnerability of the small islands to exposure from storm waves and surges. General physiographic data on the seven areas are summarized in Table 1. Reef profiles of most stations are found in Figures A-1 to 14 in Appendix A, and maps of many reefs and islands constitute Figures 2 through 37 in the text.

Climate and Oceanography

The ocean in the region of the northern Marshalls is between 4,500 and 5,400m deep (Fosberg et al, 1956). The northern Marshalls are semi arid and experience less than average annual rainfall compared to atolls and islands more to the south. The two northernmost atolls, Bok-ak and Pikaar are the driest Marshall atolls, (excluding Enen Kio (Wake) which is under U.S. jurisdiction, drier still, and further to the north). Of the six atolls and one island surveyed in September 1988, Ādkup, which is situated in the central Marshalls, is the wettest of the group. The dryness limits groundwater and vegetation development, and Fosberg et al (1956) divides the Marshalls into several vegetative zones (see Figure 1). The northern atolls are exposed to stronger tradewinds and associated wave action. Although tropical storms and typhoons tend to spawn in lower latitudes further to the west, sometimes the storms gain intensity, move into the Marshalls, usually from the south, and cause extensive damage to shorelines, islands and some reefs. Even infrequent storms can modify the distribution of islands on atoll reefs with long lasting effects, as reported for Arno Atoll (Wells, 1951). The typhoon frequency in the Northern Marshalls is of the order of 50 to 100 yrs, and the visible results of typhoons, especially on atoll islands are the record of at least a thousand years or more (MacNeil, 1969).

The major tropical current system in the northern Marshalls is a large westward flowing current between latitudes 10 and 20 degrees, north termed the North Pacific Equatorial Current (NPEC). This current mostly affects deep ocean circulation patterns off shore. Nearshore effects of the NPEC are masked by much stronger but localized currents caused by the tides, winds, and wave action.

JEMO REEF (Figures 2-4, and A-8)

Jemo̧ is the only reef of the seven visited that is classified as a table reef and is one of only 5 table reefs (compared to 29 atolls) located in the Marshall Islands. A table reef consists of an isolated flat topped coral reef which reaches the sea surface but which lacks a lagoon (MacNeil, 1969). These reefs tend to be small, sometimes linear, and are exposed to wave action due to the lack of sheltered lagoon reefs. The table reef supporting Jemo̧ Island is 8 km long, slightly arcuate, and is situated along a SW to NE axis (Figure 2). Jemo̧ Island is egg shaped and about one-third mile long.

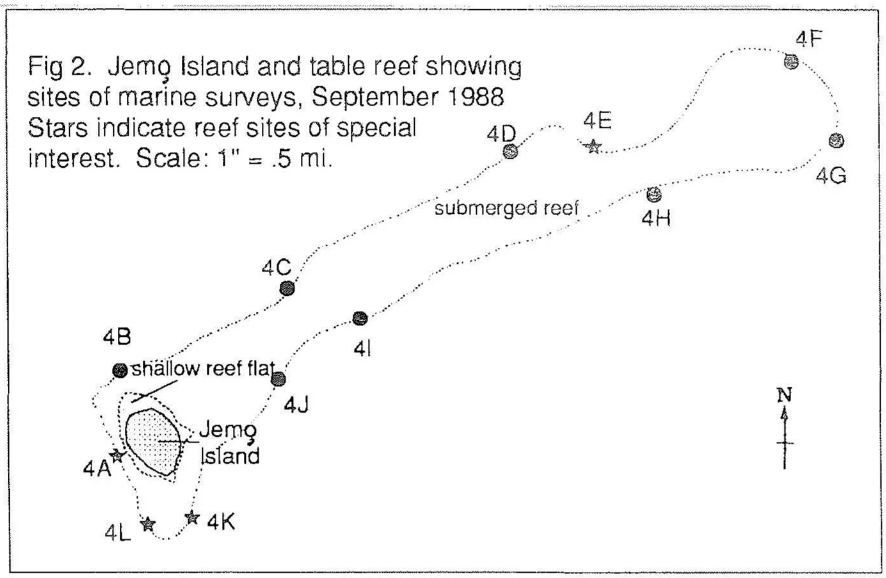


Fig 2. Jemo̧ Island and table reef showing sites of marine surveys, September 1988 Stars indicate reef sites of special interest. Scale: 1" = .5 mi.

Exposure of the reefs and island to heavy waves and storms from virtually any direction has controlled and shaped reef development at Jemo̧. Underwater observations, published charts, and color aerial photographs all document that the flanks of the table reef drop off near precipitously to great depths within a kilometer of the reef crest. Shallow reef flats emerge at low tide only at the southwest end upon which rests the single island of Jemo̧ (Figures 2-4). Elsewhere, an extensive system of sand covered surge channels (see Figures 3, 4) traverse the reef crest in a north-south axis and at depths of 2-4m. At the NE end, which receives the most exposure from trade-wind waves, the reef resembles a rounded knob in which the surge channels give way to well developed spur-and-groove formations. Elsewhere the outer margin of the reef crest consists of flat pavement-like and heavily scoured ramps descending at a moderate angle from a depth of 2-3m to a drop off at a depth of about 6-8m. Below the drop off, the reefs are steep vertical walls sometimes overhanging (Figure A-8, sites 4B, 4L, 4E, 4J, and 4D).

Perhaps due to the long NW facing axis of the reef oriented away from the prevailing NE tradewinds, typical spur and groove formations are lacking along the reef margin except at the NE end. These features, along with the prominent series of sand bottomed surge channels across the reef crest, are clearly displayed in the 1978 color aerial photographs of the island and reef at Jemo̧ taken at scales of 1:30,000 and 1:8,000.

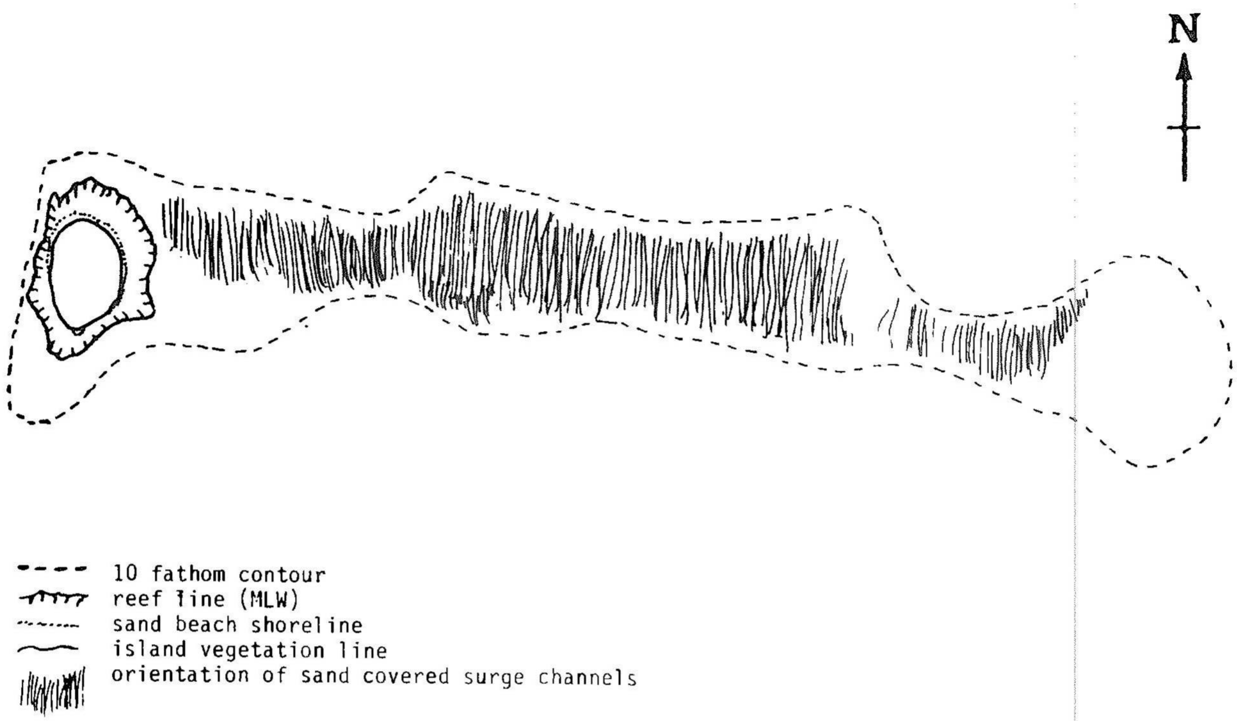


Figure 3. Jemo Island and table reef showing distribution of shallow reefs and surge channels on the reef crest. Map drawn from 1978 color aerial photographs. Scale 1:30,000.

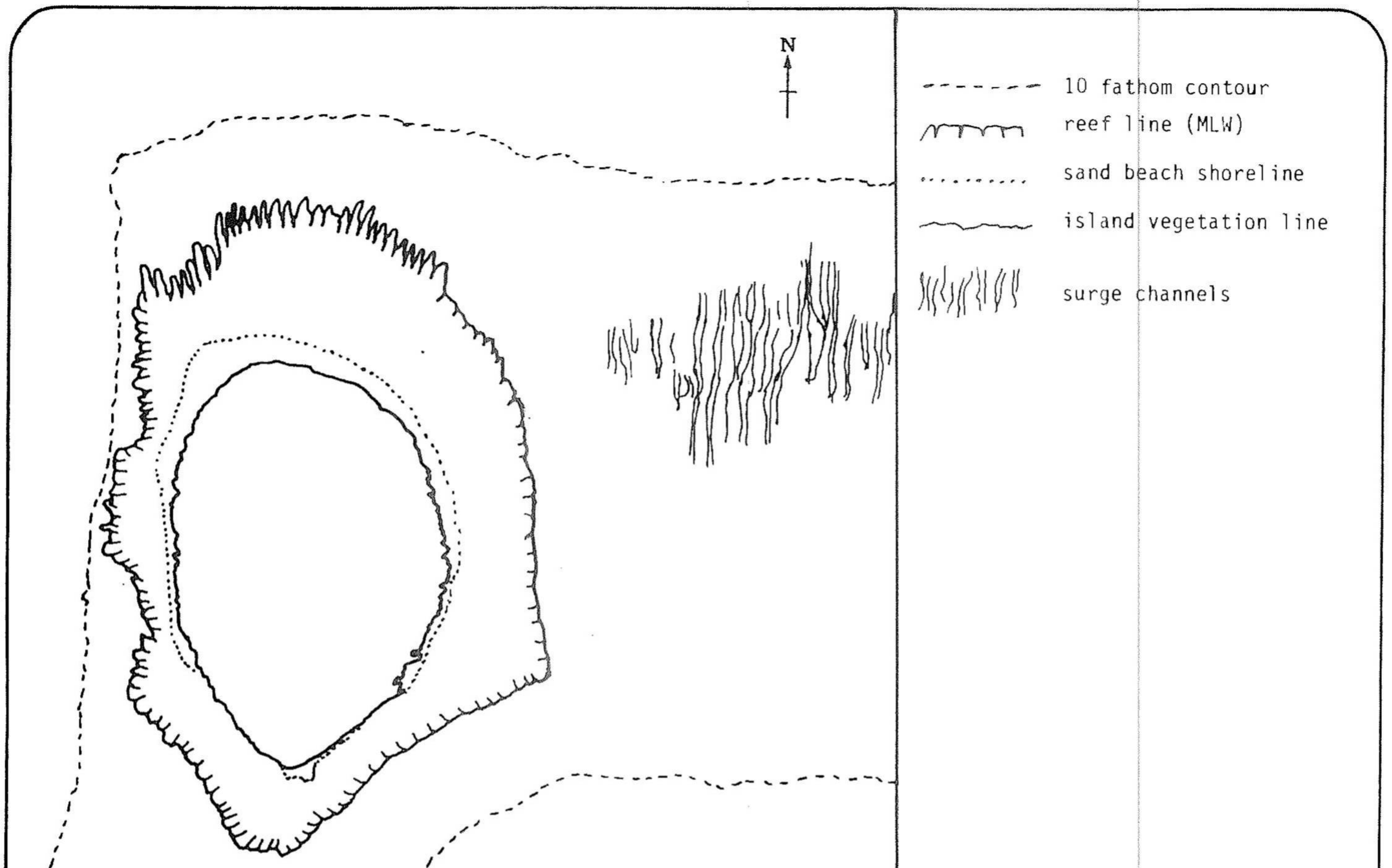


Figure 4. Close up of Jemo Island and nearby reefs. Map drawn from 1978 color aerial photos.
Scale 1:8,000

There are no major accumulations of loose boulders strewn on the reef crest. Small boulder beaches occur along the south and southeast facing shorelines of Jemo̧ Island. The reef margins off the elongate SE facing reef axis appear to be depositional in character, with sand, gravel and other sedimentary materials apparently carried through the surge channels over the crest of the reef from the other (NW) side. Thick accumulations of sediments were observed at the base of canyons between steeply sloping massive rounded reef buttresses along the SE reef margin. In contrast, the NW reef margin lacked any loose sediment, and coral formations consisted of robust, low profile colonies. The bare reef pavement ramps appeared heavily scoured. Ailuk Atoll affords Jemo reef some protection from northeast swells, Likiep, provides protection from the southwest, and Wotje and Ādkup provide protection from the southeast, leaving the northwest face of Jemo̧ reef the most exposed to heavy seas. Movement of reef materials appears to be from a northwest to southeast direction, with the northwest face of the reef potentially more exposed to damage from wave energy.

Another unusual feature of Jemo̧ reef is the truncated sheer face of the southwest end of the reef adjacent to the island. This wall drops vertically from depths of 6m to 50m or more with some major overhangs (Figure A-8). The margin of the reef is nearly perfectly straight along a northwest to southeast axis (see Figs. 3 & 4) as if a giant knife had sliced away the reef mass further to the southwest. I can think of no explanation for this unusual geomorphic feature, except that a previously existing extension of this reef to the SE may have fractured and slumped down towards greater depths, leaving a vertical face on the remaining reef.

Since none of the other table reefs in the Marshalls have been described in much detail, it is impossible to compare Jemo̧'s features to them. It is possible that Jemo̧'s table reef might be the peripheral remnant of a once larger atoll, the rest of which has been displaced by faulting below the depths required for active upward reef growth. Clearly Jemo̧'s reefs are unusual with features not having been previously reported in the scientific literature.

Despite the abundance of hard reef surfaces and transparent well illuminated waters, coral abundance and diversity were low. Coverage on the pavement terraces was low and nearly absent from the walls of the sand channels. Highest coral development occurred in a NW facing reef indentation near the NE end of Jemo̧ reef. This indentation apparently affords the reef slopes some protection from heavy wave action, allowing luxuriant, three-dimensional coral development. Typical vertical profiles of all reef sites sketched in the field are presented in Appendix A (Figure A-8 covers Jemo).

The absence of a more extensive and shallow reef flat and the presence of the surge channels on the reef crest is curious. Perhaps the reef is too narrow or wave action too severe to facilitate shallower reef flat development. Wave action was observed to be approaching Jemo̧ from all directions, although heaviest from the north during our visit. The bulbous NE terminus of the reef was the zone of maximum wave action.

Landing on Jemo̧ Island is extremely hazardous as noted in Fosberg et al (1956), Fosberg (1988), and as experienced first-hand in 1988. The transition from deep to shallow water is abrupt off the SW end (the only safe "access" point to the island) and the spur and groove formations and unpredictable wave action renders boat navigation dangerous. During our landing, the shaft of the outboard motor struck the reef and broke off, causing our skiff to swamp. The lack of safe anchorage and access must have contributed historically to the lack of permanent habitation on Jemo̧. During heavy surf it would be impossible to land at the island from any direction.

Rare Marine Species at Jemo̧

Evidence of sea turtle nesting activity was high along Jemo̧ Island's sandy beaches and the level of evidence (53 pairs of turtle tracks) was second only to Pikaar's. Signs of recent harvesting of green turtle was evident, and one nest with fresh eggs was discovered. Although uninhabited, Jemo̧ lies close to inhabited Wotje, Likiep, and Ailuk atolls. According to Fosberg (1988), Jemo̧ was in pre-European times a turtle sanctuary, and only infrequent visits were permitted; turtles and eggs were taken in limited numbers under close supervision by priests (Jack Tobin, pers comm. to Ray Fosberg). Although not rare species, numerous sharks also inhabit the reef waters off Jemo̧.

Jemo̧'s Corals

Jemo̧'s coral fauna is noticeably depauperate with only 33 species and 16 genera reported after surveying 12 separate sites. These numbers compare to 74-93 species and 29-35 genera reported from atolls subject to the same sampling intensity (Table 2) during the 1988 survey. The most common Jemo̧ species were ramose stony corals (Acropora (I) palifera, Pocillopora verrucosa, P. meandrina), robust firecorals (Millepora platyphylla), encrusting colonies (Montipora spp) massive brain corals (Platygyra daedalea, Favia spp, Hydnophora microconos) other reef corals (Symphyllia radians, Astreopora spp, Turbinaria sp, Porites spp, the soft coral Sinularia, and the blue coral (Heliopora coerulea). Maximum coral abundance and diversity occurred at depths between 7-10m and especially where reef indentations afforded corals some protection from heavy wave exposure. Free living forms such as the mushroom corals (Fungia and related genera) were not reported. Coral coverage appeared lower along the southeast facing slopes probably due to substrate instability of disturbance from moving sediment.

ATOLL GEOMORPHOLOGY AND OCEANOGRAPHY

Atolls are annular (perimeter) reefs enclosing lagoons which usually contain passes through the reefs, islets on the reef, and lagoon reef formations (MacNeil, 1969). The six remaining areas surveyed in 1988 are atolls with perimeter reefs affording protection and surrounding semi-enclosed lagoons. At least five or more small to moderate sized islets are situated on the shallow reef flats along the perimeter reefs of each atoll. All six atolls include at least one natural deep passage through the perimeter reefs, allowing sub-tidal exchange between ocean and lagoon waters. There are more islands and fewer passes on the windward side than on the leeward side. The perimeter reefs of atolls in the Marshalls are usually between 1,000 and 2,000 feet wide, with windward reefs usually slightly higher in elevation. The six atolls can be divided into two major geomorphological groups with gradients between one another along a north-south axis:

1) Small Northern Atolls. These have shallow lagoons with maximum depths of 13m or less, a very narrow single passage along the west side, and elevated (perched) water levels in the lagoon during low tide. This category includes Bok-ak and Pikaar. Tōke Atoll is intermediate between the two groups. Wake (traditional Marshallese name Enen Kio) is located further to the north of the Republic of the Marshalls, is under U.S. military jurisdiction and is more closely allied to this group. The climate is dry and prevailing trade winds are heavy. In addition, the semi-enclosed nature of the lagoons of Ebon and Namorik (Namdik) Atolls and the two semi-enclosed sublagoons of Arno Atoll, all in the southern Marshalls, show some functional resemblances to the first group.

2) Central Atolls. These have deeper, more open lagoons with maximum water depths of 49m or more, larger, deeper or more numerous passages, and lagoon tidal fluctuations more closely corresponding to those of the adjacent ocean areas. Included in this category are Roñdik, Wōtto, and Ādkup. These three atolls more closely resemble most of the other atolls in the Marshalls.

Due to Wake's proximity to Bok-ak and Pikaar, all three may have undergone a similar geological evolution. Wake has no natural passage through its reef, and the maximum depth of its lagoon is only 4m. Wake represents one extreme in the gradient between the two groups of atolls in terms of small pass development, shallowness of lagoon, and small lagoon area. At the other extreme would be the more typical atolls of the Marshalls charactered by larger and more numerous passages and lagoons, well developed perimeter reefs and islands, and passages generally concentrated along the south and west rims (Wiens, 1963).

Tōke Atoll, intermediate between the two extremes, most closely resembles nearby Utrōk Atoll, with comparable angular shape, size, moderate depth of the lagoon, and small size and position of the single deep western passage.

The Perched Lagoons of Bok-ak and Pikaar:

The raised perimeter reefs and the single narrow western passage off both Bok-ak and Pikaar atolls restrict tidal exchange between the lagoon and ocean (Fosberg et al, 1956). More water is pumped into the lagoon by wave action along the eastern (windward) reefs than exits from the lagoon through the pass and over the reefs at low tide along the western (leeward) side. This factor causes average lagoon water levels to be higher compared to those on the ocean side. Since water levels in the lagoon never get as low as the low tide levels outside the lagoon, perimeter reefs may have continued to grow upward in response to the constant washing from higher lagoon water levels.

The raised nature of the peripheral reefs, especially along the leeward rim prevents tidal exchange over the reefs except at moderate to high tide, further increasing the accumulation of water pumped in the lagoon from the windward side wave action relative to that which exits the lagoon. Coupled with the limited drainage of lagoon waters out of the narrow pass of each atoll, the "low" tide water levels in the lagoon were observed to be two - three feet higher than corresponding levels on the ocean side. Lagoon tidal amplitude is very small and is nearly completely out of phase with ocean side tidal fluctuations. During low tides on the ocean side, lagoon waters were observed to stream out of the pass, dropping up to three feet and resembling white water "rapids" over a distance of about 100m.

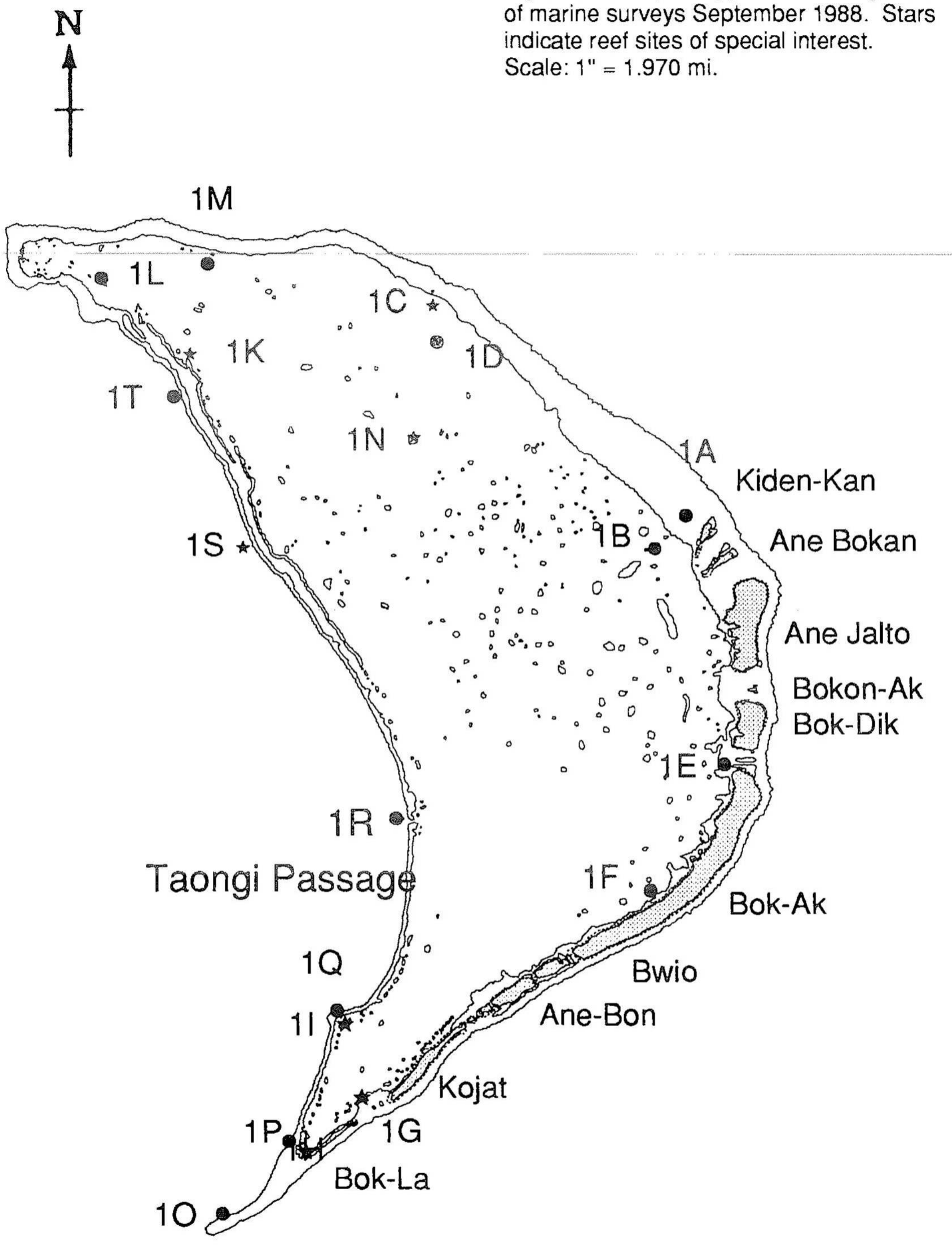
As a consequence, the leeward perimeter reefs of both Bok-ak and Pikaar atolls serve as natural dams and spillways, ponding lagoon waters and dampening outside tidal fluctuations. Only during the few hours of high tide do all perimeter and lagoon reef flats completely submerge, allowing free exchange of lagoon and ocean waters over the reef. At the time of highest tide (on the ocean tide) current flow out the channel reverses direction, running into the lagoon for an hour or so. Perhaps in response to less water level fluctuations in the lagoon, living corals and coralline algae grow to higher elevations, displaying prominent overhanging reef wall formations.

In contrast, the central group of atolls (Ādkup, Wōtto, and Rōn̄dik) display localized oceanographic conditions more typical of the rest of the Marshalls. Wave action along windward reefs pumps water over the perimeter reefs into the lagoon during virtually all stages of the tide. Water also enters the lagoon during flooding tides through all passes and over most shallow perimeter reefs. During ebb tide, water flow out of the passes, and ebb flow over leeward reefs is likely to be strong (but not specifically observed during the 1988 study). Lagoon and ocean tidal fluctuations appear more closely synchronized and show similar amplitudes. Wave action inside the lagoons is moderately high due to the more open configuration and larger size of the lagoons for the central atolls compared to those of the small northern atolls.

BOK-AK ATOLL (Figures 5-9; A-1 through A-3)

Aelon-in Bok-ak (also called Taongi, Bokaak, or Pokak Atoll) is the Republic's most isolated atoll with the nearest reefs and islands located 150 NM to the southeast at Pikaar Atoll and 300 NM to the north at Wake Atoll (Enen kio). Also an unnamed bank at a depth of seven fathoms lies 100 NM south of Bok-ak (MacNeil, 1969). Bok-ak is unusual from several respects, not the least of which is the elevated configuration of its living lagoon reefs. The atoll is crescent shaped (Figure 5), curving to the west with reef horns extending off the northern and southern tips of the atoll reef, and is about 11 miles long from reef tip to reef tip. The 1988 team was able to spend three field days at Bok-ak allowing 20 marine sites, including five leeward ocean reef sites to be surveyed (Figure 5).

Fig 5. Bok-ak (Taongi) Atoll showing sites of marine surveys September 1988. Stars indicate reef sites of special interest. Scale: 1" = 1.970 mi.



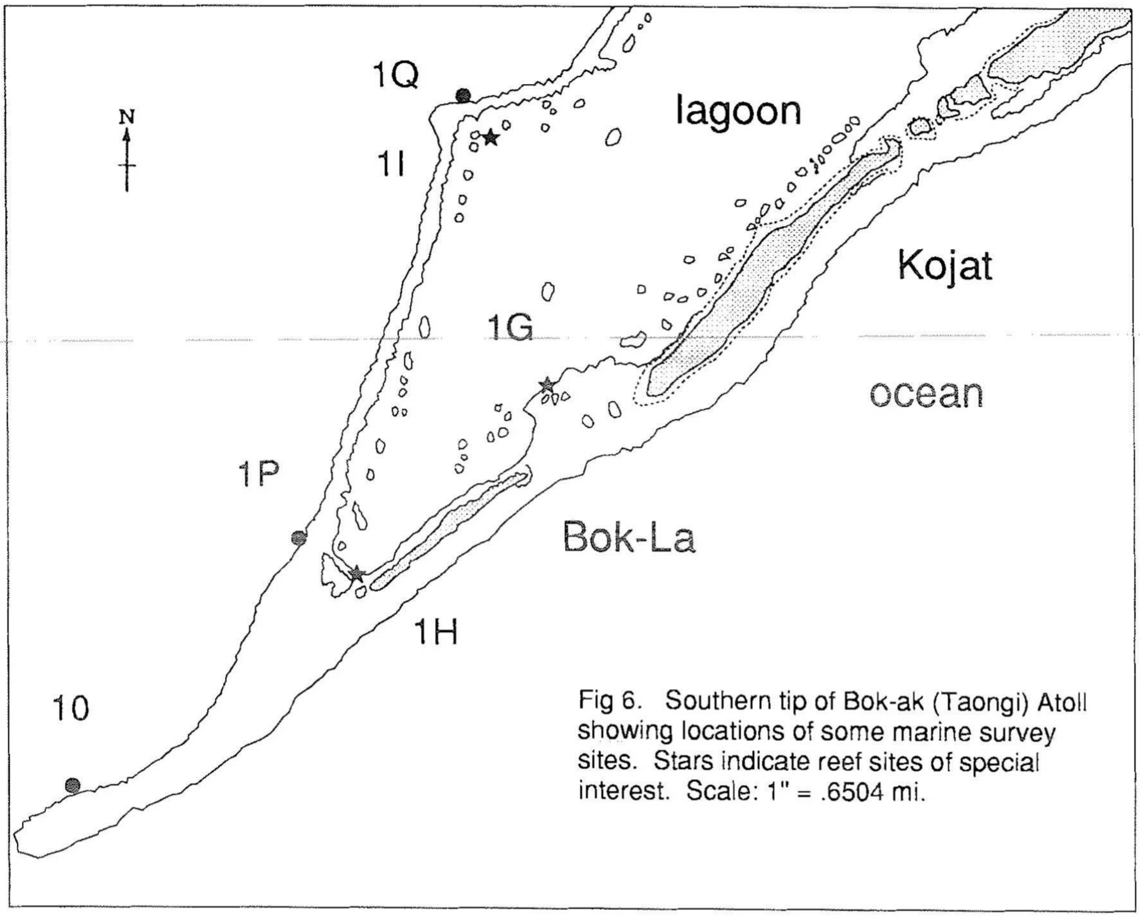


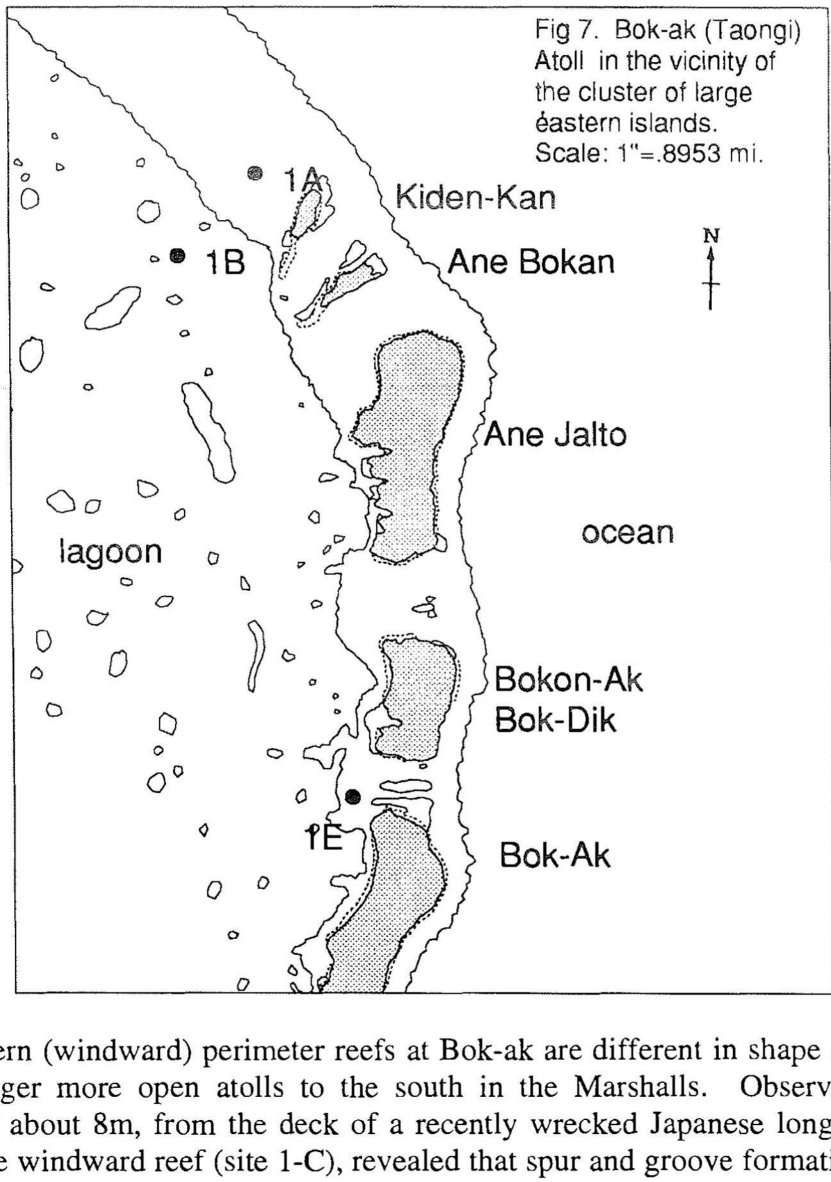
Fig 6. Southern tip of Bok-ak (Taongi) Atoll showing locations of some marine survey sites. Stars indicate reef sites of special interest. Scale: 1" = .6504 mi.

A near continuous string of islands (Figures 6, 7) extends along the SE windward reefs. The NE windward reef and the entire western (leeward) reef lacks islands. Island land area totals 1.45 square miles (3.8 km^2) for Bok-ak, the second most of any of the seven areas surveyed in 1988 after Wōtto. There is no fresh water at Bok-ak and even wells dug in the center of large islands are quite salty (Fosberg et al, 1956).

Bok-ak lies far enough north for tropical storms originating in the central Marshalls to have gained full typhoon intensity, and the atoll's islands and reefs display extensive evidence of typhoon effects (MacNeil, 1969). Boulder ramparts, beaches, and concentrations of strewn boulders are thought to have been formed during intense storms and are most concentrated on the east and SE ocean facing sides of islands at Bok-ak Atoll (MacNeil, 1969; Fosberg, 1988).

Many patch reefs throughout the lagoon are elongated into ribbon reefs with vertical or overhanging walls. The lagoon averages seven fathoms (13m) in depth with the greatest recorded depths being eight fathoms (15m), mostly in the western lagoon. The tops of many lagoon patch and ribbon reefs are awash at low tide with overhangs of profusely growing corals just below the surface. The tops of the shallowest reefs are smooth pavements of living crustose coralline algae. Over a full tidal cycle, lagoon water levels were observed to fluctuate less than one foot. At high tide all reefs and corals are flooded to depths of a few inches or more. Water levels in the lagoon never dropped below mean tide level. Sand deposits covered the floor of the lagoon while most elevated surfaces were covered with live coral. Lagoon coral communities were very healthy with only a few dead corals observed. Giant clam populations in the lagoon were huge, including the species Tridacna maxima, T. squamosa, and Hippopus hippopus. Despite an intensive search neither live or dead remains of the largest species Tridacna gigas were reported. Neither were sea turtles observed at Bok-ak. Sharks were numerous, especially black tips inside the lagoon and grey and white tip reef sharks outside the lagoon.

Fig 7. Bok-ak (Taongi) Atoll in the vicinity of the cluster of large éastern islands. Scale: 1"=.8953 mi.



Eastern (windward) perimeter reefs at Bok-ak are different in shape compared to those of larger more open atolls to the south in the Marshalls. Observations at an elevation of about 8m, from the deck of a recently wrecked Japanese longliner fishing vessel on the windward reef (site 1-C), revealed that spur and groove formations are well developed and typical. However, the coralline algal ridge was a wide irregular feature, rather than a more typical elevated ridge measuring only a few meters in width (see also Fosberg, 1988). The reef crest was generally flat but elevated 2 or more feet above mean low water. The back lagoon edge of the reef abruptly drops as a pronounced step 1-2m in depth. Elsewhere in the Marshalls back reef slopes towards the lagoon are generally more gentle. Lagoonward water flow over the reef was also not as swift as reported for many windward reef flats in the Marshalls. The higher observed lagoon water levels may prevent more rapid "downhill" movement of waters from the ocean side.

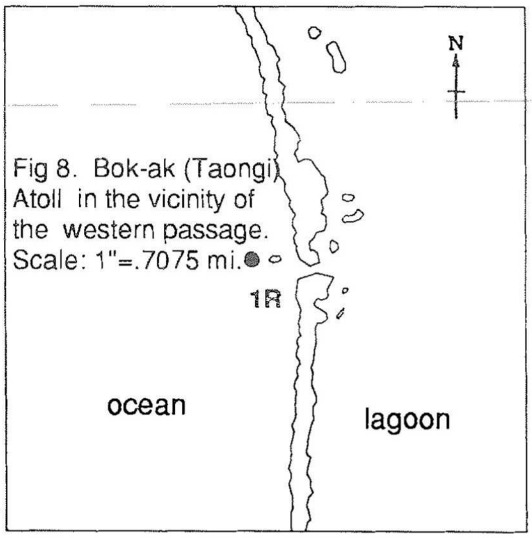


Fig 8. Bok-ak (Taongi) Atoll in the vicinity of the western passage. Scale: 1"=.7075 mi.

Leeward perimeter reefs were unusually narrow, averaging less than 100m in width (Figures 8, 9). Except for a small coralline algal ridge-like feature at the crest of the reef near its lagoon margin (see Fosberg, 1956; et al, 1988), the upper reef surface is smooth and covered with living crustose coralline algae and slopes down two to three feet from the lagoon side to the ocean side. This tiny ridge, up to 10-15 cm in height, is also reported on windward facing edges of patch reefs in the lagoon and along the lagoon shores of some islets. The living reef flat serves as a coral-algal dam and spillway, holding back higher lagoon water levels except for excess water trickling downslope to the ocean margin. Even at low tide (outside), water was seen constantly spilling over the dam and down the spillway to the ocean, with flow presumably maintained by the constant wave action pumping water into the lagoon from the windward side.

The ocean face of the leeward reefs resembled the steep slopes, reentrant/canyons, high coral cover, and diversity typically reported for such environments elsewhere in the Marshalls. Water currents were strong and turbulent off the leeward side of the southern reef extension or horn (site 1-O). Loose sediment and sand were absent from the shallow ocean reef slopes. Seven of the 20 sites surveyed at the atoll displayed exceptional or unique coral reef features (Figs. 5, 6, 9, A-1, A-2, and A-3).

One unusual feature was an ocean patch reef (site 1-S) separated from the main ocean reef slope by a deep chasm. Other exceptional sites included a windward reef flat (site 1C), lagoon patch and ribbon reefs (sites 1K, 1N, 1I, 1G and 1H).

Corals of Bok-ak Atoll

Bok-ak was one of three atolls where the most species of corals were observed during the expedition. Ninety-three species belonging to 38 genera and subgenera were reported at Bok-ak based upon surveys at the 20 field sites, including five ocean sites.

In contrast, 93 species were reported at both Tōke and Pikaar after surveys at only 13 sites which included no ocean sites at Tōke and only two ocean sites at Pikaar. Thus, despite the high number of coral species reported at Bok-ak, Tōke and Pikaar would appear to support high numbers of species, based upon equivalent sampling intensity. The condition of the coral communities of Bok-ak was healthy and flourishing at all observed lagoon and ocean reef sites. Thus a lower number of coral species does not appear to be related to environmental stress.

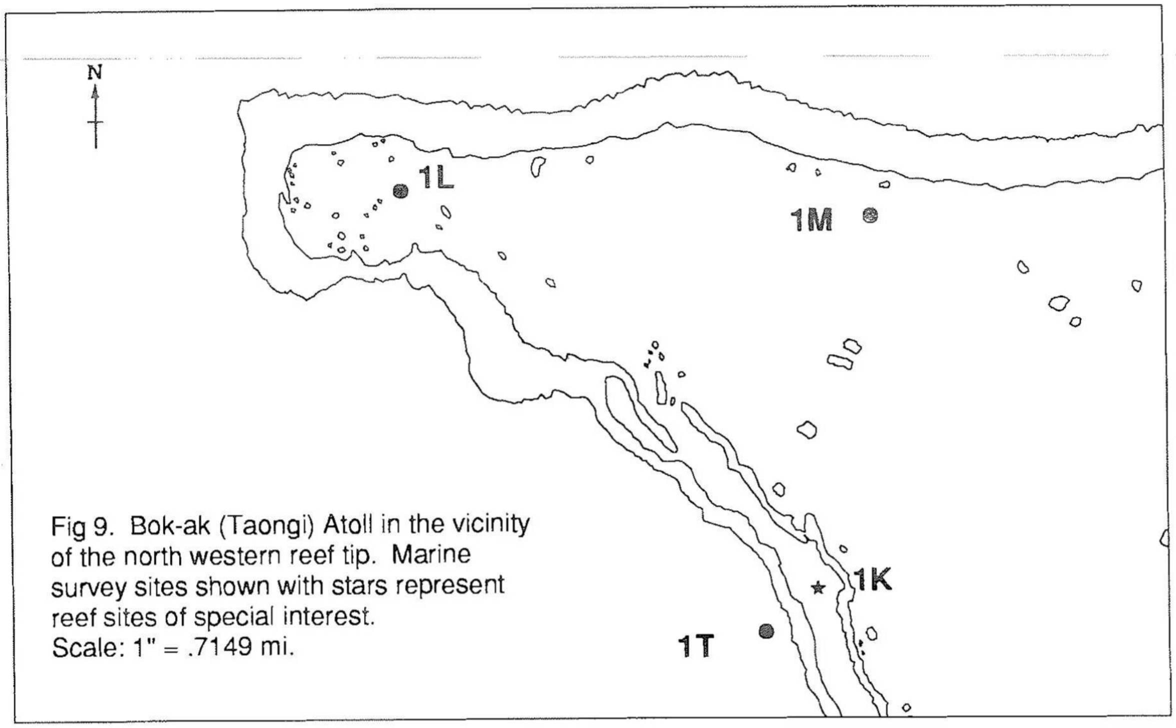


Fig 9. Bok-ak (Taongi) Atoll in the vicinity of the north western reef tip. Marine survey sites shown with stars represent reef sites of special interest.
Scale: 1" = .7149 mi.

Because of the elevated nature of the lagoon coral communities, they may be more isolated from ocean reefs due to restricted tidal exchange. Furthermore, the remote position of Bok-ak from its nearest reef neighbors may reduce the number of coral species which can successfully migrate and establish at Bok-ak. Over prolonged periods this might be reflected in fewer total species of coral that are established at Bok-ak.

Several reef genera which are common elsewhere in the Marshalls were absent from Bok-ak: Porites (Synaraea), Coscinaraea and Distichopora. Some genera were conspicuously more abundant at Bok-ak including Platygyra and to a lesser extent Anacropora. These observations lend further support to the hypothesis of geographic isolation of Bok-ak from nearby atolls.

However, coral communities at Bok-ak achieve an unprecedented level of abundance and development. Lagoon habitats were complex three dimensional coral dominated environments, with many overhangs, mounds, walls and elevated ledges. The protected shallow lagoon environment appears to promote optimal coral growth due to abundant light, transparent waters, lack of suspended sediment and only minor wave action.

Along windward perimeter reefs, the stepped back reef margins included many abundant corals: Acropora (I) palifera, other Acropora spp, Porites lobata, Cyphastrea microphthalma, Goniastrea spp, Pavona minuta, Seriatopora aculeata, Heliopora coerulea, Stylophora pistillata, encrusting Montipora spp, Pocillopora spp, Favia spp, Leptastrea purpurea, Platygyra spp, Millepora spp, and Astreopora spp.

On the slopes of lagoon pinnacles, the following corals were common: Porites cylindrica (fingercoral), Astreopora gracilis, Goniastrea pectinata, Favia pallida, Stylophora pistillata, Porites spp, Fungia fungites, Lobophyllia hemprichii, Montipora spp, Pocillopora spp, and Acropora spp, especially staghorn corals, and others.

On leeward ocean reef slopes and margins, the following corals achieved prominence: Millepora spp, Acropora digitifera, A. palifera, Porites superfusa, Montipora tuberculosa, Stylophora pistillata, Ecinopora lamellosa, Goniastrea retiformis, Favia stelligera, Turbinaria stellulata, Symphyllia spp, Favia spp, other Acropora spp (tables), Porites spp, and Cyphastrea microphthalma. Many other species were common, and the leeward ocean reef slopes displayed the highest reef coral abundance and diversity observed of any habitat at Bok-ak.

Rare Species at Bok-ak Atoll

The smaller giant clam species which were abundant in Bok-ak lagoon are considered rare species. However, there was no evidence of the rarest and largest giant clam species nor of sea turtles or coconut crabs. Bok-ak, along with Pikaar and Jemo̧ was regarded as a bird and turtle reserve by the Marshallese prior to the era of European influence (Jack Tobin pers. comm. to Ray Fosberg, in Fosberg 1988), and in the early 1960's Bok-ak was designated as a reserve by the then District Administrator of the Marshalls.

PIKAAR ATOLL (Figures 10-15, A-4 to A-5)

Aelon-in Pikaar (also called Bikar Atoll) is the Republic's second most isolated atoll with the nearest reefs and islands being Utrōk and Tōke Atolls some 80 NM (146 km) to the south and Bok-ak Atoll some 150 NM (247 km) to the north. An unnamed bank with a depth of seven fathoms lies about 50 NM (91 km) north of Pikaar Atoll. Pikaar most closely resembled Bok-ak in geomorphology but has much less land area. In fact, with only 0.19 square miles (0.49 km^2) of land, Pikaar has the least amount of land of any atoll in the Marshall Islands, and only the table reef at Jemo has less island area. Storm generated boulder ramparts and concentrations of strewn boulders occur only along the northwest shoreline of Jeliklik Island and along the lagoon face of northwestern

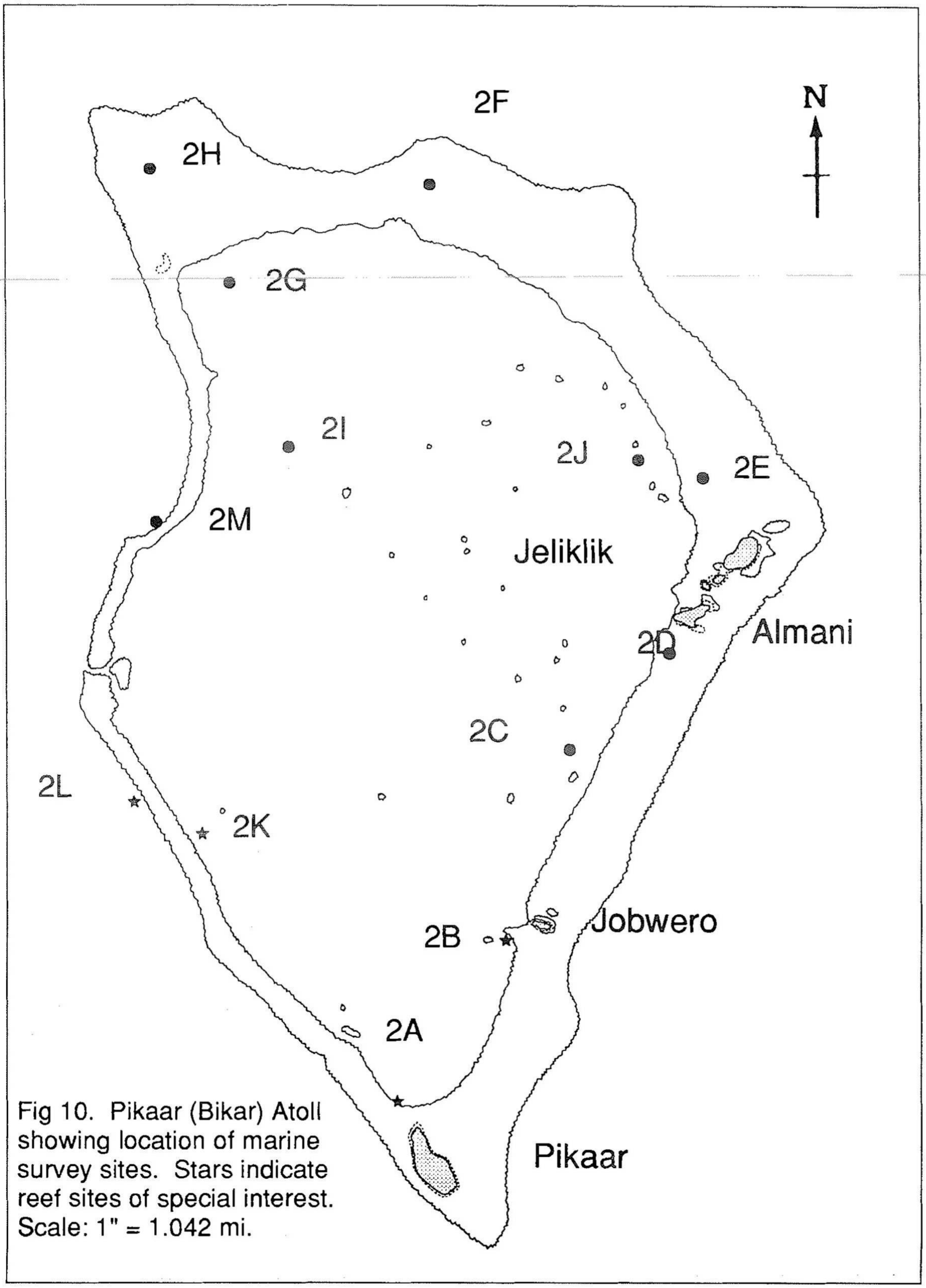


Fig 10. Pikaar (Bikar) Atoll showing location of marine survey sites. Stars indicate reef sites of special interest. Scale: 1" = 1.042 mi.

perimeter reef flats (MacNeil 1969). Although no wells have been dug, the small size of the largest islands and dryer climate argue against potable groundwater at Pikaar Atoll (Figure 10).

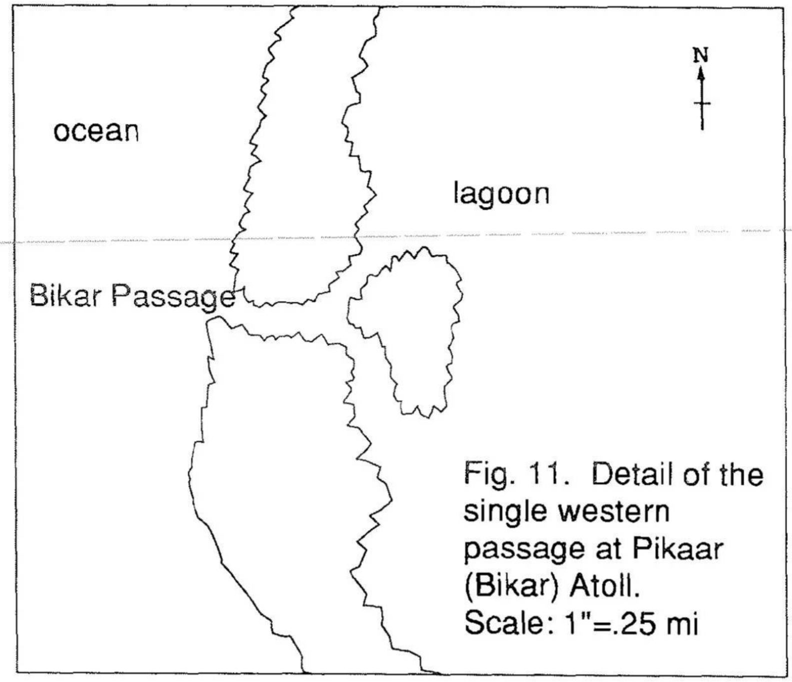


Fig. 11. Detail of the single western passage at Pikaar (Bikar) Atoll. Scale: 1"=.25 mi

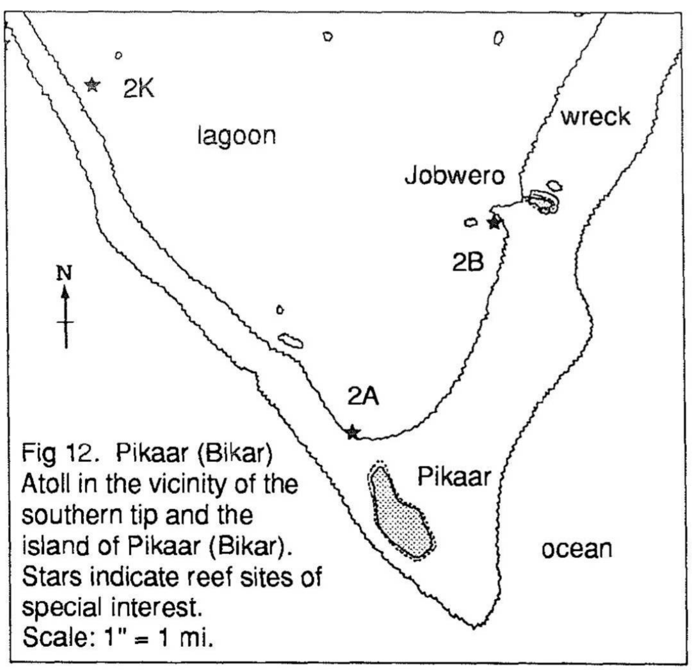


Fig 12. Pikaar (Bikar) Atoll in the vicinity of the southern tip and the island of Pikaar (Bikar). Stars indicate reef sites of special interest. Scale: 1" = 1 mi.

The top of Pikaar's reef formations are living and elevated some two to three feet above mean low water. Its one single pass (Fig. 11) is narrow and forked to the lagoon side along the western rim of the atoll. Small boat navigation through the pass at low tide is extremely hazardous, and many reef sharks patrol its waters. Pikaar Atoll's largest island is Pikaar Island, resting on the widest section of the perimeter reef at the southern tip of the atoll (Figure 12). Remaining islands are very small or are only sand cays (Figures 13-14). Pikaar's lagoon is deeper than Bok-ak's, varying in depth between five and 13 fathoms (9-24m). The lagoon near the southern tip and western pass region is shallower, averaging eight fathoms (15m), but most of the lagoon floor is situated at depths between 10-11 fathoms (18-20m). As with the reefs of Bok-ak, the tops of the shallowest reefs are smooth pavements of living crustose coralline algae. Ribbon reefs fill the lagoon with the walls dominated by live coral and with pronounced overhangs near the tops of the reefs. Sand deposits cover the floor of the lagoon.

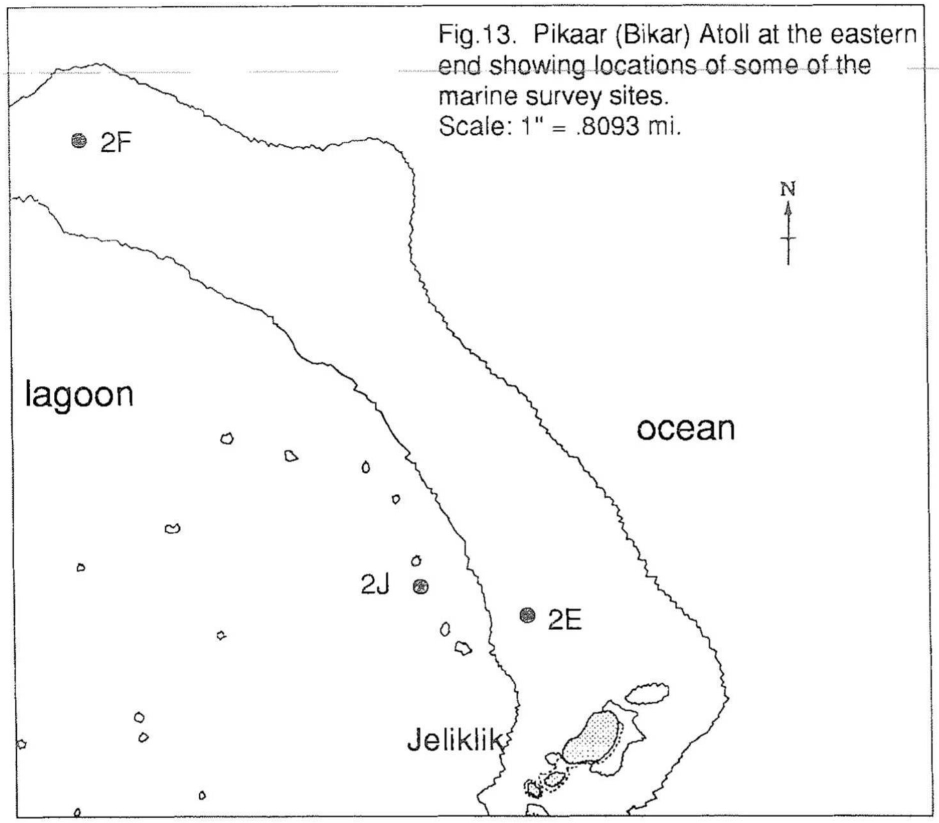


Fig.13. Pikaar (Bikar) Atoll at the eastern end showing locations of some of the marine survey sites.
Scale: 1" = .8093 mi.

Tidal characteristics at Pikaar appear to be very similar to those of Bok-ak although there was less time in the field (1-1/2 days) to observe them. At low tide, the tops of lagoon reefs are awash but rest some two to three feet higher than the margin along the ocean side of the reef at mean low water. Over a full tidal cycle lagoon water levels were observed to fluctuate less than one foot. At high tide all living reefs and corals are flooded to depths of one foot or more. Water levels in the lagoon never dropped below mean tide level.

Huge populations of giant clams (especially Tridacna maxima, T. squamosa, and Hippopus hippopus) were found throughout the lagoon, resembling those of Bok-ak. Swimming green sea turtles were observed both inside and outside the lagoon, and evidence of recent sea turtle nesting activity was evident along the sand beaches of most islands, especially Pikaar.

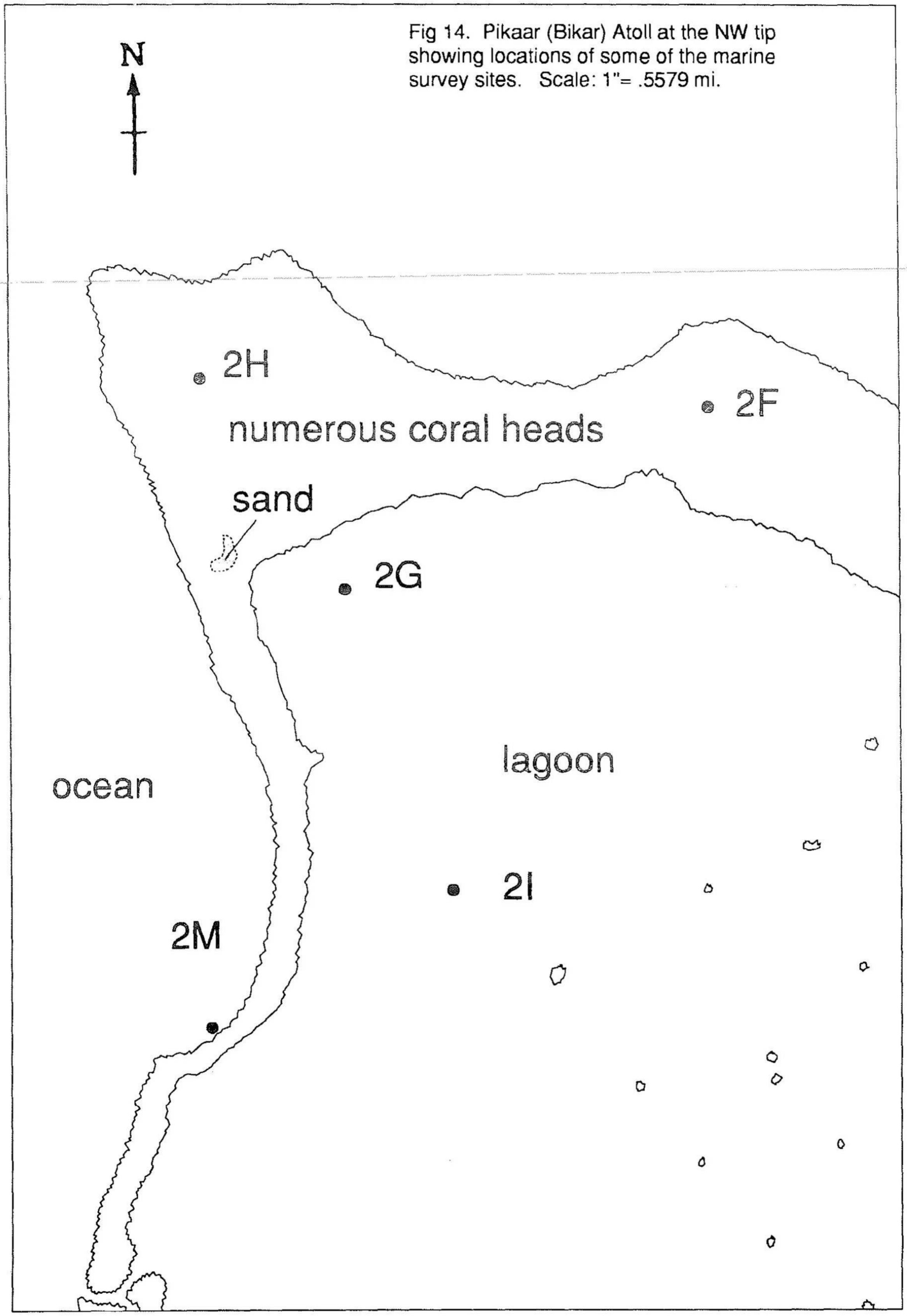


Fig 14. Pikaar (Bikar) Atoll at the NW tip showing locations of some of the marine survey sites. Scale: 1"= .5579 mi.

The windward, eastern facing perimeter reefs of Pikaar resembled those of Bok-ak in terms of form and coral species composition. The back lagoon edge of the reef flat drops down as a pronounced step one or more meters in depth. This feature shows up well in the color aerial photographs, and the stepped or double reef feature is also marked on available maps and charts. The fact that the stepped reefs were reported only from the reefs of Bok-ak and Pikaar suggests that higher average lagoon water levels may have something to do with the formation of the steps. Stepped reefs occur also along the southwest and northwest lagoon faces at perimeter reefs at Pikaar atoll. Compared to those of Bok-ak Atoll, leeward (western) perimeter reefs at Pikaar Atoll are generally wider. Only the NW section to the north of the pass region shows narrow perimeter reefs.

The perched lagoon water levels are maintained by wave action pumping water into the lagoon at a rate faster than can drain out the deep western pass at low tide. The water circulation dynamics in Pikaar's lagoon appear very similar to those of Bok-ak lagoon.

Several coral and reef habitats (sites 2A, 2B, 2C) at Pikaar displayed exceptional or unique characteristics (Figs. 10, 11, A-4, and A-5). Site 2A is a deep reef flat moat to the west of the main island (Pikaar). Site 2B is a back reef environment on the windward side, and site 2L is an ocean reef slope along the leeward side of the atoll.

Comparison between 1944-based maps/aerial photographs and 1978 color aerial photographs indicate that sandy beach habitat around Pikaar Island has increased substantially during the 34 year period (Figure 15). Hence, suitable nesting habitat for sea turtles may have increased during the interval.

Fosberg (1988) reports that Pikaar showed signs of extensive change from a typhoon between 1945 and 1952 including possible loss of some of the small islets. During our visit in 1988 there was extensive damage to the Pisonia forest on Pikaar and near total destruction of it on Jobwero and Almani islands from high winds, possibly during a recent tropical storm or typhoon.

Corals of Pikaar

Ninety-three species of corals belonging to 35 genera and subgenera were reported from the surveys of Pikaar which encompassed 13 marine sites. Of interest was the presence of the purple fan coral Distichopora on ocean reef environments at Pikaar. This species was absent from Bok-ak although a related coral, Stylaster, was common. Stylaster was absent from Pikaar, suggesting that these two different species are filling the same niches in their respective atolls, occupying similar habitats. The presence of Pectinia in Pikaar's lagoon is only the second record of this coral from the Marshall Islands. Other corals present at Pikaar but absent from nearby Bok-ak include Coscinaraea and Acanthastrea. Curiously the common corals Oulophyllia and Goniopora were absent at Pikaar although present at Bok-ak. Other "missing" corals from Pikaar

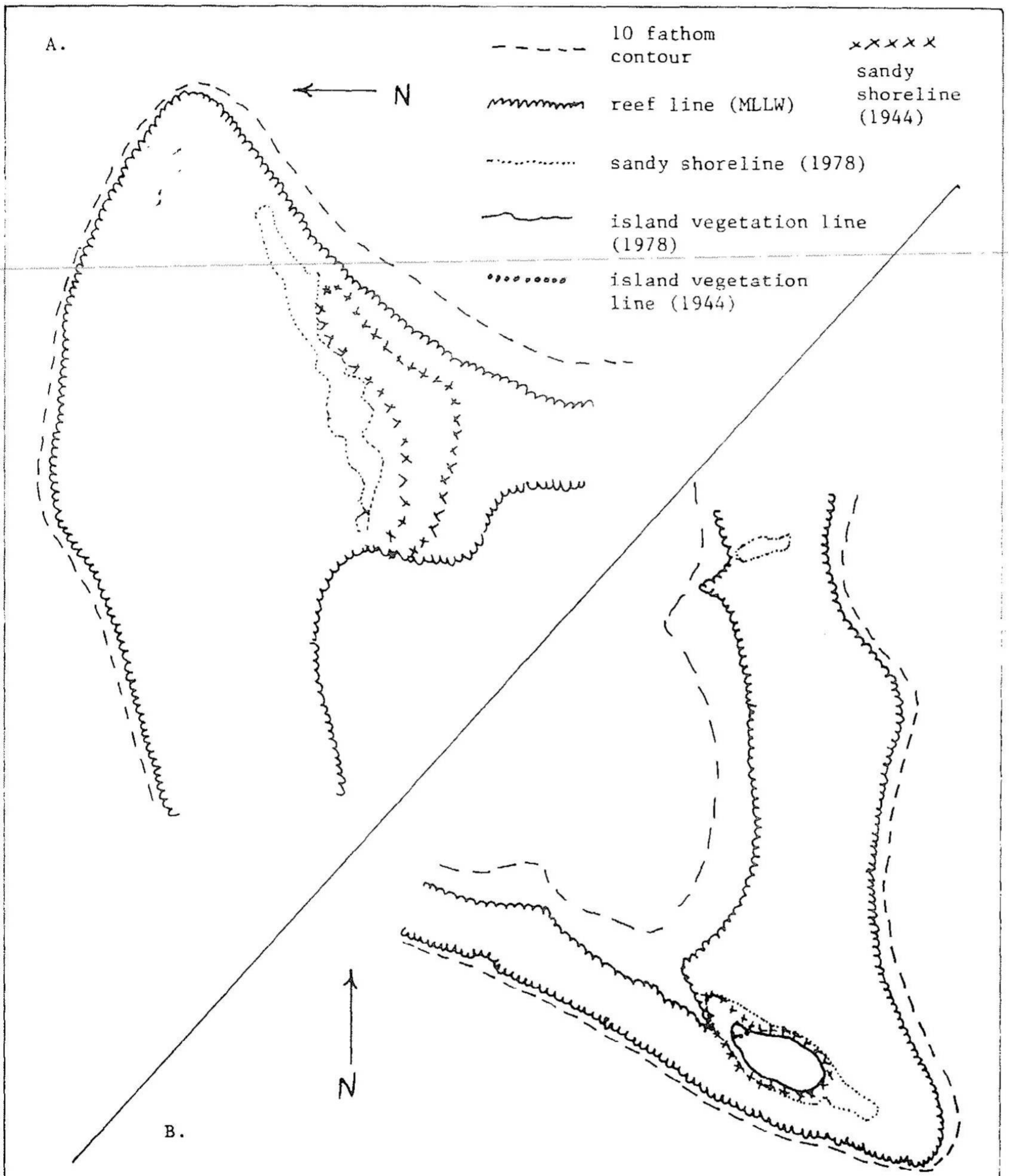


FIGURE 15. Shoreline changes between 1944 and 1978 at selected locations in the Northern Marshall Islands. A. sand cay at northeast corner of Tōke Atoll. B. Pikaar Island, southern Pikaar Atoll. Comparisons based upon U.S. Army 1944 black and white aerial photographs and E. G. & G. 1978 color aerial photographs. Scale: 1:30,000.

which are normally common reef components include Psammocora, Porites (Synaraea), Cycloseris, and Halomitra. It seems plausible that some of these and other widespread genera would have been reported from surveys conducted at more sites and in deeper water, especially along ocean facing reef slopes.

Common and abundant corals on reef flats and moat environments included the fire corals Millepora spp, the blue coral Heliopora coerulea, the corals Favia stelligera, Pocillopora spp, Pavona spp, Porites spp, Goniastrea retiformis, other Favia spp, Montipora spp, Cyphastrea spp, Astreopora spp, Leptastrea spp, Acropora spp, Seriatopora angulata, Stylophora pistillata, the soft corals Sinularia sp and Xenia sp, the free living corals Herpolitha limax and Fungia spp, the brain corals Montastrea curta and Platygyra sp, and the explanate corals Turbinaria spp and Echinopora sp.

Common and abundant corals on pinnacles and ribbon reefs included: the fingercoral Porites cylindrica, the corals Stylophora pistillata, Favia stelligera, Cyphastrea microphthalma, Acropora spp, Herpolitha limax, Millepora platyphylla, Scapophyllia cylindrica, Favites halicora, other Favia spp, Fungia spp, and Seriatopora angulata.

Common and abundant corals along ocean facing reef slopes along the leeward side of Pikaar include Pocillopora spp, Millepora spp, Acropora spp, Porites spp, Goniastrea spp, Favia spp, Montipora spp, Platygyra sp, Lobophyllia spp, Symphyllia spp, and Favites spp.

Rare Species at Pikaar

Pikaar is the most important sea turtle nesting area in the Marshall Islands. Over 264 sets of turtle nesting tracks were observed at the atoll around the perimeter of Pikaar (176), Jobwero (74), and Almani (14) islands. One set of fresh tracks was probably those of a hawksbill sea turtle while remaining tracks were of green sea turtles. One pair of green sea turtles were observed to be mating in waters offshore from Pikaar Atoll (see Thomas, 1989). Since pre-European times, the Marshallese have considered Pikaar to be a turtle and bird sanctuary (Fosberg 1988).

TŌKE ATOLL (Figures 16-21, A-6, and A-7)

At its closest point Aelon-in Tōke (also called Taka Atoll) lies only 7.3 km southwest of Utrōk (Utirik) Atoll. However, due to the position of Tōke's single deep pass along the western atoll rim, it takes about 46 km by boat to travel from the largest island of Utrōk Atoll to the largest island of Tōke Atoll (Tōke). Both atolls are roughly triangular in shape. Although Tōke has a larger lagoon area than Utrōk (94 km^2 vs. 57 km^2), the land area of Tōke is comparatively quite limited (0.57 km^2 vs 2.4 km^2). In fact, Tōke ranks only ahead of Pikaar with respect to land area for atolls in the Marshall Islands. Tōke's land area consists of five islands of which only Tōke and Allook are large enough to support permanent vegetation. One centrally located well dug at Tōke Island yielded non-potable groundwater (chlorides 440-840 ppm). Two other peripherally

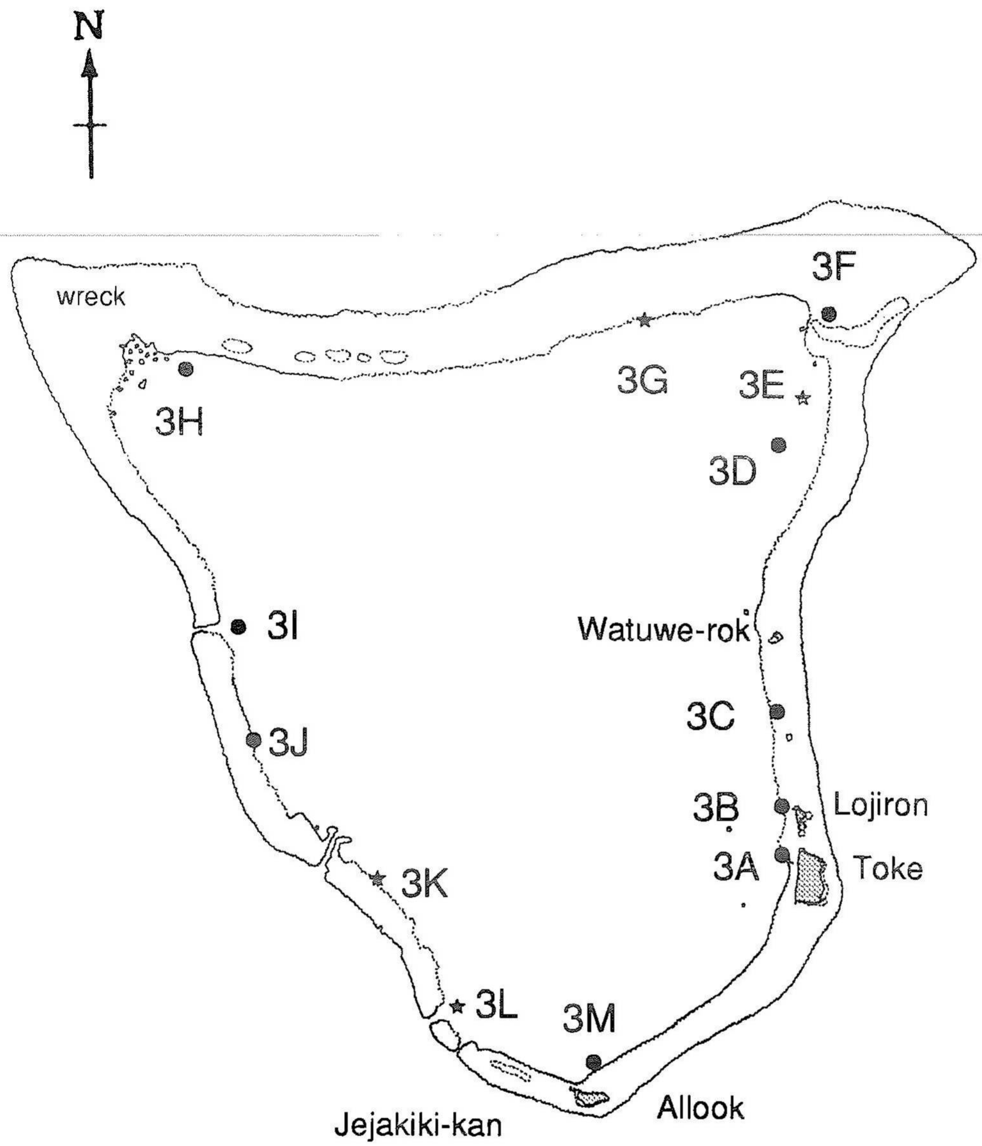


Fig 16. Toke (Taka) Atoll showing locations of marine survey sites. Stars represent reef sites of special interest. Scale: 1" = 1.970 mi.

located wells yielded very salty non-potable water (Fosberg et al 1956). Although Tōke's pass is deep and narrow, boat passage is not hazardous. Tōke's windward reefs are also afforded some protection from the upwind position of Utrōk Atoll. Storm generated boulder beaches are not well developed along Tōke Atoll's island shorelines. They are best developed along the eastern face of the southernmost island Watuwe-rok and the western (lagoon) faces of Tōke and Lojiron islands along the eastern perimeter (MacNeil, 1969). Fosberg (1988) also describes the effects of a typhoon which passed over Tōke in 1951.

Unlike the lagoons of Bok-ak and Pikaar, Tōke's lagoon is deeper (maximum reported depth of 28 fathoms or 51m) and with many soundings between 18-22 fathoms or 33-40m (Figures 16-18).

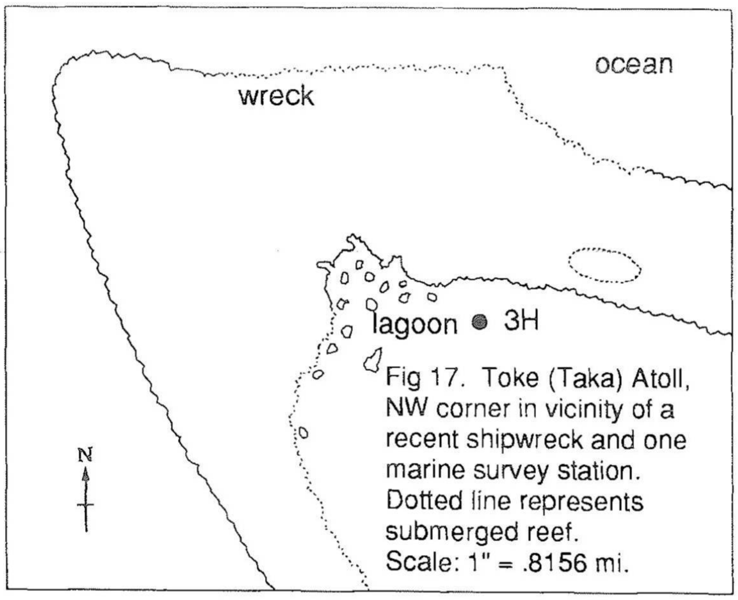


Fig 17. Toke (Taka) Atoll, NW corner in vicinity of a recent shipwreck and one marine survey station. Dotted line represents submerged reef. Scale: 1" = .8156 mi.

Tōke's lagoon has fewer pinnacles and patch reefs (less than 50 total) all of circular shape and generally concentrated in the southern half of the lagoon and near the deep western passage (Figures 16-18). Despite Utrōk's smaller size, its lagoon contains over twice as many patch and pinnacle reefs. These factors help to explain why Tōke is not permanently inhabited. Land, water, and lagoon reef resources are larger and more conveniently located on Utrōk. Fishermen from inhabited Utrōk Atoll occasionally visit Tōke to fish and to harvest shellfish and sea turtles. The land owners and managers of Tōke reside at Utrōk, but the expedition was not able to visit Utrōk because the limited field time was cut short due to an unscheduled stop at Aelon-in Kuwajleen (Kwajalein Atoll) for provisions.

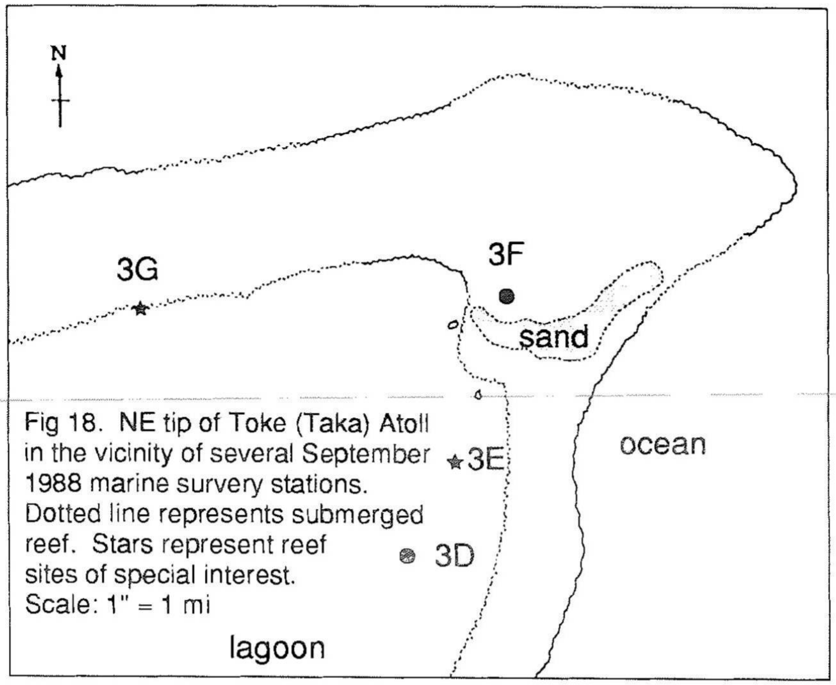


Fig 18. NE tip of Toke (Taka) Atoll in the vicinity of several September 1988 marine survery stations. Dotted line represents submerged reef. Stars represent reef sites of special interest. Scale: 1" = 1 mi

The lagoon margins of Tōke's perimeter reefs are not elevated above mean low water as is the case at Pikaar and Bok-ak atolls. Furthermore, lagoon tidal fluctuations are more closely in phase and amplitude with those on the ocean side. At the most, water levels in the lagoon at low tide were only a few inches higher than outside low tide levels. Thus, Tōke's lagoon does not have the perched or elevated lagoon reefs and water levels characterizing the other two atolls, and exchange of waters between the lagoon and ocean is more pronounced. Besides the deep passage near Tōke island with a depth of 12 fathoms (22m) and a width of over 100m (Figures 19-20), Tōke Atoll also has several other shallower passages through the western reef, three of which were visited during the 1988 surveys (sites 3I, 3J, and 3L).

Four of the 13 marine sites surveyed at Tōke displayed unique or exceptional reef characteristics. All were situated along the lagoon margins of perimeter reefs, two near the passes (sites 3K and 3L) and two in the northeast corner of the lagoon (sites 3G and 3E) where reef pinnacle and patch reef formations are slowly being buried under accumulating sand deposits washing over the reef flats from windward directions (N & E). The team was unable to visit any ocean reef slope sites at Tōke due to safety and time limitations. Observations from the ship indicate that live corals dominate the slopes of ocean facing reefs and that sharks were numerous.

One of the largest sand cays visited during the expedition occurred at the northeast corner (Figure 18) of Tōke Atoll (site 3F). Comparison between Army maps based upon 1944 aerial photographs and 1978 color aerial photographs reveal the shape and position of the sand cay has changed drastically. During the 34-year interval, the deposit elongated and shifted 200m to the north. Our sea level observations in 1988 could not determine whether additional changes had occurred since 1978. The instability of the deposit and low elevation may explain the lack of vegetation on the sand cay.

Corals of Tōke Atoll

Ninety-three species of corals belonging to 35 genera and subgenera were reported collectively from the 13 marine sites at Tōke Atoll. Of interest was the presence of Porites (Synaraea) and Sandalolitha which were absent from both Pikaar and Bok-ak. The reported absence of several common reef genera from Tōke may be attributed to the lack of observations along ocean facing reef slopes where different and more diverse coral assemblages are expected. As a result, the species diversity of corals at Tōke might be higher than observed at Pikaar and Bok-ak. The number of species reported per site was also relatively high at Tōke, and coral communities were well developed and diverse.

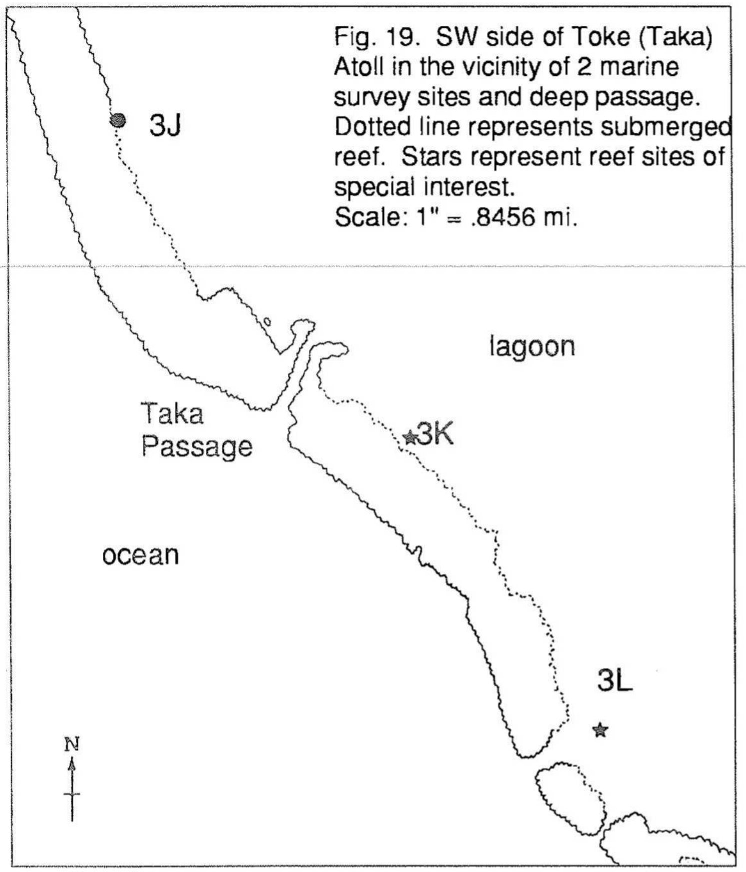


Fig. 19. SW side of Toke (Taka) Atoll in the vicinity of 2 marine survey sites and deep passage. Dotted line represents submerged reef. Stars represent reef sites of special interest.
Scale: 1" = .8456 mi.

In back reef environments along windward (eastern) reefs, the following corals were abundant or common: Acropora spp, Cyphastrea microphthalma, Pavona varians, Montastrea curta, Tubipora musica, Favia spp, Platygyra daedalea, Fungia spp, Astreopora spp, Montipora spp, Favites abdita, Pocillopora verrucosa, Sinularia sp, Porites spp, Millepora spp, Echinopora lamellosa, Turbinaria stellulata, Goniastrea spp, Heliopora coerulea, Stylophora pistillata, Psammocora profundacella, and Leptastrea purpurea.

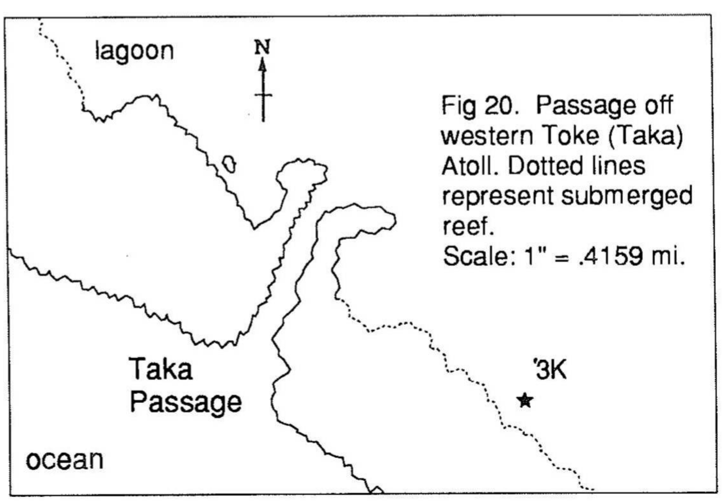


Fig 20. Passage off western Toke (Taka) Atoll. Dotted lines represent submerged reef.
Scale: 1" = .4159 mi.

Further offshore on shallow pinnacles and on the slopes of larger patch reefs the following corals were common or abundant: Porites spp (both fingercoral and massive forms), Pocillopora spp, Acropora spp, Montipora spp, Fungia spp, Goniopora lobata, Astreopora spp, Pavona spp, Tubipora musica, Coscinaraea columna, Oulophyllia crispa, Leptastrea purpurea, Seriatopora spp, Lobophyllia hemprichii, Millepora platyphylla, Stylophora pistillata, Stylocoeniella armata, Goniastrea spp, Cyphastrea microphthalma, Favia spp, Porites (Synaraea) rus, Montastrea curta, Psammocora profundacella, Echinopora lamellosa, Herpolitha limax, Leptoseris mycetoseroides, Heliopora coerulea, Scapophyllia cylindrica, Turbinaria stellulata and Favites russelli.

Rare Marine Species

Evidence of green sea turtle nesting activity was observed along the shorelines of Tōke Island (16 sets of tracks), Lojiron Island (4 sets of tracks), and Allook Island (4 sets of tracks) (Figure 21). Of the seven areas visited Tōke Atoll ranks fourth behind Pikaar, Jemo̧, and Ãdkup with respect to the level of sea turtle nesting evidence. The only sighting of a Hawksbill sea turtle during the expedition was off the NE sand cay at Tōke (site 3F). It was observed to be feeding and swimming at a depth of 2-3m off the bottom.

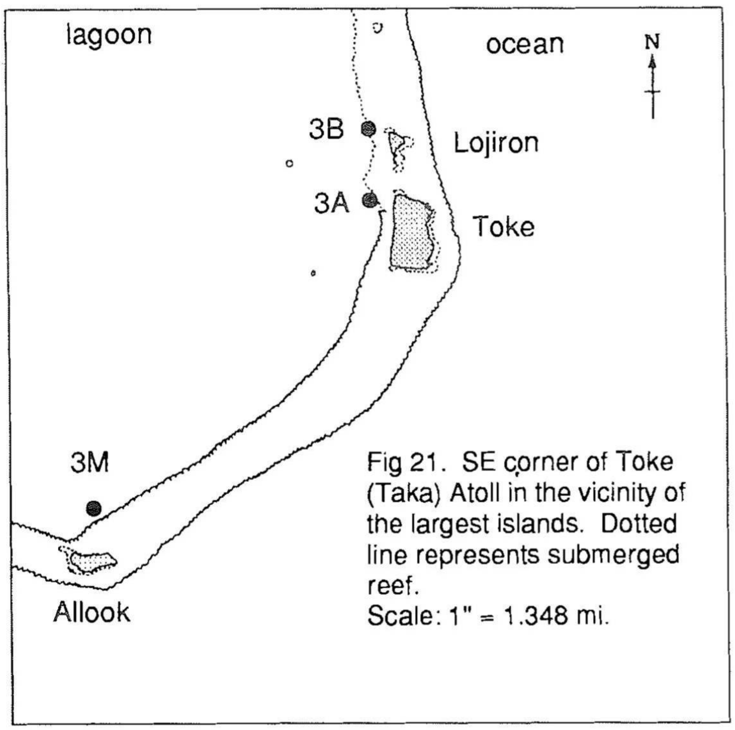


Fig 21. SE corner of Toke (Taka) Atoll in the vicinity of the largest islands. Dotted line represents submerged reef.
Scale: 1" = 1.348 mi.

Tōke Atoll was the first in which live specimens of the rare giant clam, Tridacna gigas were observed, primarily in shallow lagoon environments near islands or back reefs. However, there were many more dead shells of the species observed on the reefs (only 5 of 24 were alive). Live individuals of the smaller species were present but in smaller numbers than reported for Pikaar and Bokak. It was reported by islanders from Mājro (Majuro) and Wōtto that overseas fishermen illegally poach live individuals of T. gigas to obtain the abductor muscles which fetch high prices in Asian markets. Evidence obtained during our surveys suggest that uninhabited Tōke Atoll may be an inviting target for illegal poaching of the rare giant clam Tridacna gigas. Interviews with the residents of Utrōk might shed additional light on the extent of traditional harvesting and illegal poaching of giant clams at Tōke Atoll.

WŌTTO ATOLL (Figures 22-25, A-9, and A-10)

Originally, uninhabited Ailinginae Atoll was to be visited during the expedition. However, the failure to obtain approval to visit the atoll, and a subsequent invitation extended by the leaders of Wōtto Atoll, led the expedition to visit Wōtto instead of Ailinginae on 18-19 September 1988. Aelon-in Wōtto (also referred to as Wotho Atoll) is the only inhabited atoll surveyed during the 1988 expedition, and is only one of two atolls visited within the Ralik (western or "sunset") chain of the Marshalls. Wōtto is relatively small in terms of lagoon area and is located within the dryer belt of the RMI. However, land area is greater (4.2 km^2), the most of any of the seven areas visited during the 1988 expedition (Figures 22-23). Of the 22 inhabited atolls in the Marshalls though, Wōtto ranks only ahead of Utrōk (Utirik) and Namdik (Namorik) in terms of land area.

Its population is about 100, the smallest of any inhabited atoll, and ranks ahead of only Jabat and Lib which are inhabited table reefs. Of the 18 islands at Wōtto, only the largest (Wōtto) is occupied (Figure 24). The atoll, including its islands, reefs, and village setting, is very scenic, relatively undisturbed, and harbors considerable natural and cultural diversity. Apparently, large land areas were never cleared and planted to coconuts (Fosberg et al, 1956). The nearest atolls to Wōtto are Kuwajleen (Kwajalein) to the southeast; Ujae to the south; Bikini to the north; and Ailinginae, Roñlap (Rongelap), and Roñdik (Rongerik) to the northeast. Due to the clustering of several large atolls in the vicinity of Wōtto, only the atoll's southwest quadrant is considered vulnerable or exposed to heavy open ocean seas.

Wōtto Atoll is roughly triangular in shape with the widest reefs and the largest islands situated at the apexes. Wōtto Island, the atoll's largest, is at the NE tip of the atoll. The longest axis is the southwest facing side of the atoll, some 20 km between Majur-wor Island at the NW tip and Kapen Island (Figure 25) at the south. Most of the SW facing axis consists of several wide but shallow passages between smaller clusters of shallow reefs. The main navigational passage occurs just north of Pik-en Island near the northwest end of the axis. The three islets along the SW axis, Pik-en, Anbwil-en, and Ane-aidik are very small. The rest of Wōtto Atolls perimeter reefs along the N and E facing axes are shallow and contain numerous islands and cays. The largest sand dune reported by MacNeil (1969) in the northern Marshalls occurred along the lagoon side of Ane-aidik Island, Wōtto Atoll.

The three largest islands also display large boulder beaches and concentrations of strewn boulders most likely tossed up on the reefs during storms. The boulder beaches face seaward to the north on the two large northern islands (Majur-wor and Wōtto) and face seaward to the south off the southern islands of Kapen and Ane-jaito. A small boulder beach also occurs on the north side of Kapen Island.

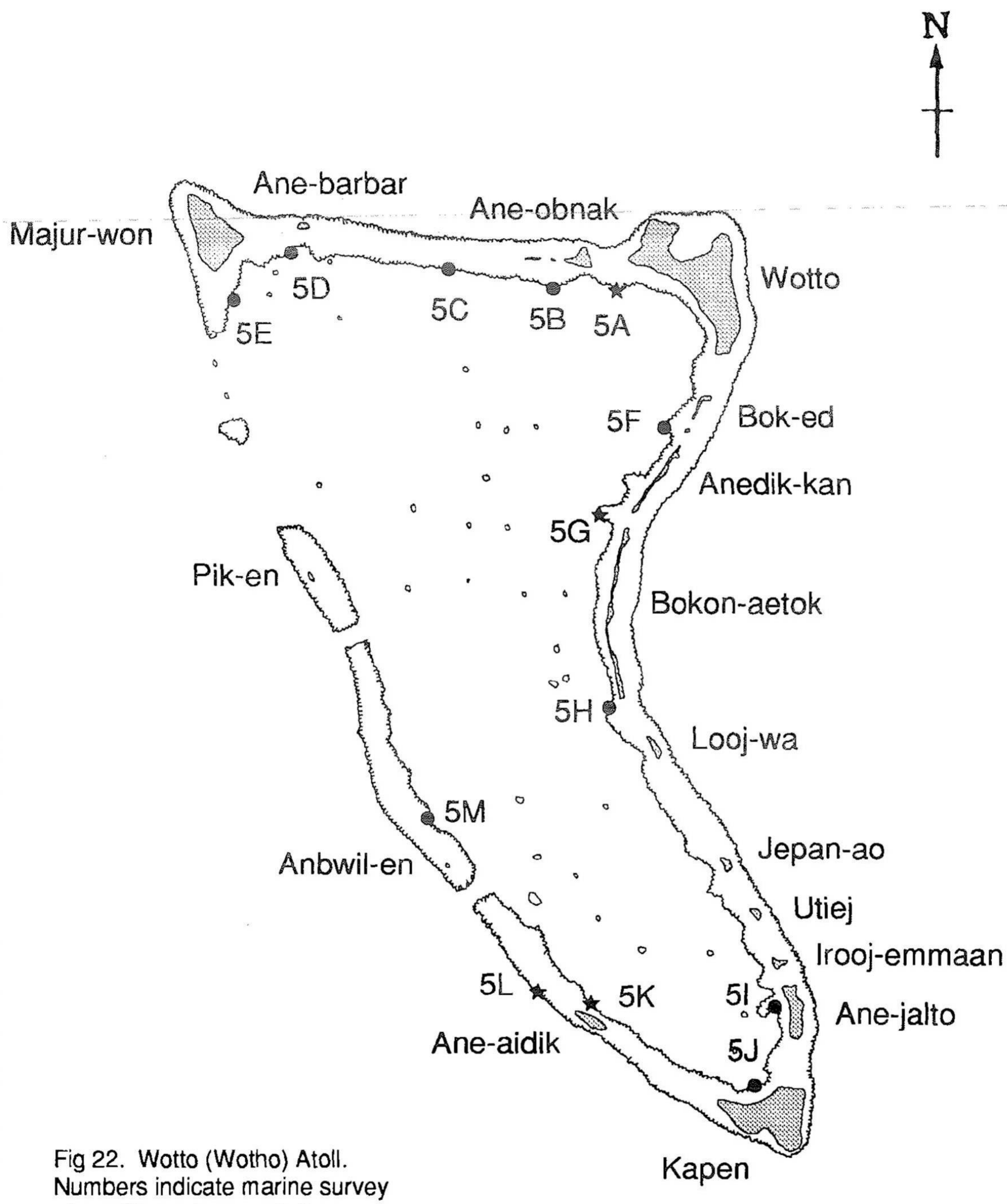
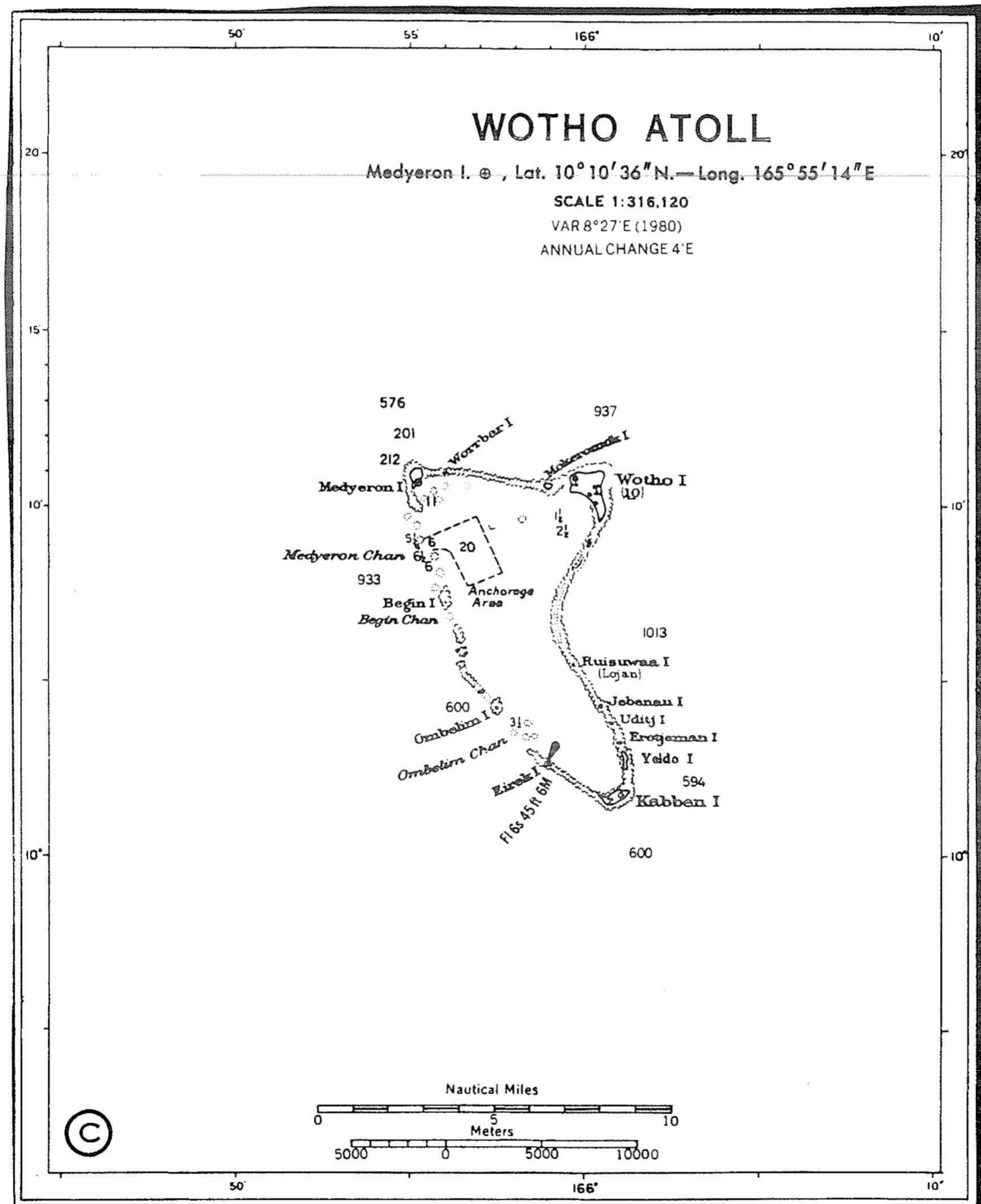


Fig 22. Wotto (Wotho) Atoll.
Numbers indicate marine survey
sites. Stars show reef sites
of special interest.
Scale: 1" = 2.058 mi.

Figure 23 . Defense Mapping Agency Chart of Wotto (Wotho) Atoll.
Scale 1:316,120. Soundings in fathoms.



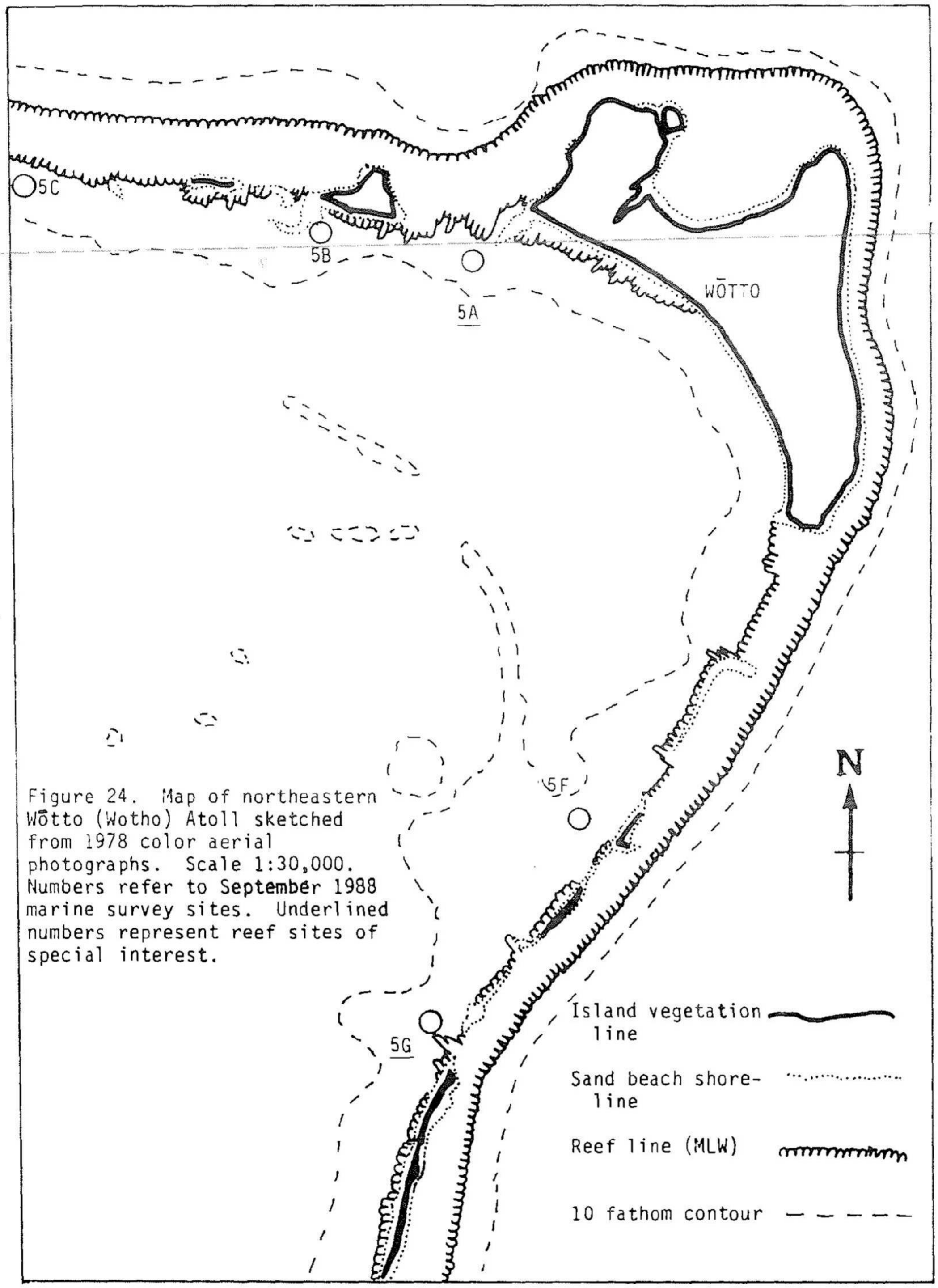
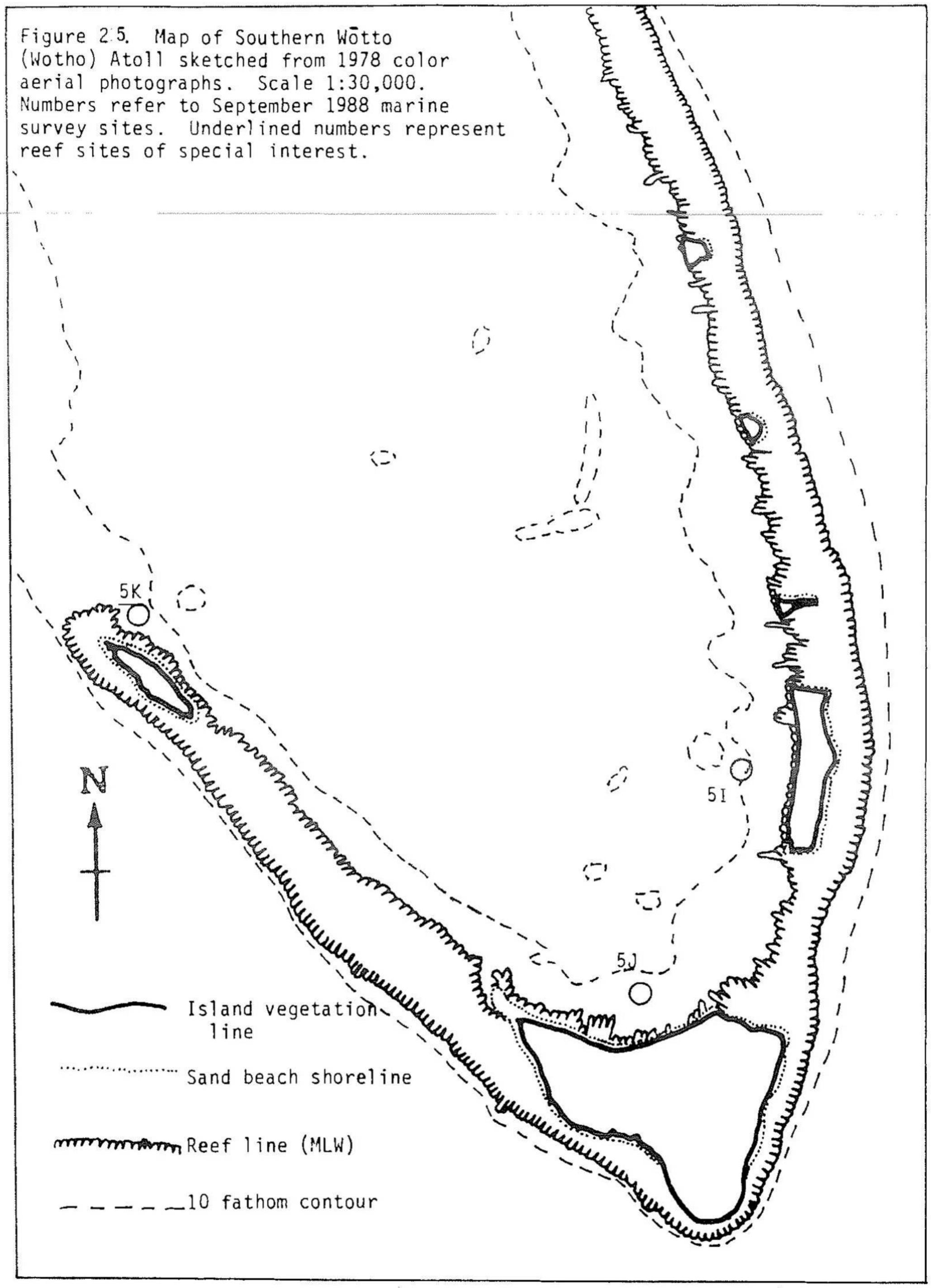


Figure 24. Map of northeastern Wōtto (Wotho) Atoll sketched from 1978 color aerial photographs. Scale 1:30,000. Numbers refer to September 1988 marine survey sites. Underlined numbers represent reef sites of special interest.

Figure 2.5. Map of Southern Wōtto (Wotho) Atoll sketched from 1978 color aerial photographs. Scale 1:30,000. Numbers refer to September 1988 marine survey sites. Underlined numbers represent reef sites of special interest.



Patch reefs are not numerous in Wōtto's lagoon and consist of three small clusters. One cluster off Kapen island in the south lagoon includes five reefs. A second cluster of seven reefs occurs in the south central lagoon east of Anbwil-en Island. The third and largest cluster of 10 reefs in the north central lagoon occurs east of Pik-en Island. Our limited time at Wōtto did not permit field visits to patch reefs in the deeper lagoon.

There is very little easily available information about the depths and bathymetry of Wōtto's lagoon. The only published soundings (Figure 22-23) show depths of at least 20 fathoms (37m) in the lagoon anchorage east of the main navigation channel which shows a depth of 6 to 6-1/2 fathoms (11-12m). The channel south of Anbwil-en Island shows a depth of 3-1/2 fathoms (6.4m). Some lagoon areas closest to Wōtto Island may be shallow, with published depths of 1-1/2 to 2-1/2 fathoms(3-4.6m). Inspection of 1978 color aerial photographs of Wōtto indicate that most of the lagoon appears deep and in excess of 10 fathoms (18m) and probably close to 20 fathoms (37m) or more. Thirteen field sites were visited at Wōtto, all along perimeter reefs (Figure 22). Only site 5L was on the ocean side of the reef.

Limited time did not permit more than cursory observations of water current and circulation patterns at Wōtto Atoll. During late afternoon fieldwork on 19 September 1988 on the shallow pass area between Ane-aidik and Anbwil-en islands (site 5L), a strong 2 kt current coinciding with rising tide was flowing north through the channel and into the lagoon. The depth of the top of reef varied from 2-3m. Wōtto's lagoon appears to be well flushed, based upon an analysis of the configuration of Wōtto's reefs and the presence of wave action along the ocean sides of the north and eastern reefs. The wave action continually pumps fresh ocean waters into the lagoon from the windward (NE) sides during essentially all stages of the tide. This cooler water probably sinks to the bottom of the lagoon displacing less dense water which exits the lagoon over the western reef during ebbing tides. As noted during our limited field observations flood tide currents are strong and ebb tide currents are expected to be strong if not stronger. Although the western passes are shallow, their great width enhances the exchange of lagoon and ocean waters during tidal fluctuations.

Corals of Wōtto

A total of 88 species belonging to 36 genera and subgenera were reported from Wōtto based upon surveys at 13 sites. However, time was very limited at several stations where observations were hampered by low light conditions during a cloudy late afternoon. In general, coral communities were diverse and in good health. Genera reported at Wōtto which were not observed elsewhere during the expedition were Cycloseris, Halomitra, and Polyphyllia, all being free living mushroom corals. The last (Polyphyllia) is a new generic record from the Marshall Islands. A few common coral genera should have been reported but were not and include: Psammocora, Lobophyllia, Hydnophora, and Echinopora. More extensive surveys on ocean facing reefs might have yielded some of these genera as well as others.

Four of the 13 stations surveyed displayed unique or exceptional characteristics worthy of some mention. Three of these were lagoon reef slope habitats (sites 5A, 5G, and 5K) and all supported live individuals of the rare giant clam Tridacna gigas. Three of the sites (except 5G) had high live coral coverage of 60% or more. The single ocean facing reef slope site surveyed showed spectacular relief and well developed coral communities (site 5C), but numerous sharks and strong currents hampered the collection of additional information. The slope was characterized by a series of large coral canyons with flat scoured floors.

Abundant and common corals on the ocean reef slope site were Millepora platyphylla, corymbose and table coral species of Acropora, Pocillopora spp, Turbinaria stellulata, Porites lobata, Montipora spp, Stylohora pistillata, Platygyra pini, Favia spp, Favites spp, Pavona minuta, Acropora palifera and Pavona spp.

Corals on a deep pinnacle along the western perimeter reef (site 5M) included Acropora spp, Millepora spp, Stylophora pistillata, Pavona minuta, Pocillopora meandrina and Montipora aequituberculata.

Abundant and common corals along the sheltered lagoon slopes (sites 5A-5K) of perimeter reefs included: Seriatopora hystrix, Acropora (many species), Astreopora spp, Stylophora pistillata, Millepora exaesa, Fungia spp, Porites spp, Montipora spp, Oulophyllia crispa, Goniastrea retiformis, Pavona spp, Pocillopora spp, Scapophyllia cylindrica, Acropora palifera, the blue coral Heliopora coerulea, Favia spp, Platygyra spp, Porites (Synaraea) rus, Coscinaraea columna, Herpolitha limax, and Cyphastrea sp.

Rare Marine Species

Giant clams of several species were reported from Wōtto including the most living specimens (15) of the largest and rarest species, Tridacna gigas. Some individuals were very large, and Wōtto was the only area where living specimens approached the numbers of dead shells of the largest species (15 vs. 16). Interviews with the islanders revealed the Taiwanese fishermen visited Wōtto "about six or eight years ago" to seek permission to harvest T. gigas. After it was granted, the fishermen proceeded to harvest many clams but taking only the abductor muscle and leaving the dead shells and remaining tissue "to rot in the sun." This experience seemed to have shocked the islanders and made them more conscious of the need to protect remaining giant clams. No doubt the presence of the islanders discourages further harvesting. Despite recording the highest number of living Tridacna gigas at Wōtto Atoll, it is important to note that the ratio of dead to live clams is still relatively high despite a hiatus on harvesting the species over a period of six to eight years. This fact points to the vulnerability of such a population to overexploitation, even from occasional or one-time harvests (Thomas 1989).

The smaller giant clam species are preferred by the islanders for consumption; for one, they are easier to collect and shuck. Although all common species of giant clams were observed on Wōtto's reefs, the smaller species seemed less numerous than reported at Pikaar, Bok-ak, and perhaps Tōke.

Green turtles nest at Wōtto but only in low numbers. The most pairs of tracks (4) were spotted on the beaches of Pik-en, (Figure 22), with two pairs of tracks observed at Long Island (Bokon-aetok) and two pairs at Kapen Island (Figure 25). During the night of 18 September 1988, the ship's crew captured a female Green sea turtle after it had laid its eggs on Long Island, and gave it to the villagers. The Wōtto islanders harvest the turtles only infrequently for special or ceremonial occasions, usually during the summer months off the beaches of uninhabited islands. The villagers seem very conscious of the vulnerability of the nesting turtle population and limit their harvesting practices accordingly (Thomas, 1989).

Coconut crabs are heavily harvested by the islanders, primarily at Kapen Island, and approximately 500 crabs per year are captured and consumed locally. The average size of the crabs during our visit was about 0.5 kg, somewhat smaller than those observed at Rondik. Harvesting pressure on coconut crabs at Wōtto could be higher except that a fuel shortage during most of 1988 prevented small boat travel and access to outer islands including Kapen.

ROÑDIK ATOLL (Figures 26-30, A-11 and A-12)

Aelon-in Roñdik (previously referred to as Rongerik Atoll) is moderately sized and is located just east of Roñlap (Rongelap) and Ailinginae, northeast of Wōtto, north of Kuwajleen (Kwajalein), west of Tōke and Utrōk, and northwest of Jemo̧ and Likiep. It is generally afforded some protection from storms and large waves by the positions of these atolls. However, Roñdik is exposed to open sea conditions from the north. Roñdik is roughly circular in outline, has the second largest lagoon area (145 km^2) and the third largest land area (0.81 sq. mil) of the six atolls and one table reef visited in September 1988. All but one (Bok) of its 17 islands are located along the eastern perimeter of the atoll (Figure 26).

Roñdik's lagoon is very open with major gaps in the perimeter reefs along the northwest and west sectors. The navigation chart of Roñdik shows several major navigable passes: Jetep̄tep and an unnamed passage to the north, Bok Passage to the west, and Enewetak Pass (Āne-wetak) to the south (Figures 27-28). Bok Passage is over three miles wide, and together with the lack of islands and shallow reefs along the west rim, renders the lagoon and lagoon shorelines of islands facing to the southwest exposed to heavy wave action.

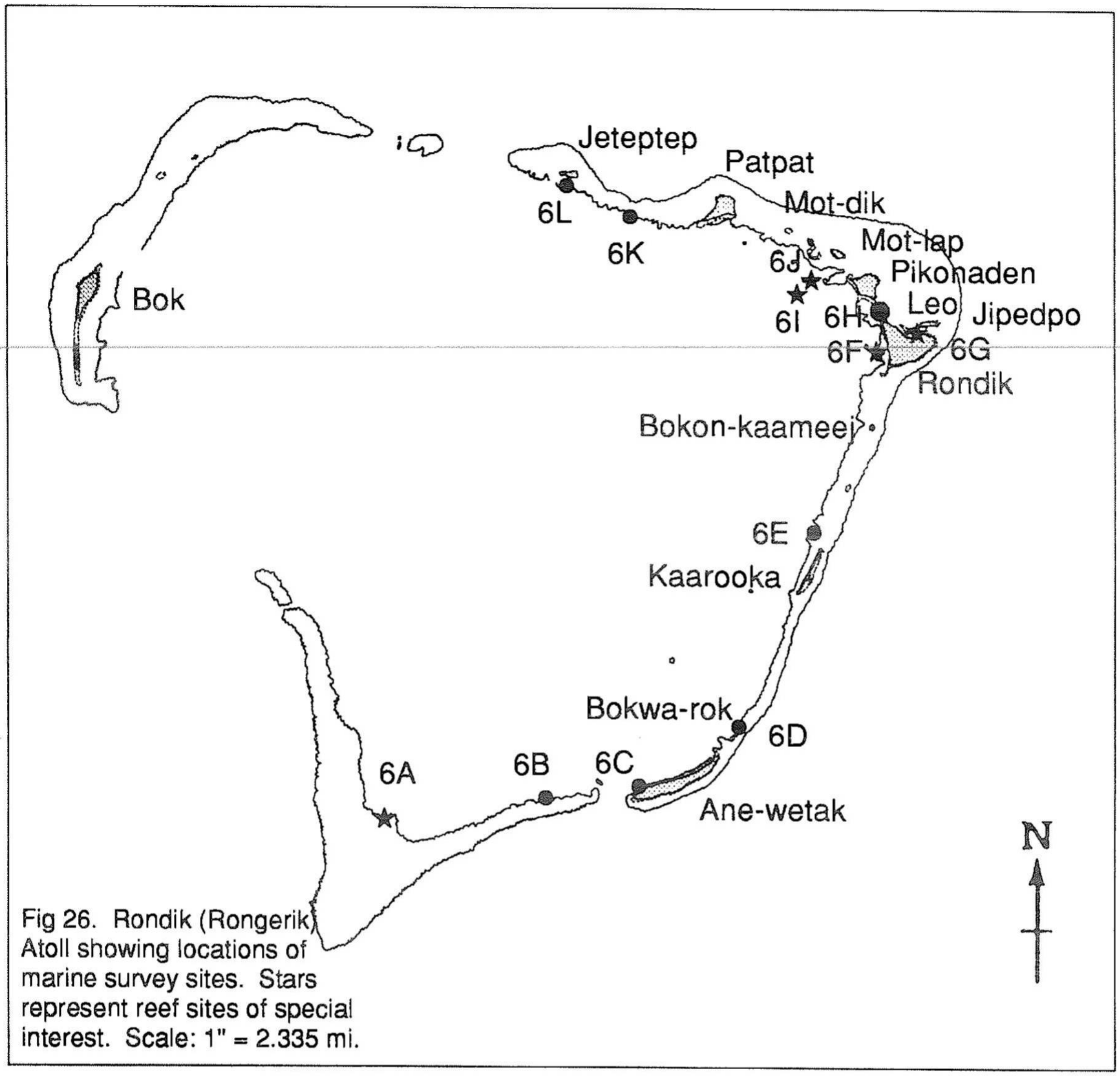


Fig 26. Rondik (Rongerik) Atoll showing locations of marine survey sites. Stars represent reef sites of special interest. Scale: 1" = 2.335 mi.

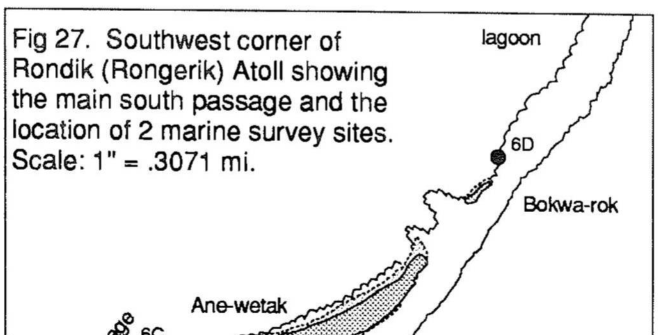


Fig 27. Southwest corner of Rondik (Rongerik) Atoll showing the main south passage and the location of 2 marine survey sites. Scale: 1" = .3071 mi.

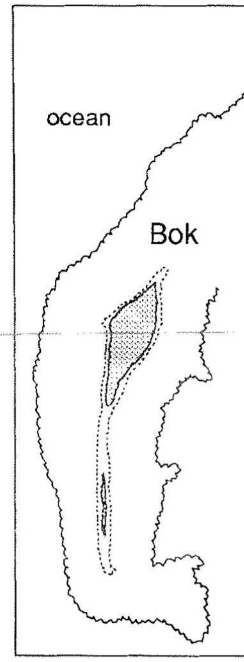


Fig 28. Western end of Rondik (Rongerik) Atoll showing Bok Island. Although this region was not visited during the 1988 survey, Bok is a suspected turtle nesting site. Scale: 1" = .9625 mi.

It is interesting to note that the shorelines of several islands and sand cays along the northeast rim of the atoll have undergone considerable change between 1944 and 1978 comparing earlier and later sets of aerial photographs. The island of Roñdik shows minor accretion of the beach and vegetation along the SW facing lagoon shoreline. However, the W tip of Roñdik, the lagoon shorelines of two large islands (Patpat and Pikonaden), and several sand cays between the islands have undergone beach erosion and some receding of the vegetation line, especially along W and SW facing shorelines. Perhaps large waves or storms traversing the lagoon from the exposed W and SW directions were responsible for these shoreline modifications. Elsewhere on the atoll, beach and vegetation lines along the shorelines of islands have remained unchanged. The lagoon side of Āne-wetak Island has an unusually high sand dune (Fosberg, et al, 1956). According to Fosberg (1988) the island was also much disturbed by construction of a radio station involving bulldozing a strip across the center and a road along the length of the seaward coast prior to 1956 (Figure 28).

Roñdik's lagoon is fairly deep (maximum reported sounding of 28 fathoms or 51m) with many pinnacles and patch reefs which breach the sea surface. Most shallow lagoon reefs are patch reefs, circular or eliptical in shape and located in the eastern and central lagoon. Primarily deeper lagoon pinnacles are found in the western lagoon and are not as numerous or spatially dense. No soundings or bathymetric data are presented for the north and southwest extremities of the lagoon.

The survey of Roñdik was cut short due to a sudden medical emergency and the need to transport a sick seaman to the nearest hospital on Epja (Ebeye) island at Kuwajleen (Kwajalein) Atoll. As a consequence, the western half of the atoll was not surveyed including Bok (Bock) island and the extensive reef and lagoon areas to the NW and SW of it. Small boat travel in the open lagoon was more turbulent the further away from the upwind (NE) reefs, and most of the 12 marine survey sites were within the lagoon shelter of the NE perimeter reef between Āne-wetak (Eniwetak) and Jeteptep islands.

Six of the 12 marine survey sites demonstrated unique or exceptional natural characteristics worthy of mention (sites 6F, 6G, 6I, 6J, 6K, and 6A) and of possible conservation importance (Figure 30). Site 6A was a shallow downwind lagoon reef

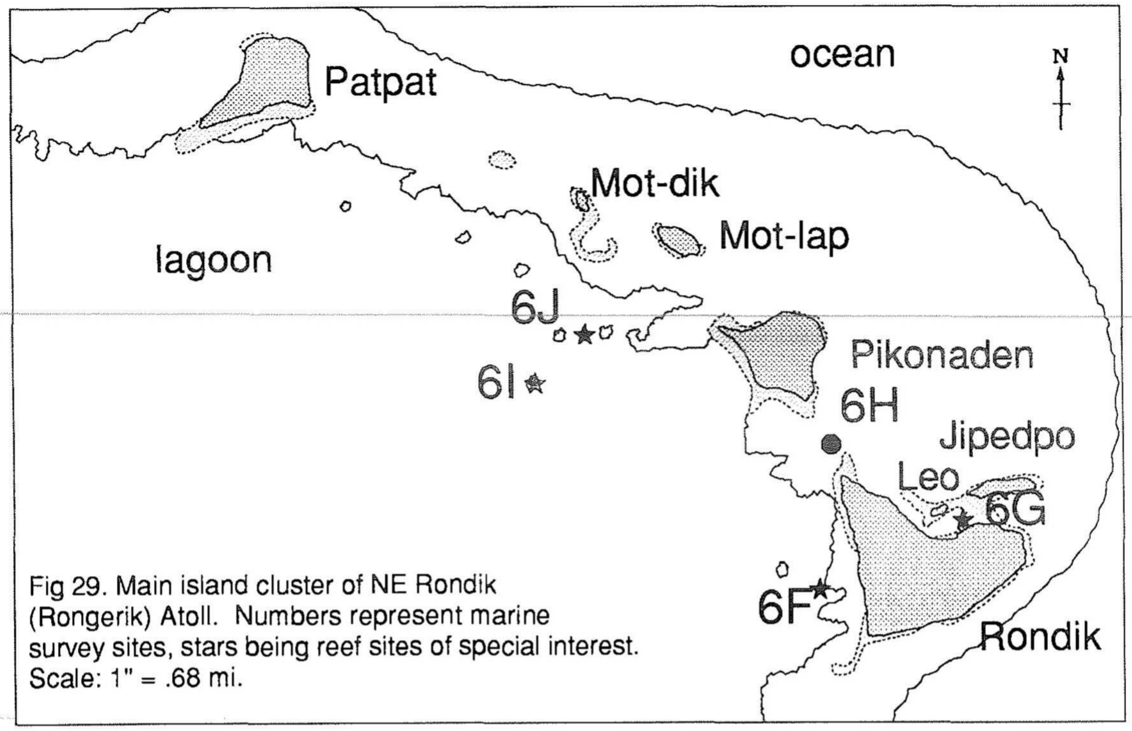


Fig 29. Main island cluster of NE Rondik (Rongerik) Atoll. Numbers represent marine survey sites, stars being reef sites of special interest. Scale: 1" = .68 mi.

complex with table corals and gigantic spectacular colonies of the yellow foliaceous coral Turbinaria. Site 6F was a shallow lagoon reef adjacent to Roñdik island with exceptional coral diversity. Also one live but six dead Tridacna gigas giant clams were reported there. Site 6G was a spectacular deep reef flat moat environment on the windward side of Roñdik dominated by extensive platforms and microatolls of the blue coral Heliopora coerulea. The high development of blue coral was unique and is probably maintained by wave-generated water currents which constantly flush clean ocean water through the moat system. Site 6I was the only deeper lagoon pinnacle reef surveyed and contained very high coral abundance (over 90% live coral coverage) and diversity of reef fishes. Sharks, however, were numerous and aggressive, preventing more detailed listing of corals. Sites 6J and 6K were shallow lagoon pinnacle habitats near the NE perimeter reef with fairly high coral coverage and very high coral diversity. The blue coral back reef zone of site 6K was exceptional, and underwater visibility and relief were also excellent.

The expansive pink sand beaches of the NE islands of Roñdik atoll are also worthy of mention. The beaches are formed primarily of the remains of pink foraminiferal tests. Although foraminiferal sand beaches are commonly observed in the Marshalls, their extensive development and coloration at Roñdik added substantially to the natural beauty and aesthetics of the atoll's island ecosystems.

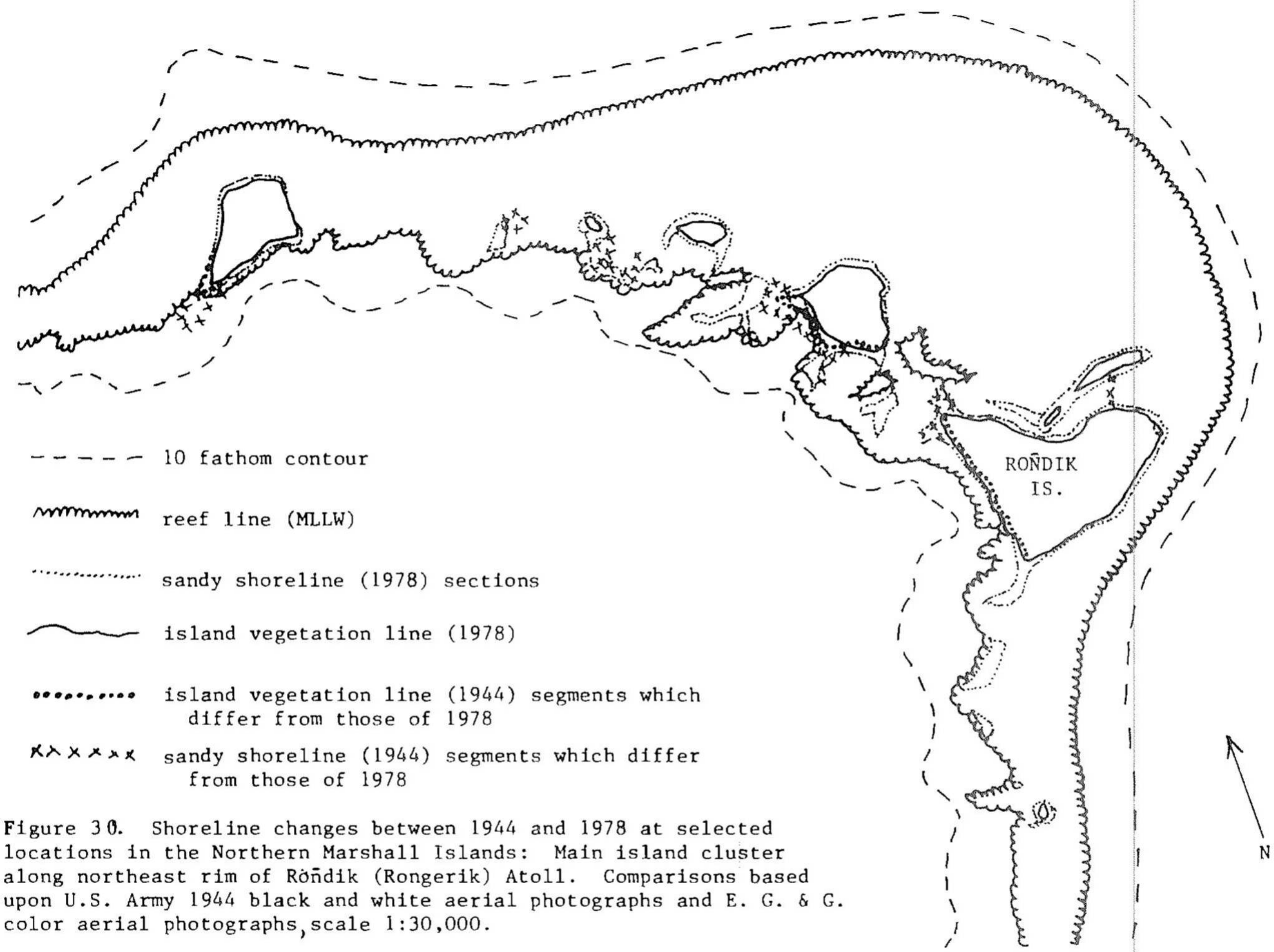


Figure 30. Shoreline changes between 1944 and 1978 at selected locations in the Northern Marshall Islands: Main island cluster along northeast rim of Rōn̄dik (Rongerik) Atoll. Comparisons based upon U.S. Army 1944 black and white aerial photographs and E. G. & G. color aerial photographs, scale 1:30,000.

Rare Marine Species

Evidence of substantial recent sea turtle nesting was observed along the lagoon beaches of Āne-wetak (Eniwetak) island. A total of 33 pairs of tracks were observed along Āne-wetak and one additional pair was observed on Kaarooka island.

A school of large bottlenose dolphins was seen swimming outside the reef on the ocean side. Although bottlenose dolphins are common throughout the tropical Pacific, marine mammals were observed only on this occasion during the 1988 expedition. There is no obvious explanation for this curious lack of sightings of marine mammals elsewhere during the northern Marshalls expedition.

The several smaller species and the rare larger species of giant clams were present at Rondik but not common. Only four live individuals compared to 16 dead shells of Tridacna gigas were observed on the reefs, suggesting heavy collection during the recent past. Except during a brief period in 1946-1948, when Roñdik was inhabited by the displaced Bikinians, there are no other known periods of occupation of Roñdik during the recent historical past. Hence the high mortality of giant clams may be best explained as the consequence of unauthorized (and unobserved) poaching.

The largest concentration of coconut crabs observed during the expedition was reported from Roñdik islet. Other large islands at Roñdik Atoll may also harbor large coconut crab populations, but only Roñdik and Āne-wetak islands are said to be planted in coconuts (Fosberg et al, 1956). Not only were the crabs very numerous, but many individuals were large, exceeding two to three kg in weight. In a few hours time, several of the ships crew were able to collect over 100 crabs without much effort, all of which were 0.5 kg or more in weight.

The large population of coconut crabs at Roñdik is best explained by infrequent harvesting pressure by islanders (since Roñdik is uninhabited), and the abundance of coconut trees. Coconuts are the preferred food of the crabs. Although coconut crab is a favorite delicacy of the Marshallese and other Pacific islanders, crab populations at Roñdik atoll may be contaminated with radionuclides.

In 1954, the U.S. accomplished BRAVO, the atmospheric testing of a large thermonuclear device (H-Bomb) at Bikini Atoll, some 230 km west of Roñdik. Due to unanticipated adverse (westerly) wind conditions and higher than expected energy yields from the detonation, radioactive fallout from the BRAVO blast penetrated the upper atmosphere and drifted east. Fallout from BRAVO was observed to contaminate Bikini, Roñlap (Rongelap) and Utrōk (Utirik) Atolls and may have contaminated other nearby atolls, some of which are uninhabited. Roñdik lies on a direct line between the contaminated atolls of Utrōk and Roñlap, and thus it is likely to have been contaminated by fallout from BRAVO. Radiological studies at Āne-wetak (Eniwetak) and Bikini Atolls reveal that the radionuclides cesium-137 and strontium-90 are taken up and concentrated in the tissues of coconut trees and nuts. The consumption of contaminated coconuts was probably the most likely pathway explaining how returning Bikinians received excessive dosage of these radionuclides during their aborted resettlement during the 1970's (see BARC, 1985; 1986; USACE, 1986). Coconut crabs can also become contaminated by eating contaminated nuts, and in turn humans can become exposed to the radionuclides by consuming effected coconut crabs or nuts. Although there has not been radiological surveys of the trees and crabs of Roñdik Atoll, the consumption of these foods poses a potentially serious health risk, especially since the coconut crab population is very large and since the crabs are a favored delicacy, in great demand.

Comparison of 1944 and 1978 shoreline configurations for NE Roñdik Atoll did not reveal significant changes (Figure 30).

Corals of Roñdik

Only 74 species belonging to 29 genera and subgenera of corals were reported from Roñdik Atoll based upon the results of visits to 12 marine survey sites. These numbers reflect lower levels and diversity of sampling at Roñdik compared to the other atolls. Only one lagoon pinnacle and no ocean reef sites were surveyed, and survey time at the most northerly sites were shortened due to the need to leave Roñdik earlier than planned due to a medical emergency. The entire western lagoon of the atoll was also left unsurveyed.

Many common coral species were not observed at Roñdik, including Stylocoeniella, Porites (Synaraea), Psammocora, Hydnophora and Leptoria. Most of these would be expected on ocean reef slopes if they could have been examined. Underrepresented during the survey were several genera and species of common free living mushroom corals. Of interest was the recording of Plesiastrea versipora at Roñdik, the only atoll where this coral was reported during the 1988 study.

Abundant and common corals on lagoon pinnacle reef environments included: Acropora spp (table and staghorn coral), Pavona spp, Stylophora pistillata, Montastrea curta, Pocillopora spp, Cyphastrea spp, Astreopora spp, Montipora spp, the blue coral Heliopora coerulea, Porites spp, the leafy yellow coral Turbinaria, the fire corals Millepora spp, Fungia spp, and Seriatopora hystrix.

Abundant and common corals along the windward (NE) lagoon perimeter reef slopes included: Heliopora coerulea, Acropora spp, Goniastrea retiformis, Fungia scutaria, Astreopora spp, Pavona minuta, Stylophora pistillata, the conspicuous table coral Acropora cytherea, Porites spp, Montipora spp, Leptastrea spp, Millepora spp, Montastrea curta, Favia spp, Pavona minuta, Turbinaria stellulata, Platygyra daedalea, Pocillopora spp, Goniastrea retiformis, Favites spp, the fingercoral Porites cylindrica, Seriatopora spp, the soft coral Sinularia sp, Cyphastrea spp, and the organ pipe coral Tubipora musica.

Abundant and common corals within blue coral dominated reef moat and back reef flat environments included: Heliopora coerulea, Stylophora pistillata, Seriatopora hystrix,

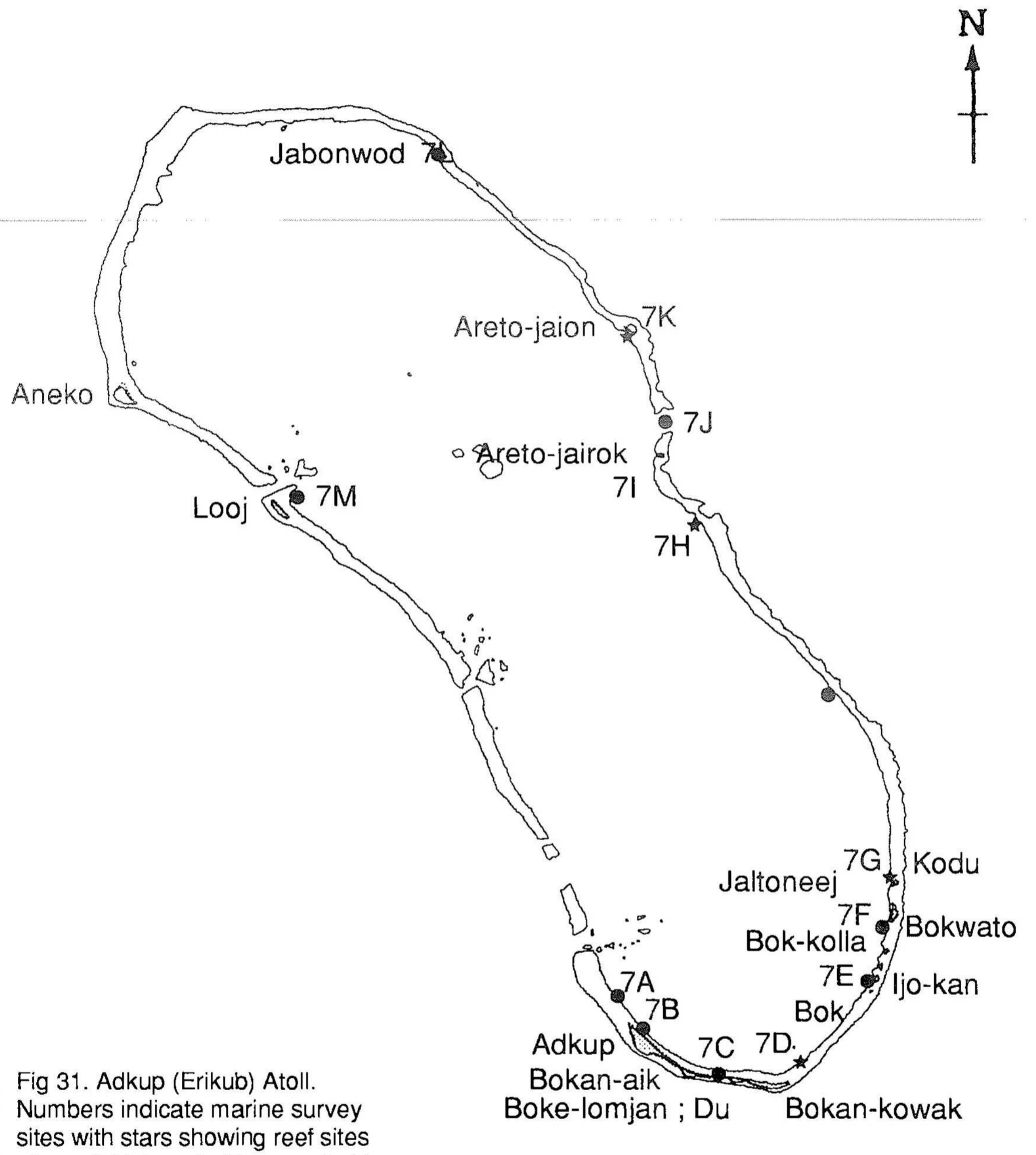


Fig 31. Adkup (Erikub) Atoll. Numbers indicate marine survey sites with stars showing reef sites of special interest. Map created by CORIAL using MARIS.
Scale: 1"= 3.146 mi.

Pocillopora damicornis, Acropora palifera, Porites spp, and Leptastrea purpurea. Giant clams were abundant in these environments and along the slopes of perimeter reefs, but most were dead and some stacked in piles - clear evidence of unauthorized poaching. Nurse sharks (a harmless species) were also numerous.

ĀDKUP ATOLL (Figures 31-37; A-13, and A-14)

Aelon-in Ādkup (also referred to as Erikub Atoll) has the form of an ellipse with its long axis (about 27 km long) facing NE and SW (Figure 31). It is the largest and most southerly of the atolls visited during the 1988 expedition. In comparison to the rest of the Marshall Islands, Ādkup is centrally located and of intermediate size in terms of lagoon surface area (232 km^2), ranking 15th of 28 atolls. In terms of land area (1.53 km^2) however, Ādkup ranks much lower, 25th, and even the table reef of Mejit has more island area. Due to its lower latitude, Ādkup probably experiences a greater average annual rainfall rate than the other six areas visited in 1988, and its islets are densely forested.

Ādkup is clustered among several other atolls including Wotje just five NM to the north, Maloelap and Aur to the southeast, and Likiep to the northwest. Perhaps due to limited land and water area, Ādkup is not permanently inhabited. However, residents of nearly Wotje regularly visit Ādkup to gather copra, fish, and other food. At the time of our visit on 22-23 September 1988, there was evidence of a very recent visit to the main island (Ādkup) of the atoll probably to harvest sea turtles, fish, and crabs. Due to its central location, Ādkup is sheltered by other nearby atolls from heavy exposure to storms, surges, and waves, except those approaching from the south.

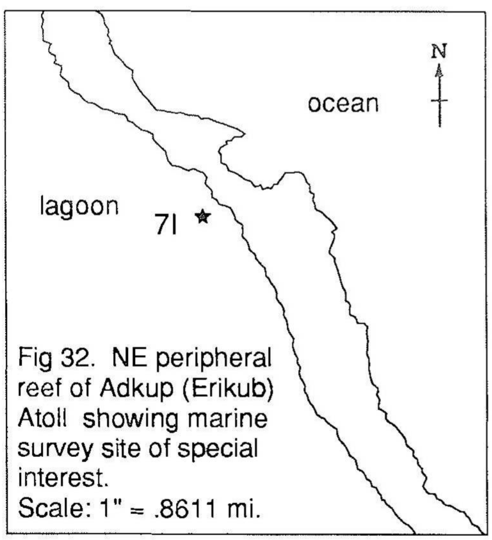


Fig 32. NE peripheral reef of Adkup (Erikub) Atoll showing marine survey site of special interest.
Scale: 1" = .8611 mi.

There are no recent available navigation charts of the atoll, and the 1978 aerial photography of the northern Marshalls did not include Ādkup. Eventually, after considerable searching, a complete set of the U.S. Army Map Service topographic series maps of Ādkup was obtained and analyzed (Figures 32-37).

Ādkup's lagoon and reefs show some unusual features. Lagoon patch reefs and pinnacles are rare, given the large size of the lagoon. Three clusters of patch reefs, each of less than 20 reefs occur opposite three of the atoll's six passes (for example Figures 31, 36). Elsewhere in the lagoon there are only a few isolated patch reefs (only seven could be counted from the AMS maps) and reef pinnacles were only slightly more abundant (for example see Figures 31-34, 36). Unfortunately, time did not permit the team to visit patch or pinnacle reefs in the deeper lagoon. A limited number of soundings have been taken in Ādkup's lagoon, especially near the passes, and reveal that the lagoon is deep. At least one lagoon area in the vicinity of the west central lagoon shows depths of 30 fathoms (55m) or more.

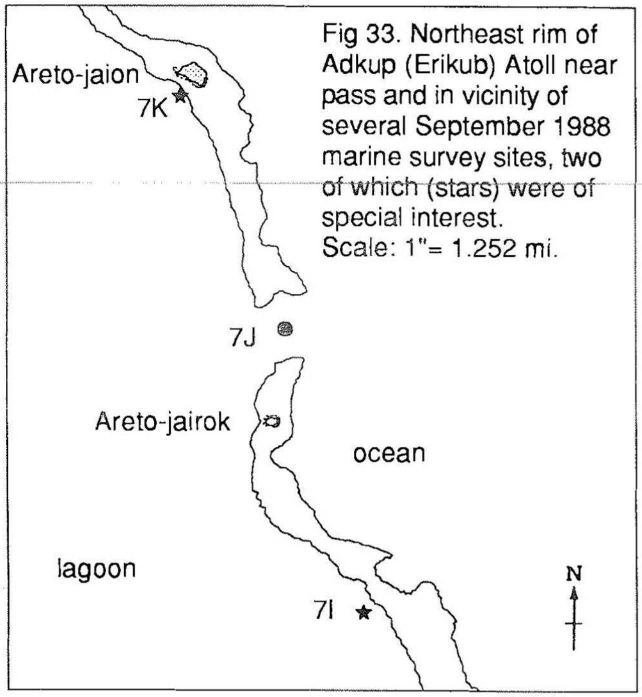


Fig 33. Northeast rim of Adkup (Erikub) Atoll near pass and in vicinity of several September 1988 marine survey sites, two of which (stars) were of special interest.
Scale: 1"= 1.252 mi.

Six deep passes cut through Ādkup's perimeter reefs (see Figures 31, 33, 34, and 36) and all are considered navigable. One pass to the north of Areto-jairok Island is on the windward (eastern) side of the atoll (site 7J; Figure 33) and is the only windward pass present at any of the six atolls surveyed during the 1988 expedition. The AMS map lists the depth of this pass at 3-3/4 fathoms (7m) and a width of about 60 m, but based upon my snorkeling observations, the minimum depth of this pass may be less (about 4m). The other passes are deeper. For example, the northwestern pass near Looj Island is 12 to 23 fathoms (22-42m) deep, and the southwest pass closest to Ādkup Island is 18-20 fathoms (33-37m) deep. Two additional deep passes are located just north of this latter pass.

The rest of the passes are generally spaced out and are probably effective in keeping all portions of the lagoon well flushed from tidal fluctuations and currents. The northeast orientation of the atoll's long reef axis maximizes the constant pumping of fresh ocean water into the lagoon from wave action along the windward ocean reef slopes. The lagoon gave the impression of a well mixed open system.

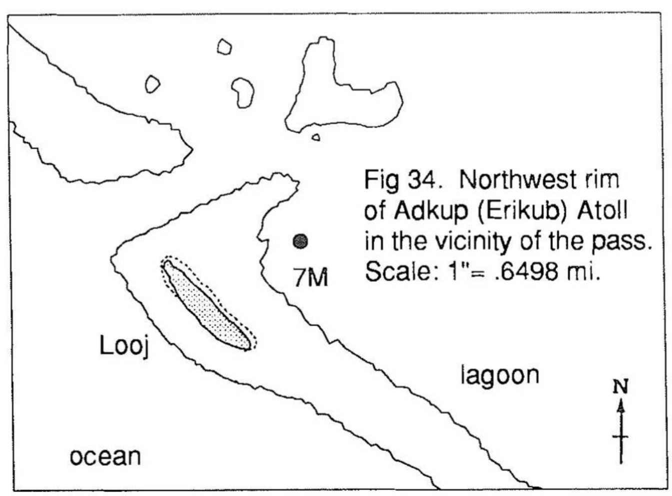


Fig 34. Northwest rim of Adkup (Erikub) Atoll in the vicinity of the pass.
Scale: 1"= .6498 mi.

Fourteen islands occur at Ādkup Atoll, but most are concentrated at the southern end where most of the land area is also situated (Figures 36, 37). To the north of this island cluster are found only three islands along the windward reef, and two islands along the leeward reef throughout the rest of the atoll.

Rare Marine Species

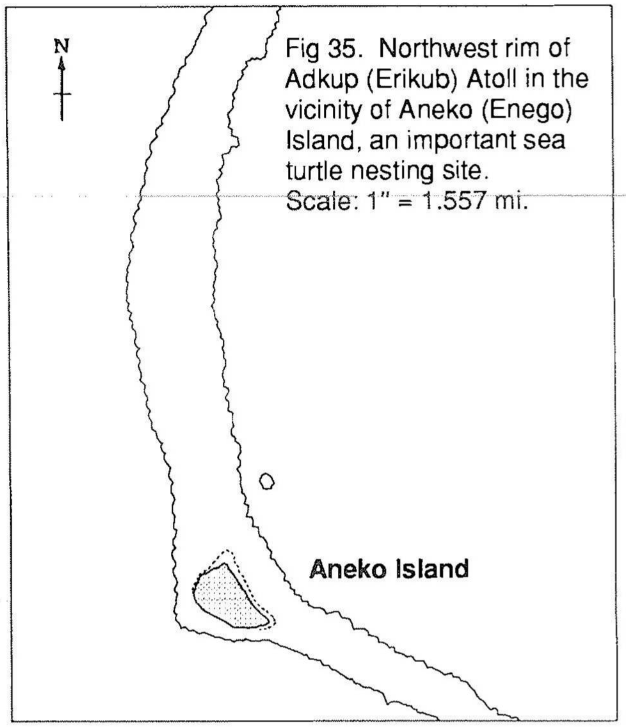


Fig 35. Northwest rim of Adkup (Erikub) Atoll in the vicinity of Aneko (Enego) Island, an important sea turtle nesting site. Scale: 1" = 1.557 mi.

There was extensive evidence of recent sea turtle nesting activity on the beaches of several islands. Twenty-three pairs of sea turtle tracks were reported from Āneko Island (Figure 35), a large island near the northwest end of the atoll. Fewer pairs of tracks were recorded on the other islets: Ādkup (13 pairs), Ijo-kan (6), Areto-jairok (3), and Looj (4). The collective totals for Ādkup atoll rank it third behind Pikaar and Jemo with respect to the level of sea turtle nesting activity recorded during the 1988 expedition. However, the nesting turtles and their eggs appear to be subject to heavy harvesting pressure. Recent human footprints were found along all beaches where turtle tracks were reported. Numerous nest marker sticks, temporary camps, and the remains of sea turtles and their eggs were also conspicuous. Most likely the turtle harvesting is accomplished by residents of Wotje, but we were not able to visit Wotje and query its islanders.

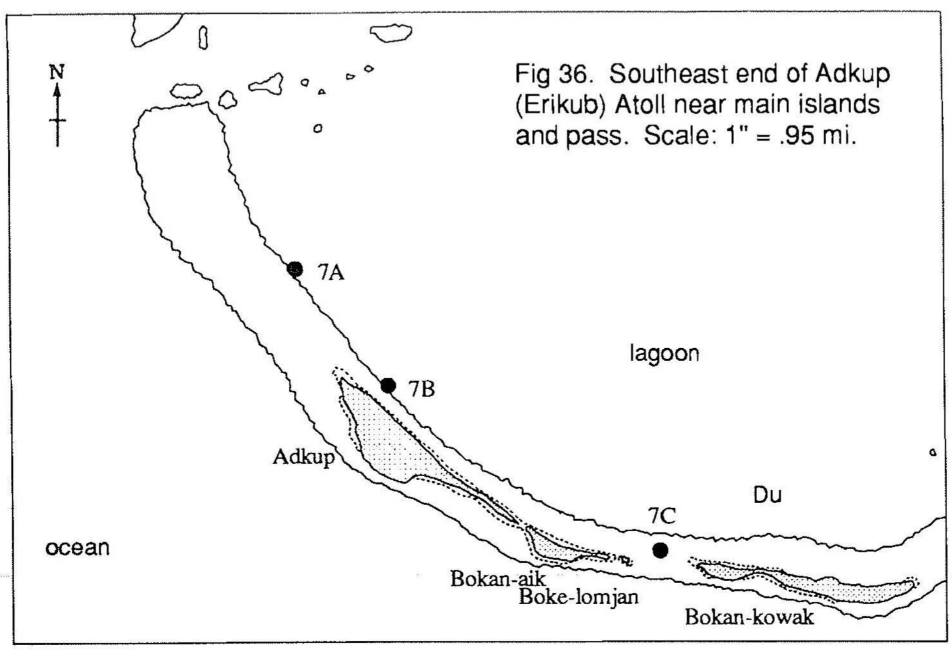


Fig 36. Southeast end of Adkup (Erikub) Atoll near main islands and pass. Scale: 1" = .95 mi.

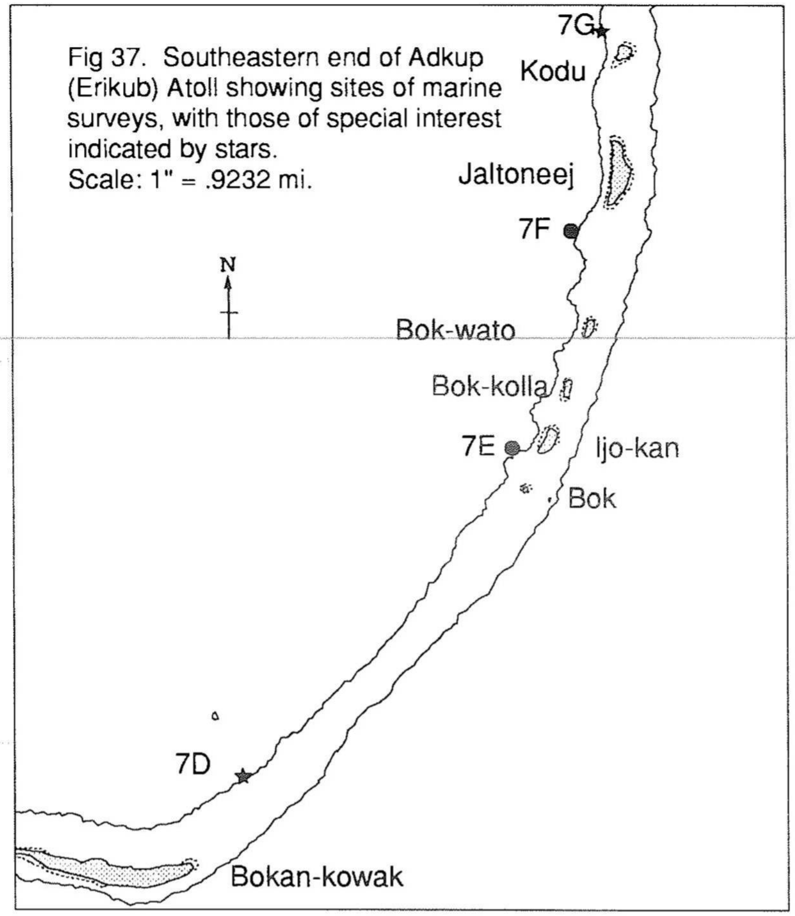


Fig 37. Southeastern end of Adkup (Erikub) Atoll showing sites of marine surveys, with those of special interest indicated by stars.
Scale: 1" = .9232 mi.

Interviews with the crew and Marshallese from Majuro indicate that Ādkup Island is famous for its large coconut crab population. Indeed crabs were reported during the survey, but most all were small. Only one crab approached the large (2 kg) size of the many large crabs observed at Rond̄ik Island (Rond̄ik Atoll). The crabs were similar in size as those observed at Kapen Island (Wōtto Atoll), but were not nearly as numerous. We conclude that the Ādkup crabs are also subject to intense harvesting pressure.

Giant clams of all four species were observed on the lagoon reefs of Ādkup but only Tridacna maxima and Hippopus hippopus were common. There were many more dead shells than live clams, and only one live individual of Tridacna gigas was reported. The lagoon slopes of the eastern perimeter reefs were unusually steep. These habitats may be suboptimal for the giant clam T. gigas at Ādkup due to substrate instability. It is also possible that the giant clam populations at Ādkup are subjected to heavy harvesting pressure from islanders at nearby atolls.

Of the 13 marine sites surveyed at Ādkup Atoll, four (7D, 7G, 7I, and 7K) were considered unique or exceptional with respect to natural characteristics. All of the sites were lagoon facing sides of perimeter back reefs and reef slopes along the windward side. All displayed complex three-dimensional coral communities on steep reef slopes characterized by moderate to high fish abundance and high coral cover and diversity. Live giant clams were present at all four sites and live coral coverage was 40% or more. At site 7D underwater visibility on the lagoon slope (low tide) was 45 m. The slope at site 7I consisted of a patch reef half buried by a sand talus where wave action and strong currents constantly transport sand lagoonward and down the slope. Site 7K included nurse sharks and several rarer corals among the 30+ species recorded.

The windward pass area (site 7J) was also of interest. At the time of my surveys (morning of 23 September 1988) a strong flood tide of two to three kts was entering the channel. The floor of the channel consisted of a hard reef pavement at a depth of 4m which gradually deepened to 15m and transitioned to a sand bottom in a lagoonward direction. The sides of the channel supported exceptional live coral development and abundant reef fish populations.

Corals of Ādkup

A total of 75 species belonging to 35 genera and subgenera were reported from Ādkup Atoll based upon observations at the 13 marine sites. The lower totals compared to some of the other atolls reflect the lack of observations on ocean reef slopes, lagoon pinnacles and other reef habitats expected to harbor additional species. One species reported from Ādkup at site 7E, Euphyllia glabrescens was not observed elsewhere during the 1988 expedition and is a rare coral elsewhere in the Marshalls. Several common genera or subgenera were not reported at Ādkup, including Stylocoeniella, Porites (Synaraea), several mushroom corals, Lobophyllia, Leptoria and others (Table 2). Some of these would be expected to be seen after more intensive surveys.

Abundant and common species along Ādkup's back reef flats and shallow lagoon reef slopes along windward perimeter reefs include: fingercoral (Porites cylindrica) Acropora spp (tables), Stylophora pistillata, Favia spp, Montipora spp, Pavona spp, other Porites spp, Acropora palifera, the soft corals Sinularia and Sarcophyton spp, Millepora spp, Pocillopora spp, Astreopora myriophthalma, Echinopora lamellosa, Cyphastrea microphthalma, Montastrea curta, Heliopora coerulea, Platygyra daedalea, Fungia spp, Turbinaria stellulata, Seriatopora spp, Favites halicora, Scapophyllia cylindrica, Goniastrea spp, and Leptastrea purpurea.

Abundant and common coral species along the windward facing lagoon reefs on the western perimeter of the atoll include: staghorn and table coral species of Acropora, Pavona minuta, Millepora platyphylla, Favia stelligera, Pocillopora spp, and Montipora spp.

CORALS: COMBINED SPECIES LIST

Prior to the 1988 surveys, coral records for the seven areas were extremely limited, a combined 35 species from Bok-ak and Rōn̄dik (Wells, 1954) (Table 3). All but four of these species were subsequently reported in 1988, and a total of 168 species belonging to 55 genera and subgenera have now been recorded for the seven areas. Several of the species and one genus (Polyphyllia) are new records for the Marshall Islands. Despite limited deep water and ocean reef sampling, the 168 species is a sizable total comparable to the faunas of Bikini, Āne-wetak (Enewetak), and Arno Atolls (Wells 1951, 1954; Maragos, 1989; Devaney and Lang, 1986), where much more extensive surveys and sampling for corals was accomplished. The species totals for the individual atolls surveyed in 1988 are lower than reported from each of Bikini, Arno, and Āne-wetak Atolls due to the 1988 sampling limitations.

IV. DISCUSSION

An excellent overview of the feasibility, justification and procedures to establish a system of protected areas in the Marshall Islands is found in Thomas (1989) and covers terrestrial, cultural, and marine factors. The present report concentrates on marine resources, and assesses the consequences of establishing marine parks and reserves (Table 5). The feasibility of other resource uses at the seven studied areas is also assessed since atolls and islands that the RMI does not establish as preserves or parks may be earmarked for other forms of development (Table 6).

Most of the Republic's natural resources are marine resources, and the seven studied areas represent a major proportion of the undisturbed reef systems in the country. Although none of the study atolls is large, the RMI is home to the world's largest atolls. More atolls are found in the RMI (28) compared to any other country except the Federated States of Micronesia (42) and French Polynesia. But unlike the FSM and French Polynesia, the RMI is comprised of only atolls, table reefs, and low coral islands. As such, the land resources are small and lack rich and abundant soil and groundwater resources. Hence the RMI must look to marine and coastal environments for future economic development. The RMI is also faced with rapid population growth and the need to reduce balance of trade deficits and unemployment. Self reliance is the central theme for the Republic's future development goals.

Fully a quarter of the RMI's atolls are uninhabited (including Ailinginae which was not studied), and at least one or two others have been temporarily evacuated (Roñlap and Bikini due to concerns over contamination from nuclear testing). Thus the RMI perceives most of these uninhabited areas as major resource development opportunities. The RMI government also recognizes and supports the traditional use of several of these atolls as wildlife reserves or "pantry" reserves, and specifically requested the study team to evaluate the uninhabited areas (and inhabited Wōtto) as possible parks and reserves. Those areas which are not established as protected areas are theoretically open for subsistence activities, resort development, small scale (nature based) tourism, agriculture, mariculture, urbanization or settlement, and industry. However, the inaccessibility, geographic isolation, small land areas, limited fresh water, and vulnerability to typhoons and other natural hazards render most of the areas unfavorable for intensive development (see Table 6).

Marine Reserves

At least portions of all seven areas visited harbor marine resources and sites worthy of marine reserve and preserve status. The entire reef ecosystems (along with the islands) of Bok-ak Atoll, Rikaar Atoll, and Jemo Island warrant reserve status, a designation which would be entirely consistent with the traditional and cultural uses of these reefs as practiced by the Marshallese for many centuries. All three areas are acknowledged reserves for either nesting seabirds, nesting sea turtles, or both. All three have unique coral reef features and habitats which have been little studied scientifically.

CRITERIA

RESOURCES USES	biological diversity	biological productivity	other natural resources	cultural importance	aesthetics	non-polluted/pristine	accessibility	water supply	protection from natural hazards	docks	airfields	power	sewage disposal	public safety	climate	land and soils	CANDIDATE ATOLLS AND REEFS
Preserves & reserves	●	O	●	●	O	●	•	•	•	•	•	•	•	•	•	•	Bok-ak, Pikaar, Jemo̧ and portions of other atolls
Parks & recreation areas	●	O	●	●	●	●	O	O	O	O	O	•	O	●	•	•	Tōke, Wōtto, portions of Rondik and Ādkup
Subsistence gathering & fishing	●	●	O	O	•	●	●	•	O	•	•	•	•	●	O	O	Ādkup, Tōke & Wōtto. Ron̄dik (marine resources only)
Aquaculture/mariculture	•	●	O	•	•	●	●	O	O	●	●	O	O	●	O	•	Wōtto, and possibly Tōke, Ron̄dik and Ādkup
Agriculture	•	●	O	•	•	O	●	●	●	●	O	•	●	●	●	●	Possibly Wōtto
Commercial fishing	O	●	O	•	•	O	O	•	•	●	●	O	•	•	•	•	Possibly Wōtto and territorial waters at other reefs
Small scale tourism	●	•	●	●	●	O	●	●	●	O	●	●	●	●	O	O	Wōtto
Resorts	●	•	●	O	●	O	●	●	●	●	●	●	●	●	O	●	None
Permanent settlements	•	•	•	•	•	O	●	●	●	●	●	●	●	●	O	●	None
Industrial development	•	•	●	•	•	•	O	●	●	●	O	●	O	●	•	●	None

● - very important   O - moderately important   • - unimportant

Table 6. Relationship between various types of resource uses for Northern Marshalls reefs and atolls and the required criteria for their feasibility

The lagoons of Bok-ak and Pikaar also support huge populations of several of the smaller species of giant clams which is perhaps the most important reason to establish them as marine reserves. The lagoons also support exceptional populations of reef corals and reef fishes and the whole ecosystems are in pristine condition. The designation of any area for reserve or protected status will require the cooperation of persons with traditional rights to these areas.

At a smaller scale there are unique or exceptional coral reef habitats at the other atolls (Wōtto, Ādkup, Roñdik, and Tōke) that also merit marine reserve designation due to the abundance, diversity or unique features of coral reef populations and reef features. For example, the pink sand beaches and high dune systems, blue coral moats and flourishing lagoon pinnacles at Roñdik deserve special recognition as do other lagoon reef formations at the other atolls.

Marine Parks and Recreational Areas

Several of the atolls offer major advantages with few disadvantages to support marine park designation. The variety, accessibility, safety, and pristine condition of lagoon reefs (and perhaps ocean reefs as well) at Wōtto and Tōke support the entire atolls being designated as National Marine Parks. Portions of Ādkup and Roñdik also contain diverse and accessible reef habitats to support at least Regional Marine Park status. These parks would serve both the residents of the RMI and visitors and would be oriented to provide recreation and educational opportunities. Visiting tourists to these parks could provide the fees to support park management, jobs, travel, and educational opportunities for Marshallese residents, including school students.

Of the four areas, Wōtto has the most potential to serve as a national park, because of an onsite residential population interested in pursuing marine park and nature based tourism. Wōtto also contains food and water supplies, and its airstrip allows the atoll to be serviced by weekly commuter flights from Mājro or Kuwajleen (Kwajalein) Atolls. The large population of American defense workers at Kwajalein may find the opportunity to visit Wōtto an attractive prospect. Many other people from the urban settings of Mājro and Kuwajleen may also be interested in experiencing the natural and cultural resources of Wōtto.

The atolls of Tōke, Ādkup, and Roñdik are somewhat less accessible to serve park visitors. The nearest airstrip and inhabited population from Tōke is at Utrōk atoll, and the Utrōk islanders need to be queried as to their interest in park designation for Tōke. Likewise, Ādkup and Roñdik are close by other atolls (Wojte and Roñlap) where airstrips are present. Wotje is inhabited while Roñlap has been temporarily evacuated. On a long range basis, park designation and development is theoretically possible for these areas, as well as for Ailinginae (which was not visited) which is also near Roñlap (see Figure 1). Park development at Pikaar, Bok-ak, and Jemo̧ is not feasible due to hazardous access, remoteness, vulnerability to large waves and typhoons, and lack of potable water. Heavy visitation to these areas could also disturb wildlife resources (especially sea turtles, sea birds, and possibly clam populations). Any form of physical development at these atolls would compromise the value of a reserve, and could disrupt reef and island ecosystems. As with any other proposed use, park designation of these areas will require the cooperation of persons with traditional rights to these areas.

Subsistence Activities

Very limited harvest of sea turtles and seabirds for ceremonial purposes has been traditionally practiced at Bok-ak, Pikaar, and Jemo̧. Such visits, if continued to be limited to one or two per year, do not pose a danger to the vulnerable wildlife at these sites and would be in keeping with long established cultural practices. However, harvesting of larger numbers of wildlife for purely subsistence purposes would be disruptive to bird, turtle and clam populations, and may endanger their status as the most important populations in the RMI.

The remaining four areas are suitable for traditional level subsistence activities and would be compatible with park reserve designations if planned properly. For example, marine resources and sites at Wōtto used for subsistence activities could be identified and sustained for such uses, and visitor or recreation sites would be best located at separate sites.

There should be controls established over the taking of rare marine species (sea turtles, their eggs, and giant clams) from Rōn̄dik and Ādkup Atolls to ensure that important breeding populations are not depleted or threatened. One way to accomplish this is first to establish critical habitat areas as reserves.

Radiological Contamination

Consumption of coconuts or coconut crabs from Ron̄dik Atoll may pose as health hazards to islanders. In addition, subsistence use of terrestrial resources from Ailinginae, if any, should likewise be discouraged until radiological surveys document that consumption of these resources will not pose a hazard to public health. It is possible but highly unlikely that consumption of marine resources from these two atolls as well as from Tōke would pose a health problem.

Resident coconuts, breadfruit, pandanus, and coconut crabs from Ron̄dik Atoll may be contaminated with the radionuclides cesium-137 and strontium-90. These radionuclides were generated during the BRAVO hydrogen bomb test at Bikini in 1954 and carried with the nuclear fallout from the blast. Although Bikini is located over 125 NM west of Ron̄dik (and 100 NM west of Ailinginae and Ron̄lap), fallout from BRAVO was reported to have been carried into upper atmospheric winds and to the east, where some of it eventually rained down on Ron̄lap and Utrōk Atolls, which were inhabited at the time. The fallout also probably rained down on other nearby atolls, but since they were uninhabited, evidence of fallout must be derived from analysis of plants and soils. Ron̄dik falls within a straight axis between Ron̄lap (25 NM to the west) and Utrōk (140

NM to the east) (see Figure 1). Thus it is highly likely that Roñdik, and perhaps Ailinginae were contaminated with the fallout.

Studies at Bikini and Āne-wetak Atolls after the nuclear testing period reveal that coconut trees (especially the living nuts) and other crops take up and bioaccumulate cesium-137 and strontium-90 in their tissues. The concentrated radiation levels in the coconuts posed a much greater health risk than radiation in the soils, because resettled Bikinians subsisted regularly off locally grown but contaminated coconuts between 1969-1978. Excessive whole body dose counts of the Bikinians in 1978 measured by Brookhaven National Laboratory prompted the evacuation of the Bikinians from their home atoll on short notice in 1978.

Coconut crabs as well as humans subsist on coconuts, and the crabs can also bioaccumulate Ce-137 and Sr-90 in their tissues by foraging off contaminated nuts, as studies by Lawrence Livermore National Laboratory at Āne-wetak Atoll have demonstrated (BARC, 1984; 1985; 1986). The radionuclides could then be passed up the food chain to man if he eats contaminated coconut crabs. Unlike the small crab populations at Bikini and Āne-wetak, Roñdik supports huge coconut crab populations. This raises the possibility of a greater public health hazard since there may be many more potentially contaminated crabs at Roñdik. Regular consumption of coconuts, breadfruit and other crops at Roñdik is more likely and could also pose a risk.

Tōke and Ailinginae Atolls were also within the fallout zone. Although Tōke's edible vegetation and coconut crab populations are very small, the extent of Ailinginae's is not known since the team was unable to visit the latter atoll. Thus radiological surveys may be warranted for Roñdik as well as Tōke and Ailinginae to document the extent of radiation hazard from ingesting food crops and coconut crabs. Roñlap, and Utrōk are presently being monitored for radiation by Lawrence Livermore National Laboratory.

Mariculture

The shallow protected lagoons and broad reef flats and shelves within the Northern Marshalls offer ideal locations for certain forms of mariculture development. Several marine species with mariculture potential were observed during the expedition including: giant clams (Tridacna, Hippopus), topshell (Trochus), black-lipped pearl oysters (Pinctada), milkfish (Chanos), mullet (Mugil) and reef groupers (Epinephelus). Mariculture would be more feasible within atoll reefs and lagoons accessible by air and sea transportation and near population centers. Mariculture thus would be feasible at Wōtto, with its airstrip, protected anchorage, resident population and proximity to urban Kuwajleen. Tōke is somewhat less feasible since the nearest airstrip and residential population is at Utrōk. Similarly, Ādkup is removed from Wotje, the nearest population and airstrip. Mariculture would more likely be developed at the populated atolls (Utrōk and Wotje) rather than at their uninhabited neighbors (Tōke and Ādkup). Roñdik is less feasible for mariculture due to the lack of inhabited atolls nearby, although Roñlap, which is serviced by an airstrip and protected anchorage was only recently evacuated and may be eventually resettled (Rongelap Reassessment Project, 1989).

The remaining reef and atolls (Bok-ak, Pikaar, and Jemo) are not feasible due to remoteness, lack of safe access, lack of safe anchorages, and relatively inhospitable living conditions. Extensive mariculture development at Pikaar and Bok-ak might also conflict with other values and uses such as protected reserves or preserves. The large giant clam populations in the lagoons of Pikaar and Bok-ak may eventually serve as important brood stock and a source of giant clam seed, if the smaller giant clam species become severely depleted in the RMI. For this reason, the giant clam populations at the two atolls should be maintained as reserves indefinitely.

Agriculture

Although the focus of this report is on marine resources, a few comments on the feasibility of agriculture at the seven studied areas can be offered. Due to lack of water and good soil, agriculture at Pikaar, Tōke and Bok-ak is not feasible. Although Jemo Island has thicker soil and more abundant water, agriculture is also difficult due to hazardous access and limited land and settlement options. Roñdik Atoll should not be considered feasible for agriculture unless radiological surveys and analyses project it to be safe. Subsistence level agriculture is already practiced on inhabited Wōtto, including some copra harvest. Likewise, Ādkup is subject to limited copra harvest, but is small land areas limit greater agricultural development.

Commercial Fishing

Commercial fishing activity by resident Marshallese would be feasible at inhabited Wōtto, which has accessible ocean fishing grounds. Fishing vessels from Wotje, Utrōk, and Roñlap could also fish the coastal waters of Ādkup, Tōke, or Roñdik, especially for game fish and tunas. Controlled commercial fishing in the lagoons of uninhabited atolls is also possible unless it competes with the subsistence needs of the nearby inhabited atolls which own or traditionally control lagoon fishing grounds. Commercial fishing is less feasible at Pikaar and Bok-ak atolls due to remoteness. Fishing in the lagoons would be further discouraged by numerous reefs and hazardous access through the single narrow meandering passes. Permanent occupation of the atolls to promote commercial fishing would be extremely disruptive to rare marine species, reef life and nesting seabirds. Controlled commercial fishing for tunas and other migratory species along the ocean sides (territorial waters) of all atolls is feasible but should be limited to Marshallese and monitored to avoid poaching of turtles, giant clams, and other rare species within or near designated marine reserves.

Small Scale Tourism

Small scale tourism in this report means small lodges or beach cabanas, limited to about 20 rooms which take advantage of the natural features, scenic beauty, and cultural resources within the vicinity of the tourism facilities (e.g. nature based tourism). This style and level of tourism at Wōtto is very feasible given the interests of the islanders to pursue it and the host of natural amenities and attributes. Reliable sources of water and food appear feasible to obtain and the major infrastructure requirements would include the accommodations, power generation (for lights and refrigeration, ceiling fans, etc.), catchment water storage, and waste disposal. Wōtto is already serviced by weekly commuter air service and has a protected anchorage. Thomas et al (1989) provides a detailed account of the feasibility of small scale tourism at Wōtto Atoll. Many existing marine resources and features could be incorporated into a tourism operation. Visitor destination attractions include flourishing coral communities at safe and accessible lagoon areas. Corals, fish, giant clams and other reef life could be observed via diving and snorkeling. Mariculture and fishing activity at the atoll could provide fresh fish and shellfish to feed visitors. Beaches and other coastal sites at islands away from the existing village could also be visited. Interpretive and educational displays regarding marine life could be established. Swimming, gamefishing, diving, some boating, and sailing activities could also be included. The focus of small scale tourism at Wōtto should be nature based, with considerable emphasis on marine resources.

Tōke Atoll also has many attributes to support tourism visitation, but accommodations for tourists would be best placed on Utrōk, subject to the views, approvals and guidance of the Utrōk people. The survey team could not find the time to visit the Utrōk islanders and obtain their views on tourism. The water and land resources at Tōke are too limited to support development of self-contained permanent tourism accommodations. Tōke would best serve as a day visitor area or for limited overnight "rustic" camping. Access to the atoll would be gained by boat from Utrōk. Land resources at Tōke are too limited to justify an airstrip, and dredging and filling to construct a reef runway could have major adverse impacts on marine resources.

Similar limitations on tourism development apply at Roñdik and Ādkup atolls. Although land resources are more abundant, the lack of permanent residents would require infrastructure development for accommodations, power, water supply and transportation. Airfields would most likely be required to attract tourists to the atolls, and reef runways would be needed. Tourism development would be expensive and would need to be well planned to avoid serious socioeconomic and environmental impacts. Most importantly, tourism development, if any, would require the approval and support of the traditional land managers, owners, and users of both atolls.

Tourism development is not feasible at Jemo, Pikaar and Bok-ak due to remoteness, hazardous accessibility, lack of reliable fresh water, lack of a permanent work force, and the significant expected economic costs and environmental impacts. Of the three areas, only Bok-ak has sufficient land for an airstrip, but substantial bird nesting on the islands poses serious constraints. Disruption of nesting activity and collisions between birds and airplanes are highly likely in nesting areas and contrary to the designation of the atoll as a wildlife refuge. Safe boat access to either Bok-ak or Pikaar would require major dredging and other coastal construction activity in the vicinity of the existing passes. Additional lagoon reefs may also need to be dredged or knocked down to provide safe access across the lagoons to the destination islands. The clearing of safe navigation channels could have major adverse effects on coral reefs and giant clam populations, and may also disturb some sea turtle nesting. Major widening or enlarging of the passes could also lower lagoon water levels, exposing and killing many shallow reef flats, disrupting lagoon circulation, and possibly degrading coral reef and giant clam habitat (see Figure 38). For these reasons permanent occupation or settlement of Pikaar and Bok-ak for tourism and other purposes (e.g. resettlement, industrial, development) would pose serious threats to the natural resources of most value at the atolls and should be strongly discouraged.

Variations in the depths of living reef flats: revisiting some widely held assumptions

It is generally thought that living reef flats on coral atolls and barrier reefs can grow no higher than mean low water due to the requirement of the reef building organisms (e.g. corals, coralline algae), to be regularly immersed in sea water for survival. As growing coral reefs reach the sea surface, further upward growth is inhibited while lateral growth lagoonward and seaward can continue (see Figure 39). Over time and with stable sea level, cessation of upward growth and continued lateral reef expansion would result in the formation of wide reef flats. Their widespread occurrence is indisputable evidence on the limitation of marine organisms to grow above a level of regular exposure to sea water.

One widely observed exception to the "mean low tide rule" is the presence of elevated living coralline algal ridges along the margins of many windward reef flats of many atolls, especially those of the RMI (Tracey et al, 1948. Wells, 1954; 1957a, b). The fact that these ridges occur only along windward reef flats suggests a relationship between the ridges and the wave action generated by the tradewinds. The most widely supported hypothesis is that the constant wave action generates wave wash or splash that constantly bathes the ridges, and keeping the reef building marine organisms (primarily crustose coralline algae and some reef corals) alive. This wave wash can regularly immerse surfaces up to two or three feet above mean low water during low tide conditions on the ocean side of the reefs which explains why ridges at this elevation remain alive. Wave wash passing over the ridge then moves downhill toward the lagoon and mixes with lagoon waters, eventually exiting through the passes or over the tops of reefs along leeward sides.

Another less widely known exception to the "mean low tide rule" became evident after the visits to Bok-ak and Pikaar Atolls. Here, not only were windward algal ridges found to be alive and growing above mean low water, but so were many other lagoon reefs. The elevated living nature of some lagoon reefs were reported by Fosberg et al (1956) and Fosberg (1988) at Pikaar and Bok-ak. These authors and the 1988 field team also observed the elevated lagoon water levels at "low tide" at these atolls. Similar elevated lagoon and leeward reef flats were also reported by Wells (1951) at Arno Atoll's northern sublagoon (Namdik), later corroborated by Maragos and Lamberts (1989). I also

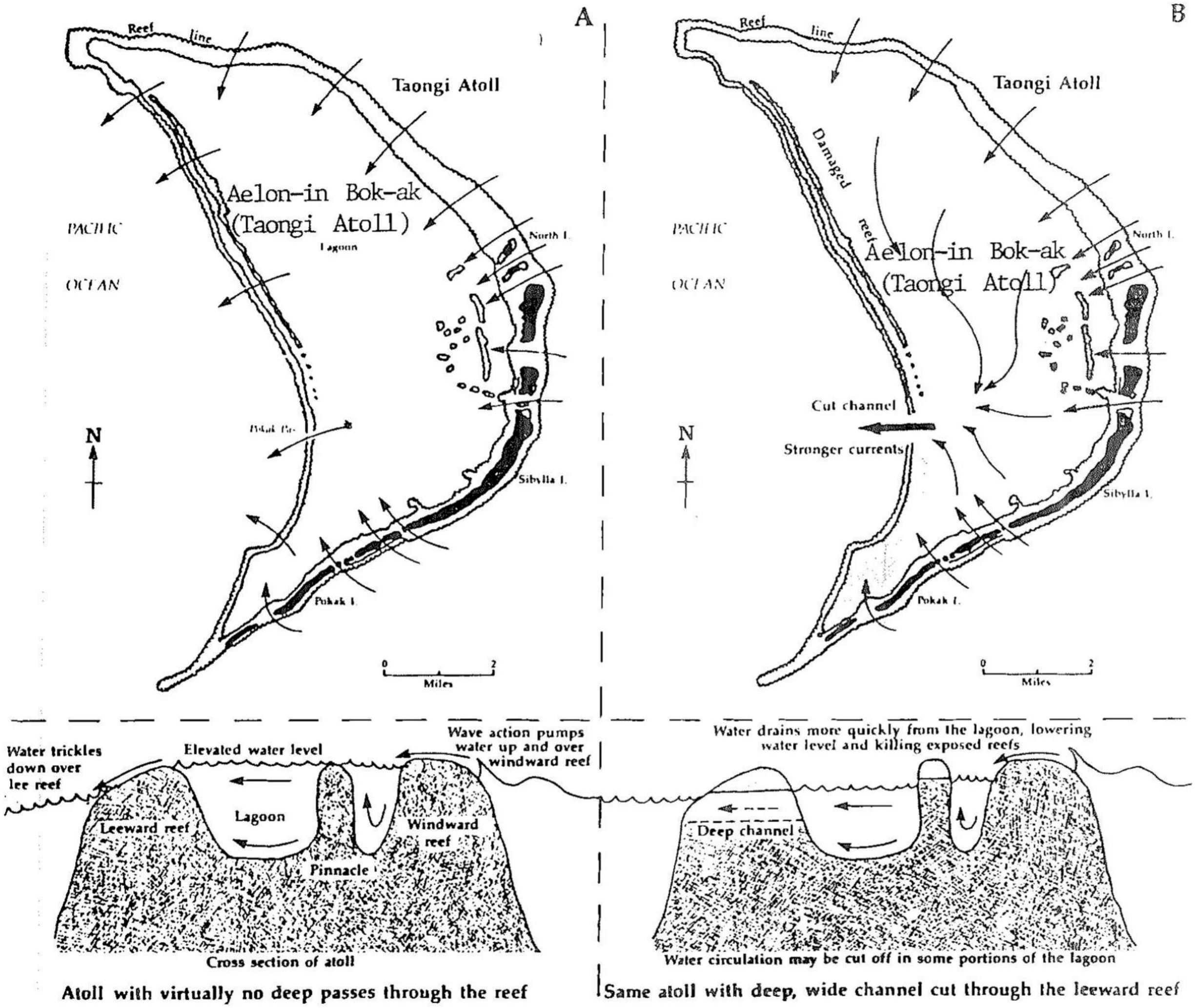


Fig. 38. Possible adverse effects of cutting channels through semi-enclosed atoll lagoons. Some atolls (such as Bok-ak, which is pictured, and Pikaar) have elevated lagoon water levels because of wave action pumping water over windward reefs and the lack of large, deep channels to drain the excess water. The reefs grow above normal ocean sea level because of constant water flow and in response to higher lagoon water level. Cutting a deep channel through such an atoll reef would cause waters to drain more quickly, lowering lagoon water level and killing emergent reefs.

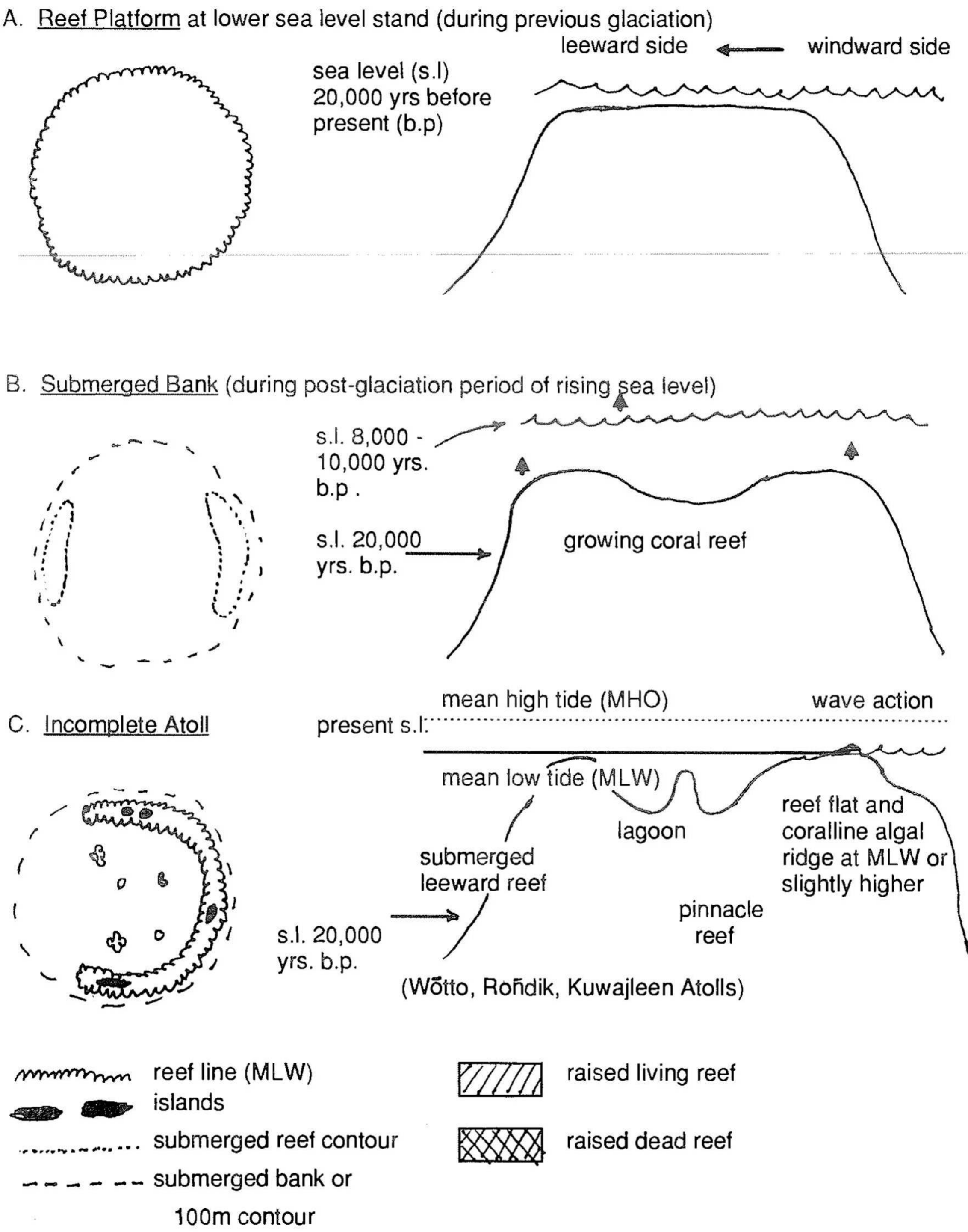
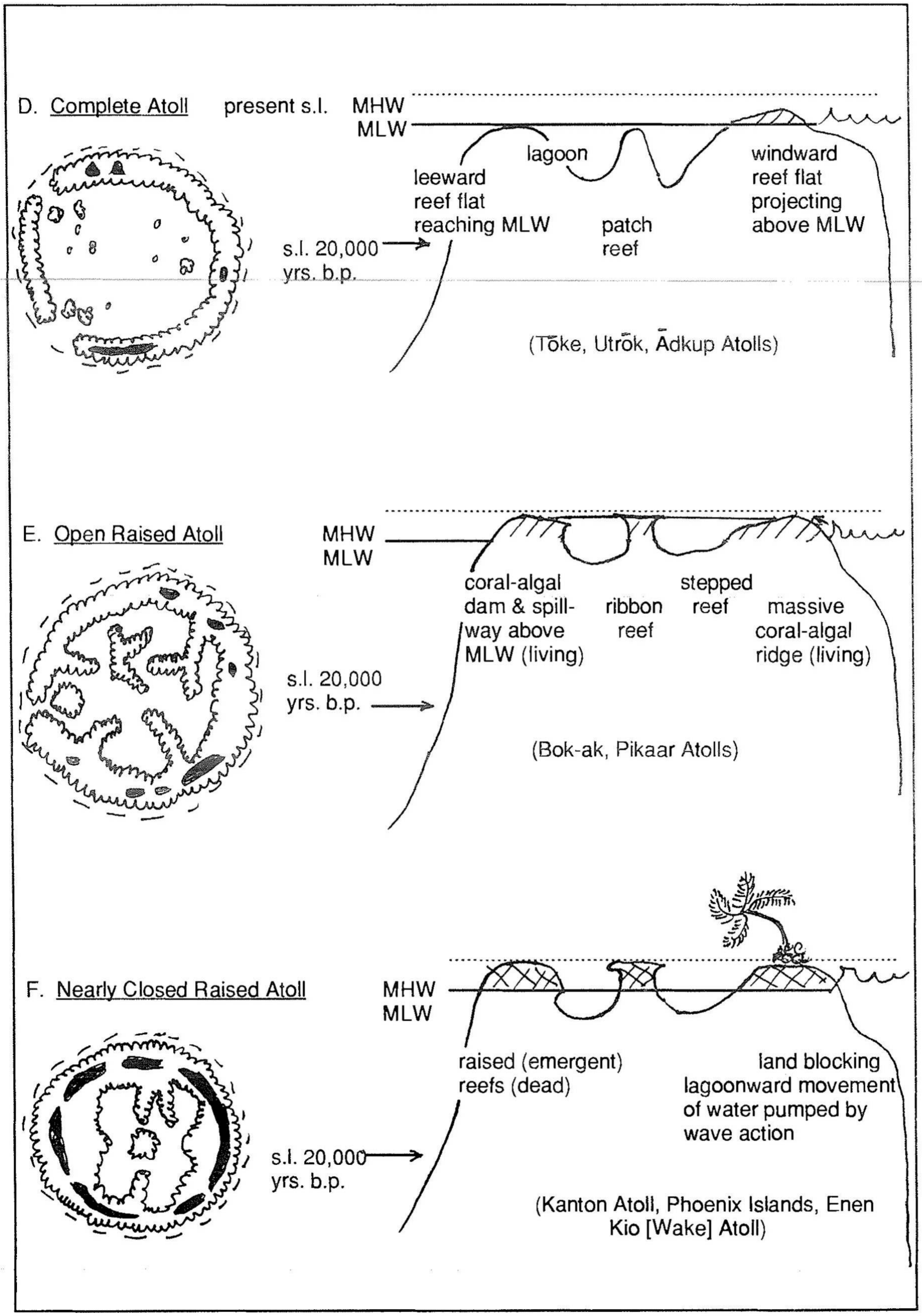


Figure 39. Progressive development of reef flat features on atolls.


D. Complete Atoll
present s.l.
MHW
MLW
lagoon
leeward reef flat reaching MLW
patch reef
windward reef flat projecting above MLW
s.l. 20,000 yrs. b.p.
(Tōke, Utrōk, Ādkup Atolls)
E. Open Raised Atoll
MHW
MLW
coral-algal dam & spill-way above MLW (living)
ribbon reef
stepped reef
massive coral-algal ridge (living)
s.l. 20,000 yrs. b.p.
(Bok-ak, Pikaar Atolls)
F. Nearly Closed Raised Atoll
MHW
MLW
raised (emergent) reefs (dead)
land blocking lagoonward movement of water pumped by wave action
s.l. 20,000 yrs. b.p.
(Kanton Atoll, Phoenix Islands, Enen Kio [Wake] Atoll)

observed elevated lagoon and leeward reefs at Namdik (Namorik) Atoll in 1971, and former residents of nearby Ebon Atoll also noted the elevated nature of perimeter reefs (pers. comm. to J. Maragos by N. Neimon). All five of these atoll lagoons have two things in common: 1) exposure of windward reef flats to prevailing wave action generated by the trade winds, and 2) restricted passages or no passages through the reef. These two factors are interrelated in explaining the presence of elevated living lagoon and leeward reefs (Figure 39). Progressive development of reef flat features on atolls explain how contemporary reefs in the northern Marshalls can grow above low tide level without the need for a higher "Holocene" sea stand. Stage A. Antecedent reef platform at the end of the previous ice age. Stage B. Subsequent melting of the glaciers causes sea level to rise, drowning the reef platform and renewing upward coral reef growth. Stage C. Upward reef growth eventually reaches sea level (mean low tide) on the windward side. Coralline algal ridges projecting above mean low tide may develop in response to constant wave action. Stage D. All perimeter (annular) reefs grow upward to mean low tide level except where passes cut through the reef. Coralline algal ridges and windward reef flats continue to broaden. Stage E. Eventually the passes close off to the extent that water pumped into the lagoon by constant windward wave action is greater than can exit the passes at low tide, causing average lagoon water levels to rise. Remaining (leeward) perimeter reefs, now constantly submerged, begin to grow upward, forming coral-algal dams, spillways, and perched lagoon reefs. Stage F. Storms naturally cast sand and rubble on top of windward reefs, forming cays, ramparts or islands, or man builds causeways along windward reefs to connect islands. In either case they block the pumping of seawater into the lagoon by wave action. As a result, water levels in the lagoon drop, permanently exposing raised reefs which dry out and die, leaving intact "fossil" raised reefs. The cutting or enlarging of passes through perimeter reefs can have the same effect by draining lagoon waters more quickly and lowering average water levels (see Figure 38).

The restricted passages result in more water entering the lagoon over windward reefs than can exit through passes at low tide. In response to the restricted discharges, average lagoon water levels increase with the excess water spilling over leeward reef flats as well as through the passes. If the passes begin to close off, restrictions increase, causing lagoon water levels to rise further. Higher water levels in the lagoon, especially during low tide, result in more and more water spilling over the leeward reef flats until the latter are constantly immersed even at low tide. Prolonged immersion may in turn ultimately cause leeward reef flats to grow upward, since the reef organisms are no longer limited by exposure at low tide (see Figure 39). Eventually, perimeter reefs along leeward sides of the atoll grow upward. Supplementing the coralline algal ridges along windward reef margins are smaller coralline algal ridges and coral-algal dams and spillways along leeward reefs. Lagoon reefs also grow upward in response to the progressively higher lagoon water levels.

Maximum upward reef growth depends upon the magnitude of prevailing wave action and the extent of open reef flats along the windward side of the atoll. Some of the kinetic energy of wave action is converted into potential energy by pumping water up on higher reef flats. Wave action can constantly pump ocean waters into the lagoon over the ridge and reef flats. If lagoonward water movement is blocked by the presence of islands or rubble ramparts created during tropical storms, lagoon water levels could drop. Man's intervention, either by building causeways along windward reefs (which blocks wave pumping of water into the lagoon), or by enlarging passes through leeward reefs (which drains water more quickly from the lagoon), can also lower average lagoon water levels. The lowered water levels could then result in the emergence and death of exposed reefs, which may have occurred at Kanton Atoll, where a near continuous causeway was built around the perimeter reefs of the atoll, and where recently exposed reefs were observed (Jokiel and Maragos, 1978; Smith and Jokiel, 1978). The hypothetical evolution of atoll reef flats based upon the above scenario is depicted in Figure 39.

Geologists often rely the elevation of previously intact fossil reef flats to estimate the extent and age of relative sea level stands in various parts of the world. Two implicit assumptions in many of these studies is that all or most modern living reef flats grow no higher than mean low water elevation, and that intact previously living reef flats found emerged on present day reefs must have formed when relative sea level was higher. Based upon the 1988 observations at Bok-ak and Pikaar, supplemented by the observations at other atolls (Arno and Namdik), the first, and perhaps both of these assumptions may be incorrect. First, in the case of Bok-ak, Pikaar, Arno, Namdik, and perhaps other atolls, many present day living reef flats occur above low tide level due to factors other than a higher sea level stand. More importantly, some of these same reefs may become reexposed due to natural factors, such as islands, cays, and rubble ramparts forming on the windward sides of atolls with elevated leeward and lagoon reef flats, thereby blocking lagoonward movement of water pumped by wave action.

As a consequence, the hypothesis of a higher Holocene sea level stand some 4,000-6,000 years ago that is based upon the evidence of higher stands of recent reefs less than one meter above present sea level may need to be reexamined. The complex interaction of prevailing wave action, restricted passages through reefs, open windward reef flats, the frequency of storms, and other factors can alternatively explain the upward growth of living reefs above normal low tide levels and their subsequent reemergence. Reliance on evidence from prehistoric reef stands in support of hypotheses on previous sea level stands must involve an examination of the geomorphology, oceanography, and geological history of the reefs in question.

Rapid Marine Field Assessment Procedures

The results of the 17 day visit to 95 marine sites and other numerous shoreline sites at seven atolls and reefs in the northern Marshall Islands demonstrate that qualitative data gathering procedures can be very useful in describing marine areas. Preliminary assessment of biological and ecological diversity can be accomplished without the need for transect and quadrant surveys if the purposes and goals of such studies are clearly identified in advance. With the primary emphasis of the 1988 expedition on evaluation of natural diversity and feasibility for park and protected area development, it was possible to collect valuable information on species, habitats, bathymetry, geomorphology, and oceanography, relying primarily on shallow water snorkeling observations. Coupled with the availability of aerial photographs, and previous map sources, field work was designed to sample a greater variety of habitats than would have been otherwise possible. Although the literature was scant and the opportunity to interview knowledgeable informants limited (since all but one of the sites were uninhabited), good maps and aerial photographs can be consulted to improve the efficiency of field work. Modern satellite imagery from the French Satellite SPOT now has resolution (10m) which can supplement photo interpretation of maps, especially where conventional aerial photographs are not available.

Collectively these data acquisition strategies may become increasingly important in evaluating the multitude of marine resources and habitats in the South Pacific. With many thousands of reefs and islands, and hundreds of atolls, many of which are remote, innovation will be required to allow rapid evaluation of particularly valuable areas. As population levels and development pressures increase, more and more natural marine areas will become vulnerable to exploitation and degradation. A systematic inventory and evaluation of candidate marine protected and park areas throughout the tropical Pacific will become an even more important goal of proponents of both conservation and development.

V. SUMMARY

Six atolls: Bok-ak (Taongi), Pikaar (Bikar), Tōke (Taka), Wōtto (Wotho), Roñdik (Rongerik), and Ādkup (Erikub) and one table reef (Jemọ) were surveyed during a 17-day expedition in September 1988 to the Northern Marshall Islands to describe coral communities and reef formations as part of a larger natural diversity survey. Only observations using snorkeling gear, underwater writing slates and underwater cameras were possible during the approximately 2-day visit to each atoll. A total of 95 sites were surveyed, ranging from 12 to 20 sites per atoll. Additional observations were made during boat travel and walks along shorelines of islands. Over 160 species of reef corals belonging to 55 genera and sub genera were reported from the seven areas, including several species and one genus as new records from the Marshall Islands. The abundance and distribution of corals varied from one atoll to the next and may reflect geographic isolation from adjacent reefs, limitations on habitat diversity (in the case of Jemo), and limitations on larval recruitment (in the case of Bok-ak and Pikaar). Several of the coral communities and habitats were unique or have not been previously described. Many sites displayed exceptional coral development, and sites of special interest were identified on maps and are highlighted in the report. The reef geomorphology of the seven areas is also described and each belongs to one of three distinct physiographic categories:

i) small semi-enclosed atolls (Bok-ak, Pikaar, Tōke)
ii) larger open atolls (Wōtto, Roñdik, Ādkup)
iii) exposed table reef (Jemọ)

Lagoon and adjacent perimeter reef formations at Bok-ak and Pikaar are elevated two or more feet above mean low tide level. These elevated reefs are living and perhaps growing, and are maintained by a combination of water being pumped into the lagoon from wave action on the windward sides, and the inability of the narrow passes to drain water from the lagoon at an equivalent rate during low tides. Unique features at both atolls associated with the elevated reefs include overhanging ribbon reefs, coral-algal dams, spillways and steep water level gradients in each atoll pass during low tide. Navigation through the passes during low tide is treacherous due to the narrow and meandering configuration of the passes, and the turbulent water flow caused by a two to three foot drop from the higher lagoon water levels over a short distance. Huge undisturbed giant clam populations (Hippopus sp. and Tridacna spp, but not the largest species, T. gigas) occur extensively in the lagoons of both Bok-ak and Pikaar. The author has never observed such high giant clam densities elsewhere in the central west Pacific. Furthermore, extensive sea turtle nesting and swimming activity was reported at Pikaar.

Tōke Atoll is more properly intermediate in form between the semi enclosed atoll and open lagoon atoll groups. Like Bok-ak and Pikaar, Tōke atoll has a single narrow pass on the western side. Unlike the other two atolls, Tōke's lagoon is deep and lacks the ribbon reef formations. Lagoon patch and pinnacle reefs are more circular in form, and lagoon reefs are not elevated above mean low tide levels as noted for Bok-ak and Pikaar. Giant clam populations at Tōke are smaller but include live specimens of the rare

largest species, Tridacna gigas. The only sighting of a hawksbill sea turtle during the expedition occurred in northeast Tōke lagoon. Although uninhabited, Tōke is near Utrōk (Utirik) Atoll. The owners of Tōke Atoll reside at Utrōk, and Utrōk fishermen occasionally visit Tōke to harvest fish and shellfish. Small boat navigation through the channel and landing small boats at islands along the lagoon shorelines are relatively safe. Several important reef areas of special interest due to good coral development and diversity were observed at Tōke Atoll.

Jemo is one of only five table reefs in the Marshalls and the only one which was visited. Due to the lack of a lagoon, and heavy exposure to ocean waves and swells from virtually any direction, Jemo's reefs have unusual geomorphology and limited coral development. Only the southwestern end of the reef is shallow enough to form a reef flat exposed at low tide, upon which Jemo Island is situated. Elsewhere, Jemo's reef crest does not emerge at mean low tide and is dominated by a curious but extensive network of sand covered surge channels oriented in a north-south axis

The outer reef margins consist of scoured sloping pavements with limited coral growth. Coral species diversity is low, less than half of that of the other areas surveyed, and is probably controlled by exposure to heavy waves and limitations in habitat diversity and abundance. The very steep, deeper reef slopes showed higher coral diversity. The best coral development occurred within a semi-protected reef indentation on the north side. Jemo's beaches support the second largest sea turtle nesting population observed in the Marshalls (only Pikaar's population is reported to be larger). Jemo island itself is relatively inaccessible due to hazardous reef conditions, lack of protection from waves, and the lack of a safe approach to the island except during calm seas. The numerous sharks and large swells would also discourage snorkeling and diving interest at Jemo.

Wōtto, Ronđik, and Ādkup are the largest of the atolls visited during the September 1988 expedition, but are relatively modest in size compared to many other atolls in the Marshalls. All three have large passes, deep open lagoons, and a diverse set of lagoon and ocean reef habitats. Wōtto and Ronđik in particular have unique and aesthetically interesting coral and beach habitats, including pink sand beaches. A blue coral reef moat occurs at Ronđik, and diverse and flourishing coral and clam habitats occur at Wōtto. Boat passage through channels and lagoon access to islands are safe. The inhabitants of Wōtto have expressed strong interest in promoting tourism at their atoll and prior to our expedition, requested financial and technical assistance to develop a tourism facility.

From the standpoint of uniqueness of reef forms, Bok-ak, Pikaar, and Jemo all warrant special recognition and research interest. The huge giant clam populations at Bok-ak and Pikaar, and the large sea turtle nesting populations at Pikaar and Jemo also argue for marine and island reserve designations. When coupled with the extraordinary seabird nesting populations at Bok-ak and lesser but important bird populations at Pikaar and Jemo, all three areas should be established as part of a system of national ecological reserves (Thomas et al 1989). Such designation will require the cooperation of persons with traditional rights to these areas. All three of these areas are unsafe with respect to boat access and landing, which reinforces their preferred status as limited entry reserves. In particular, the clam and turtle populations would be vulnerable to over exploitation, and access to the three areas should be strictly controlled in any case.

Proposals to enlarge or widen the reef passes at Bok-ak and Pikaar to promote safe boat access would result in major and perhaps catastrophic impact to lagoon reefs. Aside from direct destruction of reefs, low tide water levels in the lagoons would probably drop, exposing and killing the living tops of elevated reefs throughout the atolls' lagoons. Circulation in the lagoons would also change and possibly harm resident giant clam populations.

Tōke and Wōtto Atolls seem well suited as possible national marine parks open to both tourism and resident recreational use. Residents could manage and monitor the areas as marine parks, perhaps as part of small scale tourism development. Access and landing at both atolls is relatively safe, accessible snorkeling areas exist, and diversity and development of coral reef environments is high. Although residents expressed strong interest in tourism and marine park development at Wōtto, it was not possible to query the Utrōk islanders on their views for similar development at Tōke. Nature based tourism and park use would benefit the natural and cultural resources in both areas if properly planned and managed.

Ādkup and Rōndik atolls likewise have many attributes supporting marine park designation. Ādkup, although uninhabited, is heavily utilized as a traditional harvest ("pantry") area by visiting fishermen and islanders from nearby Wotje Atoll. Any future designation of portions of Ādkup for marine park and sanctuary status should reflect the coordination with and the views of the traditional resource users and owners. Although specific areas of both Ādkup and Rōndik are suitable candidates for marine parks or reserves, there is less justification to designate the entire atolls as reserves or parks.

Western Rōndik Atoll could not be surveyed, but Bok (Bock) island is suspected as an important sea turtle nesting area due to its extensive white sand beaches. Follow-up observations could confirm the importance of the island for turtle nesting. Rōndik Atoll's pink sand beaches, blue coral moat, and luxuriant lagoon coral formations would be of great recreational interest to both visitors and residents.

The large populations of coconut crabs at Rōndik may eventually be heavily harvested since coconut crab is a favorite islander delicacy. However, Rōndik was exposed to fallout from the "BRAVO" atmospheric thermonuclear detonation at nearby Bikini Atoll in 1954. Fallout from the blast contaminated Bikini and the atolls of Rōnlap (Rongelap) and Utrōk. Given the close proximity of Rōndik to these other atolls, a radiological survey of the atoll is warranted to determine possible health hazard from ingestion of crabmeat and coconuts. Coconuts are known to concentrate the radionuclides cesium-137 and strontium-90 in their tissues, based upon sampling of coconut trees at both Bikini and Āne-wetak (Enewetak) Atolls conducted by Lawrence Livermore

Laboratories. Since coconut is the preferred food of the crabs, radiological contamination of coconut crabs is a definite possibility. Consumption of Rōn̄dik coconut crabs should therefore be discouraged until radiological tests have determined the crabs are safe to eat.

VI. ACKNOWLEDGEMENTS

This study of reefs and corals was part of a joint project of the South Pacific Regional Environment Programme (SPREP), the East-West Center Environment and Policy Institute, the U.S. government, and the Republic of the Marshall Islands (RMI) to assess the ecological and cultural conditions of selected reefs and islands in the Northern Marshalls to determine their suitability as candidates for a system of the RMI protected areas. The study was requested by the government of the RMI. Substantial financial support for the project came from a grant from the John D. and Catherine T. MacArthur Foundation, and matching support was provided in the form of scientific participation by the U.S. Army Corps of Engineers, the East-West Center, the National Marine Fisheries Service, and the U.S. Fish and Wildlife Service. This project also contributes to the RMI Coastal Inventory and Atlas program supported by U.S. Congressional appropriations to the U.S. Army Corps of Engineers and as described in the RMI Plan of Action for Water Resources (OEA, 1989).

A number of officials in the Republic of the Marshall Islands provided critical support for the project: we thank Peter Oliver, Special Assistant to the Chief Secretary; Oscar De Brum, Chief Secretary; the late Stephen Muller, Director of the RMI Marine Resources Authority; Larry Muller, Captain of the patrol vessel Ionmeto I, and the vessel crew; Gerald Knight, Director of the Alele Museum; Alfred Capelle, RMI Resource Protection Officer; Abacca Anjain, Acting Secretary of Interior and Outer Island Affairs; and the atoll owners and land managers (alab) for granting access to their island and reefs. We thank the project leader, Dr. Lawrence Hamilton, Research Associate, EAPI for administrative support, and the late Dr. F. Raymond Fosberg of the Smithsonian Institution for sharing his extensive experience and advice on the Marshall Islands. Finally, I extend my appreciation to the other members of the expedition who assisted on the marine surveys, especially Peter Thomas, Virgil Alfred, Paul Maddison, and John Naughton; and to Linda Mizuguchi, Karen Tomoyasu, Chris Cabacungan, Jan Eber, Jody Oyama, Jennifer Gorospe, Mary Hayano, Gidget Tsui, and Karin Z. Meier for word processing and/or editing support. I thank Jim Laurel of Aspect Software Engineering Inc. and Karin Z. Meier of CORIAL for digitizing the maps, and preparing most of the map figures for this report. Finally, I thank Mr. Alfred Capelle for providing the correct spellings of place names used in the text and added to the maps.

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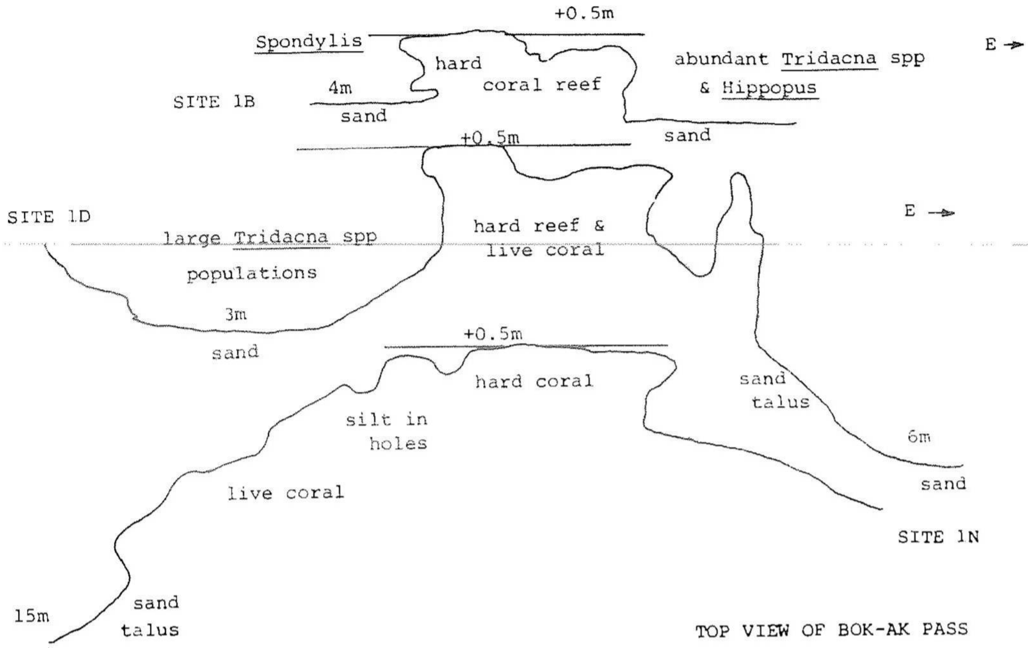
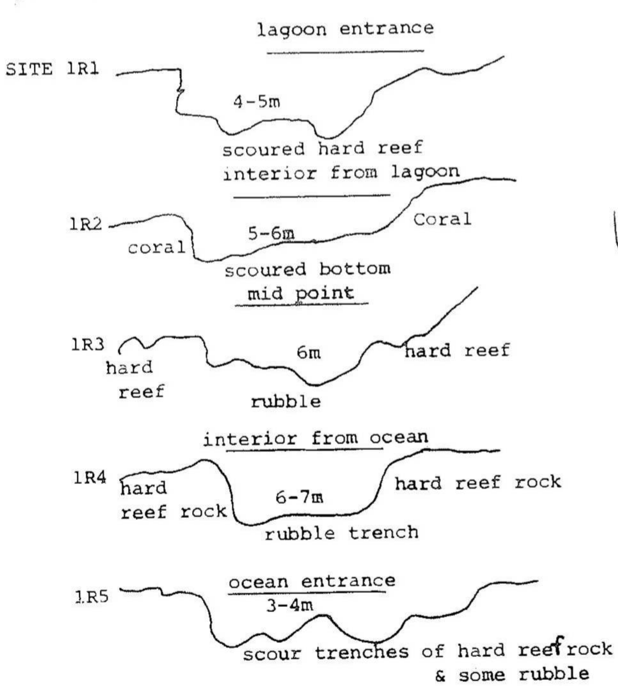
Appendix A.

Fig. A-1

BOK - AK Atoll

REEF PROFILES: LAGOON AND PASS REEFS





CROSS SECTIONS OF BOK-AK PASS

TOP VIEW OF BOK-AK PASS

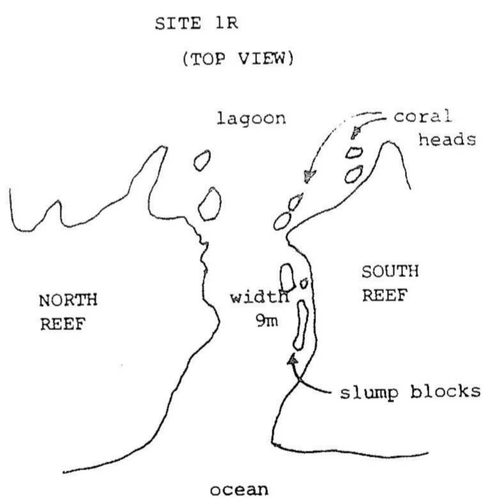


FIG A-2
BOK - AK Atoll

REEF PROFILES: EASTERN PERIMETER REEFS

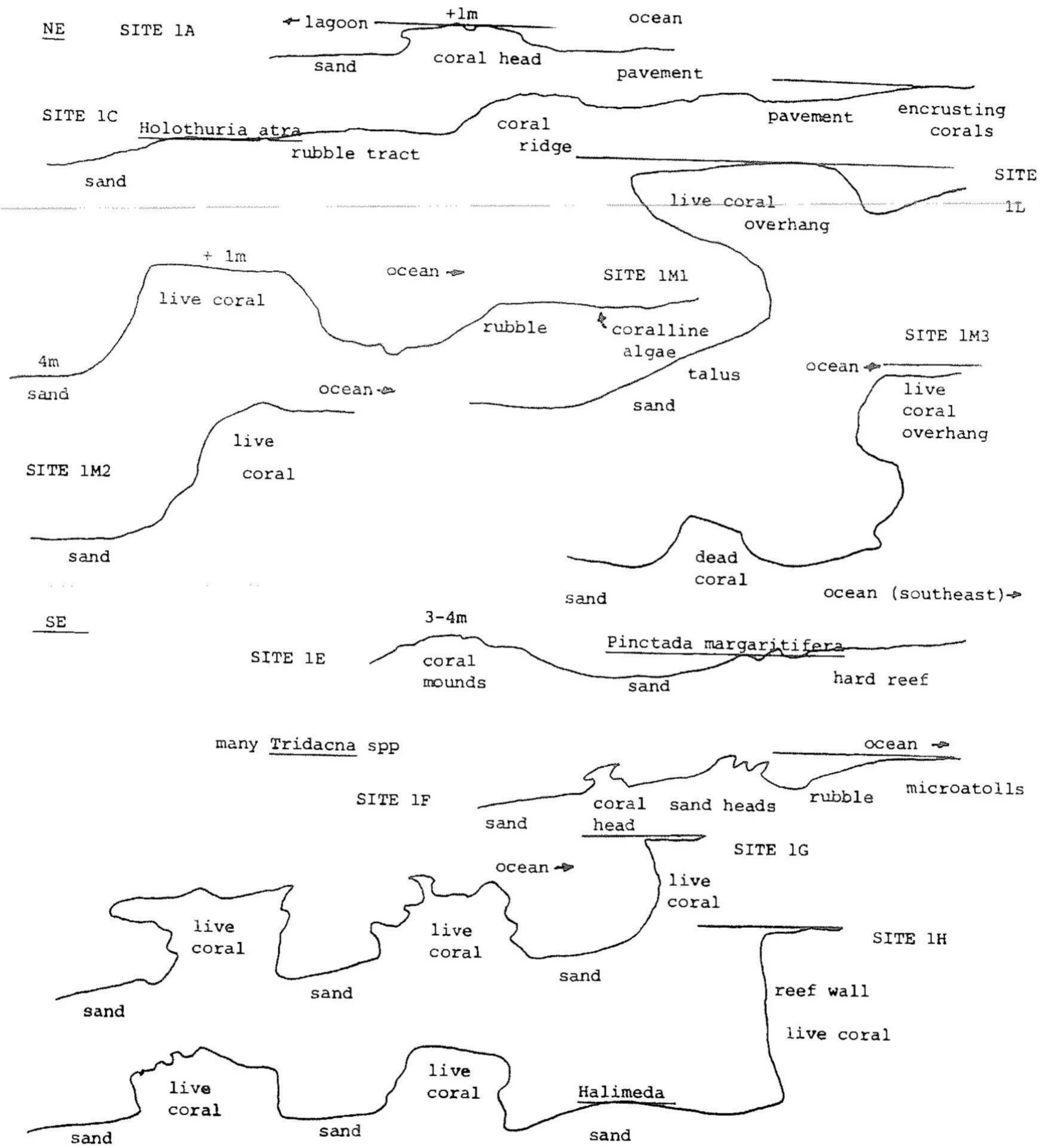


FIG. A-3

BOK - AK Atoll REEF PROFILES: WESTERN PERIMETER REEFS

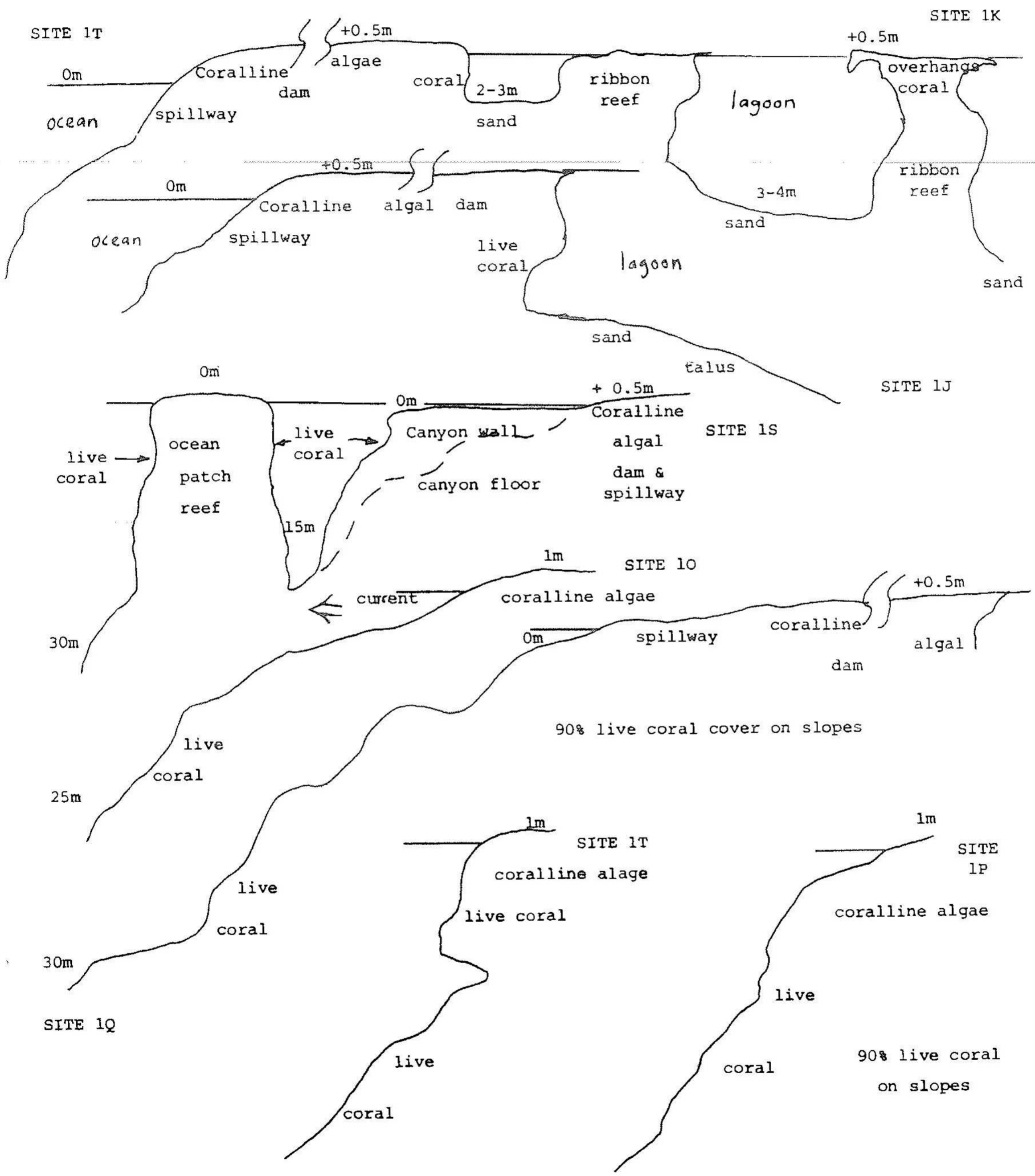


FIG. A-4

PIKAAR ATOLL REEF PROFILES: PERIMETER REEFS

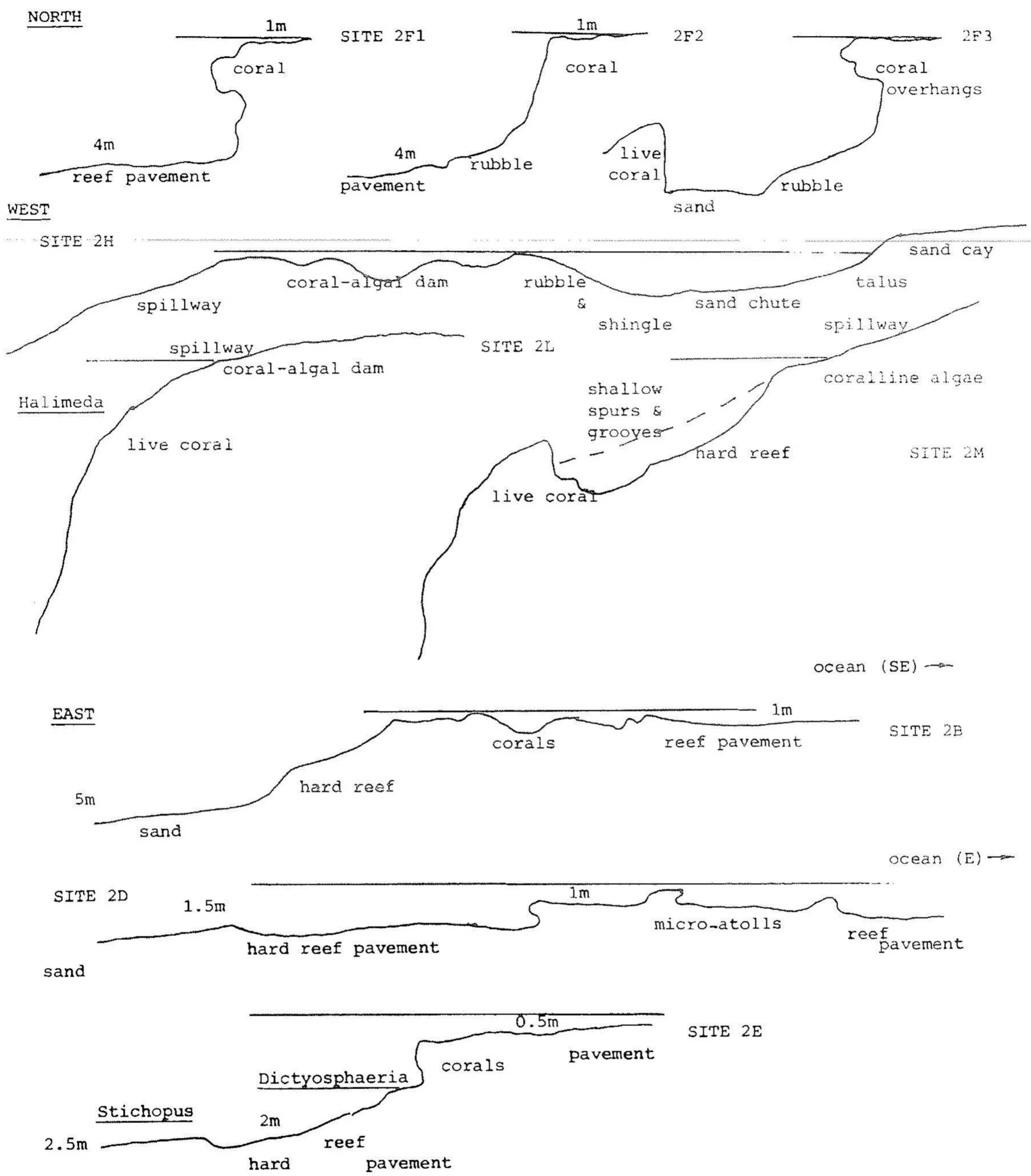


FIG. A-5

PIKAAR ATOLL REEF PROFILES: LAGOON REEFS & PERIMETER REEF

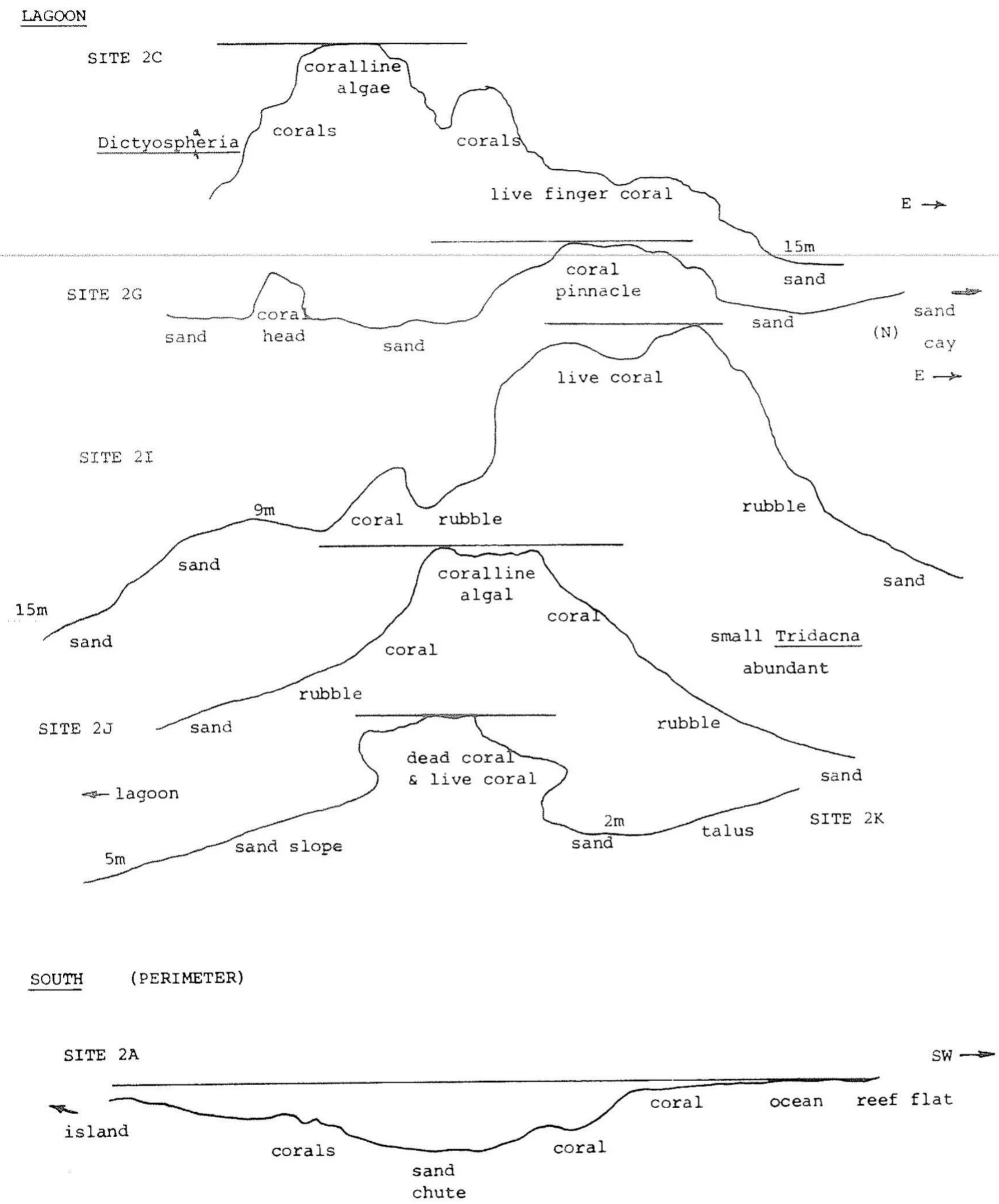


FIG. A-6
TŌKE ATOLL

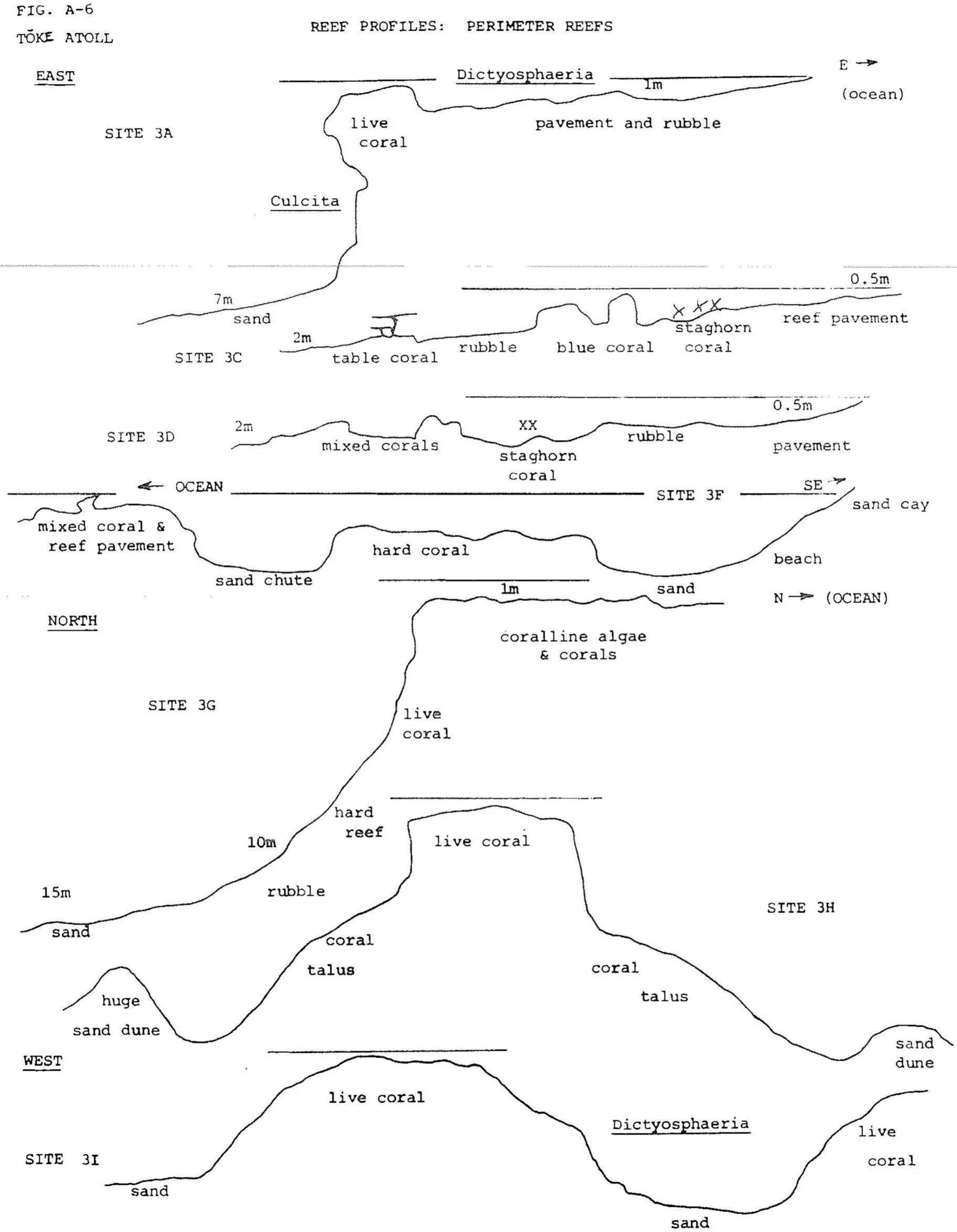


FIG. A-7
TŌKE ATOLL

REEF PROFILES: WESTERN PERIMETER AND LAGOON REEFS

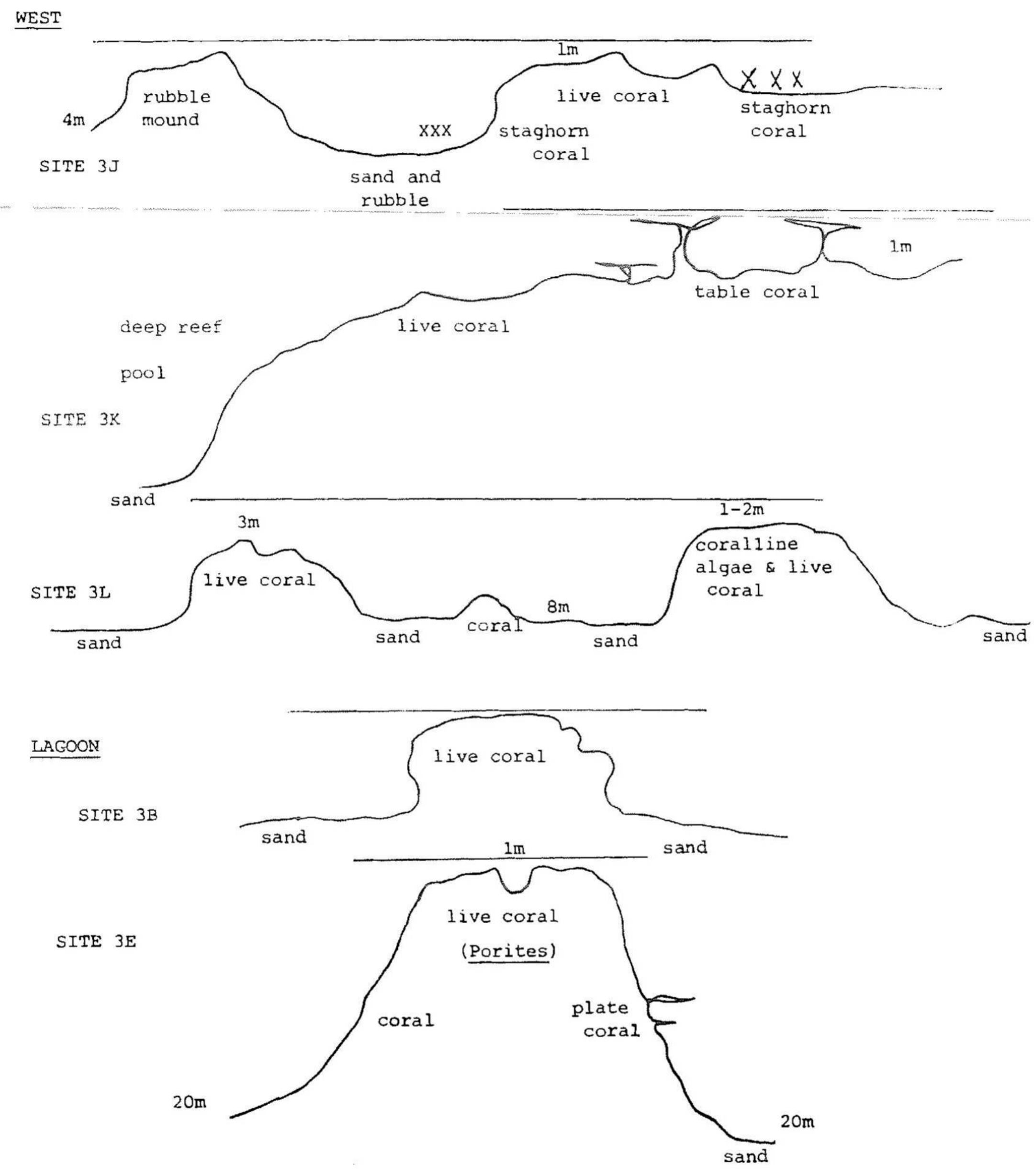


FIG. A-8

JEMO

REEF PROFILES: OCEAN SLOPES

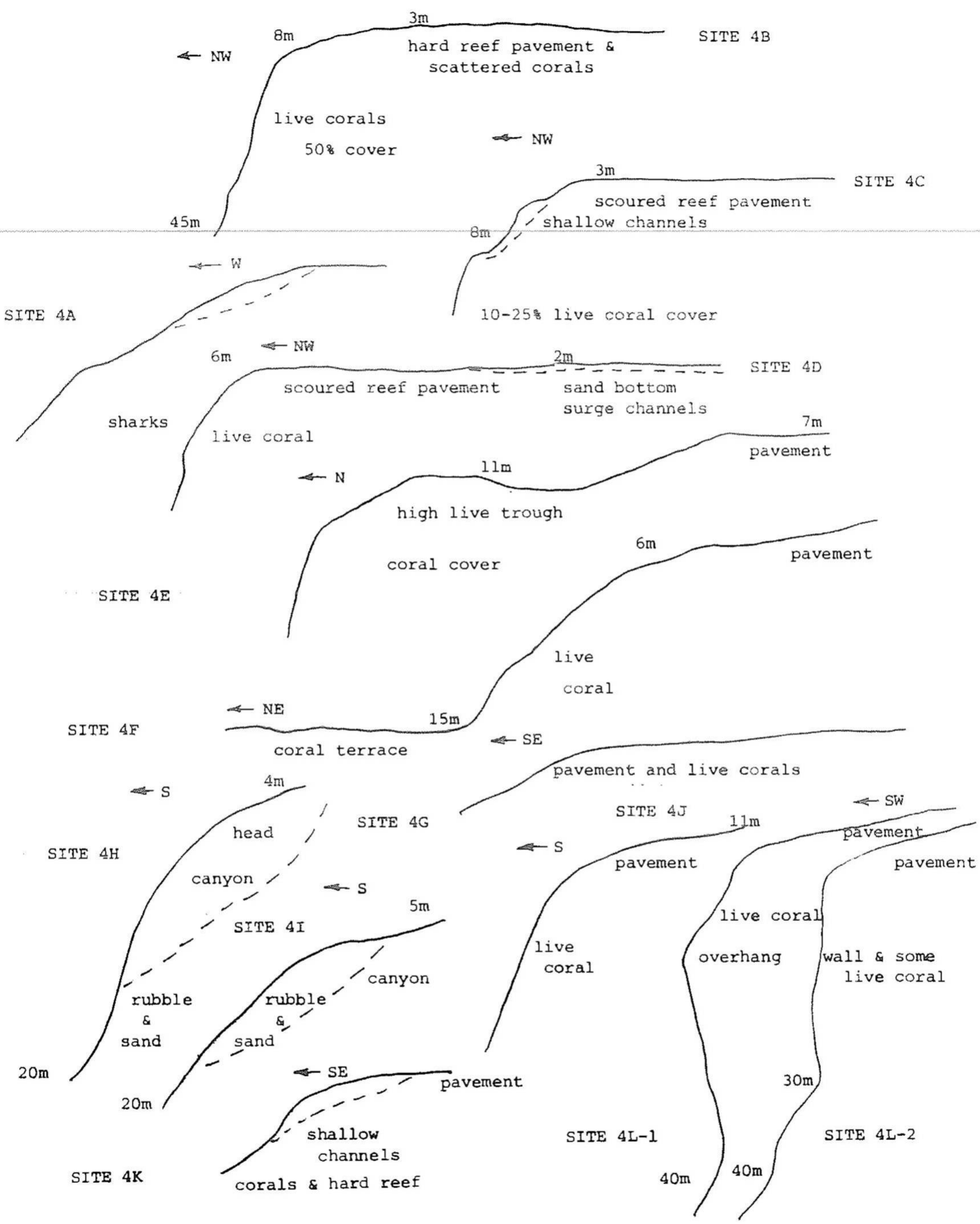


FIG. A-9 REEF PROFILES: NORTH AND EASTERN PERIMETER

WÕTTO ATOLL
REEFS

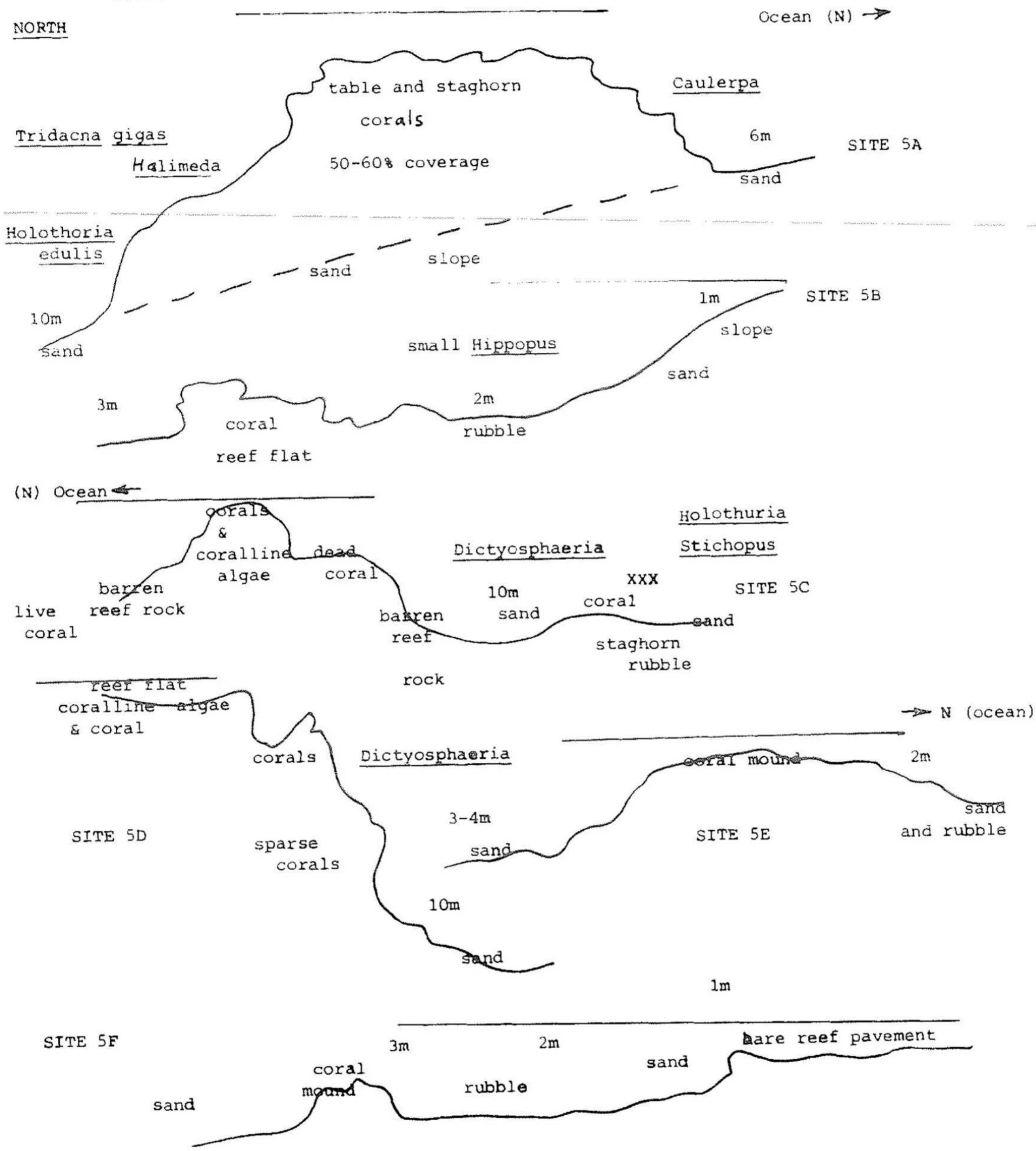


FIG. A-10

WŌTTO ATOLL REEF PROFILES: EASTERN AND SOUTHERN PERIMETER REEFS

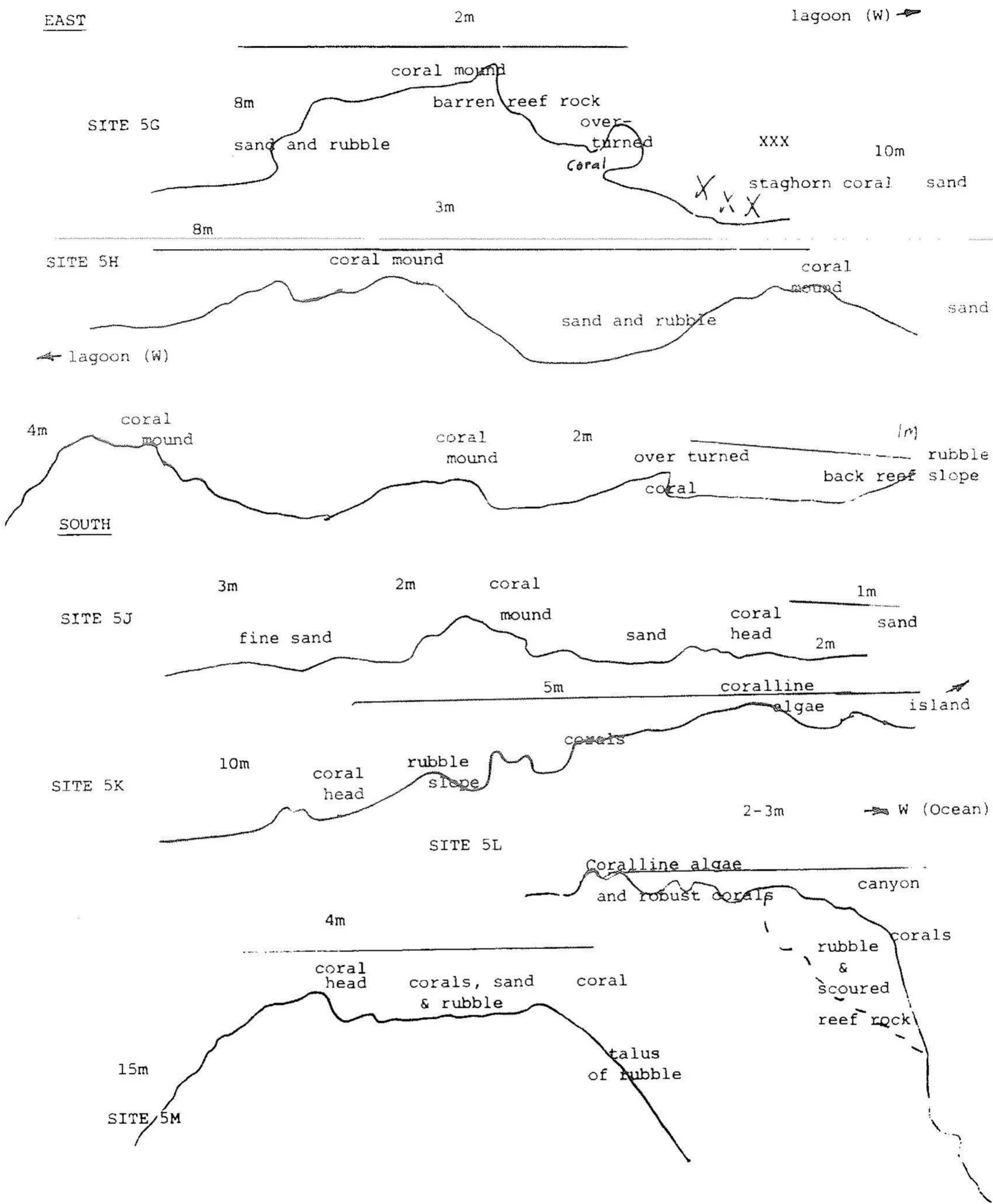


FIG. A-11

RONDIK ATOLL REEF PROFILES: SOUTHEAST PERIMETER REEFS

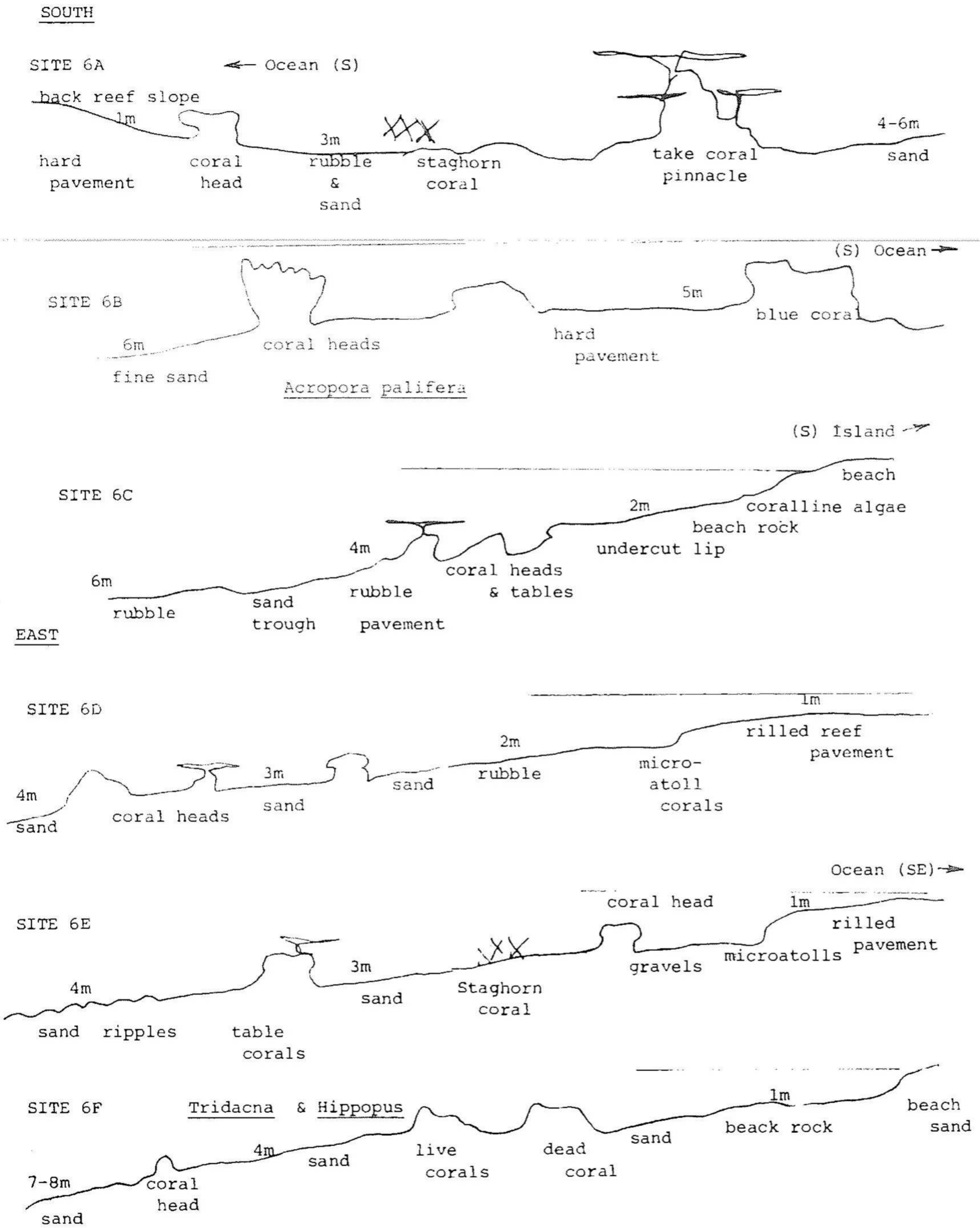


FIG. A-12
RONDIK ATOLL REEF PROFILES: NORTHEAST PERIMETER AND LAGOON REEFS

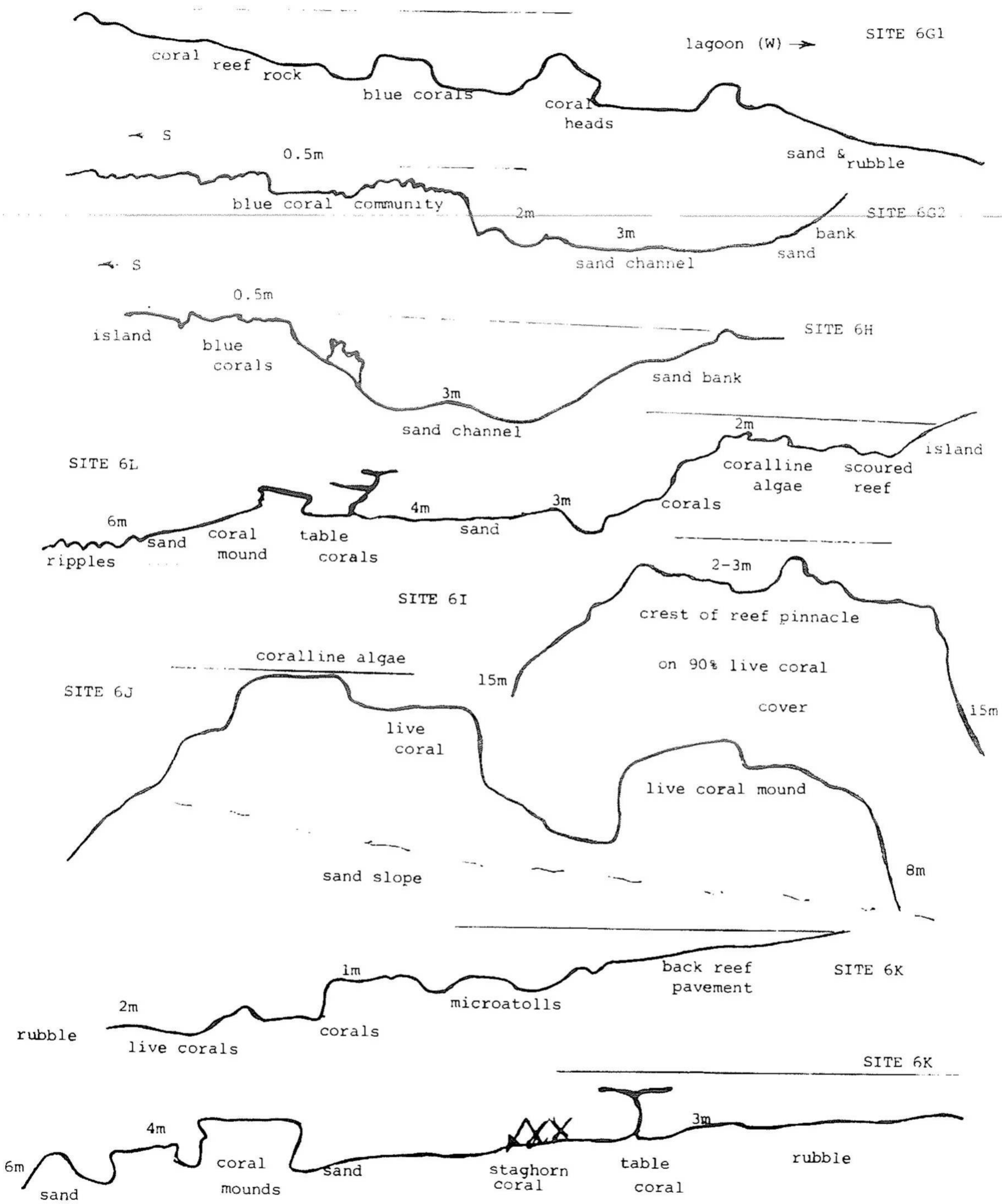


FIG. A-13

ĀDKUP ATOLL REEF PROFILES: SOUTHERN PERIMETER REEFS

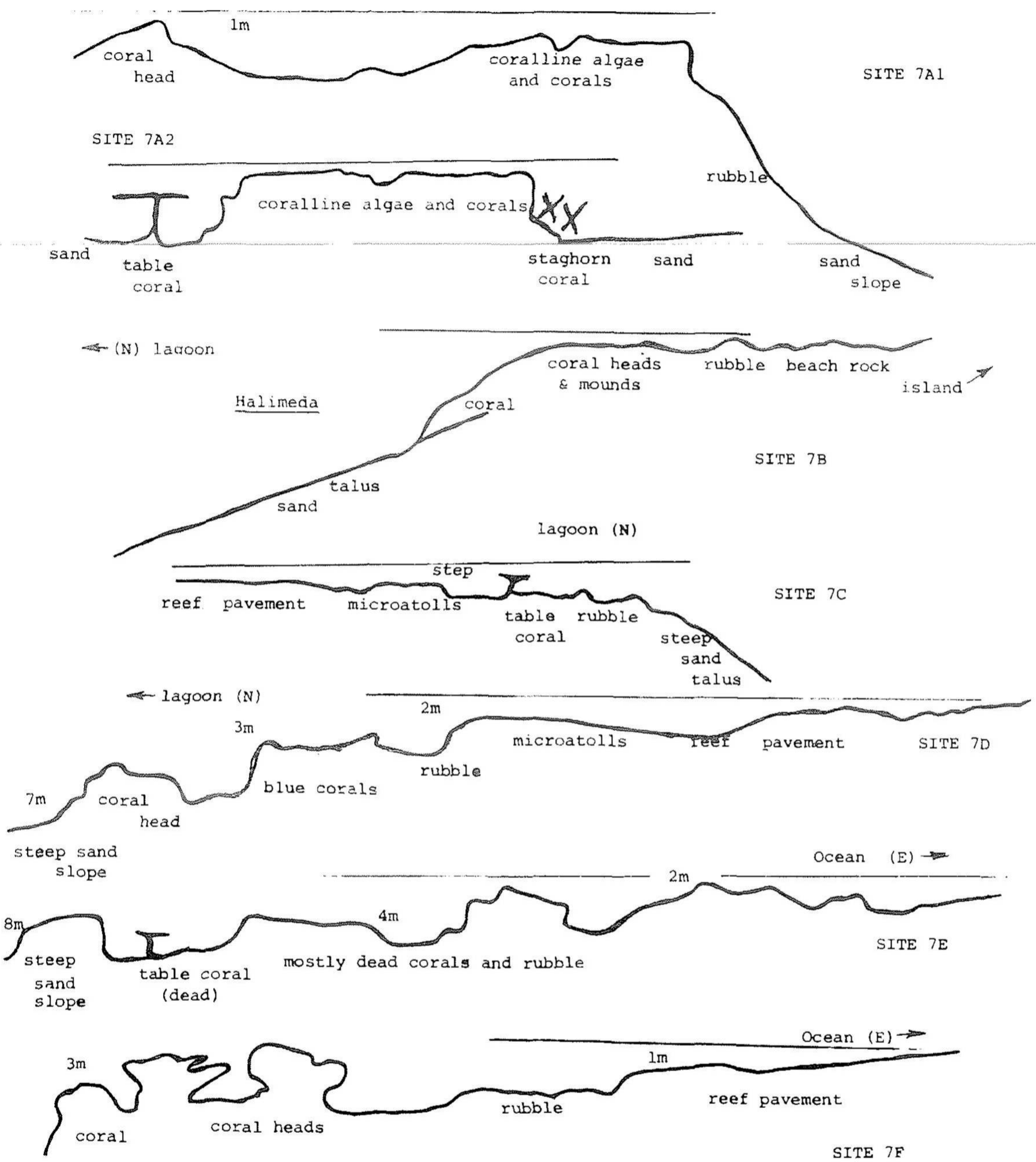
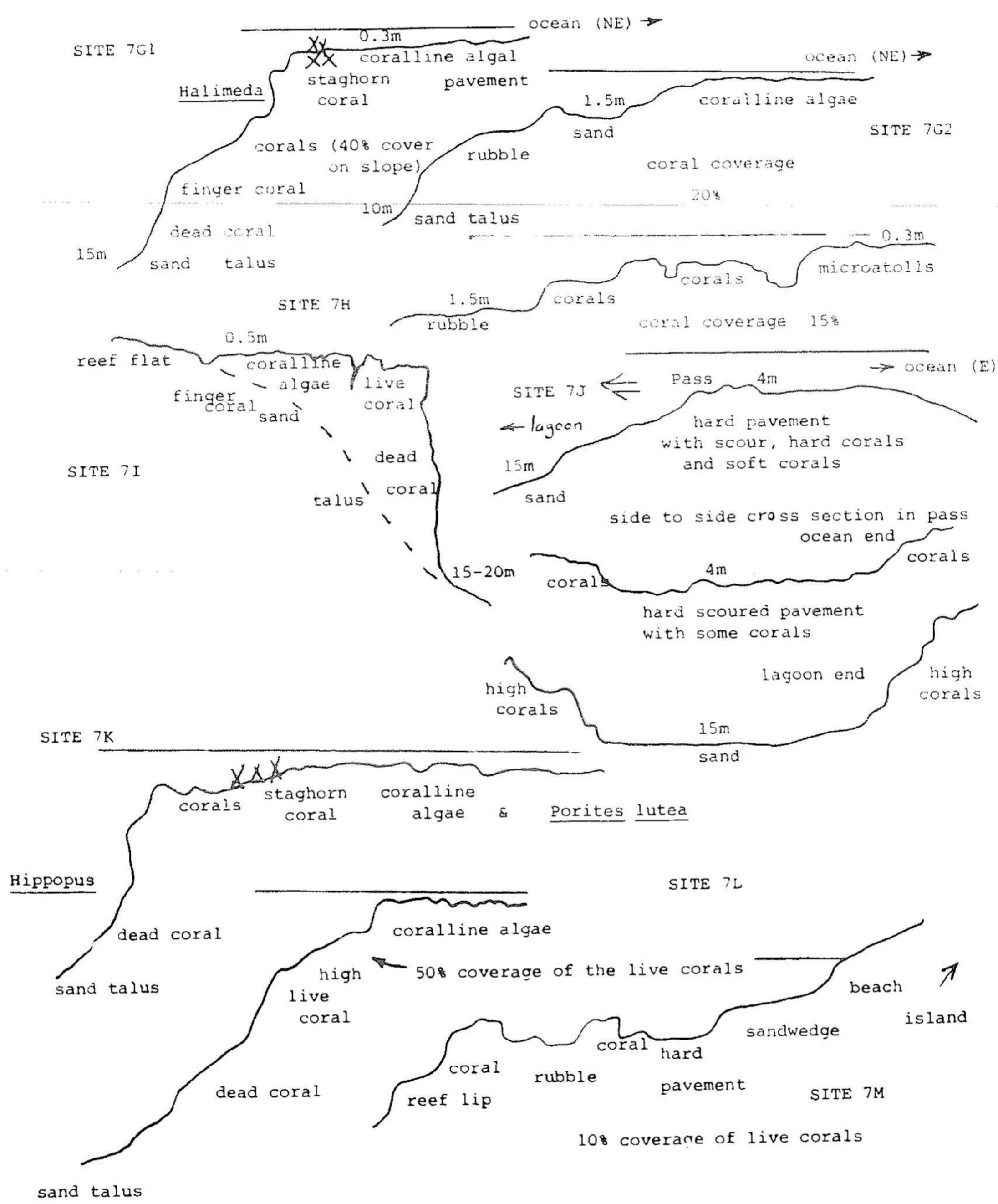


FIG. A-14

ĀDKUP ATOLL REEF PROFILES: NORTHERN PERIMETER REEFS



Appendix B.

Definitions for relative abundance terms used in the field for corals

SYMBOL	TERM	DEFINITION (WITHIN A ZONE OR HABITAT TYPE ON THE REEF)	DEFINITION (FOR THE REEF SITE AS A WHOLE)
D	dominant	the coral constitutes a majority in abundance or coverage (50% or more of total)	the coral contributes substantial abundance or coverage (25% or more of total) or is conspicuous in all zones
A	abundant	the coral contributes substantial abundance or coverage, or is very numerous	coral is conspicuous in most zones or is dominant within a single zone
C	common	coral present as several or more individuals or as a few larger colonies	coral conspicuous in only one or a few zones or locally substantial in a single zone
O	occasional	uncommon, present only as a few individuals, or present as a single conspicuous individual	present more than once but not substantially within a single zone
R	rare	reported only once as a single individual	reported only once from the reef

Appendix C.

Map sources for selected northern Marshall atolls.
AMS = Army Map Service Series W861 (all at scale 1:25,000, except Wōtto which has a scale of 1:50,000).
DMA = Defense Mapping Agency charts (various scales).

<u>ĀDKUP</u> (ERIKUB)
AMS - 8249 I SW, II NW, SW, III NE; IV NE, SE
DMA - none

<u>BOK-AK</u> (TAONGI)
AMS - 8066 III NE, SE; IV SE
DMA - 81626A (1:50, 190)

<u>JEMO̧</u>
AMS - 8152 III SW
DMA - none

<u>PIKAAR</u> (BIKAR)
AMS - 8258 IV NW, SW
DMA - 81626B, C (1:10,110; 1:50,200)

<u>ROÑDIK</u> (RONGERIK)
AMS - 7755 IV NE, NW, SE, SW
DMA - 81557A (1:50,000)

<u>TŌKE</u> (Taka)
AMS - 8155 III NE, NW, SE, SW
DMA - 81616A (1:10,000; 1:50,310)

<u>WŌTTO</u> (WOTHO)
AMS - 7352 II (1:50,000)
DMA - 81030C (1:316,120)

<u>ALINGINAE</u>
AMS - 7455 II NW, SE, SW; III SE
DMA - 81557B (1:72,500)

Appendix D.

Index of aerial photographs consulted during the study from 1978 color (EG&G) and 1944-1945 black-and-white U.S. War Dept. (VD3) sources, the latter at the Bernice P. Bishop Museum Map and aerial photo collections, Honolulu.

ROÑDIK (RONGERIK) ATOLL

EG&G Roll 8, perf 2234: frames 59-60, 62, 70-79, 82-90, 93-95, 101-110 (35 negatives, scale 1:30,000; 16 Aug 1978)

VDB - oblique aerial photos only

TŌKE (TAKA) ATOLL

EG&G Roll 7, perf 2205: frames 22-23, 102-106, 110-123, perf 2185: frames 208-216 (38 negatives, scale 1:30,000; 11 Aug 1978)

VDB - p. 40316-36 frames 1-14; VD3-AP47A figures 1-41; and VD3 - AP47B photomosaic (55 negatives, scale unknown; 5 March 1944)

PIKAAR (BIKAR) ATOLL

EG&G Roll 12, perf 2305: frames 9-94, 98-103, 121, 123, 125, 137-139 (16 negatives, scale 1:30,000; 8 Aug 1978)

VD3 - oblique aerial photos only

WŌTTO (WOTHO) ATOLL

EG&G Roll 10, perf 2259: frames 4, 6, 8, 10, 54, 56-59, 108-109, 116-118, 134-138, 153-157, (24 negatives, scale 1:30,000; 18 Aug 1978)

VD3 - AP41B frames 1-39 (39 negatives, unknown scale; 29 Feb 1944)

JEMO

EG&G Roll 1, perf 2096: frames 33, 35, 36 (3 negatives, scale 1:30,000; 29 July 1978), Roll 2, perf 2122: frame 150 (1 negative, scale 1:8,000; 5 Aug 1978)

VD3 - oblique aerial photos only

ĀDKUP (ERIKUB) ATOLL

VD3 - AP16A frames 1-8 and VD3-AP16B frames 1-2 (10 negatives, unknown scale; 4 Feb 1944)

BOK-AK (TAOGI, POKAK) ATOLL

VD3-12, frames 1-10 (10 negatives, unknown scale; 28 Mar 1945)