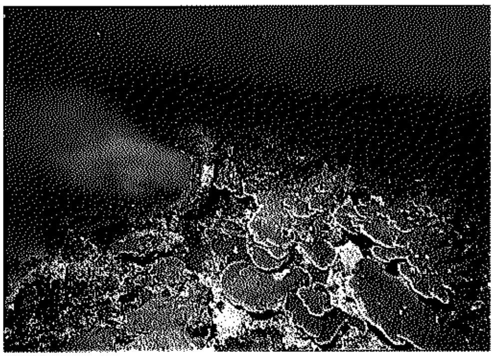
Status of Coral Reefs in the Pacific

INTERNATIONAL YEAR of the REEF 97



PSA

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SEA GRANT HAWAII

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June 1997

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PREFACE

In June of 1993, Robert N. Ginsburg of the University of Miami organized a Colloquium on "Global Aspects of Coral Reefs: Health, Hazards and History." One hundred and twenty-two marine scientists representing 22 countries attended the four-day meeting held at the University of Miami and presented the results of their research on 62 coral reefs around the world. A major conclusion of the Colloquium was that while vast areas of remote reefs have not been studied, many nearshore reefs adjacent to, or near, urban population centers are suffering significant ecological decline. Of approximately 600,000 km² of coral reefs worldwide, it was estimated that about 10% have been seriously degraded and another 20-30% may decline significantly in the next 20 years. The principal causal factors of anthropogenic origin listed by the Colloquium were overfishing, eutrophication and sedimentation. The most significant sources of impact from natural factors were listed as hurricanes, unusually high temperature associated with El-Niño-Southern-Oscillation (ENSO) events, various coral diseases, and imbalances in key predators (crown-of-thorns and urchins). The Colloquium recognized an urgent need to conduct a comprehensive assessment of coral reefs worldwide and to evaluate existing impacts. In essence, a call to action to assess the status of coral reefs worldwide was issued by the coral reef scientific community. It was the beginning of what was to become, four years later, the International Year of the Reef (IYOR).

During the time between the Miami Colloquium and the IYOR in 1997, the United States State Department initiated a similar program designed to conserve and manage global coral reef resources. This program has been named the International Coral Reef Initiative (ICRI). Its major thrust is to organize governmental partnerships with those countries that have coral reefs in order to protect, restore and sustain their coral reef resources. Many of the goals and objectives of the IYOR and the ICRI programs share common ground. This book is one example of the cooperation that exists between the two programs. By way of a grant from ICRI to the IYOR, funding was provided to the Pacific Science Association's Scientific Committee on Coral Reefs to conduct an assessment of coral reefs in the Pacific Ocean. The grant was awarded to Robert N. Ginsburg of the University of Miami. In turn, Ginsburg used part of the funds in the grant to support the activities of the PSA Coral Reef Scientific Committee. Ten internationally recognized coral reef scientists, all but one, members of the PSA Scientific Committee on Coral Reefs, were commissioned to prepare reports on the status and health of coral reefs in their region or country. Areas represented include the Central Pacific (James E. Maragos), the Eastern Pacific (Peter W. Glynn), French Polynesia (Claude E. Payri and Fabienne Bourdelin), the Hawaiian Islands (Richard W. Grigg), Indonesia (Aprilani Soegiarto), Guam and the Northern Mariana Islands (Charles Birkeland), Okinawa (Kiyoshi Yamazato), the Philippine Islands (Helen Yap), *Taiwan (Chang-feng Dai), and Thailand (Surapol Sudara).*

The Sea Grant College Program at the University of Hawaii became a fourth partner in this cooperative quadripartite by agreeing to publish the results of the studies. Richard W. Grigg as a member of the Organizing Committee of the IYOR and Chuck Birkeland as Chairman of the PSA Scientific Committee on Coral Reefs coordinated the PSA activity and are co-editors of the book.

Publication of the "Status of Coral Reefs in the Pacific" was scheduled to coincide with the VIII PSA Inter Congress held in Suva, Fiji, July 13-19, 1997. Results reported in this volume were presented and discussed at the Fiji meeting.

In brief, the results of coral reef assessments in the Pacific reported in this volume are as follows:

The condition of coral reefs in the Pacific varies enormously depending on their exposure to hurricanes and typhoons, extremes in El Niño events, and anthropogenic stress which is most pronounced in proximity to urban centers. Reefs in areas of high population density show general declines in health as measured by coral cover and the biomass and size frequency of coral reef fish. Overfishing by foreign vessels in remote areas for target species such as Tridacna, Torchus *and high priced fishes such as Napoleon wrasses and groupers is a mounting problem.*

Eastern Pacific reefs are in the worst condition having been devastated by a large El Niño event in 1982-83 and suffered secondary losses due to bio-erosion during subsequent years. Coral reefs in the best condition and least impacted by anthropogenic sources of stress (overfishing, sedimentation and eutrophication) are in the Central Pacific, including the Hawaiian Islands and the Northern Mariana Islands. In general, these reefs are under the control of natural processes although increasingly serious local impacts from various anthropogenic sources exist and are associated with a widespread trend in increasing human population.

Reefs most impacted by human activities, (primarily sedimentation and overfishing), exist in the Indo-West-Pacific and Southeast Asia regions. Recent surveys show that the percent of coral reefs described as low (0-25% coral cover) or moderate (25-50% coral cover) in Taiwan, the Philippine Islands, Indonesia and Thailand are 87%, 70%, 71% and 64%, respectively. Problems in all four areas are described as increasing, associated with increasing human population. Since most impacts are anthropogenically induced, management solutions are feasible, although socially and economically difficult. Clearly, coral reefs in the Southeast Asia region are in the most urgent need of remediation.

The editors would like to acknowledge Robert N. Ginsburg, the father of the IYOR, for his leadership and vision in establishing the program and for his help in obtaining support for the PSA activity that led to this volume. The editors also acknowledge and thank the authors of the individual chapters that make up the book. We also thank the University of Hawaii Sea Grant College Program for publishing our research results in this volume. Priscilla Billig and Diane Nakashima, Sea Grant Communications, provided editorial assistance with all aspects of the publication of the book including copy editing, layout and production. This publication is funded by a grant from the National Oceanic and Atmospheric Administration, project #M/PM-2, which is sponsored by the University of Hawaii Sea Grant College Program, SOEST, under Institutional Grant No. NA36RG0507 from NOAA Office of Sea Grant, Department of Commerce. The views expressed herein are those of the author(s) and do not necessarily reflect the views of NOAA or any of its sub-agencies.
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CENTRAL PACIFIC

CORAL REEF HEALTH IN THE CENTRAL PACIFIC

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This review covers coral reefs in the Caroline Islands (Republic of Palau and the Federated States of Micronesia), the Marshall Islands (Republic of the Marshalls and Wake Island), the Gilbert and Phoenix Islands (Republic of Kiribati), the single island Republic of Nauru, the Line Islands (Republic of Kiribati and the U.S.), the Ellice Islands (Republic of Tuvalu) and Tokelau. Islands within this region are mostly atolls and low coral islands, except for two raised limestone islands (Nauru, Banaba), and five clusters of high volcanic islands in the Carolines (Palau, Yap, Chuuk, Pohnpei, and Kosrae). Collectively, the region includes 73 fringing, 3 barrier, 93 atoll, and 7 submerged reef systems.

Prior to the western influence of the past few centuries, all of the Caroline, Marshall, Gilbert, Ellice and Tokelau Islands were inhabited or regularly visited by Micronesians or Polynesians over a period of one to three thousand years; in contrast, the Phoenix and Line Islands were uninhabited or rarely visited. During the mid-19th to 20th centuries, the islands were claimed, colonized or occupied by foreign powers (Spain, Germany, Great Britain, U.S., New Zealand, and Japan). During this period economic development focused on copra plantations, phosphate rock mining, fishing, military activities (building bases, warfare, weapons testing) and infrastructure (ports, airfields, roads, etc.). Later, several of the Line and Phoenix Islands were visited or settled to promote copra production, phosphate mining, and military activities. Eventually, the Phoenix Islands except Kanton were abandoned. Several northern Line Islands (Johnston, Teraina, Tabuaeran, and Kiritimati) are still occupied, the first as a U.S. military installation, and the last three as growing permanent settlements of Kiribati. Within the region, about 25 of the islands and atolls remain uninhabited, although there are plans to settle Kiribati islanders on several of the Phoenix Islands. By the end of the 1970s Nauru, Kiribati, and Tuvalu achieved independence; by 1986 the Marshalls and FSM achieved independence; and by 1994 Palau achieved independence. Six of the Line Islands (Johnston, Palmyra, Kingman, Jarvis, Howland, Baker) and Wake remain as sovereign territory of the U.S., while the three atolls that form Tokelau are a protectorate of New Zealand.

The reefs throughout the central Pacific region are generally in good to excellent condition, with some exceptions. Nuclear testing and base construction at Enewetak and Bikini (Marshalls), and military construction and warfare at Ulithi, Kanton, Palmyra, Wake, Tarawa, Chuuk, Kwajalein, Mili, Jaluit, Johnston, and Funafuti have resulted in permanent damage or longterm recovery of coral reefs. Infrastructure development and urban population centers within the region include Kwajalein and Majuro (Marshalls); Lelu/Tofol, Kolonia, Colonia, and Chuuk Lagoon (FSM); Tarawa and Kiritimati (Kiribati); Koror-Southern Babeldaob (Palau); and Funafuti (Tuvalu). There are also residual impacts to reef and island habitats at Nauru and Banaba from phosphate rock mining. Illegal or destructive harvesting of reef resources has also degraded reefs on many remote and uninhabited reefs, including depletion of giant clams, sharks, and other finfish, dugongs, crocodiles, sea turtles, coconut crabs, lobsters, and other shellfish.

Urbanization and related impacts to coral reefs are expected to increase from sewage pollution, rubbish disposal, dredging and filling, sedimentation, freshwater discharge, overharvesting of reef resources and oil spills. Ship groundings are also a problem. Continued rapid population growth and migration from rural islands to urban centers (urban drift) are the main causes for the increase. Higher levels of resort development and road/airfield construction may extend impacts beyond urban centers on some islands, especially Babeldaob, Majuro, Yap, Chuuk, Kosrae, Pohnpei, Funafuti, and Kiritimati. Kiribati is also now investigating the resettlement of several of the southern Phoenix Islands and is expanding resettlement on the northern Line Islands. Some of the uninhabited islands and atolls in the Marshalls and FSM may be resettled, while most in Palau have already be settled. Several atolls in the Line Islands may be proposed for waste storage, space/missile testing, and resort development that could cause impact to reefs. Subsistence fishing and copra agriculture dominate development activities on rural islands, and docks and small airfields have also been established. Except for illegal or destructive harvesting practices, adverse impacts to coral reefs on uninhabited atolls and islands remain minor. Enhanced capacity building, public education, integrated coastal resource management, and establishment of additional protected areas are recommended to help protect coral reefs. Pelagic fisheries development, mariculture, and eco-tourism would also be compatible if properly planned and implemented.

INTRODUCTION

This report summarizes existing information on the health of coral reefs in several central and central-west Pacific archipelagoes. The Caroline Islands consist of two jurisdictions, Palau at the far western end and the Federated States of Micronesia (FSM) covering the rest of the chain. The Ellice Islands are under the jurisdiction of the Republic of Tuvalu. The Gilbert Islands include the Tungaru group and Banaba (Ocean Island) of the Republic of Kiribati and the outlier island of the Republic of Nauru. The Line Islands are under the jurisdiction of the U.S. in the north and the Republic of Kiribati in the south. All but the northernmost of the Marshall Islands (Wake Atoll, under U.S. jurisdiction) belong to the Republic of the Marshall Islands. The Phoenix Islands belong to the Republic of Kiribati, and the three Tokelau Islands are a separate protectorate of New Zealand. Summary information on the eight jurisdictions and their reefs covered in this report is included in Table 1.

Physiography

The eight archipelagoes and jurisdictions straddle the Equator between the far western and the central eastern Pacific. In the west, the Caroline Islands, centered along latitudes 5-8°N,

Table 1. Summary information on the coral reefs and anthropogenic impacts on reefs in the Central Pacific covered in this report (after UNEP/IUCN 1988 and Maragos and Holthus, in press).

	FSM	KIRIBATI	MARSHALLS	NAURU	PALAU	TOKELAU	TUVALU	U.S. (Line Is)
A. GENERAL INFORMATION								
Marine jurisdiction (km²)	2,978,000	3,550,000	2,131,000	320,000	629,000	290,000	900,000	?
No. of major islands/atolls	69	36	34	1	23	3	9	7
Total land area (km²)	701	810	181	21	441	10	26	28
Population (year)	111,600 (90)	78,000 (95)	48,000 (91)	9,919 (92)	15,600 (91)	1,577 (91)	8,600 (87)	4,900 (81)
No. fringing reefs	27	15	5	1	19	—	3	3
No. barrier reefs	2	—	—	—	1	—	—	—
No. of atolls	31	18	29	—	3	3	4	4
No. of submerged reefs	1	3	—	—	2	—	1	—
Mangroves present	yes	yes	yes	yes	yes	yes	yes	no
Seagrasses present	yes	yes	yes	no	yes	no	yes	no
B. ANTHROPOGENIC STRESSES								
Military			X					X
Overharvesting	X	X	X		X	X		
Destructive fishing	X				X			
Soil erosion/sediments	X				X			
Coastal construction	X	X	X	X	X	X	X	X
Sewage/nutrients	X	X	X		X		X	X
Industrial/mining	X		X			X		
Oil spills/groundings	X		X	X	X	X	X	
Solid & hazardous waste		X	X					X
Poaching of rare spp.	X	X	X		X	X	X	
Overuse					X			
Mangrove clearing	X	X	X		X			
New settlements	X	X	X		X			

stretch over 2,000 km from longitude 131°E to 163°E. Farther east, the Marshalls, Gilberts, and Ellice archipelagoes are essentially one major chain in the central west Pacific, stretching along a NW to SE alignment between 19°N latitude to 11°S latitude and 161°E to 180°E longitude. Farther east, Howland and Baker Islands (U.S.) together with the Phoenix Islands (Kiribati) and the Tokelaus form another broad cluster of islands north of Samoa between 1°N and 9°S latitudes and 177°W and 170°W longitude. Farther east, the Line Islands including Jarvis Island and Johnston Atoll (both U.S.) stretch along a NW to SE alignment between Hawaii and French Polynesia, between 17°N and 11°S latitude and 170°W and 152°W longitudes (see Figure 1).

Islands

Collectively, the eight archipelagoes include about 182 major islands. Palau has 23 major islands, three of which are high volcanic, three are atolls, six are low coral, and the rest are high limestone islands. In addition, Palau supports over 420 "rock islands" (small raised limestone islands) as well as other small islands for a total of 591 small and large islands (see Table 2). The Federated States of Micronesia consists of four major volcanic island clusters (Yap, Chuuk, Pohnpei, and Kosrae) surrounded by 31 atolls, and six low coral islands. A total of approximately 579 low coral islets are supported by the atolls and a total of 585 large and small islands are found in the FSM (Table 3). The Republic of Kiribati consists of one high limestone island (Banaba, or Ocean Island), 18 atolls and 15 low coral islands clustered in

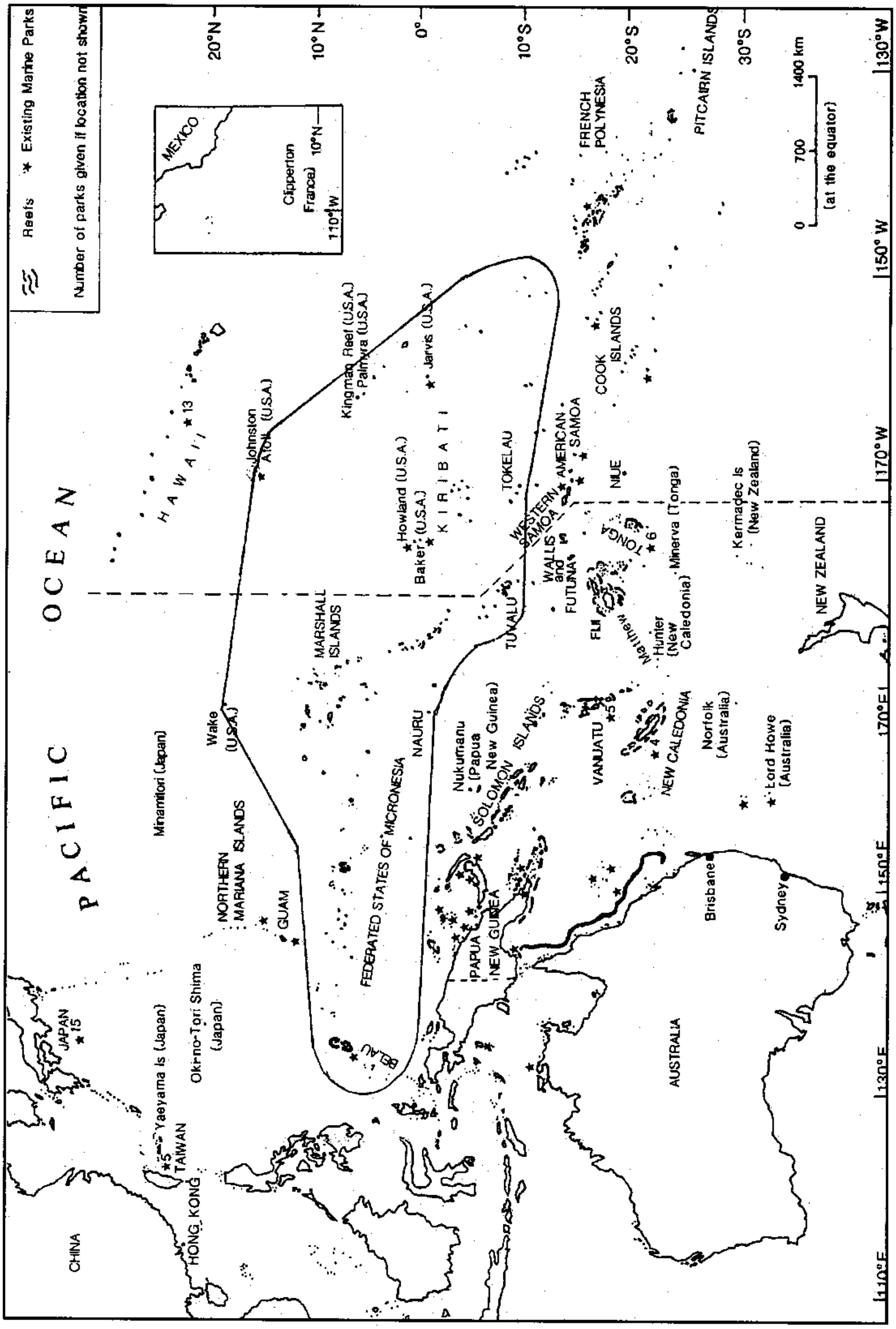

Figure 1. The archipelagos and jurisdictions of the central Pacific straddle the Equator between the far western to the central eastern Pacific. (Source of base map UNEP/IUCN 1988).

Table 2. Summary data on islands and coral reefs for Palau. After Maragos and Meier (1993a, b), Maragos et al. (1994a, b), Holthus et al. (1993a), UNEP/IUCN (1988) and Maragos and Holthus, (in press).

NAME	ISLAND TYPE & NUMBER	ISLAND AREA (km^2)	REEF TYPE	REEF PERIMETER (km)	LAGOON AREA (km^2)	NO. OF PASSES/ CHANNELS	NO. OF LAGOON REEFS
Beliliou	13 high limestone and low coral	12.7	fringing	62.4	0	2	0
Babeldaob	26 high volcanic and 41 raised limestone	374.1	fringing and lagoon fringing	143.7	0	numerous	0
Chelbacheb	420 high limestone	100	lagoon fringing	?	0	0	0
Ngeaur	4 high limestone and low coral	8.4	fringing	13.5	0	1	0
Main Palau Is.	29 low coral	?	barrier	264.7	1,021	21	1,347
Merir	1 low coral	0.85	fringing	9.5	0	0	0
Fanna	1 low coral	0.3	fringing	4.3	0	0	0
Ngercheu	1 raised limestone	?	lagoon fringing	?	0	0	0
Ngerechong	1 low coral	?	fringing and lagoon fringing	?	0	0	0
Ngerukuid	37 high limestone	0.9	fringing	?	0	0	0
Ngerekebesang	high volcanic	5.2	lagoon fringing	?	0	0	0
Ngemelachel	high volcanic	?	lagoon fringing	?	0	0	0
Oreor	1 high limestone and volcanic	9.3	fringing and lagoon fringing	?	0	several manmade	0
Ngcheangel	4 low coral	1.7	atoll	13.6	7	2	25
Ngeruangl	1 low coral	0.1	atoll	?	?	1	100
Sonsorol	1 low coral	1.9	fringing	7.0	0	1	0
Tobi	1 low coral	0.65	fringing	12.1	0	1	0
Helen	1 low coral	0.02	atoll	61.7	216	1	85
Pulo Anna	1 low coral	0.33	fringing	4.7	0	0	0
Ngeruktabel	1 high limestone	?	lagoon fringing	?	0	0	0
Ulong	1 high limestone	?	lagoon fringing	?	0	0	0
Mecherchar	1 high limestone	?	lagoon fringing	?	0	0	0
Ngerkeklau & Ngerechur	2 raised limestone	?	lagoon fringing	?	0	0	0
Velasco	none	0	Submerged atoll	?	?	1	0
Lkes	none	0	Submerged table	?	0	0	0
Total: 25							

Table 3. Summary of reef and island data for the Federated States of Micronesia. After Holthus et al. (1993a, b), UNEP/IUCN (1988) and Maragos and Holthus, (in press).

NAME	ISLAND TYPE & NUMBER	ISLAND AREA (km2)	REEF TYPE	REEF PERIMETER (km)	LAGOON AREA (km2)	NO. OF PASSES/ CHANNELS	NO. OF LAGOON REEFS
Chuuk State							
Etal	17 low coral islets	1.9	atoll	19.6	42	0	?
East Fayu	1 low coral islet	0.4	fringing (table)	7.8	0	0	0
Losap	14 low coral islets	1.0	atoll	28.3	28	3	9
Lukunor	18 low coral islets	2.8	atoll	33.8	55	1	14
Murilo	28 low coral islets	1.3	atoll	198.6	351	14	34
Nama	1 low coral islet	0.8	fringing (table)	5.7	0	0	0
Namoluk	6 low coral islets	0.8	atoll	15.4	7.5	1	4
Namonuito	12 low coral islets	4.4	atoll	230.1	?	6	5
Neoch	4 low coral islets	0.5	atoll	53.2	?	6	14
Nomwin	26 low coral islets	1.8	atoll	76.2	?	11	19
Pulap	3 low coral islets	0.8	atoll	31.0	31	3	2
Pulusuk	1 low coral islet	2.6	fringing (table)	8.9	0	0	0
Puluwat	5 low coral islets	3.4	atoll	13.3	2	1	7
Satawan	80 low coral islets	4.6	atoll	87.4	384	2	51
Chuuk Lagoon	22 low coral islets	?	barrier/almost atoll	212.1	?	17	?
Siis	low coral islet	0.65	barrier/almost atoll	?	0	?	0
Dublon (Tonowas)	high volcanic	8.8	lagoon fringe	18.91	0	?	0
Eiol	high volcanic	?	lagoon fringing	*4	0	?	0
Eot	high volcanic	0.5	lagoon fringing	*4	0	?	0
Eten	high volcanic	?	lagoon fringing	*1	0	?	0
Falo	high volcanic	?	lagoon fringing	*3	0	?	0
Fefan	high volcanic	13.2	lagoon fringing	18.62	0	?	0
Fanapanges	high volcanic	1.6	lagoon fringing	5.3	0	?	0
Moen (Weno)	high volcanic	18.8	lagoon fringing	27.7	0	?	0
Parem	high volcanic	?	lagoon fringing	?	0	?	0
Patu	high volcanic	34.2	lagoon fringing	33.0	0	?	0
Polle	high volcanic	34.2	lagoon fringing	33.0	0	?	0
Tol	high volcanic	34.2	lagoon fringing	33.0	0	?	0
Tokiu	high volcanic	?	lagoon fringing	?	0	?	0
Tsis	high volcanic		lagoon fringing	*2	0	?	0
Romonum	high volcanic	0.75	lagoon fringing	4.2	0	?	0
Udot	high volcanic	4.9	lagoon fringing	13.54	0	?	0
Uman	high volcanic	4.7	lagoon fringing	8.8	0	?	0
8 others	various high & low coral & volcanic		lagoon fringing	?	0	?	0
Fais	high limestone	2.8	fringing	6.8	0	0	0
Kosrae State							
Kosrae	high volcanic	110	fringing	53.5	?	7	2
Pohnpei State							
Ant	22 low coral islets	1.8	atoll	42.1	75	1	34

Table 3. Continued

NAME	ISLAND TYPE & NUMBER	ISLAND AREA (km²)	REEF TYPE	REEF PERIMETER (km)	LAGOON AREA (km²)	NO. OF PASSES/ CHANNELS	NO. OF LAGOON REEFS
Kapingamarangi	32 low coral islets	1.1	atoll	32.0	57	1	61
Minto	submerged reef	0	atoll reef	?	?	1	1
Mwokil	3 low coral islets	1.3	atoll	12.8	6.8	0	20
Ngatik	8 low coral islets	1.7	atoll	50.9	79	1	34
Nukuoro	46 low coral islets	1.7	atoll	21.7	27	1	31
Oroluk	1 low coral islet	0.5	atoll	99.8	421	16	52
Pakin	26 low coral islets	1.1	atoll	21.1	14	1	?
Pingelap	3 low coral islets	1.7	atoll	11.8	1.2	0	5
Pohnpei Lagoon	? low coral islets		barrier	106.6	?	13	?
Pohnpei Islands	? volcanic islands	334	lagoon fringing	143.6	0	?	?
Yap State							
Eauripik	6 low coral islets	0.2	atoll	24.5	6	?	2
Elato	10 low coral islets	0.5	atoll	29.6	7.5	3	2
Faraulep	? low coral islets	0.4	atoll	?	4.0	?	?
Gaferut	1 low coral islet	0.1	fringing (table)	3.3	0	0	0
Ifalik	5 low coral islets	1.5	atoll	10.8	2.44	1	2
Lamotrek	4 low coral islets	1.0	atoll	36.2	32	7	12
Ngulu	9 low coral islets	0.4	atoll	102.6	?	13	78
Olimarao	2 low coral islets	0.2	atoll	12.4	6	3	1
Pikelot	1 low coral islet	0.1	fringing (table)	4.7	0	0	0
Satawal	1 low coral islet	1.3	fringing (table)	5.2	0	0	0
Sorol	16 low coral islets	0.9	atoll	26.5	7.0	1	1
Ulithi	32 low coral islets	4.7	atoll	111.8	476	14	151
West Fayu	1 low coral islet	0.6	atoll	17.6	32	1	1
Woleai	18 low coral islets	4.5	atoll	32.2	28.6	6	44
Yap (Waqab)	4 volcanic islands	105.4	fringing	93.4	0	7	?
Zohhoiiyoru	none	0	submerged bank	?	?	7	2
Totals: 68							

Footnotes: [1] = includes Eten; [2] = includes Tsis; [3] = includes Falo; [4] = includes Eiol & Eot

three separate archipelagoes: Gilbert, Phoenix, and Line Islands. The atolls support 309 low coral islets, giving a total of 325 large and small islands for the Republic (Table 4). The major islands of the Republic of the Marshall Islands consist of 29 atolls and five low coral islands. The atolls support about 1,311 low coral islets, giving a grand total of 1,316 large and small low coral islands in the Republic (Table 5). The Republic of Tuvalu consists of three low coral islands and six atolls, the latter which support 120 low coral islets. Thus, the total number of low coral islands in the Republic is 123 (Table 6).

The remaining three jurisdictions are small with few islands (Table 6). The Republic of Nauru consists of a single high limestone island, and Tokelau consists of three atolls supporting 123 low coral islets. The U.S. Pacific island possessions in the Line Islands consist of three low coral islands (Howland, Baker, and Jarvis) and three atolls (Johnston, Kingman, and Palmyra)

Table 4. Summary data on the islands and coral reefs of the Republic of Kiribati. (After UNEP/IUCN 1988, Guinther et al. 1992a and Maragos and Holthus, in press).

NAME	ISLAND TYPE & NUMBER	ISLAND AREA (km^2)	REEF TYPE	REEF PERIMETER (km)	LAGOON AREA (km^2)	NO. OF PASSES/ CHANNELS	NO. OF LAGOON REEFS
GILBERT GROUP							
Abaiang	31 low coral	28	atoll	102	?	10	?
Abemama	6 low coral	23	atoll	66	?	2	?
Aranuka	14 low coral	15.5	atoll	36	?	1	?
Arorae	1 low coral	26	fringing (table)	20	0	0	0
Banaba	1 raised limestone	8.5	fringing (table)	11	0	0	0
Beru	1 low coral	21	atoll	36	?	0	?
Butaritari	23 low coral	11.7	atoll	110	?	8	?
Kuria	2 low coral	12.7	fringing (table)	27.5	0	0	0
Little Makin	7 low coral	5.4	atoll	29	?	0	?
Maiana	17 low coral	27	atoll	58	?	1	?
Marakei	2 low coral	10	atoll	26	?	0	?
Nikunau	1 low coral	18	fringing (table)	31	0	0	0
Nonouti	24 low coral	25	atoll	101	?	11	?
Onotoa	12 low coral	13.5	atoll	52.5	54	7	?
Tabiteuea	63 low coral	49	atoll	191	?	2	?
Tamana	1 low coral	5.2	fringing (table)	12.5	0	0	0
Tarawa	64 low coral	20	atoll	107	375	1	?
LINE GROUP							
Caroline	24 low coral	2.27	atoll	51	?	0	?
Filipo	none	0	submerged reef	?	0	0	0
Flint	1 low coral	2.6	fringing (table)	4	0	0	0
Kiritimati	1 high & low coral	321	atoll	144	328	2	?
Malden	1 low coral	39.3	fringing (table)	28	0	0	0
Starbuck	1 low coral	16.2	fringing (table)	25.5	0	0	0
Tabuaeran	4 low coral	33.7	atoll	51	?	1	?
Teraina	1 low coral	7.4	fringing (table)	16	0	0	0
Vostok	1 low coral	0.24	fringing (table)	4	0	0	0
PHOENIX GROUP							
Birnie	1 low coral	0.2	fringing (table)	12.5	0	0	0
Carondelet	none	0	submerged reef	?	0	0	0
Enderbury	1 low coral	5.1	fringing (table)	4	0	0	0
Kanton	4 low coral	9.1	atoll	39	?	1	?
Manra	1 low coral	4.4	fringing (table)	12.5	0	0	0
McKean	1 low coral	0.6	fringing (table)	4	0	0	0
Nikumaroro	2 low coral	4.1	atoll	17.5	?	0	?
Orona	25 low coral	3.9	atoll	28	0	0	0
Rawaki	1 low coral	0.5	fringing (table)	4	0	0	0
Winslow	none	0	submerged reef	?	0	0	0
Totals:36							

Table 5. Summary data on islands and coral reefs in the Marshall Islands. A. = atoll I. = island (after Holthus et al. 1993 and Maragos and Holthus, in press). All islands are of the low coral type.

NAME	ISLAND TYPE & NUMBER	ISLAND AREA (km²)	REEF TYPE	REEF PERIMETER (km)	LAGOON AREA (km²)	NO. OF PASSES/ CHANNELS	NO. OF LAGOON REEFS
Ailinginae A.	3.3	25	atoll	153	67.4	2	52
Ailinglaplap A.	15.0	52	atoll	754	140.0	11	114
Ailuk A.	5.4	35	atoll	233	76.2	4	201
Arno A.	13.0	83	atoll	339	155.1	7	215
Aur A.	5.6	42	atoll	242	77.5	5	37
Bikar A.	0.5	6	atoll	57	34.9	1	217
Bikini A.	6.0	23	atoll	694	104.9	8	280
Ebon A.	3.2	22	atoll	107	58.3	1	694
Enewetak A.	5.8	40	atoll	1,027	121.9	5	158
Erikub A.	1.6	14	atoll	302	81.5	6	100
Jabat I.	0.6	1	fringing (table)	0	4.9	0	0
Jaluit A.	3.6	84	atoll	697	158.3	5	470
Jemo I.	0.2	1	fringing (table)	0	2.4	0	0
Kili I.	0.9	1	fringing (table)	0	5.0	0	0
Knox A.	0.9	35	atoll	?	19.0	0	?
Kwajalein A.	16.0	93	atoll	2,849	314.3	36	358+
Lae A.	1.6	17	atoll	26.0	20.8	1	24
Lib I.	0.8	1	fringing (table)	0	5.4	0	0
Likiep A.	10.0	64	atoll	468	109.5	8	394
Majuro A.	9.0	57	atoll	296	96.4	4	345
Maloelap A.	10.0	71	atoll	1,010	?	12	71
Mejit I.	1.8	1	fringing (table)	0	10.1	0	0
Mili A.	16.0	84	atoll	767	142.7	9	118+
Namdrik A.	2.6	2	atoll	8.45	20.2	0	31
Namu A.	6.2	51	atoll	400	138.1	4	189
Rongelap	7.8	61	atoll	1,009	158.7	10	118
Rongrik	2.1	17	atoll	183	58.4	5	182
Taka	3.4	5	atoll	134	53.1	1	94
Taongi (Bokak)	4.8	11	atoll	115.8	?	1	?
Ujae	1.6	14	atoll	?	?	5	140
Ujelang	1.7	32	atoll	94	53.4	2	67
Utrik	0.5	6	atoll	93	47.2	1	114
Wotho	4.1	13	atoll	119	52.1	4	72
Wotje	8.0	72	atoll	776	127.6	8	174
Totals: 34							

Table 6. Summary data on miscellaneous islands and coral reefs of the Central Pacific (Nauru, Tokelau, Tuvalu, and U.S. Line and Marshall Is.). After Dahl (1991), UNEP/IUCN (1988) and Guinther et al. (1992a and b), and Maragos and Holthus (in press).

NAME	ISLAND TYPE & NUMBER	ISLAND AREA (km^2)	REEF TYPE	REEF PERIMETER (km)	LAGOON AREA (km^2)	NO. OF PASSES/ CHANNELS	NO. OF LAGOON REEFS
Nauru	**(independent) Totals: 1**						
Nauru	high limestone	21.2	fringing (table)	16	0	0	0
Tokelau	**(N.Z.) Totals: 3**						
Atafu	39 low coral islets	3.5	atoll	?	17	0	4
Fakaofo	60 low coral islets	4.0	atoll	?	50	0	49
Nukunono	24 low coral islets	4.7	atoll	?	98	0	?
Tuvalu	(independent) Totals: 10						
Funafuti	31 low coral islets	2.8	atoll	69	?	11	?
Kosciousko	none	0	submerged bank	?	0	0	0
Nanumanga	1 low coral	2.8	fringing (table)	9.3	0	0	0
Nanumea	7 low coral islets	3.9	atoll	28.7	?	9	?
Niulakita	1 low coral	0.4	fringing (table)	36	0	?	0
Niutao	1 low coral	2.6	fringing (table)	7.25	0	0	0
Nui	20 low coral islets	2.1	atoll	20	?	?	?
Nukufetau	35 low coral islets	2.8	atoll	39	?	?	?
Nukulaelae	19 low coral islets	1.8	atoll	29	?	?	?
Vaitupu	8 low coral islets	5.6	atoll	13.75	?	2	?
U.S. POSSESSIONS IN THE LINE AND MARSHALL ISLANDS							
Baker	1 low coral	1.24	fringing	?	0	0	0
Howland	1 low coral	1.46	fringing	?	0	0	0
Jarvis	1 low coral	4.45	fringing	?	0	0	0
Johnston	4 low coral	2.52	atoll	?	130	1	?
Kingman	1 low coral	0.01	atoll	?	?	?	?
Palmyra	56 low coral	5.67	atoll	?	?	1	?
Wake (Enen Kio)	3 low coral	7.4	atoll	?	9.7	1	?

which collectively support 60 low coral islets. Wake Atoll, a U.S. possession in the northern Marshalls, supports three low coral islets. In total, the seven U.S. possessions support 67 low coral islands.

The complexity, size, and number of islands among the eight archipelagoes decrease from west to east across the Pacific: the Caroline Islands support all of the volcanic islands and all but two of the high limestone islands as well as numerous atolls and low coral islands. The Marshall-Gilbert-Ellice chain supports only two high limestone islands with the rest consisting of low coral islands and atolls. The Line, Phoenix, and Tokelau archipelagoes support only low coral islands and atolls.

Coral Reefs and Related Ecosystems

The number and complexity of coral reef ecosystems in the central Pacific diminish from west to east and closely correspond to the distribution, type, and size of islands as described beforehand. All major types of coral reefs are found in the Caroline Islands in the far western Pacific including three barrier reefs, 37 atolls/atoll reefs, 46 fringing reefs, and several known submerged reefs. Mangrove forests and seagrass beds are also well developed throughout the Carolines, especially along the fringes of the high islands and atolls. The Marshall-Gilbert-Ellice chain supports a total of 54 atolls, 23 fringing, and several known submerged reef systems. Mangroves and seagrasses adapted to coralline shorelines are well developed in the wet equatorial belt of the northern Gilberts, but diminish both north and south of this belt; the northern Marshalls lack both mangroves and seagrasses, and mangroves are much less developed in the southern Gilbert and Ellice Islands. The Tokelau Islands consist of only three atolls, and small mangroves and seagrass communities are also present. The Line and Phoenix Islands include nine atolls, 13 fringing reefs and several known submerged reef systems. Mangroves and seagrasses are absent. In total, the central Pacific archipelagoes covered in this paper include 103 atolls, three barrier reefs, 82 fringing reefs, and at least 10 submerged reefs.

Typical Coral Reef Habitats

Caroline Islands: The Carolines support the most extensive and diverse habitats for coral reef ecosystems in the central Pacific. Excluding Christmas (Kiritimati) Atoll in the Lines, all of the large islands in the region are located in the Carolines (e.g., Babeldaob, Yap Proper, Pohnpei, Kosrae) and contribute nutrient subsidies and freshwater influences to adjacent reefs. These factors diversify opportunities for reef communities especially in the barrier reef systems (Pohnpei, Chuuk, and main Palau Islands) and in the complex fringing reef systems in Kosrae and Yap. In addition, most of the Caroline Islands are situated in the wet belt north of the Equator, along the Intertropical Convergence and the Equatorial Countercurrent. The currents and rainfall patterns help to mobilize nutrients and organics and facilitate transfer of materials and biodiversity between islands and atolls. Common habitats in the Carolines include lagoon reefs (pinnacle, patch), passes, channels, shallow reef flats, terraces, submerged reefs, slopes, reef holes, embayments, quasi-estuaries, seagrasses, mangroves, mud flats, and sand flats (see Maragos and Cook 1995; Maragos and Payri, in press).

Marshall-Gilbert-Ellice Chain

Although lacking volcanic islands and supporting only two high limestone islands, the largest concentration and longest string of atolls and low coral islands in the world are found along the Marshall-Gilbert-Ellice chain. Habitat diversity is notably higher on the atolls and especially those in the wet equatorial belt (from 7°N to 0° latitude). The Marshalls also support the largest atoll (Kwajalein) and several complex atolls with sub-lagoons (e.g., Mili, Arno). The common habitats include lagoon reefs, passes, dead-end channels, reef holes, shallow reef flats, reef slopes and deeper reef terraces, mud flats, and sand flats. The wetter atolls also support quasi-estuarine environments during the wet season. The isolated coral islets on table reefs support lower habitat diversity limited to shallow reef flats, ocean reef slopes, and some reef terraces.

Tokelau

The three atolls of the Tokelau group are very small and lack deep natural passes through perimeter reefs. Rainfall is intermediate and habitat diversity lower compared to the previous two areas. Seagrass and mangrove habitat is limited. Common coral reef habitats include lagoon reefs, shallow reef flats, reef slopes, ocean terraces, and sand flats. There is little scientific information available on the coral reefs of Tokelau.

Line and Phoenix Islands

The four northern atolls in the Lines are "wet" with plentiful rainfall (Kingman, Palmyra, Washington [Teraina] and Fanning [Tabuaeran]). Otherwise, the remaining coral islands and atolls in both the Lines and Phoenix lie in the arid zone south of the Equator except for Nikumaroro, Manra, Orona (of the Phoenix Islands), and Caroline, Flint, and Vostok (southern Lines) which are in the semi-arid zone. Consequently, habitat diversity is low compared to the other large archipelagoes of the central Pacific. Habitat diversity is higher on the atolls compared to the isolated low coral islands resting on the table reefs because of the presence of protected lagoon habitats for the atolls. Common habitats include hypo- and hypersaline lakes, shallow reef flats, lagoon reefs, reef slopes, passes, reef terraces, and sand flats. Passes are mostly shallow except for the several that were dredged through the reef to facilitate navigation (e.g., Palmyra, Johnston, Kanton, Kiritimati, and perhaps others).

Biogeography and Biodiversity

Aside from diminishing island and reef complexity from moving west to east across the central Pacific, there is also diminished habitat and species diversity when moving in the same direction. Seagrasses, mangroves, and barrier reefs decline, and atolls are less numerous relative to low coral islands. Species diversity is notably reduced from west to east. Using stony corals as an example, about 400 species have been reported from Palau, 300 from Chuuk, 200 from Pohnpei, and about 150 species from Kosrae when moving west to east across the Carolines (Maragos 1996). Despite extensive studies in many of the Marshall atolls (Wells 1954; Devaney et al. 1978; Maragos 1996; Maragos 1994; Maragos and Lamberts 1989; Lamberts and Maragos 1989), fewer than 200 species have been reported. Coral species records in the Ellice and Gilbert and Tokelau Islands are incomplete. However, good lists were developed at Kanton and McKean in the Phoenix Islands (Maragos and Jokiel 1986; Smith and Henderson 1978; Dana 1979) and at Fanning, Palmyra, and Johnston in the Line Islands (Maragos 1974, 1988; Maragos and Jokiel 1986). These reports indicate that species totals do not exceed about 110 species for either of these two island groups and that species diversity also attenuates at higher latitude (e.g., Johnston, with less than 40 species). These patterns are also consistent with what is known about coral diversity in Hawaii, where about 50 species have been recently listed (Maragos 1995).

Geographic isolation and the upstream location of the eastern coral reefs in the central Pacific help to explain some of the attenuation of species. Also, the long average distances between reefs, reduced habitat diversity, and perhaps slightly lower surface water temperatures in the equatorial eastern Pacific may further explain the pattern of species biogeography for corals and other reef organisms. Those patterns are also important factors in attempting to characterize coral reef health in this broad region.

PREVIOUS LITERATURE ON CORAL REEF CONDITIONS

Historical Information on the Central Pacific

The Carolines, Marshalls, Gilberts (including Banaba) and Nauru have been inhabited by Micronesians over the past several thousand years. The Ellice Islands [Tuvalu] and Tokelau were settled by Polynesians during the past millennium. The Phoenix and Line Islands were uninhabited when first visited by early European explorers, although there is ample evidence of brief visits by the early Polynesians (Oliver 1989). Engaged in a subsistence lifestyle, the early Micronesians and Polynesians probably had little effect on coral reefs. Some of the larger species of giant clams (especially *Tridacna gigas*) may have been overharvested on the reefs of the eastern and central Carolines; the clam is presently extirpated, yet there are abundant dead remains of the clams on many reefs.

The early 16th to 18th century European explorers generally bypassed the small islands of the central Pacific in their search for gold, silver, pearls, silks, and sandalwood, and the ship logs and written accounts of the explorers provide little early information about the reefs and islands. Mendaña (in 1567), and Francis Drake (about 1580) both probably visited the Carolines. The 18th century explorers had more contact, including John Byron who passed through the Tokelaus in 1754 and James Cook who stopped at Christmas Atoll (Line Islands) in 1777. Other than the harvest of pearl shells on a few islands, the early European explorers and treasure hunters had little effect on the reefs of the central Pacific.

Most of the islands in the central Pacific were first charted in the 19th century with James Dana and John Wilkes of the U.S. Exploring Expedition (1838-1842) providing detailed information on the islands and reefs of the Gilbert, Marshall, Line, Phoenix, and Ellice Islands (Oliver 1989; Dana 1875).

Traders, whalers, and beachcombers followed in the wake of the explorers but caused little if any impact to coral reefs other than the harvest of pearl shell, pearls, trepang and other commodities of value to the Orient and Europe. In time, European, American, Australian, and New Zealand missionaries and merchants took up permanent residence on the major islands, developing copra plantations and other business ventures. The discovery of the value of guano as an agricultural fertilizer led to widespread expeditions to many islands to dig, bag, and haul away guano, especially from the arid and semi-arid islands and atolls of the central Pacific. Sometimes boat landings and tram lines were constructed. Once the guano deposits were exhausted, the islands were abandoned. Old maps of the Phoenix and Line Islands provide ample evidence of the activities of the guano diggers, but impacts to coral reefs were probably minimal: a few lakes and navigation channels were excavated or blasted on some of the islands. In 1858 the U.S. Congress passed the Guano Act to promote American exploitation of guano deposits on unclaimed islands. Claims for over 48 islands were filed in accordance with the Act, but only a few of these remain under U.S. jurisdiction today (Oliver 1989). The larger-scale mining of phosphate rock by the British on Banaba, or Ocean Island, (Gilberts) resulted in some minor effects to reefs during the construction and use of boat moorings and cantilevers to transport phosphate rock to ships.

The emergence of Germany as a world power and major political force in the Pacific during the latter half of the 19th century led to the rest of the political powers (including France, U.S., Britain, Australia, New Zealand, and Spain) laying claim to many potentially strategic and valuable islands in the Pacific. The small islands in the central Pacific were not spared: the Marshalls went to Germany while Spain reasserted its claim to the Carolines. Britain extended its jurisdiction over the Gilbert and Ellice Islands. After winning the Spanish-American War in 1898, the U.S. seized Guam, and Germany purchased the Caroline and Mariana Islands from Spain. Eventually, the Tokelaus became a protectorate of New Zealand.

The outbreak of World War I in Europe in 1914 led Japan to seize all of Germany's Pacific island possessions (including the Carolines, Marshalls, and Nauru). Later, the advent of global air travel in the 1920s and 1930s led to another "land rush" for Pacific islands by the Americans, Japanese, British, and French. By the mid 1930s virtually all other islands in the Pacific had been claimed. Airfields, seaplane runways, ramps, and docks were constructed on many islands to support air travel (Oliver 1989) and some impacts to coral reefs may have taken place from dredging, filling, and blasting.

Transoceanic telegraph cables were also laid across the Pacific at the turn of the century including the construction of cable stations at Fanning (Tabuaeran) and Christmas (Kiritimati) (Oliver 1989).

In the late 1930s the Japanese, British, Americans, New Zealanders, and Australians began to fortify many islands in the central Pacific, constructing garrisons, airfields, docks, and airplane refueling stations, and accomplishing dredging and filling at adjacent reefs (see Woodbury 1946; Dawson 1959; Maragos 1993). Bases were established at Tarawa, Wake, Midway, Kanton, Funafuti, Johnston, Palmyra, Howland, Jarvis, Baker, and Christmas in the central Pacific. The Japanese established bases on Enewetak, Kwajalein, Mili, Jaluit, Ulithi, Chuuk (Truk), Yap, Peleliu, Koror, and other islands in the Marshalls and Carolines. Battles and bombing raids during World War II damaged many reefs including those at Mili, Jaluit, Chuuk, Peleliu, Tarawa, Enewetak, Kwajalein, and Ulithi.

The nuclear testing programs and postwar reconstruction resulted in additional damage to reefs from dredging, filling and causeway construction at Majuro, Enewetak, Bikini, Tarawa, Johnston, (see Brock et al. 1965, 1966), Malders and Christmas. Ballistic missile testing at Johnston, Kanton, and Kwajalein stimulated additional construction impacts to reefs as a result of channel and quarry blasting, causeway construction, shore protection, and land reclamation (Maragos 1993; Smith and Henderson 1978). The nuclear tests themselves caused large scale and "permanent" impacts to reefs at Bikini and Enewetak, excavating craters on reefs up to two kilometers in diameter.

Recent Trends and Effects

The post-war era ushered in improved medical, sanitation, nutritional, and economic conditions and led to rapid population growth in all of the inhabited archipelagoes. In addition, settlements were attempted by the British on uninhabited islands in the central Pacific; those on the Phoenix Islands failed, but those in the northern Line Islands succeeded (Fanning, [Tabuaeran], Christmas [Kiribati], Washington [Teraina]) and are continuing to grow rapidly as new centers in the Republic of Kiribati. The settlements and population growth increased subsistence effects and harvesting levels on reef resources. Other uninhabited atolls in the Carolines (Oroluk, Helen) and the Lines (Palmyra and Caroline Atolls) have also been settled or are proposed for settlement. Several of the northern atolls of the Marshall Islands are also being proposed for settlement, and the Republic of Kiribati is actively planning for the resettlement of Nikumaroro, Orona and Manra in the Phoenix Islands. The main effects of the settlements and resettlements would be the depletion of commercial species on the islands, including giant clams, coconut crabs, nesting seabirds, nesting sea turtles, pearl shell, trochus, and possibly sharks.

Recent economic development throughout the insular Pacific has also promoted the rapid development of urban and political centers in the central Pacific; these include Funafuti (Tuvalu), Tarawa and Christmas (Kiribati), Majuro, Kwajalein and Ebeye (Marshalls); Yap, Chuuk, Pohnpei, and Kosrae (FSM), Koror and Babeldaob (Palau), and Nauru. The rise of the urban centers has also fueled rapid in-migration from rural "outer" islands and atolls, adding to the effects of crowding. In turn, coastal construction for ports, shore protection, land reclamation, navigation channels and road causeways have affected many beaches and reefs in the urban centers (Maragos 1993; Biosystems Analysis, Inc. 1995). In addition, sewage discharges, rubbish disposal and industrial pollution have polluted some inshore waters, potentially degrading marine environments. Excessive harvesting of fish and shellfish for subsistence and sale is also a consequence of overcrowding in the urban centers.

Fuel spills and ship groundings occur both in urban centers and remote reefs, the consequences of increased shipping. Over the past two centuries, many groundings have been unreported and impacts to reefs undocumented. The recent grounding of a large transport vessel at Satawal (Yap) illustrates how such events can often result in catastrophic impact to reefs and dependent subsistence communities (Maragos and Fagolimul 1995). Adequate documentation, mitigation and restoration of reefs from the impacts require rapid scientific response and adequate communication and logistic arrangements, often difficult in the central Pacific. The remote islands of the region are also targets for unauthorized harvesting and poaching of rare species. Beyond the watchful eyes of inhabited islands, primarily Asian fishermen are illegally harvesting reef fish, giant clams, sharks, lobsters, trochus, pearl shell and other valuable reef resources. In Palau rare crocodiles and dugongs are poached.

Modern Reef Research in the Central Pacific

The establishment of the Palao Tropical Biological Station at Koror by the Japanese in the mid 1930s marked the beginning of modern coral reef research in the central Pacific. In addition, scientists from the Universities of Hawaii and Guam have participated in many expeditions, and the operation of the Mid Pacific Marine Laboratory for many years at Enewetak Atoll opened up atoll reef ecology and biology to many scientists. Presently the only other research facilities in the central Pacific are the Atoll Research Programme, operated by the University of the South Pacific in Tarawa, the private Coral Reef Research Foundation in Palau, a new coral reef research facility in Pohnpei, and a new reef laboratory at Johnston Atoll. Mariculture facilities are established on several reefs including Kosrae, Pohnpei, Palau, Arno, Mili, Tarawa, and other islands, most of which include research. Expanded research facilities are also planned for Palau and possibly the Marshall Islands.

Recent Scientific Literature

Outside of the Caroline and Marshall Islands, there has been little recent survey work on central Pacific reefs. Other than a study of sea turtles by Balazs (1983) and inspection of maps, there is no information available for the reefs of Tokelau. Early work in Kiribati includes Banner and Randall (1952) at Onotoa (Gilberts); Johannes et al. (1979) and Bolton (1982) at Tarawa; Stoddart (1976) in the Phoenix Islands; Smith and Henderson (eds) (1978) at Kanton; and Dana (1979) at McKean, Phoenix Islands. The most important studies in the Kiribati Line Islands include Chave (1970) and Chave and Kay (1974) at Fanning, Helfrich (1973) at Christmas, and Kepler and Kepler(1995) at Caroline Atoll, Flint Island and Vostok Island. Maragos (1988) describes corals and reefs at Palmyra, and Brock et al. (1965, 1966) and Maragos and Jokiel (1986) describe the reefs and corals of Johnston Atoll in the U.S.

Lines, including the impact of coastal construction. Coral reef research at Funafuti (Ellice Islands, Republic of Tuvalu) has been more extensive but has concentrated on reef geology and atoll and island formation (David and Sweet 1904; Maragos et al. 1973; Baines et al. 1974, and others) with additional biological observations by Gardiner (1898) and Finckh (1904) which are now a century old. Kaly and Jones (1988, 1989, 1990a, 1990b) have investigated the reefs and effects of channel blasting on coral reefs at three other atolls in Tuvalu (Niutau, Nui, and Nanumea) and have developed guidelines for minimizing the impact of these activities on coral reefs. Zann (1985) describes traditional management of marine resources in Kiribati and Tuvalu. A detailed assessment of Tarawa lagoon has also been recently completed (Biosystems Analysis, Inc. 1995).

Considerable coral survey work has been accomplished in the Marshalls with much of it concentrated in the urban centers. The nuclear testing program in the Marshalls attracted considerable coral reef research (Wells 1954; Emery et al. 1954), including nearby Arno Atoll (Wells 1951). Recent studies in the Marshalls include Devaney et al. (1978) at Enewetak, Agegian et al. (1987) at Bikini, and Maragos (1986) at Bikini. Coastal resource inventories and atlases have also been published for Arno, Majuro, and Kwajalein Atolls, including observations on corals and reefs (Maragos and Lamberts 1989; Lamberts and Maragos 1989; Titgen et al. 1988; Maragos et al. 1993a, b; AAA Engineering and Drafting and the University of Hawaii Sea Grant College Program 1989a, b; and Manoa Mapworks and the University of Hawaii Sea Grant College Program 1989). Ecological studies have also been conducted as part of the ongoing operations of the Kwajalein Missile Range (e.g., Losey 1972; Jones and Randall 1973; Amesbury et al. 1975, and others). Six uninhabited and one inhabited atoll in the northern Marshalls were also surveyed during a biodiversity assessment in 1988 (Thomas et al. 1989; Maragos 1994) including visits to Bokaak, Pikaar, Taka, Rondik, Adkup, Wotto, and Jemo.

The Caroline Islands have attracted even more attention from reef scientists during the past two decades, especially at the urban centers of the FSM and Palau. Notable studies include Eldredge et al. (1975) at Kosrae; Birkeland et al. (1980) at Pohnpei; Holthus et al. (1993) for Oroluk and Minto; Amesbury et al. (1976, 1977a, 1977b) and Tsuda (1978) at Yap; Holthus (1985, 1987) for Pohnpei; and Devaney et al. (1975) and Tsuda et al. (1975, 1977) for Chuuk. Coastal resource atlases and inventories have been produced or are in preparation for all four urban centers in the FSM, including ERS-USACE (1986, 1987), Orcutt et al. (1989), Maragos et al. (1997), Manoa Mapworks (1985, 1987), Manoa Mapworks and the University of Hawaii Sea Grant College Program (1988), and Cheney et al. (1982). In Palau, coral reefs near the urban center have been surveyed (Birkeland et al. 1976; Randall et al. 1978) as part of proposed developments, and some sites have been monitored for two decades (Birkeland and Randall 1996). A broadscale rapid ecological assessment of the entire archipelago of Palau was accomplished in 1991-1992 (Maragos et al. 1994a, b; Maragos and Cook 1995; Donaldson 1992, 1993). In 1975, Grigg conducted a survey of commercial species of black coral in Palau (Grigg 1975).

Table 7 summarizes information on reef coral abundance and species richness obtained from many of the above central Pacific reef studies. Important regional overviews of the coral reefs in the central Pacific are included in Wiens (1962), Johannes (1978), Dahl (1980, 1991), IUCN (1986), WCMC (1991), Maragos and Payri (1996), Maragos and Holthus (in press), Kelleher et al. (1995), Smith (1995), and Guinther et al. (1992a, b).

Table 7. Summary of available information on live coral (at four levels) and species richness (at five levels) at reef survey sites in the central Pacific. Numbers below the headings are the percentages of the total sites for a survey at each level. The references in the right column are the sources of the information. N = total number of sites for each survey. An asterisk (*) indicates a quantitative (transect, quadrat, point intercept, etc.) survey and the absence of an asterisk indicates a qualitative survey where values were visually estimated by the investigator. Adapted from Maragos and Payri (1996).

ARCHIPELAGO government	ISLAND(S)	N	PERCENT LIVE CORAL LEVELS				SPECIES RICHNESS LEVELS					REFERENCE(S)
			0–25	26–50	51–75	76–100	1–15	16–30	31–45	46–60	>60	
CAROLINE IS.												
FSM	Kosrae	52	29	10	29	33	33	27	29	10	2	USACE (1989)
	Pohnpei	* 6	50	50	–	–	–	–	–	–	–	Birkeland et al. (1980)
	Pohnpei	8	–	–	–	–	–	75	25	–	–	Valentine (ed) (ND)
	Chuuk	73	3	19	31	45	–	7	29	56	36	Maragos and Meier (1997)
	Yap	* 3	33	67	–	–	–	–	–	100	–	Amesbury et al. (1976)
	Yap	* 6	100	–	–	–	–	62	19	19	–	Amesbury et al. (1977a)
	Yap	* 4	100	–	–	–	–	80	20	–	–	Amesbury et al. (1977b)
	Yap	48	–	–	–	–	6	54	31	8	–	Orcutt et al. (1989)
	Satawal	* 16	88	12	–	–	62	38	–	–	–	Maragos and Fagolimul (1996)
Palau	Malakal	* 4	50	–	50	–	–	–	25	–	75	Birkeland et al. (1976)
	Ngerekebesang	* 10	40	40	10	10	–	–	17	50	33	Randall et al. (1978)
	six SW is.	49	–	–	–	–	6	10	51	27	6	Maragos (1993)
	Main is.	63	–	–	–	–	6	6	44	24	19	Maragos and Meier (1993)
ELLICE IS.												
Tuvalu	Funafuti	* 2	100	–	–	–	100	–	–	–	–	Baines et al. (1974)
	three atolls	* 38	61	39	–	–	100	–	–	–	–	Kaly and Jones (1990a)
MARSHALL IS.												
Rep. of Marshalls	Kwajalein	* 4	25	–	50	25	–	17	–	33	50	Jones and Randall (1973)
	Kwajalein	* 3	100	–	–	–	67	33	–	–	–	Amesbury et al. (1975)
	Kwajalein	18	–	–	–	–	6	61	22	11	–	Titgen et al. (1988)
	Bikini	21	67	24	10	–	29	57	29	5	–	Maragos (1985)
	Majuro	33	48	21	6	24	45	45	9	–	–	Lamberts and Maragos (1989)
	Arno	34	62	18	12	9	–	–	–	–	–	Maragos and Lamberts (1989)
PHOENIX IS.												
Rep. of Kiribati	Kanton	* 7	29	71	–	–	–	–	–	–	–	Jokiel and Maragos (1978)
LINE IS.												
U.S.	Palmyra	20	45	15	10	30	67	24	5	5	–	Maragos (1988)
Rep. of Kiribati	Fanning	* 1	–	–	100	–	–	–	–	100	–	Maragos (1974b)
MEAN VALUES			54	20	16	9	24	28	17	21	11	

Anthropogenic and Natural Disturbances on Coral Reefs

Most of the coral reefs in the central Pacific are not subjected to major anthropogenic stress, except those in the urban centers and several remote or uninhabited reefs subjected to destructive and unauthorized fishing and poaching. Table 1B summarizes the author's assessment of the extent of anthropogenic stresses on coral reefs at the country/government level in the region.

Upland soil erosion and terrigenous sedimentation affect reefs only in the urban centers of the five volcanic island clusters in the Carolines: Kosrae, Pohnpei, Chuuk Lagoon, Yap and Koror/southern Babeldaob. Military testing and training have declined significantly in recent years and is now only active at Johnston and Kwajalein Atolls. However, there are severe residual effects from prior nuclear weapons testing at Bikini and Enewetak Atolls and military construction activities at Palmyra, Johnston, Wake, Kanton, Kwajalein, and to a lesser extent Funafuti. The use of dynamite for fishing is still a serious problem in western Chuuk Lagoon and may be problems elsewhere in the Western Caroline Islands. Several types of coral reef impacts are related to urban growth and economic development and include overharvesting of fishery resources, coastal construction (including shoreline erosion, dredging and filling), sewage/nutrient discharges, industrial discharges and runoff, rubbish and solid waste dumping, and mangrove clearing. The urban centers most affected by these activities include the five mentioned above for the Carolines, as well as Majuro and Kwajalein (Marshalls), Tarawa and Christmas (Kiribati), Nauru, and Funafuti (Tuvalu).

Population migration (settlements, resettlements) potentially threaten coral reef resources at three of the Phoenix Islands (Manra, Orona, Nikamaroro), one of the southern Lines (Caroline Atoll), one of the FSM islands (Oroluk), and one or two of the SW Palau islands (Helen Atoll, Fanna Island). Atolls and islands most likely to be subjected to illegal poaching or destructive fishing include the remote uninhabited reefs: Ngeruangl and Helen (Palau), Neoch, Oroluk, Minto, West Fayu, Gaferut, Pikelot, Olimarao (FSM), Jemo, Ailinginae, Adkup, Taka, Pikaar, Bokaak, Rondik, and Knox (Marshalls), Palmyra and Kingman (U.S. Lines), and the seven uninhabited Phoenix Islands (Orona, Manra, Nikumaroro, McKean, Rawaki, Enderbury, and Birnie), a total of approximately 26 atolls and islands. Ship groundings and oil spills can potentially threaten any reef—urban or remote—and especially in the central Pacific where most islands are low to the horizon and difficult to see or detect from a distance from fast moving vessels, especially at night.

On a "worst" case basis fewer than 40 of the 180 major islands and atolls in the central Pacific are being subjected to chronic anthropogenic stress at any level, and only at about 16 of these are the impacts to reefs chronic or potentially severe: these include the 12 urban centers and five of the abandoned military installations (Bikini, Wake, Enewetak, Kanton, Palmyra). Thus, less than 10% of the reefs of the central Pacific are being subjected to chronic and/or severe anthropogenic stress. However, continued rapid population growth in the future decades, coupled with global climate change and non-sustainable forms of development, could radically alter the present situation. The small size and low topography of most of the islands makes them vulnerable to catastrophic effects; there is little margin for error.

Natural disturbances to reefs in the central Pacific are many, but only a few of them are important: tropical cyclones, crown-of-thorns (*Acanthaster*) outbreaks, and episodes of coral bleaching, the last possibly due to temporary warming of sea surface temperatures. All of these disturbances are temporary in nature, but can have longterm effects on reefs, especially if the "recurrence" interval of the stress on a particular reef is less than 10 to 20 years, the minimum time needed for most reefs to recover completely from severe natural disturbances. Fortunately, tropical cyclones are generally uncommon throughout the region; storms tend to intensify and cause damages at higher latitudes in the Pacific. However, several storms over the past several decades have resulted in longterm impacts to coral reefs and hardship to adjacent residents including typhoon Ophelia in 1958 which struck the southern Marshalls and Carolines, typhoon Bebe in 1972 which struck Funafuti before heading toward Fiji, and typhoons Owen and Mike which struck the Carolines in 1990 (Blumenstock 1961; Maragos et al. 1973; Holthus et al. 1993).

Crown-of-thorns starfish outbreaks have occurred frequently in the region, but generally the outbreaks are of short duration and coral communities recovery quickly afterwards. However, the *Acanthaster* infestation at Malakal in Palau, although small in extent, appears to be chronic, based upon two decades of monitoring (Birkeland and Randall 1996). It is not clear what is perpetuating the infestation, although the site is near the Koror urban center and sewage discharges.

There is little documentation of the frequency and extent of coral bleaching in the central Pacific region, because it is difficult for scientists to maintain constant vigilance in this remote region. However, coral bleaching episodes appear to be common occurrences in the eastern Pacific, including Samoa and French Polynesia, and it is possible that the Tokelaus, Lines, and Phoenix Islands may also experience bleaching events periodically.

Anthropogenic stress, coinciding with the occurrence of major natural disturbances, could have longterm adverse effects on some coral reefs. For example, coral recovery may be postponed or inhibited in the presence of chronic anthropogenic disturbance, such as from sewage pollution. Reefs in south Kaneohe Bay did not begin to recover from previous dredging impacts until the major sewage outfalls were removed from the bay (Maragos et al. 1985). Similarly, coral reefs near the urban Pago Pago center of American Samoa have been slow to recover from a series of tropical cyclones which struck the islands during the past decade (Maragos et al. 1994c). In a similar way, stressed coral reefs in the urban centers in the central Pacific may also find it difficult to recover quickly from major natural disturbances such as tropical cyclones and crown-of-thorns infestations.

Coral Cover and Diversity as Indicators of Coral Reef Health

On healthy pristine reefs in the central Pacific, coral cover varies substantially depending upon habitat and sediment dynamics. Coral coverage is highest along the seaward reef slopes, lagoon reef slopes and the walls and floors of channels which do not accumulate sediment. In contrast, the floors of lagoons, deep reef holes, inner reef flats, deep channels, and deep offshore terraces tend to accumulate sediment unless strong currents continually sweep through these habitats. Many coral species are not adapted to living in sediment deposits, and coral cover is generally lower. Although deeper (subtidal) reef flats and outer reef margins away from heavy wave exposure can support high coral coverage, eventually upward reef growth transforms these habitats into flat "pavement" zones devoid of live coral. Since corals are truly marine organisms, they cannot survive above the depth of mean low water, including the shallow "healthy" pavement zones of reef flats.

The information summarized in Table 7 shows that no clear generalizations can be drawn about the relationship of coral cover to coral reef health. The lower levels of coral cover at Funafuti in 1972 are explained by the catastrophic damage inflicted by tropical cyclone Bebe which struck the atoll two months previous to the survey (Maragos et al. 1973; Baines et al.

1974). Other lower coral cover estimates for the Marshalls reflect that many survey sites were on shallow reef flats where coral abundance is naturally lower even under "healthy" conditions. Some lower coral cover estimates in the urban centers of the Caroline and Marshall Islands reflect the effects of chronic anthropogenic effects, but coral cover is also high at slightly greater distances from the urban centers, such as in Chuuk Lagoon. Greater exposure to prevailing wave action also tends to reduce coral cover as is evident within the windward spur and groove reef formations for many atolls and islands. Thus, it seems that coral cover is only useful as an indicator of reef health when it is monitored at the same sites over time in habitats where coral cover is expected to be high (in the absence of stress).

Review of the information in Table 7 reveals that despite the healthy nature of most of the reefs in the central Pacific, over half of the survey sites revealed live coral coverage estimates of 25% or less. Many of the survey sites were on shallow reef flats and other healthy habitats not conducive to high coral cover.

Coral species richness as an indicator of reef health or stability is complicated by biogeographic factors. Reefs in the western central Pacific have many more coral species than those in the eastern central Pacific. The size of the reef, proximity to nearby reefs, habitat complexity and latitude also influence the total complement of coral species found on a reef or an island group. The data in Table 7 display that species richness shows no apparent trend except for the higher values in the western vs. the eastern Pacific. As with coral cover, species richness may be a useful indicator of reef health if monitored at the same sites over time within an archipelago. If an investigator is trying to assess reef health on the basis of a single survey, it is important to evaluate all key habitats at each site and draw conclusions by comparing similar habitats from different sites and from different times as part of a monitoring program. Other parameters such as size frequency distributions of populations of corals and other reef organisms also need to be included (see Birkeland and Randall 1996).

CONCLUSIONS

Coral reefs in the central Pacific appear to be in excellent health except near the few urban centers in the Caroline, Marshall, Gilbert, Ellice and Line Islands. Reefs at a few formerly used military installations have also not recovered completely from the previous impacts of coastal construction and weapons testing. Rapid population growth throughout the region, however, will threaten additional reefs by expanding the zone of impact at existing urban centers, stimulating the development of new urban centers on rural islands, and creating new settlements at presently uninhabited islands. Aside from controlling population growth and nonsustainable forms of development, the countries in the region need to cooperate more fully in monitoring their reefs especially at remote locations and in following through with enforcement actions and sanctions.

Most of the governments in the region have important characteristics in common: small islands; limited water resources; limited agricultural potential; considerable fisheries, mariculture and tourism potential; and limited commercial mining potential. Clearly the reefs of the region are most important for the future sustainable development and continued subsistence lifestyles in the central Pacific. The region also represents the last frontier in the Pacific for large expanses of pristine coral reefs, many of which are uninhabited or sparsely inhabited. Many of the uninhabited islands should be considered for formal protection as parks and preserves, but the entire Pacific region should share in the financial, social, educational, and training requirements to achieve this end since the entire region would benefit from the protection afforded to these reefs. Education and public awareness programs are also needed to improve management of coral reefs in these urban centers and perhaps to restore important reefs that are badly degraded. It is beyond the scope of this report to outline a detailed plan to conserve the reef ecosystems and resources of the central Pacific.

Available information on coral abundance and species richness was not very useful as indicators of reef health, principally because of the uncoordinated manner in which it has been collected over the past half century. The conclusions on the excellent state of reefs in the central Pacific were based upon the extensive observations of many researchers over the past few decades and the author's best professional opinion based upon countless observations of many reefs in the region. Consultation with previous historical literature, survey reports, maps, and knowledgeable people in the islands themselves also formed much of the basis for this conclusion. Only through implementing a well organized and coordinated long range monitoring program will a documented basis for assessing reef health be assured.

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EASTERN PACIFIC

ASSESSMENT OF THE PRESENT HEALTH OF CORAL REEFS IN THE EASTERN PACIFIC

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Reef-building corals in the eastern Pacific occur from the upper reaches of the Gulf of California, Mexico, through Middle America to the southernmost coast and offshore islands of Ecuador. Oceanic islands also included in the eastern Pacific region are the Revillagigedo Islands (Mexico), Clipperton Atoll (France), Cocos Island (Costa Rica), and the Galapagos Islands (Ecuador). The limits of reef construction extend from approximately 24°N, from near the tip of Baja California, to 2°S, including the mainland coast of Ecuador and the southern Galapagos Islands.

Thirty-three species of reef-building scleractinian corals and hydrocorals in 11 genera make up the Recent eastern Pacific fauna (Glynn, in press). The main reef-building genera are Pocillopora *(5 species)* Porites *(1 species) and* Pavona *(4 species). Other genera are often present, but unimportant in terms of reef building (*Psammocora, Leptoseris, Gardineroseris, Millepora*), rare (*Acropora, Siderastrea*) or not associated with reef formations (*Diaseris, Cycloseris*).*

Pocilloporid fringing reefs occur south of La Paz, Baja California, at Cabo Pulmo and Los Frailes, in the Revillagigedo Islands, and at a few localities along the mainland coast of Mexico (Reyes Bonilla 1993a). Several recently discovered pocilloporid fringing and patch reefs at Huatulco, Oaxaca, suggests that this area harbors the highest density of coral reefs on the Mexican west coast. Most eastern Pacific reef formations occur at shallow depth i.e., 6-10 m. Clipperton Atoll, located about 1,300 km SW of Acapulco, is the best developed coral reef in the eastern Pacific (Glynn et al. 1996). A reef surrounds the entire atoll and is built principally of Porites, *with* Pavona *and* Pocillopora *also contributing to its structure. High live coral cover at Clipperton extends to 50-60 m depth. In general, eastern Pacific pocilloporid reefs are fragile and tend to develop in bays or along shores protected from strong swells. Massive reefs built of* Porites *and* Pavona *are, however, occasionally well developed at more exposed sites.*

Most of the Central American coast between Huatulco, Mexico, and Costa Rica is unexplored relative to coral reef development. Aside from relatively small patches of reef corals present off the south coast of El Salvador, coral reefs are not known along this coastal stretch until reaching Costa Rica. Perhaps numbering 100 or more, fringing and patch reefs occur along the coasts and on offshore islands from Costa Rica to Ecuador (Glynn and Wellington 1983; Guzman and Cortes 1993). Coral species richness is highest off Costa Rica (20 species) and Panama (23 species). Although several species occur in the southern Central American area, many of these, about 50% of the fauna, are rare or have recently experienced local to regional extinctions (Glynn, in press). The majority of the reductions in population size were coincident with the 1982-83 El Niño disturbance. Prolonged sea warming caused coral reef bleaching, which resulted in high coral mortality (Glynn 1990; Guzman and Cortes 1993).

In addition to El Niño-related disturbances, heavy sediment loading resulting from poor land management (Cortes 1990), phytoplankton blooms (Guzman et al. 1990), intense upwelling pulses (Glynn and D'Croz 1990), extreme low water exposures (Glynn 1976), tectonic activity, volcanism, and anthropogenic contaminants (Guzman and Cortes 1993) have all had measurable impacts on eastern Pacific coral reefs. Moderate levels of predation by *Acanthaster planci* can reduce live coral cover, affecting relative abundances of corals and coral species diversity in certain areas (e.g., Gulf of California, Mexico, and Gulf of Chiriqui, Panama), but sea star outbreaks have never been observed in the eastern Pacific (Glynn 1974). Hurricane damage to reefs is also relatively rare, affecting chiefly the Mexican coast, Revillagigedo Islands, and Clipperton Atoll.

Local fishermen are the principal users of eastern Pacific coral reefs, from which are harvested fishes, spiny lobsters, shellfish (conch and scallop), and ornamental corals. Until recently, pocilloporid corals were collected and sold as souvenirs from reefs in Mexico and Costa Rica. This practice has been outlawed and is reasonably well enforced. Live rock is still occasionally harvested illegally and shipped chiefly to the U.S.A. An especially destructive form of exploitation has been observed recently in Panama. This involves breaking live reefs apart with tuna bombs and then dredging through the broken corals in order to collect sea shells, which are sold to collectors.

The only known mooring buoy established on a coral reef is at Devil's Crown, Floreana Island, Galapagos Islands. However, the buoy is not regularly maintained and is not always functional. A line of anchored buoys was also laid recently to mark the bounds of a large pocilloporid reef (La Entrega) at Santa Cruz Bay, Huatulco, Mexico. Unfortunately, several of the anchors were dropped directly on live corals.

The greatest value of eastern Pacific coral reefs is for fishing and tourism. Regrettably, most fishermen exploit the reefs for fishes and shellfish with little concern for their preservation. Recreational diving is increasing rapidly, and this is exercised mainly by foreign tourists.

PRESENT CONDITION

Coral reefs in many eastern Pacific areas are in reasonably good condition (i.e., they appear to be undergoing net positive vertical and horizontal growth). However, coral reefs in several areas have been severely degraded, largely a result of the 1982-83 ENSO, and are currently in an erosional mode. Nearly all coral reefs in the equatorial eastern Pacific (Galapagos Islands, Cocos Island, mainland Ecuador, Colombia, Panama, and Costa Rica) experienced 50 to 99% mortality, which was coincident with the 1982-83 ENSO (Glynn 1990; Glynn and Colgan 1992; Guzman and Cortes 1992). Coral reefs in the Galapagos Islands (Glynn 1994) and at

Cocos Island (Guzman and Cortes 1992) have shown virtually no recovery since 1983. Reefs in these areas continue to decline due to concentrated corallivory on surviving corals and continuing bioerosion (Reaka-Kudla et al. 1996). Elsewhere, coral recruitment is evident with slow to moderate recovery taking place. In the northern part of the eastern Pacific region (Mexican mainland coast, Revillagigedo Islands, and Clipperton Atoll), most coral reefs exhibit high to moderately high coral cover or are experiencing coral recruitment following bleaching events.

Following is a brief review of coral reef degradation by locality.

Galapagos Islands

All known coral reefs in the Galapagos Islands are seriously degraded. The chief causal factors are ENSO 1982-83 coral bleaching and mortality, anchor damage and fishing activities. The reef structures are 80-100% degraded (i.e., most to all reef surfaces show some signs of damage: dead and eroded corals or collapsed frameworks); 100% of the reefs are affected.

Mainland Ecuador

Many of the Ecuadorian mainland coral reefs are damaged. The causal factors are as above; 50% degradation; 80% of the reefs are affected.

Colombia

All coral reefs at Gorgona Island were affected by the 1982-83 ENSO (Prahl 1983, 1985); 20-30% degradation; reefs have recovered substantially, now with 40-50% cover (Vargas-Angel, pers. comm.). There are some indications that river-born sediments are beginning to affect the coral reefs of Gorgona Island (Vargas-Angel, pers. comm.). In recent years the course of the Rio Patia has been altered such that its effluents flow more directly toward Gorgona Island. Malpelo Island: no quantitative data available, but live coral cover relatively high (Vargas-Angel, pers. comm.). Ensenada de Utria National Park: live coral cover has declined in recent years due chiefly to increased sedimentation stress (Vargas-Angel 1996); 40% degradation; 100% of reefs affected.

Panama

The coral reefs in Panama are located in the Gulf of Panama: Taboga, Otoque, Bona, the Pearl Islands, and Iguana Island, and at most islands in the Gulf of Chiriqui: Coiba, Contreras, Secas, Canal de Afuera, and Montuosa. Also, there are several mainland reefs in the Gulf of Chiriqui. The Taboga Islands reefs appear to be most affected by a fish meal plant (Taboguilla Island), siltation (Taboga Island), and mechanical damage by fishermen. Degradation ranges from about 50% to complete destruction (or burial). About 80% of the reefs are affected. The reefs in the Pearl Islands were about 50% degraded by the 1982-83 ENSO with nearly all affected. Several of these are showing reasonable recovery. A rare group of *Gardineroseris planulata* colonies at Contadora Island is threatened by building and boating activities. Trash is often dumped on top of nearshore colonies. Reefs in the Gulf of Chiriqui suffered about 40-80% degradation during the 1982-83 ENSO and all (100%) were affected. Most of these reefs are showing signs of recovery, however, shrimp boats anchoring near them (e.g., at Uva Island) sometimes drag their anchors over the reefs or run aground, causing extensive damage. Some of the fishing boats discard trash (e.g., motors, cables, nets) directly on the reefs.

Costa Rica

Reef formations in mainland Costa Rica occur mainly at Cano Island, in Golfo Dulce, and along the Guanacaste coast. ENSO-related damage to most of these reefs was similar to that noted above for coral reefs in the Gulf of Chiriqui, Panama. The oldest, fringing, poritid reef at Punta Islotes, located in Golfo Dulce, was not examined during the 1982-83 ENSO but nonetheless has been severely degraded in recent years. The living coral cover on this reef is now less than 2%. Increased sedimentation and turbidity were associated with the final stage of reef degradation, probably a result of recent deforestation, mining, and road construction (Cortes et al. 1994). Since so little information is available on the coral reefs of the Guanacaste area, it is premature to assign quantitative values on the extent of degradation or the proportion of reefs affected. All of the coral reefs at Cocos Island, located several hundred kilometers offshore, were severely (90-95%) damaged by the 1982-83 ENSO (Guzman and Cortes 1992). Post ENSO disturbances caused by *Acanthaster* predation and bioeroders have further degraded the Cocos reefs.

Nicaragua, Honduras, El Salvador, Guatemala

Virtually no literature exists on the extent of reef development along the Pacific Central American coast from southern Nicaragua to southern Mexico. Coral communities are known to occur in El Salvador, but these have not been properly described and their condition is unknown.

Mexico

Seventeen pocilloporid reefs have been observed recently in the Bahias de Huatulco area of southern Mexico. Three of these reefs are mostly dead, with less than 3% live coral cover: Santa Cruz fringing reef, Riscalillo reef, and a patch reef offshore of a Club Med resort. The cause of death is unknown, but the Santa Cruz and Club Med reefs are located near extensive development activities, such as harbor dredging and jetty construction. The only other published information on disturbances to Mexican coral reefs pertains to reefs in the southern part of Baja California. Reyes Bonilla (1993a, 1993b) refers to pocillopoird mortality at Cabo Pulmo during the 1987 El Niño, which amounted to no more than about 10% of the coral cover. It is possible that the 1982-83 ENSO had some effect on corals in this area, but no observations were reported. Significant local coral mortality also was noted at Los Cabos sometime between 1988 and 1989. For example, Wilson (1990) described 70-95% mortality of *Pocillopora* spp. at Punta Palmillas and Cabo San Lucas from unknown causes. Reyes Bonilla (1993a) speculated that extreme low sea temperatures could affect corals in this area. Likely, although undocumented, sources of damage caused by humans are anchor damage, extraction of corals for sale as curios, the collection of fishes for the aquarium trade, siltation due to land clearing and hotel construction, and the discharge of sewage. Although no literature was found dealing with the coral reefs of the Revillagigedo Islands, it seems probable that the reefs there would experience occasional hurricane damage.

Clipperton Atoll

Outside of isolated dead patches of *Pocillopora* sp. and *Porites lobata* colonies that had experienced partial mortality, the extensive reef formations surrounding this atoll appeared healthy. Overall, probably <5% of the coral cover was dead.

GENERAL

As a rough approximation, about 10-20% of the coral reefs in the equatorial eastern Pacific region are still in a pristine state. While damage due to ENSO is evident on all reefs, they are now dominantly in a recovery phase. Perhaps 60-80% of the coral reefs in the northern eastern Pacific region are in a pristine state (Reyes Bonilla 1993a).

The following is a subjective ranking of the most serious human-induced stressors to coral reefs in the eastern Pacific region.

1) Physical destruction of reef frameworks by anchors, fishing nets, trash (plastic bags, discarded clothing, scrap metal, etc.) and boat groundings.
2) Siltation stress from river discharge in areas with poor land management (e.g., clear-cutting of forests, mining activities, hotel and road construction).
3) Increased nutrient and sewage runoff near reefs.
4) Harvesting of seashells, coral rock and tropical fishes.

A subjective ranking of natural disturbances follows.

1) Coral bleaching and mortality (El Niño-Southern Oscillation).
2) Severe upwelling events (cold water stress and increased competition with non-calcifying epibenthos due to elevated nutrients). Bioeroder populations, such as sponges, bivalve mollusks, and sea urchins, also interfere with corals on local scales.
3) Flooding episodes with high river discharge carrying sediments and contaminants.
4) Localized mortality due to *Acanthaster* and *Jenneria* (a gastropod) corallivore activities.
5) Tectonism and volcanism affecting reefs on local scales.

No statistical data are available on coral reef resource exploitation in the eastern Pacific.

Scientific Importance and Research

In recent years (since about the 1970s), much of the research on eastern Pacific coral reefs is being conducted by resident scientists at local laboratories rather than by visiting scientists from distant institutions. This offers several advantages, including the opportunity to carry out continuously monitored studies, to observe unexpected events firsthand, and to address scientific problems that are locally relevant.

Several notable studies have been conducted by reef researchers at the Charles Darwin Research Station (Galapagos Islands, Ecuador); the Universidad del Valle, and the Universidad de los Andes (Colombia); the Departamento de Biologia Acuatica, Universidad de Panama, and the Smithsonian Tropical Research Institute (Panama); the Centro de Investigacion en Ciencias del Mar y Limnologia (CIMAR), the Escuela de Biologia, Universidad de Costa Rica (Costa Rica); the Centro de Investigacion Cientifica y Educacion Superior de Ensenada, and the Departamento de Biologia Marina, Universidad Autonoma de Baja California Sur (Mexico).

Guzman and Cortes (1993) offer an informative overview of the sorts of research that have been conducted on eastern Pacific coral reefs: physical oceanographic influences (e.g., tides, currents, upwelling, El Niño events), reef growth history, paleoclimate analyses, systematics, biogeography, ecology (coral growth, competition, predation, bioerosion, symbioses), natural and anthropogenic disturbances, coral community recovery, and management and conservation. More recently molecular genetic studies on the systematics of pocilloporid corals and the identity of dinoflagellate strains vis-a-vis coral bleaching have been initiated at the Smithsonian Tropical Research Institute in Panama.

Some of the more pressing research needs are listed below: (1) develop an inventory of the regional distribution of coral reefs and their species composition; (2) establish research collections of corals and other reef-associated species; (3) establish an international network of coral reef monitoring to assess water quality (e.g. temperature, salinity, sediment loading, turbidity, irradiance, nutrients) and the condition of coral reefs, and to quantify variations in the abundances of key (e.g., chief calcifiers, corallivores, herbivores, bioeroders) reef species; (4) determine environmental impacts, both natural and anthropogenic. Financial support is needed to coordinate these tasks among the various research groups. Planning and training workshops are necessary to decide on critical study areas, and to intercalibrate instruments and standardize methodologies and sampling protocols.

Management

Although some attention has been directed toward the management of eastern Pacific coral reefs, generally these efforts have been inconsistent, transitory and largely ineffectual. A mooring buoy is sometimes available at a popular diving site (Devil's Crown, Floreana Island) in the Galapagos Islands. I am aware of only one other attempt to protect a coral reef from boat traffic, namely the buoy line established on La Entrega reef, Santa Cruz, Huatulco, Mexico. Coral populations that were devastated by the 1982-83 ENSO have been restored by transplantation efforts at selected sites in the Galapagos Islands (Academy Bay; Glynn 1994), and in Colombia (Gorgona Island), Panama (Iguana Island), and Costa Rica (Cano Island) (Guzman 1991). Several national parks or protected areas now exist near coral reefs in Ecuador (in the Galapagos Islands and on the mainland), Colombia (Gorgona Island, Utria), Panama (Iguana Island, Coiba Island and surroundings), Costa Rica (Cocos Island, Cano Island and several mainland sites), and Mexico (Revillagigedo Islands, Huatulco and other mainland sites). While the protection of coral reefs within most of these parks is a priority, they are seldom patrolled by park rangers or law officers. Therefore, much unnecessary destruction continues.

From the ranked list of stressors noted above, the most serious anthropogenic impacts affecting coral reefs appear to be (1) physical damage, (2) siltation, (3) runoff (sewage, contaminants and nutrients, and (4) harvesting (overfishing). Runoff is often exacerbated by natural flooding in high rainfall areas. ENSO events and strong upwelling episodes may also add to the various anthropogenic coral stresses already noted. As for corrective measures to reduce damage, access to coral reef zones should be limited to small boats, artisanal fishermen and swimmers. Tourists and the local populace should be educated regarding the fragility of coral reefs. No dumping of trash on or near coral reefs should be allowed. Clear cutting and construction projects near reefs should be discouraged. An attempt should be made for conservationists and park managers to work closely with developers and others exploiting coral reef resources.

In order to slow down present day degradation of coral reefs in the eastern Pacific, each nation with coral reef resources should establish management teams to work closely with the public and scientific community. While the scientific expertise is now in place in several Latin American countries, trained management personnel are nearly universally in short supply. Most users of coral reefs are ignorant of the many benefits they offer and do not understand the importance of protecting them for sustainable use. Thus, a program involving managers, conservationists, educational institutions, and scientists should be established immediately to educate the public and users of coral reefs on their importance and value to future generations.

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FRENCH POLYNESIA

STATUS OF CORAL REEFS IN FRENCH POLYNESIA

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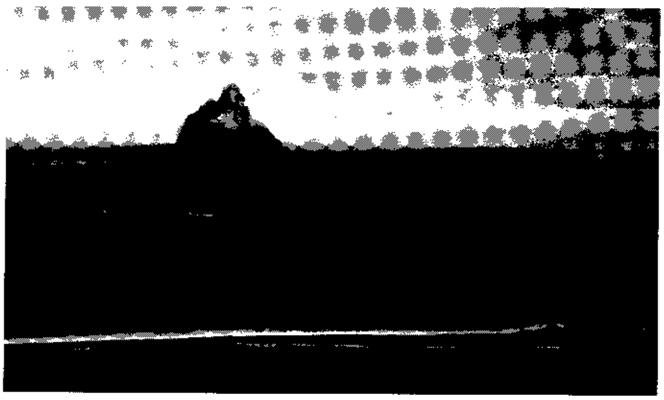
French Polynesia extends over 2,500,000 km² of ocean from 134°28'W (Temoe) to 154°40'W (Scilly) and from 7°50'S (Motu One) to 27°36'S (Rapa) (Figure 1). Emergent land totals about 4,000 km² and there is about 7,000 km² of lagoon. The islands are located in a general NW-SE orientation, their age decreasing from northwest to southeast, and they form five distinctive archipelagoes: Society, Tuamotu, Gambier, Marquesas and the Austral Islands. There are around 130 islands, of which 84 are atolls; most of the remainder are high volcanic islands, many being very mountainous with inaccessible interiors.

Since 1965, numerous missions have been undertaken to study the marine life of the area within the context of interdisciplinary studies of island ecosystems (Salvat 1976). The main objectives of research programmes are to study the wealth and productivity of reef ecosystems. A bibliography of the main references on the reefs of French Polynesia is given in Gabrié and Salvat (1985). Around 70 islands have been visited by scientists from the MNHN-EPHE (now CRIOBE) and publications have appeared on 30 of these islands.



The Tuamotu Islands are the best known scientifically. Moorea, Tahiti and Manuae in the Society Islands are also well known. Missions were also undertaken to the Marquesas and Gambier Islands. Extensive work, largely fisheries oriented, is carried out by ORSTOM which is based on Tahiti (Monnet et al. 1986). Additional work on fisheries, particularly the pearl fishery, is carried out by EVAAM.

The population of French Polynesia has increased rapidly since the 1920s, reaching about 212,100 in 1994. Over 70% of the population is concentrated on the Leeward Islands, particularly Tahiti and Raiatea, placing the reefs and marine environments of this region under greatest pressure. The other high volcanic islands are less at-risk due to their lower populations, but atoll environments are very vulnerable. Reefs are being affected by dredging, coastline alteration, filling, and discharge of sewage. The discharge of sewage and industrial effluents is widely recognized as a problem, as well as the disposal of rubbish.

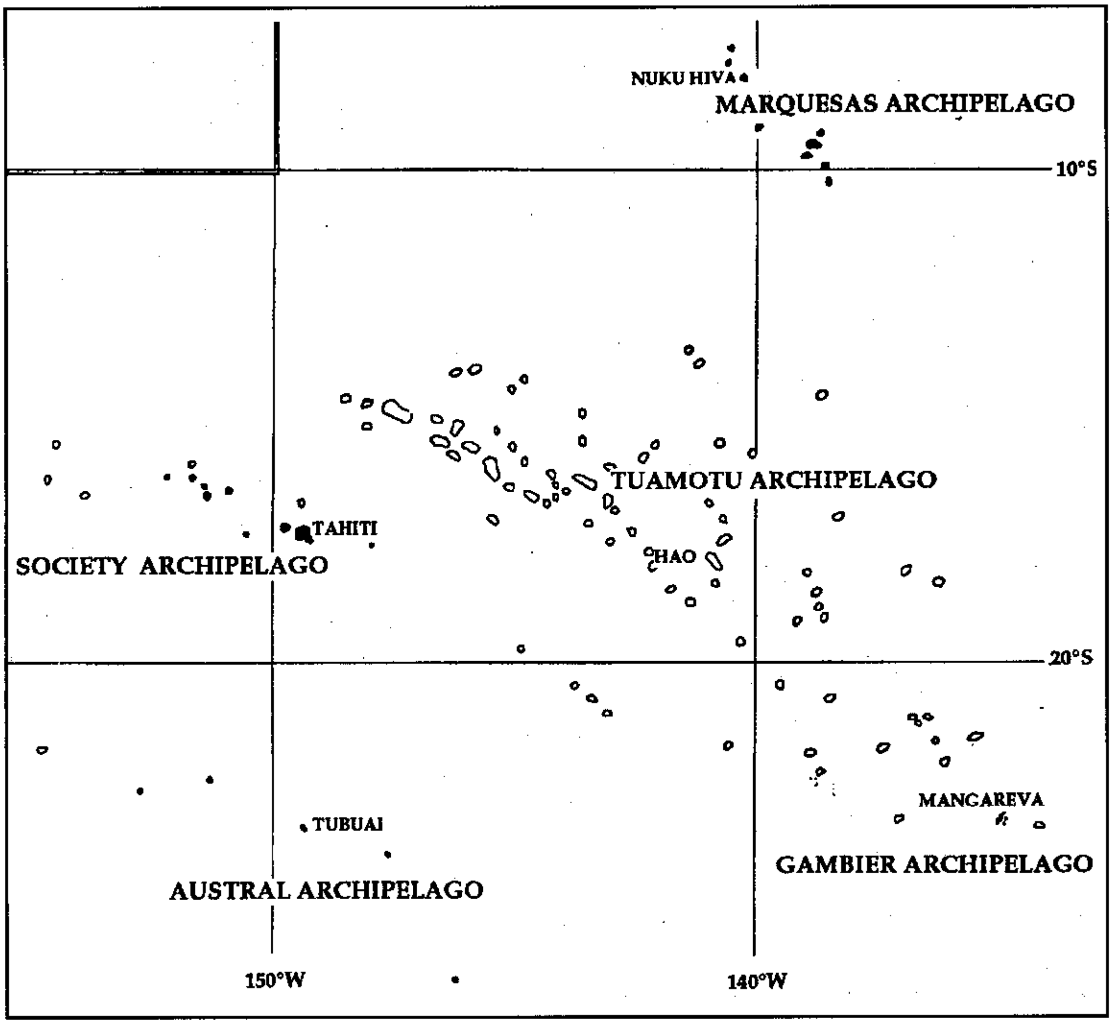


Figure 1. Map of French Polynesia.

The tourist industry is expanding rapidly and tourists have increased in number from 82,822 in 1975 to 140,000 in 1993 (Gabrié 1995). This growth is facilitated by the improved domestic flight service and the construction of hotels on many islands. Reef-related activities are of growing importance. The number of islands with resorts is increasing although Tahiti and Moorea still account for more than 80% of the total hotel capacity (Gay 1993). A recent trend is the development of resorts on the atolls and the resultant increase in domestic air services. Many of these hotels cater to reef-related recreational activities. In addition, there are recreational boating activities concentrated around the main islands (Tahiti, Moorea, Bora-Bora). The following recreational activities may have impacts on reefs: walking on the reef; collecting shells; diving and snorkeling; and a variety of motorised vessels used by tourists. These activities in general only take place in limited areas of reef, immediately in front of hotels, but the impact they have, and the relative importance of the different activities, is difficult to assess as no studies have been carried out. Tourists also may have disruptive effects on seabird colonies if they are allowed uncontrolled access, as on Tetiaroa. The development of fisheries, pearl culture and tourism create many user conflicts and cause pollution to the environment. Nuclear testing on Moruroa and Fangataufa Atolls is now stopped but environmental risks still exist.

The Reef and Natural Conditions

The main reef formations are found around the high islands and atolls although there are several oceanic banks of variable form (e.g., Ebrill Reef in the Gambier Islands and Moses Reef in the Austral Islands). Lying at the easternmost extremity of the Indo-Pacific Province, French Polynesia is at the limit of the axis of decreasing species richness and has a comparatively poor coral fauna. This is accentuated by the prevailing currents and winds which hinder the dispersal of larvae from the western Pacific, relatively low water temperature compared to the western Pacific, and the remoteness of the islands from continental masses. Many western Pacific genera are not found (e.g., *Symphyllia, Oulophyllia, Seriatopora, Goniopora* and the families Merulinidae and Euphyllidae) and only 18 species seem to be endemic to the region. Other characteristics typical of a marginal area are a high species diversity within some genera (e.g., *Psammocora, Pocillopora, Leptoseris*, and to a lesser extent *Montipora*) and an abundance of some taxa which are uncommon or absent in the central Indo-West Pacific such as *Sandalolitha* and *Porites irregularis.*

The eastern trade winds predominate from October to March. Annual rainfall affects the mean temperature through a warm rainy season from November to April and a relatively cool and dry season exists from May to October. From April to June, there are long calm periods broken by occasional cyclones, which generally arrive from the northeast and northwest. Within this general pattern, there are significant differences between the archipelagos (SPREP 1980a, 1980b, 1980c). Cyclones have been rare in the past, averaging one per century to the north of the Marquesas, one to three per century from the Marquesas to the region north of the Tuamotu group, four to eight per century from the Tuamotu group to the Gambiers and one every two or three years in the Austral areas. The year 1982-83 was exceptional in that five cyclones occurred (Nano, Orama, Reva, Veena and William), related to the abnormal El Niño conditions of that period, and were accompanied by abnormally low sea levels. Tides are semi-diurnal, with an amplitude rarely exceeding 40 cm. Sea water temperature decreases southward and eastward to Rapa where the minimum temperature suitable for coral growth is found. Summer temperatures are 26-30°C and winter temperatures are 20-22°C.

Status of Coral Reefs

The Scleractinia of French Polynesia are described by Chevalier (1981) and listed in Pichon (1985a); 168 species in 51 genera have been identified, including a few ahermatypic forms such as *Culicia* and *Tubastraea* but do not include deep-water ahermatypic corals. Although the Acroporidae show the highest species diversity, the Poritidae and Agaricidae are dominant in biomass, particularly around high islands, and the Pocilloporidae and some Faviidae are abundant in the atolls. In general, the coral fauna of the high volcanic islands surrounded by fringing or barrier reefs is richer than that of low atolls on banks. Many species are found only on the reefs adjacent to volcanic islands. For example, *Psammocora, Synaraea, Pachyseris, Pavona* and closely related genera are more abundant on fringing or barrier reefs than on atolls. Generally, the fauna of the outer slope and reef rim varies only slightly from one atoll to another but the coral fauna of the lagoons may be very different depending on depth and degree of exchange with the open ocean. Open atolls have a richer fauna than closed atolls, and in the former, the greatest coral diversity is found near the passes. In closed or semi-closed lagoons, the coral fauna may be much impoverished and dominated by *Porites* and *Acropora*. The Tuamotu and Society Islands have a moderately high coral diversity, with large reefs and a variety of reef types. These two groups of islands are of particular interest as they were the subject of Darwin's early studies of reef morphology and evolution (Glynn and Wellington 1983).

Status of Other Organisms on the Reefs

Richard (1985) provides a list of all marine invertebrate, fish and algae species recorded in French Polynesia and a bibliography of references related to marine fauna and flora. The marine molluscs have been particularly well studied (Salvat 1967, 1970, 1973a; Lavondes et al. 1973; Richard 1974; Salvat and Rives 1975). *Cypraea obvelata* is endemic to French Polynesia. *Tridacna maxima* is the only member of the family Tridacnidae to occur in French Polynesia (Richard 1977); it is found in all the archipelagos except the Marquesas. *T. maxima* is very abundant in the lagoons of the Tuamotu atolls. Although not exploited to any great extent at present, its high productivity has considerable potential.

The fish of French Polynesia have been described by Randall (1973, 1978), 800 species in 90 families have been recorded. A total of 246 fish species have been recorded in the Gambiers (Fourmanoir et al. 1974). The fish fauna of the Marquesas is described by Plessis and Mauge (1978); it seems to resemble that of the rest of Polynesia but is slightly less diverse. Marine algae are listed by Payri and Meinesz (1985).

Major Disturbance and Exploitation

French Polynesia periodically suffers severe hurricane damage. However, it is not known to what extent the reefs and damaged by these events. Three of the five cyclones which affected French Polynesia in 1982-83 passed close to the Society Islands and caused significant reef damage, as well as in other areas (Dupon 1986). Furthermore, from mid-March to the end of May 1983, the mean sea level dropped by as much as 20-25 cm below normal in the Society Islands (Rougerie and Wauthy 1983) causing extensive death to corals, algae and reef biota close to the surface. For example, large areas of the reef died at Moorea. This prolonged period of low sea-level and cyclonic disturbance was probably related to the abnormal El Niñowhich occurred at that time (Glynn 1984; Pirazzoli 1985).

There have been some outbreaks of *Acanthaster planci*, for example in Moorea 1978-83, which affected shallow water, coral communities and increased the amount of macroalgal growth. Since 1980, and all around the world, coral bleaching events are of increasing importance. These events are correlated with periods of El Niño and unusual high temperatures. In 1983, 1984, 1987 and 1993, bleaching was moderate, while in 1991 and 1994 most reefs in the Society Islands were affected. Subsequent coral mortality occurred on some reefs (Salvat 1992a, 1992b).

Fishing is an important activity, ranging from traditional subsistence to commercial fisheries. At the end of 1990, the annual catch from the lagoon by the artisanal fisheries was about 5,500 tons; by comparison, offshore production was 2,100 tons (Chauvet and Galzin 1990). Thus, 72% of the fish landed in French Polynesia in 1990 came from the lagoon and 28% from the open sea. Much of the catch comes from the Tuamotu atolls, but because of population increase, the production of the Society Islands is suddenly becoming important. The catch is generally consumed locally although exports are starting with the growth of Papeete as a port and the development of domestic flights. More than 64% of the fish sold in Papeete market comes from the Tuamotu Atolls, 23% from the Society Islands and 13% from other archipelagos. Some deep-sea fishing occurs on the outer slopes of some of the atolls. Lagoonal fisheries include fish, molluscs, crustaceans and echinoderms. Overfishing has been reported in a number of areas (Serra et al. 1995).

In certain areas of the Society Islands extensive overfishing of coral reef fishes has occurred as a result of spearfishing and the use of fine meshed nets. Many areas are almost completely devoided from mature-sized fish, which means that breeding populations have been severely depleted. It appears that accurate figures of fish landings are only available for fish sold through the fish markets in Tahiti. Production was 2,300 tons in 1991 but fell to 2,000 tons in 1992. No figures are available for the number of fish and species composition of fish harvested by traditional subsistence fishermen. Ciguatera is a widespread problem and major research on this is carried out at the Louis Malarde Institute on Tahiti.

Trochus niloticus was introduced in 1954 and some commercial exploitation has occurred since 1972. Bag limits have been introduced and certain areas declared off limits for collecting this species, but these regulations are rarely enforced. The commercial viability of the green snail (*Turbo marmoratus*), which was introduced in 1967, is in doubt although currently no legal fishing is allowed. The indigenous species *Turbo setosus* and the giant clam *Tridacna maxima* are decimated because of increasing human predation.

Three species of sea turtles are traditional Polynesian food, although they have been protected since 1971. A recent regulation passed in July 1990 reinforces this protection, but currently no detailed information is available on turtle numbers.

Pearl oysters were intensively collected for their mother-of-pearl (*Pinctada margaritifera*) from the early 19th century to about 1950 when production started to fall due to overexploitation. Exploitation peaked at 1,400 tons although maximum sustainable yield is probably about 1,000 tons. Both the mother-of-pearl and pearl industries are now thriving as a result of the development of culture techniques. Exports of the highly valued black pearls from the black lip oyster have increased since 1972 due to increased culture operations following a decline in natural stocks in the 1970s. The pearl industry has the highest export value of any product in Polynesia since 1983. Black pearls constitute over 80% of the total value of exports from French Polynesia, about 8 billion of CFP (Gabrié 1995). Of the 152 fishing cooperatives in French Polynesia, 91 are concerned with mother-of-pearl and pearl culture. These are found on 46 islands and atolls. Hatchery production has not been successful and natural stocks are used; either adults are collected by divers, or spat are collected and reared. Growth of pearl farming has created a demand for living oysters which are able to withstand the grafting operation. After high mortality rates in mollusc populations in 1984 and 1985, a general research programme on the mother-of-pearl oyster has started with participation of EVAAM, IFREMER, ORSTOM and UFP with the help of the Territory Department of Fisheries. Studies deal with the biology, physiology and ecology of the oyster and its environment.

A major problem in the Society Islands is the use of coral sand from the lagoon as a source of road building materials. A number of studies to investigate the damage this causes have been carried out (de Vaugelas 1979; Gabrié et al. 1985; Masson and Simon 1985; Porcher and Gabrié 1985; Porcher and Gabrié 1987).

Maria Tugaoen fish-feeding in Bora Bora.

Coral Reef Management, Recommendations and Legislation

Since 1984, the Territory has full power over environmental matters (law No. 84-820) of 6.9.84) and there is legislation for a certain number of ad hoc problems which are listed below:

Decision no. 88-183/AT of 8.12.88 prohibits the use of SCUBA equipment for spearfishing, of SCUBA for all fishing or collection of all marine animals, of certain toxic substances for fishing and defines the limits to the use of meshed nets.

Decision no. 88-184/AT of 8.12.88 protects some marine species (*Charonia tritonis, Cassis rufa* and *C. cornuta, Turbo marmoratus, Trochus niloticus, Tridacna maxima, Atrina vexillum* [giant mussel], *Scylla serrata, Lisiosquilla maculàta*, mantis-shrimp, manta ray). Fishing is limited to certain areas and for limited periods each year with bag limits. In some areas, no fishing is allowed.

Decision no. 90-83/AT of 13.7.90 protects three species of marine turtles (*Chelonia mydas, Dermochelys coriacea* and *Eretmochelys imbricata).*

Decision no. 90-93/AT of 30.8.90 protects all "black coral" species (Cirripathes and Antipathes).

Until 1995, the Planning Code of French Polynesia allowed the classification of sites but without enforcement: 164 sites are classified as cultural heritage and 29 as natural heritage, but the Code is not adapted for protection of lagoonal environment (Hutchings et al. 1994).

In December 1995, the Territorial Assembly adopted the following International Conventions (Gabrié 1995):

The Apia Convention (1976): to create protected areas (natural ecosystems, geological sites, cultural sites).

The PROE Convention (1986): for the prevention of pollution in the South Pacific and for the protection of rare and fragile ecosystems.

The Washington Convention: to protect the endangered species, *Tridacna maxima* (clam), *Antipatharia* sp. (black coral), *Scleractinia*, Milleporidae, Stylasteridae, marine turtles *Chelonia mydas*, *Dermochelys coriacea* and *Eretmochelys imbricata*, and cetaceans. Moreover, French Polynesia is a member of the Convention on International Trade in Endangered Species (CITES) of Wild Flora and Fauna which regulates the international commercial trade of hard and black corals (Callister 1995).

The Convention for the protection of cultural and natural worldwide heritage (Paris 1972).

The Convention of Bonn (1985): Protection of migratory species.

The Worldwide Convention for the Biodiversity (1992).

The Man and Biosphere Programme (UNESCO): creation of reserves of the Biosphere (as Taiaro Atoll).

There are currently several research and monitoring programmes. The Territorial Observation Network for the Marine Environment is pioneered by the Delegation of the Environment; the Network for the Monitoring of Swimming Beaches operates under the Ministry of Health. An environmental observatory has been planned for 1996 to compile data provided by research departments in the Territory. A research programme named "Anthropic" is conducted by ORSTOM to study anthropogenic pressures in the lagoon. The Delegation of the Environment works on the development of management plans. One of these plans is the Management Plan of Maritime Areas (MPMAs). The procedure outlining MPMAs is defined by a decision (no. 92-221) of the Territorial Assembly. The purpose of MPMAs is to determine the conditions of use, development, protection or enhancement of lagoons or maritime seaboards (Serra et al. 1995). At this date, no MPMAs has been approved; however 10 geographical zones were selected as priorities for the 1994-98 period. The funding of the MPMAs is provided in part from territorial funds and in part from credits allocated as part of the 1994-98 Development Contract entered into between the French State and Territorial authorities. A detailed study of Bora-Bora was undertaken to establish a Marine Territorial Park but to date the park has not been declared (Hutchings et al. 1994).

An integrated Coastal Zone Management Plan for the entire region will lay down guidelines for coastal marine activities and exploitation of its resources (Gabrié 1994). A public awareness-building action to preserve the natural heritage provided by lagoons has been undertaken by the Delegation of the Environment and the Department of the Sea.

Marine and terrestrial protected areas have been established.

Marine Protected Areas (about 0.1% of the total lagoonal area):

- Tuamotu group: Taiaro Atoll (W.A. Robinson Reserve Integrale); Biosphere Reserve (MAB Programme), 923 ha.
- Society Islands: Manuae (Scilly) and Bellinghausen (Motu One) Atolls; Territorial Reserve, 10,400 ha and 960 ha.
- Marquesas: Islet of Motu One

Terrestrial Protected Areas:

- Society Islands: Te Faaiti natural park (Tahiti, 750 ha)
- Marquesas: Islets of Mohotani (1,554 ha), Eiao (5,180 ha) and Hatutaa (1,813 ha).

The main problem is the lack of enforcement of these restrictions.

Future Trends and Conclusions

Lack of protection of coral reef environments is a problem in French Polynesia in spite of an existing database and access to highly qualified scientists and managers.

With a rapidly expanding population and attempts to increase tourism, the pressure on the reefs and the surrounding areas will only increase. Unless measures are taken to control fishing, water quality, restrict the discharge of untreated sewage and terrestrial runoff, the reefs will continue to decline. Urgent action is required by the Territorial Government to implement and enforce the management of coral reefs and lagoon environments, but currently their protection does not appear to be a priority. Hopefully this will change before it is too late.

Characteristics of the Main Islands

SOCIETY ISLANDS	Characteristics
Bellingshausen (Motu One)	Closed atoll with 4 islets; triangular reef.
Bora-Bora (Pora-Pora)	30 km^2, high volcanic (727 m); deep large lagoon with one pass; well developed reef islands on wide barrier reef; considered one of the most beautiful islands in the world.

Characteristics of the Main Islands (continued)

SOCIETY ISLANDS	Characteristics
Huahine Nui and **Huahine Iti**	73 km^2, twin volcanic islands (435 m and 669 m); surrounded by narrow barrier with five passes; barrier reef raised at north to form cultivated terrace; fringing reef around island largely dead.
Maiao (Tubuai-Manu)	9.5 km^2 almost-atoll with volcanic ridge (154 m); 7 islets on barrier (Tapuaemanu) reef; ridge flanked by coral flats and barrier reef.
Maupiti	13.5 km^2, almost-atoll with small residual volcanic island (380 m) separated from a wide barrier reef flat by shallow, partially reticulated lagoon; barrier reef with well developed islands; central island flanked by well-developed fringing reef; considerable freshwater inflow; abundant reef life and lagoon fish fauna.
Mehetia (Mahetia, Meetia)	2 km^2, high volcanic (433 m), still active; youngest island in Societies situated close to a hot spot; no true fringing reefs but coral colonies found on submarine volcanic slopes, particularly *Pocillopora*.
Mopelia (Maupihaa, Mopihaa)	2.6 km^2, atoll with many islets; reef with narrow pass; coralline algal ridge; corals play very small role in reef formation.
Raiatea and **Tahaa**	194 km^2 and 88 km^2, high volcanic (1,017 m and 590 m); barrier reef encircling both islands; lagoon continuous apart from two short sections on west and penetrates deeply into bays, becoming larger north of Tahaa.
Tetiaroa	1,288 ha, atoll with 13 islets around enclosed lagoon; 6 islets have seabird rookeries, including Tahuna Rahi and Tahuna Iti; privately owned with hotel.
Tupai (Motu Iti)	21 km^2, only atoll in Leeward Islands; barrier reef with two motu; narrow shallow closed lagoon with numerous coral patches and abundant phytoplankton; partly private.
TUAMOTU ISLANDS	
Morane	Atoll; enclosed lagoon, 3 islets.
Maria	Atoll; enclosed lagoon.
S. Marutea	Atoll; 18 km long with islets; 1 pass into lagoon.
Actaeon Group	
Matureivavao	
(Maturei Vavao)	Atoll, low, with enclosed lagoon.
Tenarunga	Atoll; low, with enclosed lagoon.
Vahanga	Atoll; low, with enclosed lagoon.
Tenararo (Tenaroa)	Atoll, low, with enclosed lagoon.
Fangataufa (nuclear testing site)	Oblong atoll; lagoon 40-42 m deep (10 km); 1 pass into lagoon; reefs consist of coralline edge, reef-flat, inshore belt.
Tematangi	Atoll; low, with enclosed lagoon.
Tureia	Atoll; low, with enclosed lagoon.
Vanavana	Atoll; narrow strip of land enclosing lagoon.
Nukutipi	Atoll; 4 km; enclosed lagoon; badly damaged by cyclones; privately owned; proposed for future studies.

Characteristics of the Main Islands (continued)

Duke of Gloucester Group	Characteristics
Anuanurunga	Atoll; 4 islets on reef.
Anuanuraro	5 km enclosed lagoon; privately owned.
Hereheretue	Atoll; enclosed lagoon, molluscs studied on 2 reefs.
Reao	Narrow atoll and enclosed lagoon (22 x 4 km); molluscs studied on 5 reefs; densities of *T. maxima*; 50-70/km^2 over 370 ha of lagoon coast; *Porites mordax* and *Acropora formosa* very abundant in lagoon but coral diversity low.
Pukarua (Pukaruha)	Atoll; enclosed lagoon (13 x 3 km).
Tatakoto	Atoll; low with enclosed lagoon (15 x 6 km).
Pinaki	Atoll; 3 islets to north-west of reef.
Nukutavake	Coral island with no lagoon (5 x 2 km).
Vairaatea	2 islands; barrier reef.
Vahitahi	Long atoll with enclosed lagoon.
Akiaki	Small round island with enclosed lagoon.
Ahunui	Enclosed lagoon.
Paraoa	Enclosed lagoon; turtles.
Manuhangi	Enclosed lagoon.
Nengonengo	Nearly circular atoll; pearl-rich lagoon.
Hao (military site)	Atoll (56 x 15 km); 1 pass into lagoon; considerable research works.
Amanu	Atoll
Ravahere	Atoll; enclosed lagoon.
Marokau	
Reitoru	Atoll; enclosed lagoon.
Haraiki	
Hikueru	Atoll (12 km); no passes into lagoon.
Tekokota	Atoll; enclosed lagoon.
Tauere	
Rekareka (Rekareta)	Atoll; enclosed lagoon; no freshwater.
N. Marutea	Atoll; submerged barrier reef.
Nihiru	Circular atoll with enclosed circular lagoon.
Pukapuka	Atoll; enclosed, very shallow (less than 5 m) lagoon.
Fakahina (Fangahina)	Atoll
Fangatau (Angatau)	Atoll; enclosed lagoon (7 x 4 km)
Disappointment Group (Pukarua)	
Napuka	Irregularly shaped atoll; closed lagoon; narrow reef; study of fishing; proposed for future research.

Characteristics of the Main Islands (continued)

TUAMOTU ISLANDS	Characteristics
N. Tepoto	No lagoon but central depression, 1.6 km diameter; proposed for future research.
Takume	Atoll (23 x 7 km); 2 passes into lagoon.
Raroia	23.3 km^2, oval atoll with many islets around lagoon, 1.8 m deep.
Taenga	Southern reef awash.
Makemo	2 passes into lagoon.
Katiu	Atoll (24 x 13 km); low; 2 passes into lagoon.
Hiti	Atoll; enclosed lagoon.
Tuanake	Small boat entrance only to lagoon.
S. Tepoto (Eliza)	Atoll; small boat entrance only to lagoon.
Motutunga	Atoll
Tahanea	Atoll; 3 passes into lagoon.
Anaa	Atoll; 11 islets, with enclosed lagoon (30 x 10 km); 600 million individuals of *Cardium fragum*; proposed for future research.
Faaite	Atoll
Fakarava (Fakareva)	Rectangular atoll with islets confined to east of lagoon (56 x 24 km); 2 passes into lagoon.
Raraka	Circular atoll
Kauehi (Kaueki)	Circular atoll
Aratika	Triangular atoll (37 x 24 km) with 2 passes into lagoon.
Toau (Toua)	Untouched by ciguatera poisoning.
Niau	Atoll (5 m); elliptical with completely enclosed lagoon; fringing reef.
Kaukura	Atoll; 2 narrow passes into lagoon (47 x 13 km).
Apataki	Atoll (30 x 24 km) with 3 passes into lagoon.
Arutua	Circular atoll (28 km); 1 pass into lagoon.
King George Islands	
Tikei	Small, low coral island (3 m); fringing reef.
Takaroa	Atoll (28 x 8 km); 1 pass into lagoon.
Manihi	Atoll; shoaly lagoon; coral diversity greatest near pass; *Leptoseris* and *Pachyseris* found only here.
Ahe	Atoll (24 x 9 km); 1 pass through lagoon.
Makatea	28 km^2 (7 x 4.5 km); only raised atoll in French Polynesia, 113 m; terraced with central hollow; partly surrounded by fringing reef extending out 100 m from base of vertical cliffs which flank almost all coast; coral cover low; corals diverse on outer slopes only. Makatea was intensely mined for phosphate from 1917 to 1966; it was once the most populated island in the Tuamotu group but is now inhabited by only 30 copra workers.

Characteristics of the Main Islands (continued)

GAMBIER ISLANDS	Characteristics
Temoe (Timoe)	6.9 km^2; low coral atoll (1.8 m) with lagoon (23 m max. depth) enclosed by reefs 91 m wide.
Mangareva	13 km^2; high volcanic (445 m) fringing reef on exposed south coast, 150 m wide, sometimes discontinuous; well-developed reef on cast south of Rikitea, near Teonekura and to northeast of village between Kureru and Teauouo; in Rikitea Bay, reefs are largely covered with sand; wide (100-500 m) reefs are found on the gentle slope, in very shallow water at low tide, on the north and west sides, mainly around headlands.
Aukena	13 km^2; volcanic (198 m), reefs best developed (unusually) on more exposed southeast coast; fringing reef extends from Teanakoporo to Mata Kuiti, about 500 m wide with some rich coral and algal growth; on northwest small discontinuous reefs found.
Akamaru	18 km^2; volcanic (246 m), few reefs due to exposure, always non-emergent.
S. Lagoon Islets	
Manui	Volcanic; reefs virtually absent.
Kamaka	Volcanic; 176 m; few reefs.
Makaroa	Volcanic; reefs virtually absent; visited for fishing.
Tarauruoa	Volcanic; reefs virtually absent.
Totegegie	Volcanic; reefs virtually absent.
Motu-Teiko	Volcanic; reefs virtually absent.
Taravai	5.7 km^2; volcanic (256 m); south coast exposed with only narrow reefs, sometmes discontinuous; east coast also exposed, reefs well developed only to north of village of Taravai; a reef also occurs in the shallow channel between this island and Agakauitai; discontinuous fringing reefs on west coast.
Agakauitai	Volcanic, 146 m; reefs same distribution as those around Taravai.
MARQUESAS ISLANDS	
Motu One (Hot de Sable)	Cay situated on a volcanic plug, with no vegetation; consists of sand and its formation regularly changes; fringing reef; the only coral island in the Marquesas; to the east of the islet is a large stand of *Hydrolithon (Porolithon)* and calcareous algae considered unique in French Polynesia; *Chelonia mydas* nesting area.
Hatutaa (Hatutu)	1,813 ha (8 x 3 km); high volcanic (420 m); seabirds.
Eiao	52 km^2 (13 x 7 km); high volcanic (577 m); seabirds.
Motu Iti	3 low barren dry islets.
Nuku Hiva	330 km^2 (32 x 20 km); high volcanic (1,208 m); fringing reef in some bays; those at Taiohae, Tai-Oa, Controleur, Anaho, Hatiheu, and Haaopu; red tide recorded.
Ua Huka	77 km^2 (15 x 8 km); high volcanic (854 m); reefs in bays of Hane, Vaipaee and Hatuana; islet (Motupapa) with seabirds.
Ua Pou	105 km^2 (15 x 10 km); high, volcanic (1,252 m); reefs in bays of Hakahetau, Hakanahi, Hakahau, Hohoi, Hakatao and Hakamaii; flat-topped islet (Motuoa) with seabirds.

Characteristics of the Main Islands (continued)

MARQUESAS ISLANDS	Characteristics
Fatu Huku (Fatu Hutu)	1.3 km^2 (4.5 x 0.8 km); dry rocky islet (359 m); seabird rookery.
Hiva Oa	320 km^2 (35 x 13 km); high, volcanic (1,190 m); fringing reef in bays of Taaoa, Punahe, Hanamate, Puamau and Hanaiapa.
Tahuata	50 km^2 (15 x 9 km); high, volcanic (1,050 m); fringing reef in bays of Motopu, Hana Hevane, Hana de Toi, Vaitahu and Hapatoni; reefs most abundant at Hana Hevane and Motopu.
Mohotani (Motane, Mohotane)	15 km^2 (8 x 2 km); (520 m); dry; seabirds.
Thomasset Reef (Ariane Rock)	Isolated rocky islet.
Fatu Hiva	80 km^2 (15 x 7 km); high, volcanic (960 m); very few corals; reefs at Tataaihoa Point and Omoa Bay.
AUSTRAL ISLANDS	
Marotiri (Bass Is)	0.26 km^2; 9 volcanic rock pinnacles (105 m) without vegetation, including Marotiri Nui, Marotiri Iti and Vairiavai.
Raivavae (Raevavae)	16 km^2; 9 km long, high volcanic (437 m); fringing reefs and almost continuous barrier reef and reef islets; lagoon fauna poorer than that of Gambiers, despite similar latitude; fauna of outer reefs similar.
Tubuai	48 km^2; high volcanic (422 m); surrounded by barrier reef with 7 islets; rich coral fauna (77 species, including sp. not found elsewhere in Polynesia).
Rurutu	29 km^2; high volcanic (389 m), some elevated reef limestone makatea.
Rimatara	Low (95 m), volcanic and makatea; fringing reef.
Maria (Hull)	1.3 km^2; 4 islets, dense atoll forest triangular reef, shallow lagoon.

ACRONYMS

ADB: Asia Development Bank

CEP: Centre d'Expérimentation du Pacifique

CITES: Convention on International Trade in Endangered Species

CRIOBE: Centre de Recherches Insulaires et Océaniques en Biologie et Ecologie

EPHE: Ecole Pratique des Hautes Etudes

EVAAM: Establissement de Valorisation des Activités Aquacoles et Maritimes

IFREMER: Institut Français de Recherche pour l'Exploitation de la Mer

IUCN: The World Conservation Union

MAB: Man and Biosphere

MNHN: Museum National d'Histoire Naturelle, Paris

MPMAs: Management Plan of Maritime Areas

ORSTOM: Institut Français de Recherche Scientifique pour le Développement en Coopération

PROE: Programme Régional Océanien de l'Environnement

SMSRB (exSMCB): Service Mixte de Surveillance Radiologique et Biologique

SPREP: South Pacific Region Environment Programme

UFP: Université Française du Pacifique

UNDP: United Nations Development Programme

UNEP: United Nations Environment Programme

UNESCO: United Nations Educational, Scientific and Cultural Organization

WWF: World Wildlife Fund

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HAWAII

HAWAII'S CORAL REEFS: STATUS AND HEALTH IN 1997, THE INTERNATIONAL YEAR OF THE REEF

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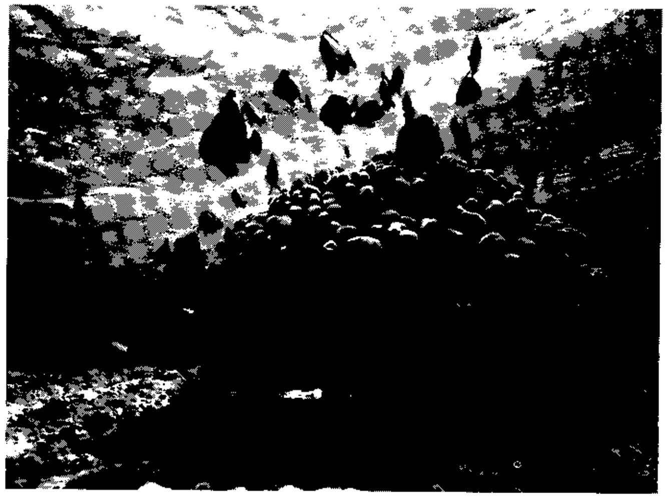

It is difficult to overstate the value of coral reefs to the State of Hawaii. Coral reefs are central to a $700 million and growing marine recreation industry. Coral reefs serve as habitat for many subsistence and commercial fisheries, as well as the basis of a highly diverse ecosystem. Coral reefs protect island shorelines against the destructive forces of storms and high waves. Many island cultural activities are dependent on coral reef resources. In their beauty, isolation and ecological sensitivity, coral reefs are symbolic of larger island vulnerabilities. Their conservation is vital to the state.

Assessment is the first step in protecting and managing coral reef ecosystems. In cooperation with international efforts by the United States to determine the status and health of coral reefs worldwide (The International Coral Reef Initiative — ICRI and the International Year of the Reef — IYOR), a poll of experts and a literature survey of coral reefs in the main Hawaiian Islands were conducted in 1996 and 1997. While the results of this survey indicate that most coral reefs in Hawaii are presently healthy, problems of resource overutilization and environmental degradation are increasing. The most serious problem is overfishing. There is an immediate need for improved fishery management and strengthened enforcement. Stream and non-point source runoff is the cause of eutrophication and sedimentation in some embayments and areas with confined circulation. Improving the water quality of these environments is of economic significance for growing recreational uses by residents and tourists alike. The vitality of Hawaii's healthy reefs must also be maintained to insure their productivity. To accomplish these goals, a major commitment by the State of Hawaii to manage coral reef resources is needed.

INTRODUCTION

Coral reef ecosystems in the Hawaiian Islands represent an extremely valuable natural resource to the state's economy. The marine recreation industry alone generates over $700 million annually to state revenues. Coral reefs are of further value to the state for the protection they provide to the coastline from waves and destructive storms. Coral reef organisms constitute a major source of sand for Hawaii's beaches. Coral reefs also are habitat to numerous nearshore fisheries including reef fish, lobsters, and bottom fish, which collectively generate about $20 million in landings annually and are an important source of food for local and restaurant consumption. In addition to species of commercial value, coral reefs are the habitat for 700 species of fish, 400 seaweeds, 1,000 mollusks, and 1,350 invertebrates, including 47 species of reef-building corals (Armstrong 1983; Maragos 1995).

As an ocean state, the shore and nearshore represent one of Hawaii's greatest natural resources. No point in the state is more than 29 miles from the sea. Hawaii's peoples are dependent on the marine environment for a diverse array of needs encompassing economic, environmental and cultural values. The protection and sustainable use of the nearshore environment, including coral reef ecosystems in all aspects, is vital to the welfare and quality of life for residents and visitors to the islands.

Growth in both Hawaii's resident and visitor populations is placing increasing pressure on nearshore coral reef ecosystem resources. The resident population is about 1.2 million and growing at a 1.6% annual rate. Between five and six times this many tourists visit Hawaii every year. Human activities which potentially can affect coral reefs in Hawaii include a variety of land uses such as construction, agriculture, deforestation, and erosion caused by introduced animals, all of which lead to increased runoff and possible impact from sedimentation and non-point source pollution. Activities which have potential negative impact to coral reefs include sewage disposal, land runoff, dredging, and shoreline construction or modification. Other human impacts include fishing (overharvesting), boating (anchor damage) and diving (collecting).

Although numerous studies of coral reef ecosystems in Hawaii have been conducted in recent decades, no systematic survey covering all islands has ever been done and no comprehensive monitoring program of reef resources exists in the state. In view of the value of coral reef resources to Hawaii and the present lack of information concerning their health, a statewide survey of their status and health is of fundamental importance. The opportunity to conduct such a survey in 1997 was presented by international program activities associated with the ICRI and the IYOR. Both programs provided funding to the PSA *Scientific Committee on Coral Reefs* to conduct a survey. The results of this survey apply to the main Hawaiian Islands (Figure 1) and are presented below.

METHODS

Several agencies in the State of Hawaii and many individuals representing diverse organizations and backgrounds worked together to conduct a statewide survey of the status and health of coral reefs. Informally this effort has been called the Hawaii Coral Reef Initiative. The State Coastal Zone Management Program provided early leadership for the project and linkage with the ICRI program of the U.S. State Department. Volunteer efforts by Dr. Mike Hamnett of the Social Science Research Institute of the University of Hawaii, Dr. Jim Maragos of the East-West Center, David Raney of the Sierra Club, and Peter Rappa of the University of Hawaii Sea Grant College Program were also invaluable in organizing meetings

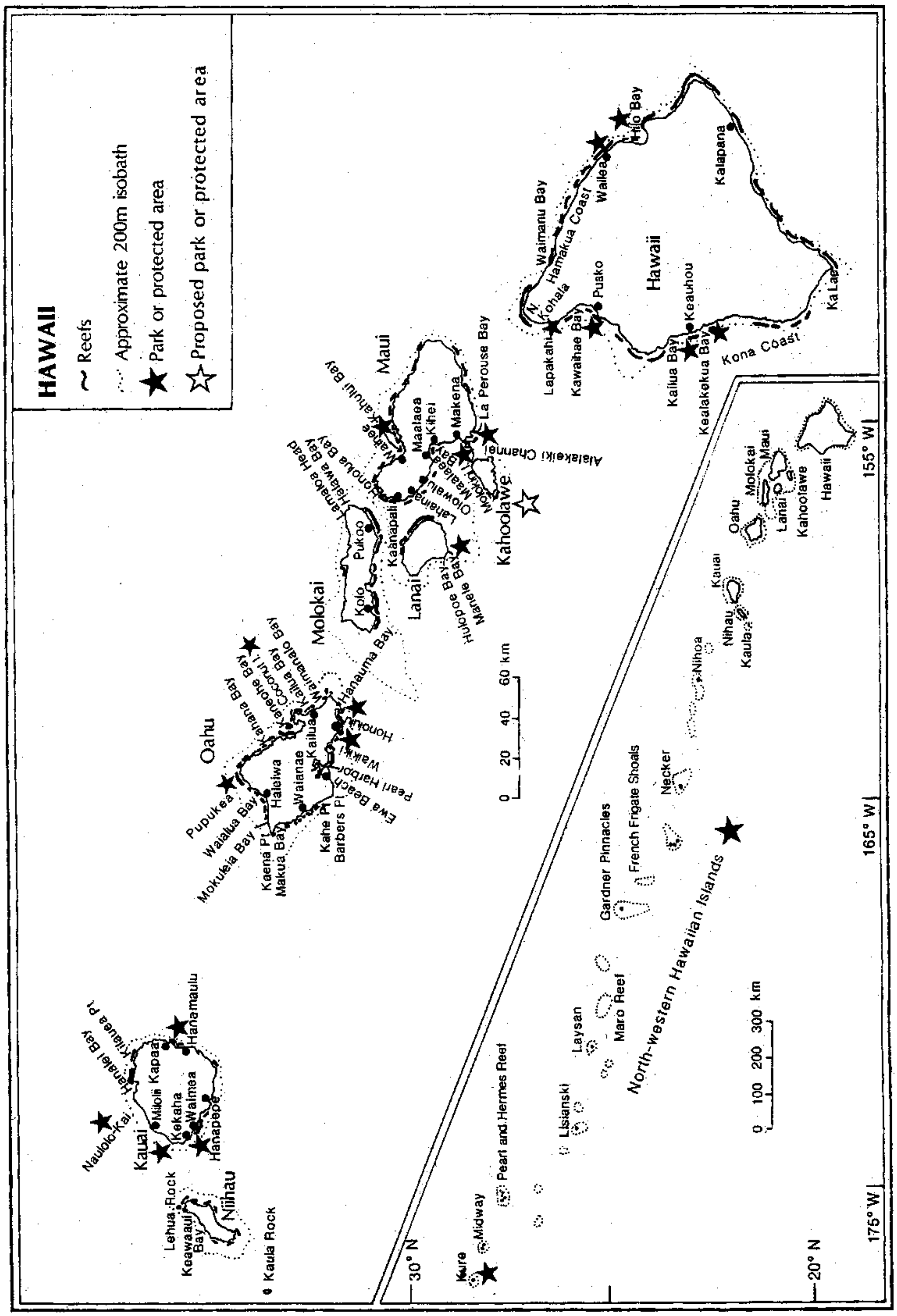

Figure 1. Map of the Hawaiian Islands.

and compiling information. Other individuals active in helping to gather data and information for the survey are listed in the acknowledgments.

The objectives of the survey were to (1) describe the current status and health of coral reef ecosystems and coral reef resources in the main islands of the State of Hawaii, (2) make this information available to the scientific community and to the public in order to increase awareness of problems facing coral reefs, and (3) generate information necessary to formulate improved management plans and activities for the sustainable use of coral reefs in Hawaii in the future, including monitoring of reefs and designation of additional protected reef areas.

The survey was conducted using a participatory process by holding workshops among invited experts. Meetings were held on all islands during 1996 through 1997. At each meeting, the discussion was led by individuals deemed to be the most knowledgeable in the group. Each island was divided into sectors containing similar habitat and each sector was discussed and evaluated by the group. Data or information generated included (1) a description of naturally controlling factors, (2) an evaluation of the importance of anthropogenic stressors in each sector, and (3) an overall judgment as to the "health of the reef" in that sector. Health was defined as the natural state of the reef minus losses or changes due to anthropogenic stressors. A reef in a perfectly natural state regardless of abundance or diversity of corals and associated organisms was considered pristine. Reefs suffering various degrees of change due to anthropogenic factors were judged to be in a moderate, fair or poor condition. An attempt was made also to estimate the coral cover in all sectors on all islands. In cases where published data were available from the scientific or gray literature, this information was incorporated into the evaluation process (Maragos and Elliott 1985; Grigg et al. 1988).

RESULTS AND DISCUSSION

General Status of Coral Reefs in Hawaii

Coral reefs in Hawaii are characterized by low biodiversity. Only 47 species of reef-building corals have been recorded in the Hawaiian Archipelago (Maragos 1995) compared to over 500 in the Indo-West-Pacific zoogeographic realm. The absence of more species of coral is generally attributed to geographic isolation of the Hawaiian island chain (Kay 1980; Grigg 1988), although unfavorable winter temperatures particularly in the northern half of the chain may also limit some species and contribute to poor reef development.

In general, the growth of coral reefs (carbonate accretion) and the community structure of coral reefs in Hawaii are naturally controlled by wave forces and depth (Grigg, in press; Dollar 1982). Most coastline areas in the state are exposed to the open ocean. Coral reef communities growing in such areas are frequently disturbed by wave-induced mortality caused by breakage, scour and abrasion. Reefs growing at or near the surface are constrained by sea level (depth). The only significant buildups of modern reef carbonates during the Holocene (last 10,000 years) that exist in the main islands are found in areas that are sheltered or partially sheltered from long-period, large, open-ocean swell and at depths not constrained by sea level. Such areas are typically restricted to embayments and are sheltered from wave exposure by nearby or adjacent islands. In all exposed areas, Holocene reefs are thin and transient veneers, at most several meters thick growing on Pleistocene (>10,000 years) foundations. Veneers are no thicker than the height of the largest living colony. In other words, no accretion of living corals is taking place. Living corals are dying as fast as they are being replaced by natural processes. Physical and biological processes of erosion are removing limestone as fast as it accretes.

The community structure of coral reefs in Hawaii is also controlled primarily by wave energy and depth. This does not mean that other natural factors such as sedimentation, turbidity, light, nutrient concentration or biological factors are not important. In some environments, in fact, one or more of these variables might be of overriding significance. The ecological status of any given reef is further complicated by the presence of anthropogenic stressors. The impacts associated with these stressors are superimposed or are additive to the effects of natural controlling factors, and sometimes it is difficult to separate effects when they operate in combination. The distinction between, and deconvolution of, natural versus anthropogenic impacts can be extremely difficult and requires the experience of highly trained ecologists. This problem limits the value of information gathered by volunteers lacking such training.

In cases where the ecology of coral reefs is under the primary and dominant control of wave forces, the potential effects of pollution may be of little consequence except as it relates to aesthetic values or water quality and human health. Impacts related to point and non-point source pollution, therefore, would be expected to be of most significance in wave-sheltered environments or in bodies of water with a high residence time, such as embayments and lagoons. None of the above discussion however, would apply to reef fisheries. The degree of anthropogenic impact to fisheries would be expected to be a function of habitat and fishing pressure irrespective of exposure or shelter to large open ocean long-period swell.

Oahu

Much of the open coastline of Oahu is fringed by coral reef habitat with low natural coral cover under the control of wave stress. Most living coral communities are thin veneers growing on fossil beach rock or Pleistocene limestone foundations. The best reef development is found in embayments or areas sheltered (Kaneohe Bay) or partially sheltered (Hanauma Bay) from large, open-ocean, long-period swell. Reef communities are generally healthy except for local areas where usage of the shoreline is high or certain embayments where water circulation is restricted. Many of these environments have been degraded by non-point source runoff containing high sediment loads. Most notable is the south end of Kanoehe Bay where sewage discharge prior to 1976 resulted in a significant decline in coral ecosystem health. Coral communities were largely replaced by filter-feeding organisms (Smith et al. 1981). The bubble algae, *Dictyosphaeria cavernosa*, also overgrew or infiltrated colonies, particularly *Porites compressa*, the dominant coral on patch reefs and fringing reefs in Kaneohe Bay. Sewage discharges in the bay were diverted offshore in 1977 and since that time, the bay has undergone gradual recovery although it is still subject to periodic influxes of fresh water, sediment and nutrients during high rainfall events (Jokiel et al. 1993), and setbacks in recovery have occurred (Hunter and Evans 1995). Other coral habitats in embayments impacted by sediment-laden runoff on Oahu include Pearl Harbor, Kahana Bay, Kewela Bay, Kaiaka and Wailua Bays and the southeast corner of Moanalua Bay at shallow depths (0.5-2.0 m) off Hawaii Kai. Non-point source runoff from the Ewa plain has also altered shallow habitat in shallow water favoring the growth of numerous species of algae. The most significant alteration to nearshore habitat has been off Waikiki and Honolulu where former wetlands and estuaries have been converted to harbors, parks and beaches fronting hotels.

The most serious anthropogenic impact to coral reef ecosystems islandwide is overfishing. Gill netting and spearfishing are the most damaging forms of fishing. State fishery regulations are largely ignored and rarely enforced except in Hanauma Bay, a Marine Life Conservation District.

Notwithstanding these problems, many improvements in coastal environments have occurred. All shallow nearshore sewage discharges have been replaced by deepwater outfalls and former impacts on coral reefs have been eliminated (Grigg 1995). Better land management practices and the curtailment of dredge and fill activities have greatly reduced sedimentation problems to coral reefs islandwide. As a result of the federal Endangered Species Act passed in 1972, the taking of green turtles (*Chelonia mydas*) was banned. This has led to a dramatic comeback in green turtle populations throughout the state although not without new problems. Many green turtles in recent years have been afflicted by external tumors. The cause is unknown. Oahu, being the population center in the State of Hawaii, ranks highest among the main islands in terms of both coral reef resource problems and the need for better longterm management.

Maui

Maui, the second largest island in the state, is made up of two large coalesced shield volcanoes, Haleakala and West Maui. Consistent with the other islands, most coral reefs on Maui are under the primary control of wave forces. The best reefs are off Honokowai on the west end and along the stretch of coastline between Olowalu and Papawai Point off the south coast of West Maui, both at depths of 10-20 m. Coral cover in these areas ranges between 50 and 80%. Both of these areas were sheltered from the impact of large swells (up to 5 m) generated by Hurricane Iniki in 1992. Exposed areas, some with reefs containing 50% or more coral cover, were devastated by Iniki resulting in mortality up to 100% (Eric Brown, Pacific Whale Foundation, pers. comm.). Other pristine reefs exist at 30-40 m depth in the Auau Channel and at Molokini Crater where they are totally sheltered from wave stress.

The two most significant environmental problems affecting coral reefs on Maui are overfishing and increases in various species of algae. The only areas not overfished are those least accessible; deep reefs off Hana, Keanae and Kaupo on East Maui and Honokohau on the northwest tip of the island. Outbreaks of algae periodically occur off Spreckelsville to Kanaha, Honokowai and Waialea. Their cause is not well understood, but increases of species in shallow water (*Hypnea, Acanthophora, Sargassum, Dictyota*) may be related to the leaching of nutrients from cesspools and non-point source runoff at times of low circulation. The species of *Hypnea* and *Acanthophora* are introduced to Hawaii and their abundance may reflect a lack of natural predators or competitors (Steve Dollar, pers. comm.). Outbreaks in deep water of the algae species *Cladocera* appear to be related to periodic natural upwelling. Increases in algae may also be related to overfishing of herbivorous fishes and the low abundance of echinoids and herbivores. In recent years, turtle nesting has increased at Kaloia Beach near Maalaea.

Lanai

Coral reef ecosystems off Lanai appear to be under the control of natural forces. Reefs along the southern half of the island are wave controlled. Those on the northern half are very well developed although natural sediment runoff results in episodic mortality. While limited by these factors, virtually all reefs on Lanai are in a healthy condition. And although all reefs are overfished, none are impacted by pollution. Turtle populations are very high, and nesting is common on sandy beaches along the northwest end of the island.

Molokai

Except for widespread overfishing, the only significant anthropogenic problem for coral reefs on Molokai is sediment laden runoff. Historically, natural runoff has been exacerbated by land erosion caused by overgrazing by alien species (feral ungulates), agricultural practices resulting in loss of ground cover and some construction (earth moving). Natural runoff from 34 perennial streams adds to this problem. The area most seriously affected is about 10 km of fringing reef and lagoon off the southwestern end of the island.

Fifteen historic fishponds exist on the southeastern coast. None are in use today although they may inadvertently help to curtail sediment-laden runoff from entering the nearshore environment. In 1972, an outbreak of the starfish *Acanthaster planci* was discovered off the southeast coast (Branham et al. 1972) on reefs at depths between 15 and 25 m. Although some initial attempt was made to control (eradicate) the outbreak, it appeared to return naturally to a normal abundance level over a period of several years.

The fringing reef off the south coast of Molokai is the largest and longest reef of this kind in the Hawaiian Islands. Its size may be related to wave shelter afforded by the island of Lanai situated south of Molokai (Figure 1).

Kahoolawe

Kahoolawe is the smallest of the eight main Hawaiian Islands. It is also the driest, receiving less than 63 cm (25 inches) of rainfall annually. It has no perennial streams. Its location in the rain shadow of East Maui accounts for its low annual precipitation. For years, the U.S. military used Kahoolawe as a target for live-firing and bombing. This, in addition to land erosion caused by feral ungulates, created significant amounts of sediment that (in spite of low rainfall) was transported by runoff into nearshore environments. However, all of the goats on Kahoolawe have been recently eradicated.

In 1994 the military returned control over the island back to the State of Hawaii and the bombing ceased. Since that time, the reefs have been gradually recovering from conditions caused by previous high rates of sedimentation. Hurricane Iniki in 1992 helped to remove large amounts of sediment from the bottom in shallow water along the southern coast (Paul Jokiel, pers. comm.). Aside from this historical problem, the only other anthropogenic source of impact to the coral reefs of Kahoolawe is overfishing. While small fishes are diverse and abundant, the absence of large fishes and lobsters and few sharks are evidence of high fishing pressure (Ernest Reese, pers. comm.). The best reefs on the island are found off Hakio-awa. Interestingly, little ordnance can be found on any reefs around Kahoolawe today, suggesting rapid overgrowth by coral and/or high accuracy of the military target practice.

Hawaii

Hawaii is the largest and youngest island in the main Hawaiian Islands. It is made up of five large shield volcanoes (Mauna Kea, Mauna Loa, Hualalae, Kilauea and Kohala). A dramatic difference exists between windward and leeward coral reefs on the Big Island. On the entire windward coast, except for Hilo Bay, coral reef communities are under the control of wave forces. Early successional stages dominate and consist of scattered coral colonies or thin crustose veneers growing on basalt foundations (Grigg and Maragos 1974). In contrast, the leeward side of the island is shielded from trade winds and large north and northwest swell. Along the leeward coast, the richest coral reef communities exist near wave base between 15 and 27 m depth. In this zone, climax communities dominated by *P. compressa* are common.

Periodically, however, even this zone is disturbed by large wave events (waves up to 7 m or larger) produced by exceptional kona storms. The return period for storms of this intensity is about 40 years (Dollar 1982). Events of this severity, depending on the magnitude, can and do set back the successional process to time zero (Grigg and Maragos 1974; Grigg 1983; Dollar and Tribble 1994), Figure 2. Consequently, there has been virtually no accretion of a limestone reef foundation off the coast of Hawaii and fringing reefs have not developed.

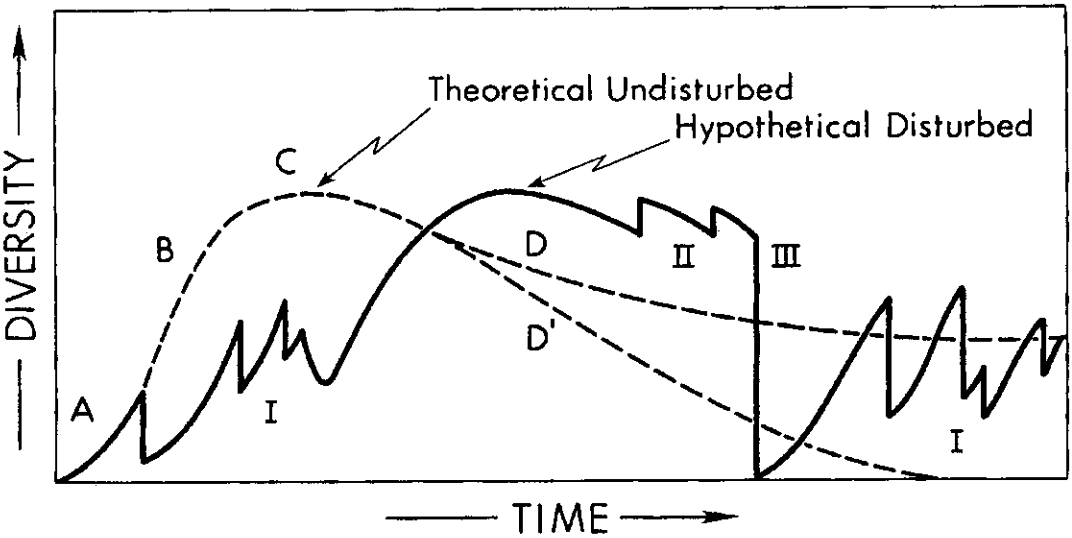

Figure 2. Theoretical model of succession of coral reef communities and hypothetical case illustrating the effects of various intensities and frequencies of disturbance. From Grigg 1983.

Anthropogenic impacts to coral reefs are superimposed on the effects of natural controlling factors. Four sources of human impact are of particular significance on the island of Hawaii. The oldest source of anthropogenic impact is bagasse and sediment contained in sugarcane waste waters discharged into the sea along the Hamakua Coast. At peak discharge levels in the early 1970s, about 24 km of coastline and reef habitat were severely impacted. Since that time, however, all of the sugar mills along the Hamakua Coast have closed and all areas formerly affected are now under recovery (Grigg 1985; Dollar 1994).

On the leeward coast, overfishing, aquarium fish collecting and groundwater intrusion are the most serious anthropogenic induced impacts to coral reefs. Overfishing is a problem on all islands. Aquarium fish collecting is highly selective and localized; however, competing private interest groups (mainly SCUBA charter companies) claim that impacts are significant. Groundwater intrusion is common along the shoreline and within nearshore shallow reefs. The source is percolation of rainfall or water used for agriculture, golf course or other commercial purposes, through highly porous volcanic soils. Groundwater is often enriched with nutrients including silicate, nitrate and phosphate. Even so, dilution is so great in the receiving waters that the biological responses of the benthos are nil or highly localized (Dollar and Atkinson 1992). Less than 1% of the coastal habitat is altered by intrusion of groundwater. With the exception of significant declines in reef fish biomass, coral reef ecosystems on the Big Island can be described as generally healthy.

Kauai

Kauai is the oldest of the main Hawaiian Islands. Its single shield volcano is estimated to be about 5 million years old. Kauai is also the wettest island. Mount Waialeale receives over 1140 cm (450 inches) of rainfall per year (Armstrong 1983), and is one of the wettest spots in the world. Thirty-eight perennial streams drain upland watersheds and deliver large quantities of sediment-laden water to virtually all coastal environments. This is the most important factor that distinguishes Kauai from the other islands and appears to be responsible for the lack of well developed fringing reefs islandwide. Coral reef habitats in shallow water and embayments with restricted circulation are the most severely impacted. As opposed to the other islands, this may explain why the best shallow reefs on Kauai occur on the northeast and north coasts. Because of wave exposure, the receiving waters off these coastlines are the most vigorously mixed (Don Heacock, per. comm.). Suspended sediment in the nearshore waters along the north and northeast coast rarely settles before it is transported offshore by coastal currents.

The fate of sediment introduced into the ocean from coastal developments (hotels, condominiums and golf courses) is similar. A before/after survey of the coral reef communities off the Princeville development at Anini Beach on the north shore actually showed that small increases in coral cover and diversity occurred after 15 years (Grigg 1995; Figure 3). Increases were attributed to the lack of severe storm wave events during this time frame and the lack of sediment accumulation on the bottom.

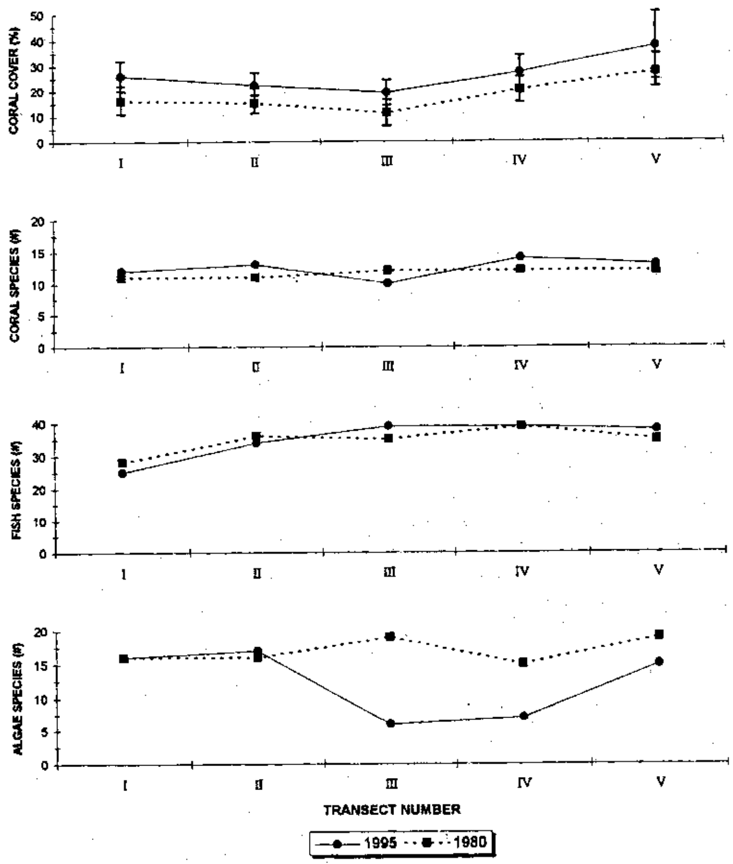

Figure 3. Quantitative marine assessment of coral, fish and algal populations along five transects offshore of the Princeville, Kauai, area surveyed in 1980 and 1995. Horizontal scale, 1.5 cm = 1 km.

Water quality is also affected by widespread runoff from Kauai's 38 perennial steams. In particular, on the southwest coast in shallow water between Kekaha and Port Allen, nearshore environments are dominated by algae. Brown nutrient-rich water is persistent in this area. The lack of echinoids and low abundance of herbivorous fishes also may contribute to conditions favoring algae. As with all the other main Hawaiian Islands, overfishing on Kauai is perceived by fishermen and scientists to be a serious problem.

The best reefs exist in deep water (15-25 m) with the least exposure to sediment-laden runoff from streams. The reefs off Poipu and Makahuena are the best examples, although both areas have been impacted recently by Hurricanes Ewa (1982) and Iniki (1992). Limestone fossil reefs are particularly abundant off the entire southern half of Kauai at depths of 30-70 m. Abundant populations of the black coral *Antipathes dichotoma* are found in this unique habitat.

CONCLUSIONS

1. Growth and community structure of coral reefs in the main Hawaiian Islands are primarily under the control of wave forces and depth.
2. With the exception of Kauai, where sediment-laden runoff is a serious limiting factor, the best reefs in the main Hawaiian Islands are found in embayments sheltered or partially sheltered from long-period, large, open-ocean swell.
3. In all areas exposed to large, open-ocean swell, coral reefs in the main Hawaiian Islands consist of thin and transient veneers of modern limestone growing on antecedent foundations. Virtually no accretion has occurred during the entire Holocene (last 10,000 years).
4. Impacts from anthropogenic factors on coral reefs are superimposed on naturally controlling forces. In general, they are only important in environments where wave forces are not the dominant controlling factor. These environments typically are embayments and lagoons or are areas of low water circulation where the residence time of the overlying water column is high. These environments constitute less than 10% of the coastline in the state.
5. All coral reef habitats in the main Hawaiian Islands are overfished in various degrees. It is not likely that this problem will be solved until the enforcement of existing regulations is greatly strengthened and more restrictions in fishing effort and certain gears (particularly gill nets) are imposed.
6. With the exception of overfishing, about 90% of the coral reefs in the main Hawaiian Islands are healthy. Anthropogenic impacts are serious in localized areas where water circulation is restricted. Sedimentation and eutrophication are the most serious general problems. Each main island in the chain is characterized by specific but localized anthropogenic induced problems that are geographically unique.

A major commitment by the State of Hawaii is needed to improve the management of coral reef resources statewide. Overfishing is a serious problem on every island and is in need of remediation. In general, the water quality of embayments and areas of confined circulation is in need of improvement with better control of non-point source runoff. Increasing recreational and commercial uses of coral reef resources and environments is of major economic significance. State government needs to devote more resources for the management of coral reef resources to insure their future health.

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INDONESIA

ASSESSMENT OF THE PRESENT HEALTH OF CORAL REEFS IN INDONESIA

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The Indonesian Archipelago probably is one of the largest archipelagoes in the world. It stretches along the equator and is roughly 5,000 km long and 2,000 km wide. It consists of more than 17,000 islands with about 81,000 km of coastline. The marine and coastal areas of the Indonesian Archipelago are among the most productive in the world. The warm, humid tropical climate and high rainfall allow extensive coral reefs, dense mangrove and other ecosystems to flourish along the coast. These ecosystems are the most productive ecosystems, but unfortunately they are also very sensitive and vulnerable to environmental changes and pressures. Due to the economic benefits that can be derived from these rich and diverse ecosystems, the Indonesian coastal areas are densely populated. Over 60 percent of the 190 million population lives in coastal areas, resulting in a rather high level of exploitation of natural resources and degradation of the environment. Indeed, population pressure associated with strong economic activities has caused a large-scale destruction and serious degradation of the coastal and marine environment.

Coral reefs are distributed widely in Indonesia. The majority of the reefs are in the form of fringing reefs, however, there are also limited development of barrier reefs and even atolls. For centuries, Indonesian coastal communities have benefited from the reefs, be it renewable resources, such as variety of reef dependent fishes, molluscs, seaweeds and other living resources, or the nonrenewable ones, such as coral rock, gravel, sand and seashells. However, when exploitation increases uncontrollably, pollution increases, such that many reefs in Indonesia are severely damaged today. Field studies and surveys carried out in the last 10 years have shown that about 42 percent of Indonesian coral reefs are in poor condition, 28 percent in fair condition, 24 percent in good condition and only less than five percent are in excellent condition. In order to alleviate this critical problem, a new initiative has been formulated and implemented through developing marine parks and conservation areas, as well as through integrated planning and management of coastal areas. A major rehabilitation and management project on coral reefs is now being launched with financial support from the World Bank, Asian Development Bank, Global Environment Facilities, Australian Aid, Japan International Cooperation and other donor agencies.

This paper is a brief review on the state of knowledge and assessment of the health of coral reefs in Indonesia. It also chronicles efforts of rehabilitating and managing the reef resources through community awareness and participation.

The Physical Environment of Indonesia

Geographically, the Indonesian Archipelago is located between the 94 and 141 degrees East Longitude and between the 6 degrees North and 11 degrees South Latitude. The archipelago is situated between the Pacific and the Indian Oceans and between the Asian and the Australian Continents. It consists of 17,508 islands with about 81,000 km of coastline. Some of the large islands are: Irian Jaya (the western part of the island of Papua), Kalimantan (the Indonesian part of the island of Borneo), Sumatra, Celebes, Java, Madura, Bali, the Nusa Tenggara or lesser Sunda Island.

While the land area is only 1.94 million km^2, the surrounding sea area covers about 3.1 million km^2. The 200 Mile Exclusive Economic Zone adds 2.7 million km^2 of sea area alone. Thus, the seas and coastal areas are the dominant physiographic features of Indonesia (Soegiarto and Polunin 1981).

Due to its geographic location, the Indonesian Archipelago is governed by monsoons, which have a strong impact on the biology and oceanography of Indonesia as well as its adjacent seas. In addition, the Indonesian Archipelago provides an inter-ocean link between the warm water pool of the Western Pacific Ocean and the Eastern Indian Ocean. The heat flux and water mass transfer between the two oceans through this link is estimated to be considerable and has a large, perhaps even global scale, impact on the ocean climate. El Niño Southern Oscillation, or ENSO is another phenomenon that is part of the Pacific-Indian Ocean interaction. ENSO generates adverse climate effects both regionally (the Pacific basin) and globally (Soegiarto 1993). ENSO events have a strong effect on the general conditions of the coral reefs, agriculture and fisheries in the region (Harger 1995).

State of Knowledge and Distribution

Knowledge of coral reefs in Indonesia goes back to as early as the 16th Century, when Dutch naturalists marvelled at the beauty of tropical marine biota called coral reefs in the Netherlands East Indies (now called Indonesia). For example, the famous naturalist G.E. Rumphius collected and identified a number of coral reef dependent biota on the island of Ambon, the Molluccas, East Indonesia (Sirks 1945). However, the modern studies on the formation, geomorphology and some environmental factors, as well as the biology of coral reefs in Indonesia, were first carried out in Batavia Bay (now known as Jakarta Bay), at the northwest coast of the island of Java by Sluiter (1889), Umbgrove (1928), and Verwey (1930, 1931a, 1931b). This knowledge on corals and other reef species was further enhanced with the organization of the Siboga Expedition in the Indonesian Archipelago between 1899-1900 (Soegiarto and Polunin 1989), in particular their taxonomy. Sluiter (1880) also measured the growth rate of corals after the eruption of Krakatau volcano in 1883. Other studies on growth rate and oxygen consumption of various species of corals were made by Kuenen (1950), Boschma (in Kuenen, 1950), and Verstelle (1932). Sixty-three coral species were first reported by Umbgrove in 1928 from the Jakarta Bay; 58 species were described from Ambon. The number of species was increased to 177 by Verwey and Umbgrove after they used diving gear (Umbgrove 1939a, 1939b). Additional records of coral species and other coral reef biota were added through various international expeditions in the Indonesian Archipelago, such as the Challenger Expedition (reported by Quelch 1886), Siboga Expedition (Alcock 1902; Horst 1921, 1922; Boschma 1923) and the Snellius Expedition (Wijsman-Best 1974, 1976).

After Indonesia proclaimed independence in 1945, the role of Dutch scientists was replaced by Indonesian scientists. Since late 1960 many reports and publications by young Indonesian scientists started to accumulate. The studies were not only on corals (e.g., Sukarno 1977a , 1977b), but also on other biota such as algae and seaweed farming (Soerjodinoto 1968; Soegiarto et al. 1977), crustacea (Romimohtarto and Moosa 1977), stomatopods (Moosa 1975), and many other reef biota groups.

Earlier reviews of Indonesian coral reefs were made by Molengraaff (1929) and Umbgrove (1947). The more recent and comprehensive reviews of coral reefs were made by Soegiarto and Polunin (1981), Sukarno et al. (1983) and Sukarno et al. (1986).

From these references it is clear that coral reefs are distributed widely in the Indonesian Archipelago. All types of reefs are found, from narrow to very broad fringing reefs, barrier reefs and even atolls. For example, the Taka Bone Rate (in Dutch was called Spermonde) is one of the largest atolls in the world. However, until now an exact figure on the area of coverage of coral reefs in Indonesia has not been available. Some have estimated (e.g., BAPPENAS 1993; GOI 1995) that two-thirds of the 81,000 km long Indonesian coastline is protected with coral reefs. In the author's opinion, this is probably an over-estimate. One problem is a very long coastline, and a high number of islands make it difficult to ascertain the aerial coverage of reefs in Indonesia. The most quoted Indonesian coral reefs distribution was that of Molengraaff (1929). Various newer maps on coral reefs have been published (e.g., by the Naval Hydro-Oceanography Office). However, they are mostly based on the results of the Dutch hydrographic surveys made in the 1930s, which are no longer accurate and reliable.

From various sources (e.g., Soegiarto and Polunin [1981], BAPPENAS [1993]), it is noted that Indonesian waters are close to the center of coral diversity. About 350 species of scleractinian corals, belonging to 75 genera, have been recorded. Soegiarto and Polunin (1981) have also compiled numbers of species of other coral reef biota, such as algae, molluscs, crustaceans and fishes.

Function and Value

Coral reefs represent a unique, complex tropical shallow water ecosystem. Coral reefs function as living environments, they serve as physical protection for other ecosystems, they are sources of numerous living resources and, of course, they are exquisite examples of natural beauty.

As living environment, coral reefs function as habitat for many species of organisms. Many species are of economic importance. The interdependencies of these organisms with the environment, as well as to other organisms, make the web of life in the coral reef ecosystem one of the most complex on earth.

Because of their massive structure, coral reefs function as physical protectors of coastal and island ecosystems from the erosive effects of waves. Extracting coral rock weakens its protective function and results in coastal abrasion. Unfortunately, for centuries coastal communities have mined the coral rock, coral gravel and even coral sand for construction materials or as material for producing lime. A few examples can be mentioned in Bali (Halim et al. 1980; Praseno and Sukarno 1977; Sastrowardoyo 1980). The genera of *Porites*, *Goniopora* and *Goniastrea* are commonly used for this purpose. Whereas the more exotic and colourful species of *Tubipora musica*, *Acropora* sp., *Pocillopora* sp. and *Montipora* sp. are used as decorations for aquariums, gardens and homes. Many species of corals are cleaned, bleached and dried, and sold to tourists.

Other resources that have been extracted from coral reefs are sea shells. Three species have dominated the trade. They are *Trochus niloticus* shell, used for buttons, *Pinctada* spp., better known as pearl oyster for making various shell handicrafts, and *Tridacna* spp. or the giant clams, which are used as material for exotic tile making. There is a number of species of molluscs that are edible as consumed by local fishermen, or even for export, such as *Tridacna* spp., *Trochus* spp., *Heliotis* spp. (Sukarno et al. 1983).

However, the most valued living resources extracted from coral reefs certainly are the varieties of fishes for consumption and export. Due to high gross productivity, coral reefs support a high density and diversity of fishes and other biota. Fish species such as *Caesio* spp., *Siganus* spp., *Lutjanus* spp., *Epinephelus* spp., *Caranx* spp., are among the most valued reef fishes in Indonesia. In addition, Indonesia has been known internationally as an exporter of ornamental fishes. The volume and value of live fish exports are continuously increasing. Approximately 280 species of aquarium fishes and 99 other marine organisms are exported from Indonesia for international trade (Kvalvagnaes 1980).

Other export commodities from coral reefs are seaweeds, crustaceans, pearls, dried sea cucumbers, etc. In recent years, the export of dried seaweeds has been very substantial. They are mostly *Eucheuma* spp. for carrageenins and *Gracillaria* spp., *Gelidium* spp. and *Hypnea* spp. for "agar-agar." *Euchema* spp. are now cultured in many parts of Indonesia, such as Bali, Southeast Celebes, Nusatenggara, Molluccas. The value of these exports are about US $3 million annually (Soegiarto et al. 1978).

Due to its natural beauty, coral reefs are also important for tourism. Many parts of Indonesia have developed marine resorts based on coral reefs. For example, the Seribu Archipelago in Jakarta Bay, Bali Islands, Bunaken in North Celebes, Maumere in Flores, Biak in Irian, and Banda Islands in the Molluccas. Hundreds of thousands of tourists from all over the world are lured to these tropical areas and produce an important source of foreign exchange revenue for Indonesia. The development of marine tourism also generates other businesses, such as diving, boat charters and handycrafts.

Thus, coral reefs offer many benefits to the population of Indonesia in the form of food, medicine, shore-protection, aesthetics, recreation and tourism. Millions of people are dependent, mostly at subsistence level, on coral reefs. Therefore, if coral reefs are severely disturbed, many native communities will be immediately affected.

Environmental Problems and Disturbance

Scientists are actively trying to determine the status of the health of coral reefs worldwide. All agree that human activities represent a primary source of reef degradation. Natural events, such as earthquakes, volcanic eruptions, tsunamis, ENSO events, longterm changes in temperature and sea level rise, also contribute to environmental perturbations within coral reef ecosystems. The following is a summary of the most important factors causing reef degradation in Indonesia:

- **Overextraction of Coral Rock, Gravel and Sands from Coral Reef Ecosystems for Lime Production, Roads and Other Construction.**

  From the existing records, these extractions have been going on since the 17th century for port, road or fort construction in Jakarta, Banda, and other parts of Indonesia (Soerjodinoto 1954). Activities increase as demands for construction materials increase.

For example, Umbgrove (1947) reported up to 25,000 m^3 of corals had been harvested annually from Jakarta Bay alone. This volume has increased substantially in recent years. Sastrowardoyo (1980) calculated that at least 144,000 m^3 of corals have been harvested to be used as lime production in Bali, one of the famous tourist destinations in Indonesia. It means that about 2.88 km long, 100 m in width with 0.5 m thickness of reefs will be destroyed every year, just for this purpose. It should be noted that Bali Island has only about 39 km of reef protected coastline.

- **Explosives for Fishing.**

  This habit may have started during the World War II when Japanese soldiers threw hand grenades onto the reef to kill fish. Unfortunately, this illegal fishing practice is now widespread throughout Southeast Asia. Fishermen make explosive devices from carbides and other chemicals that can be purchased freely in the market (Kvalvagnaes and Halim 1979). This activity is even done in marine-protected areas, such as Pombo Island in Ambon (Sumadhiharga 1977). The extent of damage from dynamite fishing to coral reefs in Indonesia is devastating and widespread.

- **Toxic Chemicals.**

  The use of toxic chemicals called "potas" (potassium or sodium cyanide) to catch aquarium fishes and other economic important fishes in reefs has increased since 1970s (Sugondo 1976). In recent years, the activity of catching "napoleon fish" or humphead wrasse (*Cheilinus undulatus*) for Hong Kong or Taiwan is a lucrative market that has increased tremendously. Originally, activities were focused on Philippine coral reefs but in recent years this fishery has spread to reefs around Celebes, the Molluccas and Irian. The "napoleon fish" are sold in Hong Kong restaurants for as much as US $180 per kg. The fish lips, known as an exceptional delicacy, are sold for as much as US $225 per plate in certain exclusive restaurants in Hong Kong. Similar high prices have been reported for other reef dependent fishes such as highfind grouper or barramundi cod. Conservative estimates of the annual trade of live reef fish caught from Indonesia, range between 20,000 to 25,000 tonnes (Johannes and Riepen 1995).

  Recent studies reveal that cyanide kills reef corals at concentrations hundreds of thousands times lower than concentrations used by divers to catch valuable trade fishes. The impact of the cyanide poisoning fishing is therefore devastating to Indonesian coral reefs. It is estimated that if this practice is not banned, the majority of coral reefs in Indonesia will eventually be wiped out (Johannes and Riepen 1995). The live fish traders will then move to new areas such as Papua New Guinea and the Pacific coral island groups.

- **Pollution.**

  Sediments, oil and various chemicals also damage coral reef ecosystems, although these effects are still somewhat localized.

The use of fish traps and boat anchors of divers and tourist groups also contribute to the physical damage of coral reefs.

Indonesia also has its share of coral reef destruction from natural hazards, such as earthquakes, volcanic eruptions and tsunamis. The Krakatau volcanic eruption in 1883 damaged all coral reefs around the islands and along the coastal areas in the Sunda Strait. More recently earthquakes and tsunamis were recorded on the southern coast of Lombok Islands in 1988 and in Maumere, Flores, in 1992. The 1988 Api volcano eruption in Banda, the Molluccas, also destroyed part of the Banda coral garden.

Assessment

Realizing the widespread destruction of coral reefs in Indonesia, the Center for Research and Development in Oceanology (CORD) has been instructed to carry out nationwide surveys on the extent of damage in the last 10 years. These surveys include rapid transecting methods developed under ASEAN-Australian cooperation to estimate the percentage of living coral cover (Harger 1986). Living coral cover does not alone determine the health or the productivity of the reef ecosystem, however, at least it is an indicator of the health of the reef.

For the purpose of conducting assessments on the coral reefs, the Indonesian Archipelago has been divided into seven areas. Training in assessment methodology has been provided to young scientists since 1980s. Altogether some 210 participants have participated in the assessment. The results to date (GOI 1995) indicate that on average, 42.4% of the assessed reefs are poor, 28.6% are fair, 24.4% are good, and only 4.6% are in excellent condition (Table 1). In general, the coral reefs in the eastern part of Indonesia are in better condition than those in the central part. The western area is in the worst condition. Repeated surveys carried out in some coral islands in Jakarta Bay between 1985 and 1995, indicate that the extent of destruction is increasing.

Table 1. Status of Indonesia coral reefs.

No.	Location	No. of Stations	Very High Cover	High Cover	Moderate Cover	Low
West Indonesia						
1	Sunda Strait	16	0	1	6	9
2	Belitung Islands	7	0	2	3	2
3	Seribu Island	40	0	4	8	28
4	Natuna Island	11	2	5	3	1
5	Nusakambangan Island	3	0	0	1	2
6	West Lombok	2	0	1	0	1
7	Bali Islands	14	0	0	2	12
8	Kangean Islands	7	0	4	3	0
Central Indonesia						
9	Sumbawa Islands	3	0	3	0	0
10	Komod Islands	6	2	2	1	1
11	Selayar Islands	5	0	2	3	0
12	Taka Bone Rate Islands	5	1	0	4	0
13	Tukang Besi Islands	5	0	0	3	2
14	Banggai Islands	14	1	6	5	2
East Indonesia						
15	Tobelo Islands	14	0	4	2	8
16	Morotai Islands	14	0	0	1	13
17	Ambon Bay	10	1	5	2	2
18	West Seram	4	0	3	1	0
19	Banda Islands	7	1	5	1	0
20	Kai Islands	17	2	3	7	5
21	Padaido Islands	13	0	3	6	4
	Total	217	10	53	62	92
Percent		4.6	24.4	28.6	42.4	

Very High = living coral cover 75-100%; High= living coral cover 50-75%; Moderate = living coral cover 25-50%; Low = living coral cover 0-25% (Source: Center R & D in Oceanology [unpublished])

Role of Research

In the first half of the 20th century, research on coral reefs was carried out mostly by Dutch scientists, such as Molengraaff, Umbgrove, Verweys, Kuenen (see also "State of Knowledge" in this paper) in Jakarta Bay or through specially organized expeditions, such as the Siboga (1889-1900) and Snellius Expeditions (1929-1930). It was only after the 1960s that Indonesian scientists started to carry out research on coral reefs. Research topics included taxonomy of reef dependent biota, geomorphology, productivity, fisheries, impacts and monitoring of marine pollution, earthquakes, volcanic eruptions, tsunamis and *Acanthaster* infestations.

Research on aquaculture of seaweeds and other reef-dependent species has also been conducted in various parts of Indonesia (Soegiarto et al. 1978). These include *Eucheuma* spp. for carrageenins, *Gracillaria* spp., and *Hypnea* spp. for "agar-agar." Culture on pearl oysters, siganid fishes, sea cucumbers, etc. for commercial purposes, or giant clams (*Tridacna* spp.), *Trochus* shells for re-stocking of depleted stocks is also now carried out in Indonesia, such as in Ambon, Ujung Pandang, Manado and other marine research centers.

Monitoring of coral reefs for destruction by earthquakes, volcanic eruptions, and tsunamis is continuing in various parts of Indonesia such as the Krakatau Islands, Maumere Bay, and Banda Islands. Results of monitoring of reefs after the 1988 Api volcano in the Banda Islands, indicate that even in five years after the eruption, damaged reefs have almost recovered completely. Some of the reef species such as *Acropora* spp. and *Tubipora* spp. recover so fast that they tend to reduce overall diversity.

Screening for bio-active substances for food, medicines or even for family planning purposes from reef biota has been carried out in Indonesia. The Indonesian Institute of Sciences has established a National Working Group on the development of Marine Biotechnology consisting of biotechnologists, microbiologists, virologists, chemists from various leading agencies, research institutions and universities in this field. Cooperation with leading institutions in this field from other countries is being developed (e.g., with the U.S. National Cancer Institute).

Coral reef research has always been an important part of research activities in Indonesia. The program activities may be carried out by an individual research institute or university, or in the form of cooperative activities with foreign scientists. Some of the past cooperative programs include the Rumphius Expedition (1981, 1983, 1986), the Snellius II Expeditions (1984-1985), Moyo Islands (1993), Derawan Islands (1993), Rinca Islands (1994), and the Takebonerate Atoll (1994) National Expeditions.

Management, Conservation and Regulations

The overall responsibility and management of coral reefs in Indonesia is unclear. Whether it is the authority of the central government or the provincial, local or regional government is still a question. This is perhaps one of the greatest shortcomings of the bureaucratic system in Indonesia.

Exploitation of living resources falls under the jurisdiction of the Director General of Fisheries. However, the extraction of non-living resources is regulated by provencial and regional governments. The State Minister for the Environment has the responsibility of policy formulation, as well as preparing legal documents on the environment, including those for coral reef ecosystems. The Directorate General of Forest Protection and Nature Conservation is the management authority for marine parks and conservation areas, whereas the Indonesian

Institute of Sciences (LIPI) is the scientific authority. In Table 2 is a list of agencies and their responsibilities in coastal areas, including coral reef ecosystems.

Table 2. Principal Indonesian agencies and their roles relating to coastal resources management, including coral reefs.

Level	Agency	Role
National	Department of Forestry/Directorate General of Forest Protection and Nature Conservation (PHPA)	Directorate of National Parks and Recreation Forestris responsible for national park; Directorate of Nature, Conservation responsible for area identification, deliniation and planning; Sub-directorate of Marine Conservation.
	Department of Agriculture/Directorate General of Fisheries	policy, planning and implementation of fisheries programs; licensing, extension services, research
	Department of Communications/Directorate General of Sea Communications	responsible for shipping support, licensing, navigational aids and safety; lead agency for marine emergency preparedness and response (e.g,. oil spills)
	Department of Mining and Energy/Directorate General for Oil and Gas	regulates oil and gas exploration and production over the sea, sea bed, leasing and oil industry, environmental safety
	Department of Home Affairs/Directorate General for Regional Development	monitors, evaluates and controls regional development (e.g., tourism industry)
	Department of Industri	administers industrial development including waste management
	Department of Public Works	coastal engineering and development infrastructure
	Department of Security and Defense/Navy	security in territorial waters, hydrographic mapping
	Department of Education and Culture/ Universities	marine science education and research
	Ministry of State for Population and Environment (KLH)/Management of Environmental Impacts (BAPEDAL)	national coordination of coastal zone management issues (Deputy Ministry II [Natural Resources Management]); BAPEDAL monitors marine environmental impacts and manages the AMDAL (EIA) process necessary for development projects
	Indonesian Institute of Sciences (LIPI)	the Research and Development Centre for Oceanology undertakes research and provides scientific advice for other agencies involved in marine issues
	National Planning Board (BAPPENAS)	responsible for allocating funds, according to development plans (25-yr, 5-yr, annual), for development projects
Regional 1	Governor's Office/Planning Agency (BAPPEDA I)	administers regional (provincial) government; development planning, implementation and evaluation
	Forestry (KANWIL Forestry)	overall administration of conservation areas
	Population and Environment (BKLH)	regional coordination of environmental issues
Local 2	Bupati's Office/Planning Agency (BAPPEDA II 3)	administers and plans development of the Kabupaten
	Tourism (DINAS PARIWISATA)	administers accomodation, promotion and guide licensing
	Forestry (DINAS KEHUTANAN)	administers conservation areas
	Fisheries (DINAS PERIKANAN)	administers subsistence/commercial fishing

Notes:
1) = Indonesia has 27 Provinces administered by a Governor, who exercises considerable autonomy
2) = There are 246 Regencies or sub-Provincial units in the Provinces
3) = BAPPEDA I and II are Provencial and Regencial Planning Unit, respectively

Due to this complex and sectoral approach of management, coral reefs in many instances are considered a "no man's land." This confusion contributes to the rapid destruction of coral reefs in Indonesia and a new effort has been formulated for closer and more pro-active coordination among the relevant agencies concerned with the management of coral reefs.

In order to protect and to conserve entire reef systems, a number of marine parks and conservation areas have been developed throughout Indonesia. As of 1990 about 2.6 million ha of marine and coastal area distributed over 23 sites (Table 3) have been set aside under various forms of protection. Seventeen out of these sites are specifically coral reef conservation areas. The projected coverage of protected marine areas will be ten million ha by the year of 2000 (BAPPENAS, 1993).

There have been a number of national, provencial and even traditional laws, rules and regulations established to protect and conserve coral reef ecosystems in Indonesia. The General Provision on Environment, Act No. 4 of 1982, provides for general policy and authorizes the office of the State Ministry of Environment to protect, develop and manage the living, natural, socio-economic and human environment in Indonesia. Other legislation and regulations which are related to the management and protection of marine and coastal ecosystems, including coral reefs, are:

- Act No. 9 of 1985 on the management of fishery resources
- Act No. 5 of 1995 on the conservation of biological resources and their ecosystems (This is also the ratification of the Biodiversity Convention of 1992)
- Government Regulation No. 51, 1993, on environmental impact analyses and assessments
- Presidential Decree No. 43, 1973, on the CITES (Convention on International Trade of Endangered Species)
- Presidential Decree No. 32, 1990, on protected and conservation areas.

In addition, there are also many Ministerial Decrees as well as Provencial Regulations to protect and manage natural ecosystems, including coral reefs. Unfortunately, however, the enforcement of these Acts, Decrees and Regulations in the field are weak. Therefore, efforts on coral reef protection and management suffer continuously.

New Initiatives

Considering the critical level of coral reef degradation in Indonesia and the ecological and socioeconomic importance of this resource, two major initiatives on managing and protecting coral reefs have been developed by the Indonesian government. The first one is through the integrated coastal area development. In this effort, as the International Coral Reef Initiative (1995) has recommended, Indonesia plans to incorporate integrated coastal management measures into local, national and regional coastal development plans and projects, and support their longterm implementation. These measures will serve as the framework for achieving the sustainable use of, and maintaining the health of, coral reefs and associated environments. This major initiative has been formulated in the form of MREP (Marine Resources and Evaluation Project) supported by ADB (Asian Development Bank). It has been implemented for five years (1992-1997) on specific pilot sites in 10 provinces, such as in South Sumatra-Bangka Island, East Java, Bali-Lombok, South Celebes, Southeast Celebes and the Molluccas. This project is in the process of completion and the data and information

Table 3. Established marine conservation areas and their special function.

Province	Name of Area	Status 1	Year 2	Total Area (ha)	Ecosystem
Aeh, Sumatera	Weh Isl.	A	1982	2,600	Coral Reef
Lampung	Krakatau Isls.	B	1990	11,300	Coral Reef
Sumatra	Southern Bukit Barisan 3)	B	1990	201,600	Coral Reef
Jakarta	Seribu Isl.	B/D	1982	108,000	Coral Reef; Mangrove; Turtle Nesting
West Java	Dua Isl.	B	1974	30	Mangrove; Bird Sanctuary
	Sangiang Isl.	C	1985	70,035	Mangrove; Coral Reef
	Leuweung Sancang 3)	B	1990	638	Sea grasses; Coral Reef
Central Java	Karimun Jawa	B/D	1986	111,625	Coral Reef
East Nusa	Maumere Bay	A	1987	59,450	Coral Reef
Tenggara	Tujuh Belas Isl.	B	1987	11,900	Coral Reef
West Nusa	Moyo Isl.	A/C	1986	6,000 (A)	
Tenggara				22,250 (C)	Coral Reef
West Kalimantan	Karimata Isl.	B	1985	77,000	Coral Reef; Sea grass
East Kalimantan	Semana Isl.	C	1982	220	Green Turtle Nesting
	Sangalaki Isl.	A	1982	280	Green Turtle Nesting
Central Kalimantan	Tanjung Keluan	A	1984	2,000	Beach Forest
South Sulawesi	Takabone Rate Atoll	B/D	1989	530,785	Coral Reef; Green Turtle Nesting
North Sulawesi	Bunaken	B/D	1986	75,265	Coral Reef; Mangrove
	Arakan Wowontulap	B	1986	13,800	Dugong Habitat
The Molluccas	Pombo Island	A/B	1973	1,000	Coral Reef
	Banda Island	A/B	1977	2,500	Coral Reef
	Kasa Island	A/C	1978	1,100 (A) 900 (C)	Coral Reef
	Aru Island	B	1991	114,000	Hawksbill; Turtle Nesting
Irian Jaya	Cendrawasih Bay	B/D	1990	1,453,500	Coral Reef

1) Status: A = Recreation Park
B = Strict Nature Reserve
C = Wildlife Reserve
D = National Park

2) Year of Establishment

3) Extension of Terrestrial Nature Reserve

are now being analysed and assessed for integrated planning and management of the coastal areas under study.

The second initiative is specifically geared to rehabilitate and manage coral reef ecosystems through the development of community awareness and participation. This initiative is called COREMAP, which stands for Coral Reef Rehabilitation and Management Project. This US $120 million project will be supported by the World Bank, GEF (Global Environment Facility), ADB, AusAid (Australian Development Aid), JICA (Japan International Cooperation Agency) and some other donor agencies and countries. The primary objectives of this major project are (GOI, 1995):

- to rehabilitate degraded coral reefs to the extent of protecting and managing their biodiversity and utilization on a sustainable basis
- to maintain the functions and value of the coral reef ecosystem and its economic and social benefits through the management network, institutional coordination and increase public awareness and participation on coral reef management.

These objectives will be reached through the accomplishment of four secondary objectives:

- to provide an integrated management network to cover priority areas and to develop management measures specific to each priority area
- to strengthen coordination among agencies and institutions involved in the management of coral reefs
- to strengthen the human resources at academic and institutional levels in the development and application of coral reef rehabilitation and management techniques
- to improve public awareness and participation in the management issues of coral reefs.

Currently, this major initiative is still under preparation and intensive discussion and negotiation with the major donour agencies. It is expected that the project will start in 1997.

CONCLUSIONS

Coral reefs are distributed widely in the Indonesian Archipelago. Intensive research of coral reefs in Indonesia was carried out by Dutch scientists in the first half of the twentieth century and has been developed further by Indonesian scientists since the 1960s.

Coastal communities have benefited from coral reef resources for centuries. Unfortunately, due to uncontrolled and illegal methods of resource extraction, coral reefs have been severely damaged in many parts of the archipelago. Although there already exist a number of government Acts, Regulations, Decrees and other management measures, enforcement is still very weak.

In order to alleviate this critical problem, two major initiatives, MREP and COREMAP, are being formulated and implemented in order to protect and conserve the coral reef ecosystems and utilize their resources sustainably. The approach is to increase community awareness and participation in the planning and management process and strengthen the coordination among the relevant agencies and institutions responsible in the management of coral reef ecosystems in Indonesia.

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MARIANAS

STATUS OF CORAL REEFS IN THE MARIANAS

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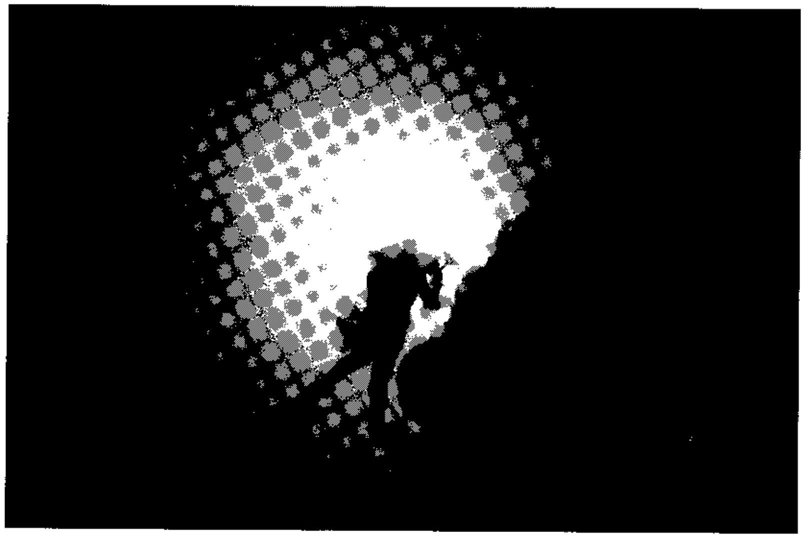

The coral reefs of the Marianas are subjected to strong natural forces such as typhoons, earthquakes and volcanoes. Although these are large-scale forces, the degree of damage to reefs is contingent on factors such as angle of coastline and stability of the substratum, so severe damage is localized. The frequency of typhoons has conditioned coral morphology to withstand their effects more than in most other local sites. Fish populations have been seriously affected by human fishing pressure in the Southern Marianas and exhibit substantial decreases in catch per unit effort, decreases in abundances of fishes, and major shifts in relative abundance with the decrease in species targeted by fishermen. The most insidious effects are decreases in reproductive potential (as much as 95%) for populations of fishes which are still common but which show major decreases in size distribution. Data from permanent transects show that coral communities have withstood effects of increased tourism since the 1970s, but increased rates of sedimentation and overfishing of herbivores may have reduced the rates of coral replenishment.

ENVIRONMENTAL SETTING

The Southern Marianas (Guam, Rota, Aguijan, Tinian, Saipan, and Farallon de Medinilla) have well-developed coral reefs with reef flats wide as 600 m (Tumon Bay, Guam) and with barrier reefs across lagoons as broad as 3.5 km (Garapan on Saipan and Cocos on Guam). The Northern Marianas (nine islands from Anatahan to Farallon de Pajaros) do not have well developed coral reefs. Coral communities in the Northern Marianas are found growing on volcanic substrata, although a few small "embryonic" or "apron reefs" (reefs which may have spur-and-groove formation, but do not reach sea level) can be found.

Differences in reef development are not due to better conditions for healthy coral growth in the south. Corals in the Northern Marianas appear to be just as vigorous. The massive construction of southern reefs and lack of substantive reefs in the north can be attributed largely to differences in age between the Northern and the Southern Marianas. The Southern Marianas formed in the Eocene, about 43 million years ago when the Pacific Plate changed direction from moving northward to northwestward. As the plate moved northwestward, it collided with, and began subduction beneath, the Philippine Plate. Volcanic activity and uplift where the Philippine Plate met the Pacific Plate created a base of volcanic islands. Reef-associated limestone began to be deposited. Some limestone deposits in Saipan have been determined to be over 40 million years old. Over this long history, coral reef growth has been extensive and now the Southern Mariana Islands are largely makateas, or raised limestone islands on a volcanic base.

In contrast, the Northern Marianas Islands are active, or recently active, volcanoes that began formation in the Pliocene about three million years ago. The oldest dated rocks are about 1.3 million years old (Randall 1995).

Geological faulting of large areas in the Southern Marianas, especially along the west coast of Guam and the east coast of Saipan, have created large oblique surface areas in shallow water which allow for extensive reef growth on reef flats and lagoons. In contrast, the young islands in the north are quite vertical as they undergo uplift. A bibliography of geological literature for the Marianas is available (Siegrist 1992).

The Southern Marianas has a greater number of species and families of coral-reef organisms than the Northern Marianas, partially because of the greater number of habitats such as lagoons and bays that have developed along the coasts with more oblique surface areas. About 159 species (43 genera) of reef-building (hermatypic) corals have been recorded from the Northern Mariana Islands and about 253 species (56 genera) from the Southern Marianas (Randall 1995). This is substantially fewer than are known from Palau (421 species, 75 genera; Maragos et al. 1994), the Philippines (411 species; Veron 1993), the Great Barrier Reef (343 species, Veron, 1993), the Yaeyama Islands in southern Japanese waters (363 species; Veron 1993), or the Marshalls (ca. 300 species; Randall 1995). This may be partially a result of the major currents being from the east rather than the west. There have been about 35 species of alcyonaceans documented from Guam (Gawel 1977; Benayahu 1997).

To date, about 933 species (112 families) of fishes have been documented in the Southern Marianas and 427 (72 families) species have been found in the Northern Marianas (Donaldson et al. 1994). So far, about 1,300 species of marine molluscs have been documented from the Southern Marianas (G. Paulay, pers. comm.) and 520 species have been found in the Northern Marianas (Kurozumi and Asakura 1994). Although the Southern Marianas have been surveyed more, the Northern Marianas has also been well surveyed.

There may be more species of coral reef animals to be added to the list for the Northern Marianas, but the greater richness in numbers of species in the Southern Marianas is evident.

About 3,500 species representing all taxa from coral reefs of the Southern Marianas are documented by specimens or valid published records catalogued on computer at the University of Guam Marine Laboratory. The taxonomic accounts of many of the groups of coral reef organisms can be found in the journal *Micronesica.* Some groups of the invertebrate fauna of coral reefs in the Northern Marianas (molluscs, polychaetes [17 families], and crustaceans [Amphipoda, Stenopodidea, Caridea, Palanulidae, Anomura, Brachyura, Stomatopoda], echinoderms and didemnid ascidians) are recorded in Asakura and Furuki (1994). About 700 publications and technical reports concerning the coral reefs of Guam and the other Marianas are listed in a pamphlet available from the University of Guam Marine Laboratory.

NATURAL DISTURBANCE

Geological: Earthquakes and volcanoes

Frequent volcanic activity at present and in the recent past in the Northern Marianas has repeatedly cleared areas of living coral by depositing lava or pyroclastic ash and cinder. For example, an eruption in 1981 did extensive damage to coral communities on Pagan (Eldredge and Kropp 1985).

The Southern Marianas are on the Philippine Plate which overlies the subducting Pacific Plate. Hence, earthquakes are frequent. An earthquake in August 1993 that measured 8.2 on the Richter Scale moved the entire island of Guam a few centimeters to the east. Although the earthquake was felt over a large area, the damage to coral communities was restricted to particular reefs that developed massive structures on unstable substrata in protected areas such as Apra Harbor. Fifteen-foot deep crevasses and major slumps of coral reef were observed. Reefs that developed on foundations of solid limestone of previous reefs or on baserock of volcanic origin were not so severely affected.

Climatic: Typhoons and ENSO

The Marianas lie in the Western Pacific Monsoon Trough which receives about half the tropical cyclones of the world. In the Caribbean, hurricanes strike individual islands every 15-20 years, but Guam has felt the impact of 52 major typhoons in the last 48 years. In 1992, the eyes of three major typhoons passed over Guam in three months and two other typhoons passed within 70 miles. When typhoons pass nearby, the reefs receive the full impact of heavy wave action. However, contrary to what might be expected, the typhoons affect the coral reefs on Guam to a lesser extent (Randall and Eldredge 1977) than the Caribbean (Stoddart 1962; Tilmant et al. 1994). On Guam, severe damage is localized to areas that are usually protected from heavy wave action by the shape of the coastline.

In areas normally protected from strong wave action, coral reefs sometimes develop on loose rubble on or unconsolidated substratum. If undisturbed for decades, these reefs can grow to several meters in height and tens of meters in length. Although they may weigh many tons, waves from severe typhoons can move them when they stike the coast. R.N. Ginsburg coined the term "reefbergs" for sections of reef that are moved by cyclone-generated waves or by earthquakes. This phenomenon does not exist in areas regularly exposed to strong wave action.

Heavy wave action from typhoons does not substantially affect corals and coral reefs on coasts normally exposed to strong wave action on Guam, except locally where loose materials exist. The corals on the open coast are constantly conditioned to withstand heavy wave action, generated relatively frequently by typhoons. Under these high-energy conditions, coral colonies grow firmly attached to solid areas of the substratum and tend to develop an encrusting or massive colony morphology. Corals growing on weakly attached sections of substratum create larger surface areas as they grow and this provides a greater surface on which water movement can apply force and break loose the coral colony and weak substratum. This happens continuously so that weak substrata and delicate branching corals are constantly removed such that no large scale damage occurs. The typically high-energy environment of the Marianas is the generally accepted explanation for the paucity of large sponges, ascidians, crinoids and gorgonaceans in shallow water of the open coasts. These organisms are generally restricted to harbors or to deeper water (> 20 m depth) on the exposed coasts.

During an El Niño event, trade winds weaken in the eastern Pacific and the major wind patterns sometimes reverse in the western Pacific. Without the normal trade wind, the sea level can drop to unusual levels for extraordinarily long periods of time. This exposes coral reefs and kills large numbers of organisms (Yamaguchi 1975). Some of the previously large populations of marine invertebrates in Pago Bay, Guam, have not returned for over 30 years.

Biological: Crown-of-thorns starfish outbreaks

An outbreak of tens of thousands of *Acanthaster planci* occurred in 1968-70, of which about 63,000 were eradicated. During this time, most of the corals along 35 km of coastline (the northwest quarter of Guam) were devastated, but all recovered to a reasonable degree by 1981. Since 1978, there have been a number of aggregations of hundreds to thousands of *A. planci*, but control programs have been discontinued for a decade.

Similarly, there was an outbreak *Acanthaster planci* on the Southern Mariana Islands of Rota, Tinian, and Saipan in 1969-70. About 14,000 were killed in a control program. Throughout the Southern Marianas, *Acanthaster planci* is a steady factor that accounts for minor coral mortality.

DISTURBANCE FROM HUMAN ACTIVITIES

Sedimentation

Since 1975, the rate of soil erosion on Guam has doubled. For example, the erosion off the Ugam River Watershed was 55,342 tons in 1993. This was 1.96 times the the sediment yield in 1975 (DeMeo 1995). The erosion is especially affected by badlands and constuction of roads. Badlands are mainly caused by erosion following range fires set by poachers, a common occurrence on Guam. Badlands develop when rains follow the range fires before vegetation has re-established. The average rate of erosion of badlands on Guam is 243 tons/acre/year.

Construction is also a major source of sedimentation. For various political and economic reasons, erosion-prevention safeguards were bypassed when the main roads were upgraded and a radio station was constructed south of Agat, Guam. The erosion from these construction projects was apparently responsible for a spectacular burial of the coral communities along the coast directly below the construction (see photograph in Richmond 1993).

OVERFISHING

Munro and Williams (1988) claimed that coral reef fisheries on Guam are too lightly exploited to draw any reliable conclusions about the limits of coral reef fish productivity. In 1984, however, there was a substantial increase in commercial fishing of reef flats on Guam. Over the 12 years since 1985, the total catch of nearshore reef fishes steadily decreased from 103 to 28.4 metric tons (a 72% decrease, Figure 1) and the catch per unit effort (CPUE) decreased from 0.69 to 0.15 kg h^{-1} (a 78% decrease, Figure 2).

The decrease in CPUE represents an even more substantial change in the reef fish populations than the data indicate for three reasons. First, the CPUE is expressed in weight, but there is also a change in the species composition from the targeted species to species less desirable.

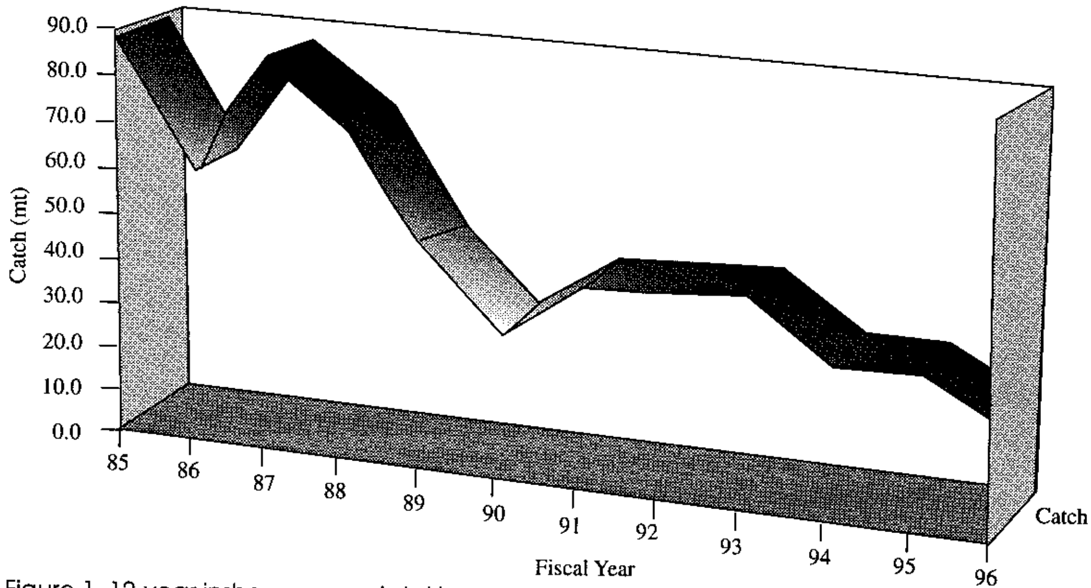

Figure 1. 12-year inshore survey: total harvest (without seasonal catch).

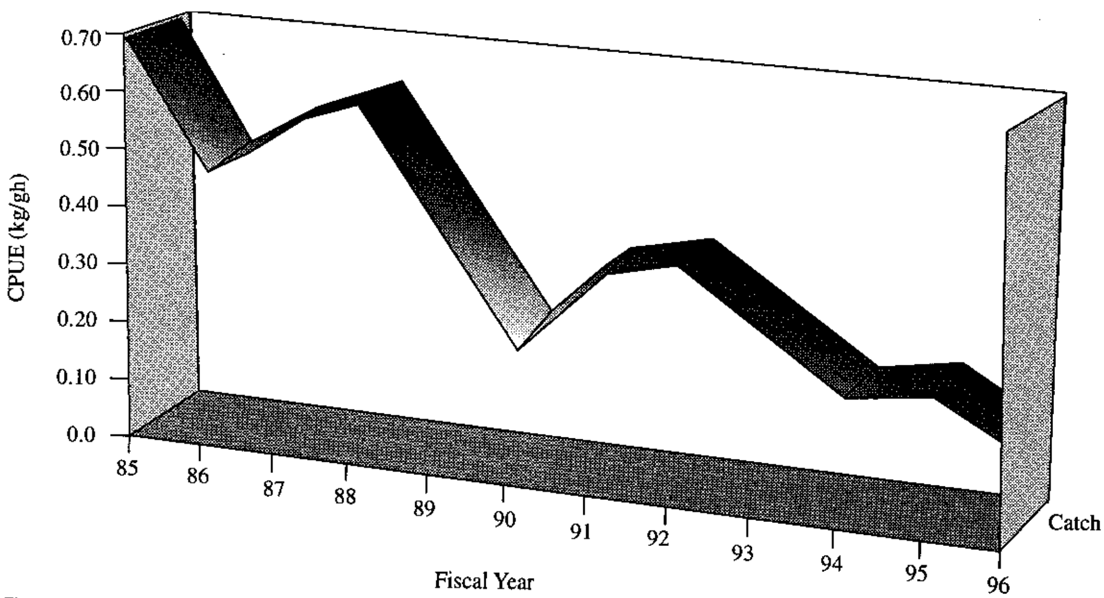

Figure 2. 12-year inshore catch survey: catch per unit effort (kg/h).

Only three years ago, the catch of gill nets on Guam's reef flats generally included 18-25 species, including 10-15 kg of the favored *Mulloidichthys flavolineatus*, as well as lethrinids, gerreids, and leiognathids. By 1997, 50% of gill net sets are now empty. Prevalent fishes are now the less desirable *Myripristis* and *Neoniphon*. Likewise, spearfishing once brought in *Scarus microrhinos* and *Naso unicornus*, but now the smaller scarids and acanthurids make up the bulk of the catch. The decrease in abundance of large scarids and acanthurids may explain the decrease in coral recruitment on Guam during the past decade (see the section on Present Condition below).

The second reason the decrease in CPUE represents a more substantial change in the reef fish populations than the data indicate is that while the CPUE was decreasing, the number of fishermen was also decreasing. The drop in CPUE was so dramatic, that many of the sport and subsistence fishermen quit fishing altogether. Not only are there fewer fishermen to compete for the catch, there is simultaneously a lower rate of catch per fisherman.

Third, and most serious, is that in earlier years, a larger portion of the weight was made up of larger individuals. In later catches, each kg of weight was made up of a greater number of individuals and each of these individuals has less reproductive potential per kg than existed previously (Birkeland 1997). In 1991, the reproductive potential of the *Mulloidichthys flavolineatus* population was only 5% of its potential of several *M. flavolineatus*, albeit smaller.

Coral reef fish populations do not always recover after decades of being unexploited. An offshore pinnacle was discovered near Guam in 1967. It was harvested down in a few months (Ikehara et al. 1970), but steady monitoring by the Department of Aquatic and Wildlife Resources, Government of Guam, has shown that fish populations have not recovered during the subsequent 30 years.

The fisheries of the Marianas north of Anatahan have not been overexploited to the extent of the Southern Marianas because of economic constraints due to distance.

Tourism

About 1.3 million tourists visited Guam in both 1995 and 1996. Of these, over 10% were motivated to dive on Guam's coral reefs. On the average, visitors stay three days, dive two of these days, and make two dives per day, or four dives with SCUBA. This indicates that well over half a million person-dives are made on the reefs of Guam by tourists. Additional dives are made by residents and military personnel. The average total expenditure per tourist in 1996 was $1,143, although it is possible that those who dive may spend more because of the expense of gear rental and boat trips. If tourists that come to Guam for diving on coral reefs spend an average amount, this activity can be said to bring in about $148.6 million to Guam annually.

Most of the diving by tourists is concentrated at five locations. The stress to the reef from this activity has not been well documented. Incidental observations since 1975 suggest that gorgonaceans and antipatharians are not as common in shallow water as they once were. The gorgonacean *Acabaria* used to be in the Blue Hole and is no longer seen there. Most of the decrease in abundance occurred in the late 1970s, and so this may be the result of collection by residents and military divers rather than tourists. Tourists concentrate more on photography and observation, while the military divers allegedly collected sea fans and black corals for decoration. Turnover in military residing on Guam result in a continuous pressure.

PRESENT CONDITION

Of greatest concern over the health of coral reefs in Guam at the present time is a possible decrease in recruitment of corals. In the late 1960s, average coral cover on Guam was about 50% (Randall 1971). Extensive predation by the crown-of-thorns starfish *Acanthaster planci* reduced some of these areas to less than 1% cover, but within 12 years these same areas recovered dramatically (e.g., 0.9% living coral in 1970 to 65% in 1981 [Colgan 1987]). Some of this robust recovery must have resulted from larval recruitment other than just growth of remaining fragments of living coral because the number of species in the study areas increased from 84 in 1970 to 154 in 1981 (Colgan 1987).

However, there are two indications that corals have not been replenishing their populations since the late 1970s: the percent cover of living coral seems to be decreasing and the recruitment of small corals has decreased. The few transects taken on coral communities in the 1960s generally showed over 50% living coral cover (Randall 1971). In compiling information from technical reports, theses, and publications, data on percent living coral cover showed that for 113 transects taken in the Southern Marianas, only 7 of the 113 transects taken in the 1980s and 1990s had over 50% cover of living coral; and 88 (78%) had less than 25% cover of living coral. This corroborates testimony of local scientists and sport divers that percent cover of living coral has decreased and percent cover of algae has increased. However, the locations of the transects were not selected randomly, but were taken for various unrelated objectives, and testimony from memory is not necessarily dependable. Memory tends to make the past seem better. It would be best to resurvey as many of the old transects as possible before concluding that cover of living coral has changed.

A more direct measure of a decrease in the rate of recruitment of coral populations is on data on coral settlement on plexiglass fouling panels. In 1979, Birkeland et al. (1982) set out 525 plexiglass fouling panels on the outer reef slopes of Guam and obtained 278 coral recruits. In 1989 and 1991, C. Birkeland and K. Sakai set out 468 plexiglass fouling panels of the same materials and experimental design, and obtained only two coral recruits. Paul Chirichetti set out 224 plexiglass fouling panels in 1992 and likewise obtained a total of only two coral recruits. Further replication of the studies using plexiglass fouling panels are planned to resolve these differences (0.53 corals per panel) in 1979 versus (0.004 and 0.009 corals per panel) in 1989 to 1992, respectively.

Three hypotheses could explain the apparent decrease in the rate of replenishment of coral populations. First, Birkeland et al. (1982) noted that competition for space is not an important factor in determining rates of coral recruitment on Guam, in contrast to the continental areas of the Caribbean and eastern tropical Pacific. On the oceanic island of Guam, the rate of recruitment is most strongly affected by availability of planula larvae in the water column. A positive feedback may exist between decreased abundance of living coral cover and the production of planula larvae.

Second, increased rates of sedimentation on Guam may decrease space available for coral recruits in several ways. Planulae of most species of coral cannot settle successfully on loose sediment, and some require chemical cues from the substratum that can be masked by sediment. For example, some species of *Acropora* require certain species of crustose coralline algae for metamorphosis (Richmond 1997). Some upright fleshy algae and filamentous algae can live under higher levels of sedimentation than can crustose coralline algae. In particular, Richmond suggests that *Acropora* is no longer found at the site south of Agat because heavy sedimentation occurred on the reef during construction of the radio station and coastal road.

We found a few patches of crustose coralline algae, but only in shaded spaces on the underside of overhangs where it may have been too dark for small *Acropora* to grow. After disturbances to coral reefs, the first colonizers may be filamentous algae. When the rates of sedimentation are high, the filamentous algae may trap sediment at the basal portions of their strands and thereby prevent crustose coralline algae from settling.

A third hypothesis is that over-exploitation of herbivorous fishes allows the filamentous and fleshy algae to dominate exposed surfaces of the reef. The apparent decrease in ability of corals to replenish their populations in the early 1980s is roughly correlated with the beginning of the decrease in fish populations.

Decreases in species richness and percent cover of living coral associated with increased sedimentation has been documented for Ylig and Fouha Bays on the east and west coasts of Guam, respectively (Randall and Birkeland 1978).

However, there is some indication that the decrease in living coral cover is not universal on Guam. Transects surveyed on the Tumon Bay reef flat in 1977 (Amesbury et al. 1993) were re-surveyed in 1991 by Amesbury and others. Although the echinoderms decreased in abundance from 143.8 to 87.6 per 100 m^2 and fishes decreased from 60.6 to 26.0 per 100 m^2, the corals seemed to increase from 2.1 to 3.7 percent cover. Although the small amount of coral cover is a weak basis for conclusions from this resurvey, there is certainly no evidence for a decrease in coral cover. Although the Tumon Bay surveys were on a reef flat (depth 1 m or less) rather than on a forereef slope like most of the others (3 to 20 m), it is the only set of data in which the same transect was resurveyed after a decade. Before generalizations can be made about whether coral communities of Guam are deteriorating, the same transects must be resurveyed. There are, however, specific localized areas in which the reef comminities have deteriorated (e.g., south of Agat near the construction sites of the radio station and coastal road) (see photograph in Richmond 1993).

Coral communities of the Northern Marianas from Anatahan north, are in a fairly natural condition partially because of the small human populations and the lack of major land-clearing or construction activities. The main damage is from typhoons and/or lava and ash deposits from active volanoes, but these effects are quite localized.

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OKINAWA

RECENT STATUS OF CORAL REEFS IN OKINAWA, JAPAN

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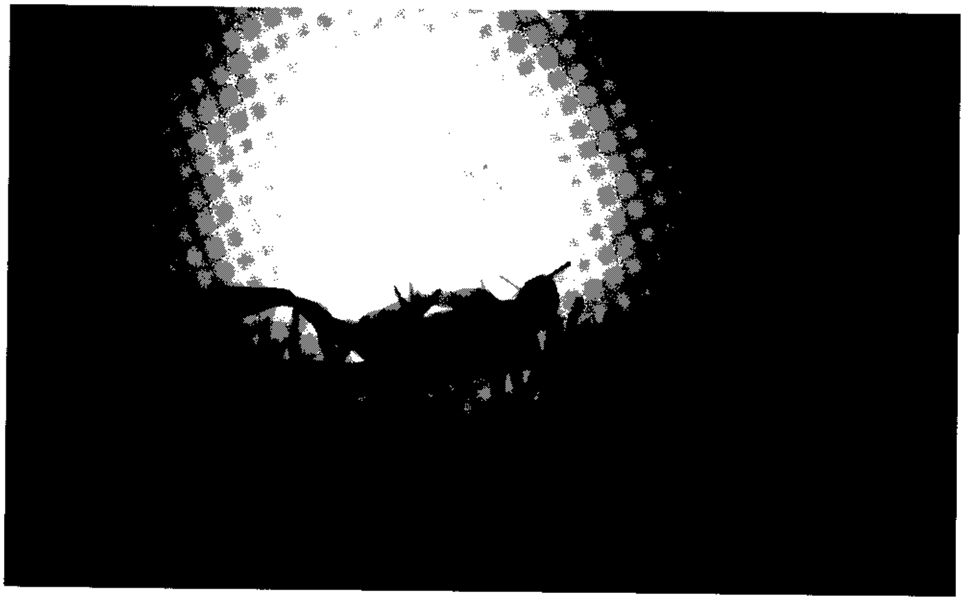

This paper is a review of scientific papers and government reports describing the recent status of coral reefs in Okinawa. The results indicate that coral reefs in the islands of Okinawa were devastated by Acanthaster planci, *the coral eating crown of thorns starfish during the period 1974 to 1977. Since then, corals have recovered in some areas, but they are now under attack by* Acanthaster *once again. As a consequence, coral coverage remains at low levels. In 1992, about half of the coastline was devoid of coral cover. However, the most recent study (Arakaki & Yamazato 1997) shows some coral recovery although not without an increase in the starfish population. The second most important factor causing a deterioration in coral growth is sedimentation, but its effect is limited to coral communities close to river mouths.*

INTRODUCTION

In the early 1970s, major symptoms of an outbreak of *Acanthaster planci* were first noticed on the coral reefs of Okinawa. Since that time nearly 30 years have passed. During this period, warnings about possible destruction of coral reefs appeared repeatedly in the news media. Scientists published their fears in nontechnical or technical publications. In spite of these fears, the situation has not improved.

There are many causes for the destruction and deterioration of coral reef communities. Some are human induced and others are natural hazards. The most important cause of coral reef destruction in Okinawa has been predation by *Acanthaster planci*, the crown-of-thorns starfish and human-induced sedimentation.

In this report, I described how these two factors have damaged coral reef communities in Okinawa and adjacent islands. There are many other islands in Okinawa Prefecture and the Ryukyu Islands. However, since the most extensive and continuous surveys are in the Okinawa Islands, the information presented here for these islands is considered representative of all the Ryukyu Islands.

Coral Predation by *Acanthaster planci*

The first symptom of coral predation by *Acanthaster planci* was noted in 1969 on the central western coasts of Okinawa Island (Yamazato 1969). Coral reefs along this entire coast were completely destroyed by 1977. Predation spread from this area toward the north and south, finally reaching the eastern coast. During this period of migration of the starfish, some coral regrowth appears to have taken place (Figure 1).

We attempted to trace the course of migration of the starfish and the accompanying change in coral coverage in 1972 (Nishihira & Yamazato 1974). This was done by placing 82 observation stations along the coast of Okinawa Island, and observing the distribution of starfish, fresh feeding scars and coverage of living coral colonies. In the subsequent surveys, the same stations were used as study sites, so that the comparative data was obtained in each survey.

As can be seen in Figure 1, coral coverage at the central four stations on the western coast of the island was nearly zero in 1972. The starfish population was large at these stations but slowly moved south and north, indicating migration of starfish populations toward the tip of Okinawa Island (Okinawa Tourism Development Corporation 1976). Eventually, the starfish population at the station where the population first exploded became quite small. There was a discontinuous distribution of *Acanthaster planci* on the eastern coast, with two stations of the central eastern coast where the starfish first appeared.

It appears that the starfish population increase spread from a narrow area in 1969 to a much larger area by 1972. Figure 1 illustrates the results of such surveys made in 1972, 1976, 1984, 1987 and 1992. These data are reported by Nishihira & Yamazato (1974), Okinawa Tourism Development Corporation (1976), Coral Reef Survey Committee (1984) (see also Yamazato 1987; Sakai et al. 1988), Coral Reef Preservation Committee (1987), and Okinawa Prefecture (1992). All of the surveys were compiled by Yanagiya (1993). The present author participated in the surveys of the first three reports.

The data indicate that the area of decrease in coral coverage off the central western coast extended southward from 1972 to 1976. At some stations, coral coverage recovered by 1984 but decreased again in 1987 and 1992. This shows that when coral coverage recovers, the starfish can sometimes build back up. Similar changes were observed in other areas, particu-

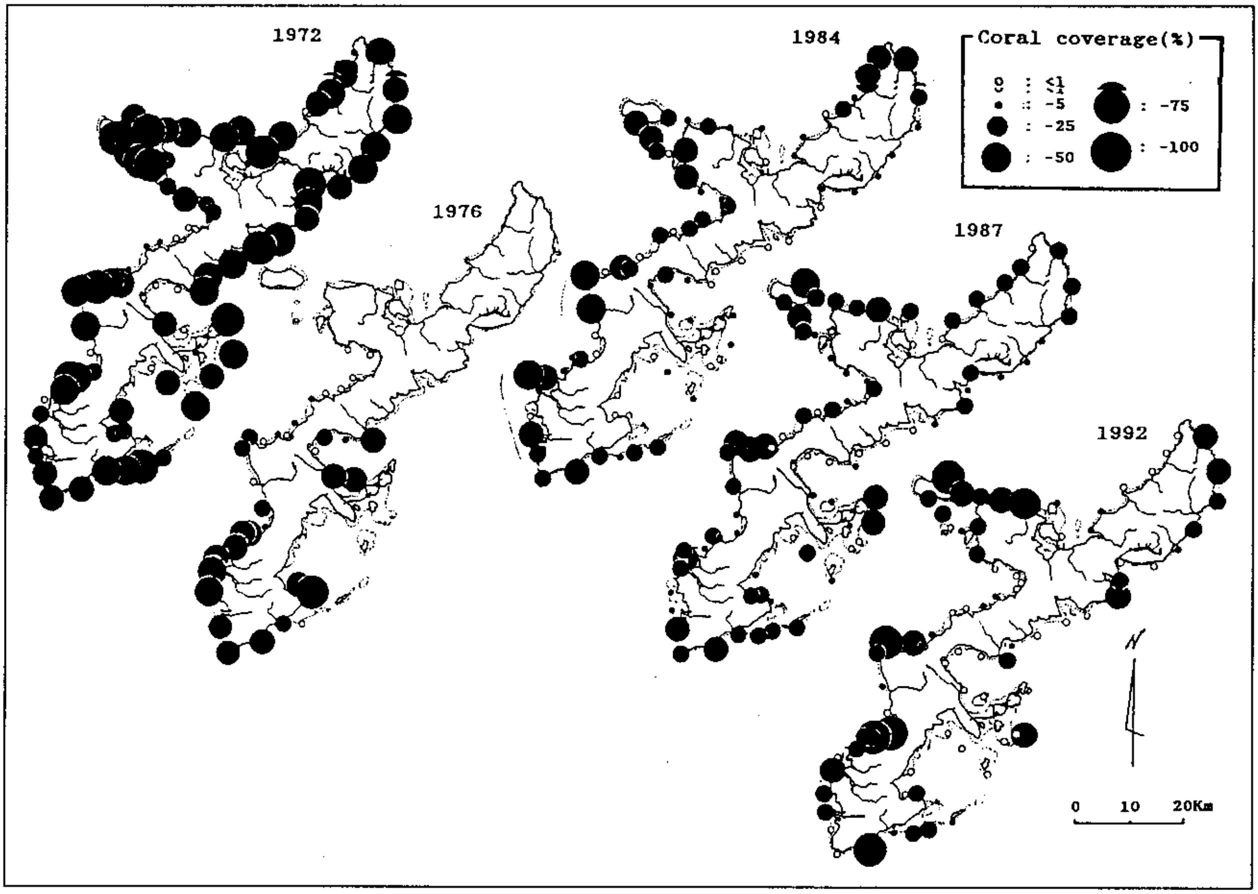

Figure 1. Changes in coral coverage around Okinawa Islands. Compiled from Nishihara & Yamazato (1974), Okinawa Tourism Development Corporation (1976), Coral Reef Survey Committee (1984), Coral Reef Preservation Committee (1987), and Okinawa Prefecture (1992). From Yamagoya (1993).

larly off the northwestern coast, where coral coverage was low in 1984, recovered in 1987, but then decreased again in 1992. On the eastern coast, coral had decreased substantially by 1984 and has remained low ever since (Figure 1).

CORAL RECOVERY

After devastation of corals at most stations off the eastern coast in 1984, no regrowth has been observed in 1987 and 1992 except at a few stations (Figure 1). It is not clear if this is due to lack of coral recruitment or renewed attacks by the starfish. However, data on the recruitment of *Acropora* shown in Figure 2 indicate that some recruitment has occurred on the northern half of the eastern coast. This suggests that a renewed attack by the starfish is occurring. This is supported by data on abundance and feeding scars which show an increase in 1993 (Figures 3 and 4).

In the summer of 1996, aggregation of starfish was again observed off the central west coast off Okinawa where the original 1972 population outbreak took place. This has led to an effort by village fishermen to remove the starfish. They removed 81,000 starfish (28 tons) in six days (*Okinawa Times*, Nov. 17, 1996). After this we made a brief survey of the starfish and the conditions of corals. We chose seven stations in the central western coast where coral

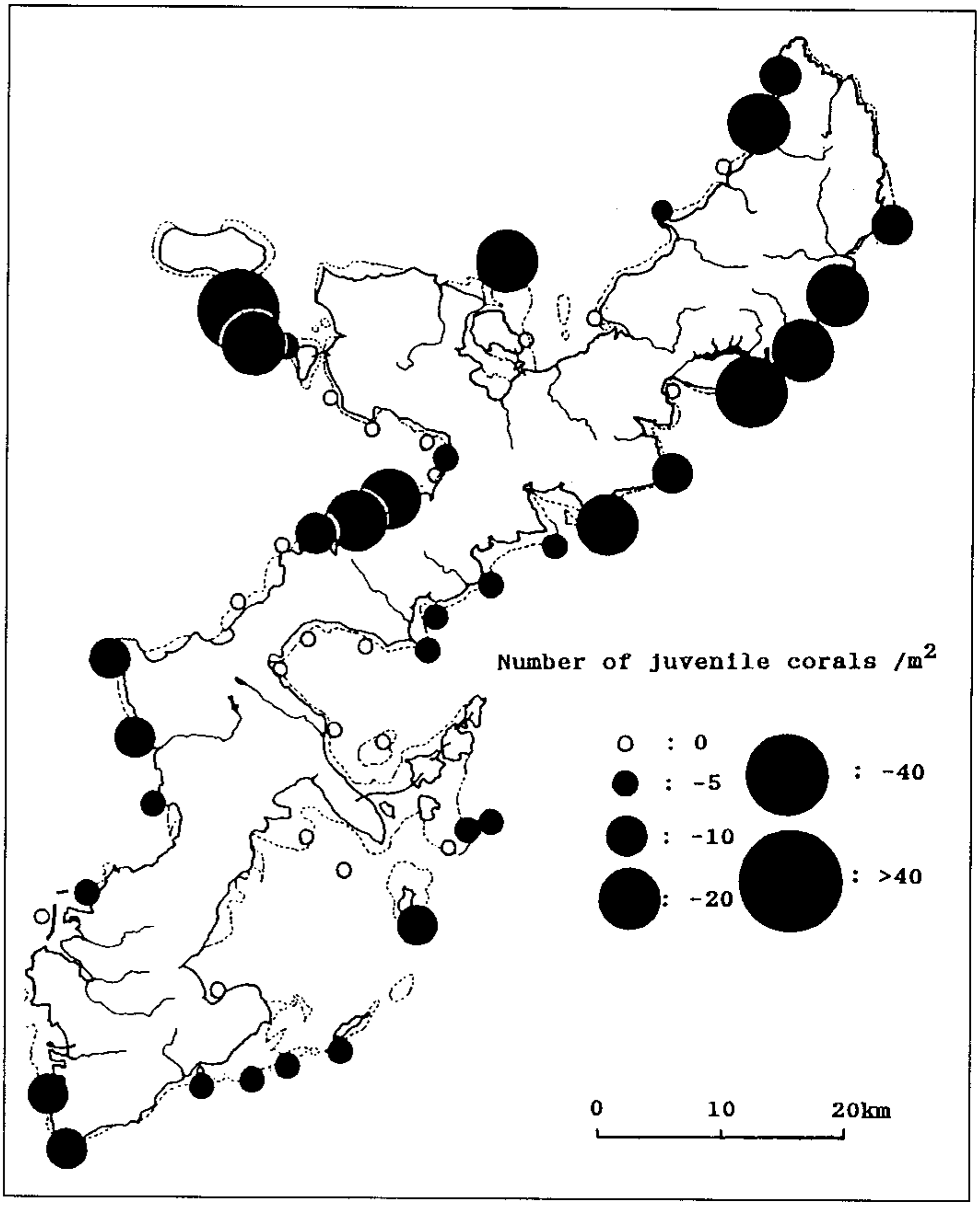

Figure 2. Number of newly settled colonies of Acroporid corals on denuded substratum around Okinawa Islands. The data (no/m^2) are means of several quadrats. From Yanagiya (1993).

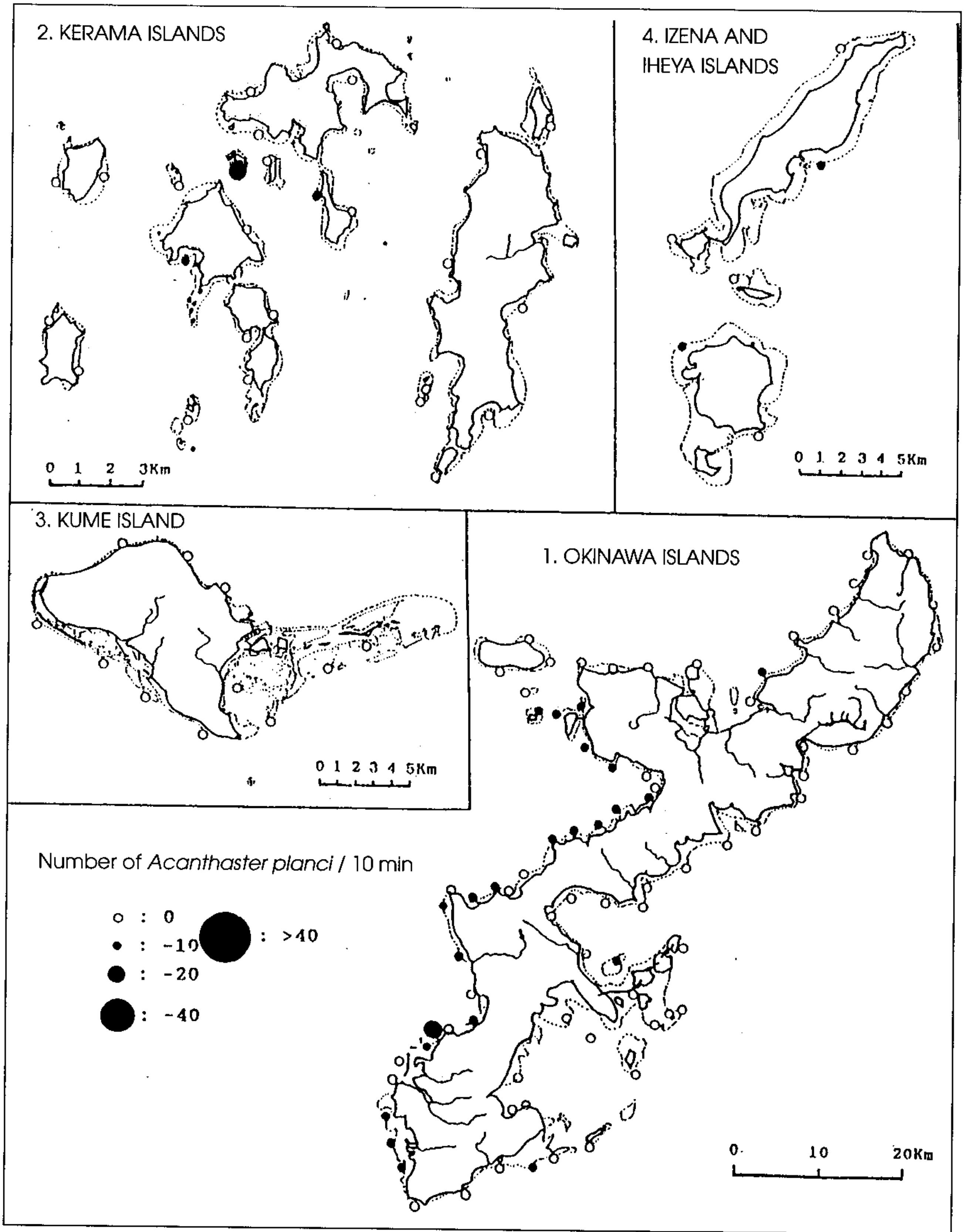

Figure 3. Number of *Acanthaster planci* detected within 10 minutes around Okinawa Islands. From Yanagiya (1993).

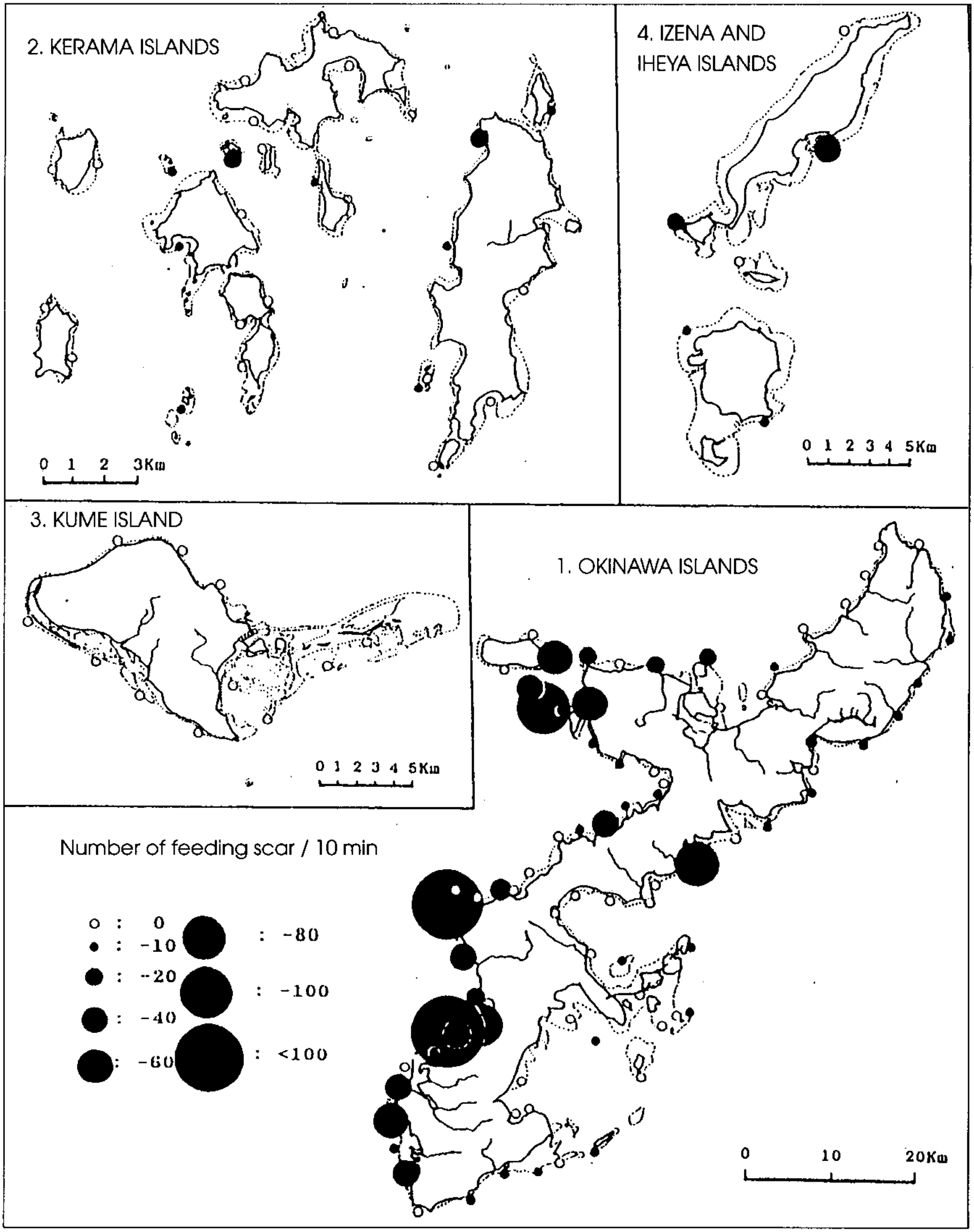

Figure 4. Number of fresh feeding scars of *Acanthaster planci* detected within 10 minutes around Okinawa Islands. From Yanagiya (1993).

coverage was between <1% and 5% in 1976, Figure 1. The results of our 1996 survey show that coral cover has changed at these stations in the following manner from the southernmost station to the area northward, 70% to 25%, 75% to 75%, 50% to 50%, 40% to 5%, 0.5% to <1%, 55% to <1%, 100% to 5%.

SEDIMENTATION

The second most important factor affecting coral growth in Okinawa is sedimentation from terriginous run-off. On Okinawa Island many human activities, including large scale agricultural land reforms, river bank construction works, road construction works and other civil works, cause sedimentation. The sediments caused by these activities, flow out to the coast through rivers, or directly, in the case of coastal construction works. Of the sediments transported out to the coast, the particles larger than silt deposit at river mouths and along the coastline, whereas fine particles such as silt and clay remain in suspension for a long period, eventually flowing out through boat channels.

On fringing reefs with well developed lagoons, coral growth is found on the reef flats and the outer slopes. Corals usually do not grow on the sandy bottom of the lagoons, unless there are rocky or other hard substrates. In certain cases branching corals form mounds on sandy substrata. On narrow fringing reefs that do not have a lagoon separating coral communities from the shore, coral communities are directly subjected to terrestrial sedimentation.

Such conditions as described above were observed along the central eastern coast in 1974 (Yamazato 1975) and 1977 to 1979 (Okinawa General Affairs Bureau 1978, 1979; Yamazato 1987). About 40 km of coastline along the eastern coast were surveyed in 1974, 1977 and 1978 for the effect of sedimentation on coral reefs. Out of 15 stations surveyed in 1977, nine stations had significant deposition of terriginous sediments. These stations were all located inside the lagoon on sandy or gravel bottoms or on patch reefs. Among nine stations, six had almost no corals, indicating that there may have not been any corals originally. The remaining three had some corals dead and alive, and the dead corals appeared to have been killed by sedimentation. Six out of 15 stations which did not have deposition of sediment had good coral coverage from 50 to 100%. Most of these stations were located on the outer fringing reef. One was a patch reef about two kilometers away from the nearest river mouth. From these results, it can be concluded that the fringing reefs separated by a lagoon are not normally subjected to sedimentation. In contrast, coral assemblages within the lagoons can be affected by sediments flowing out from nearby rivers.

In 1977, 1978 and 1979, a more detailed survey was conducted, in order to determine the effect of sedimentation flowing out of rivers on coral assemblages along a four kilometer stretch of fringing reef and lagoon. Terrestrial sediments were only found along the coast adjacent to the river mouths. Sediments did not reach the fringing reef about one kilometer away from river mouths nor the lagoon about half a kilometer away from river mouths. Sediment transport mainly takes place along the coast directly on either side of river mouths and is transported only short distances toward the sea.

Unfortunately, the fringing reef of this coast was subjected to the starfish attack, and corals on these reefs were completely devastated by 1977. For this reason, it is difficult to separate the effects of the starfish feeding from those of sedimentation. However, the fact that many individuals (32 to 34 colonies per square meter) of very small colonies occur in two stations with the largest number of species of corals, indicates that these corals may be the new recruits of corals once devastated by the crown-of-thorns starfish.

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PHILIPPINES

ASSESSMENT OF THE PRESENT HEALTH OF CORAL REEFS IN THE PHILIPPINES

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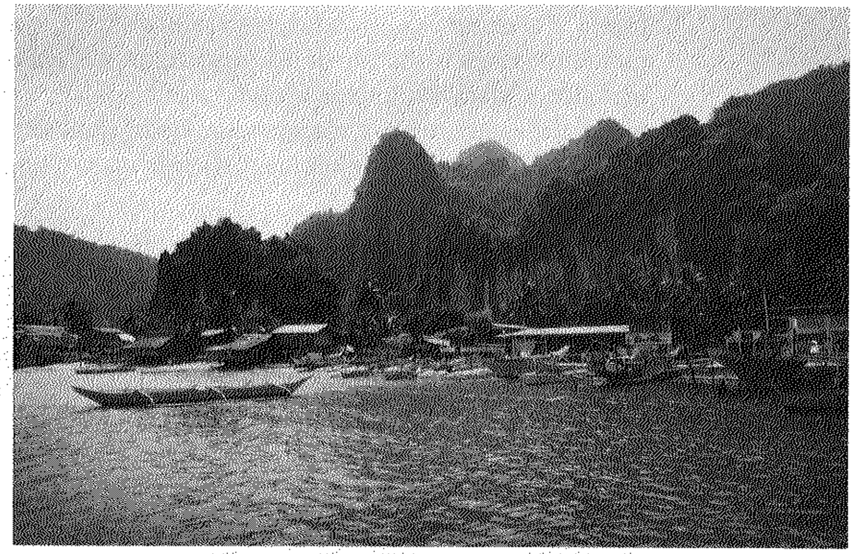

The Philippines lies at approximately 4°-22° N latitude and 112°-127° E longitude. These coordinates place it in the tropical Indo-West Pacific. It is bordered on the east by the Pacific Ocean and on the west by the South China Sea. The closest neighbors are Taiwan and the People's Republic of China to the north and northwest, respectively, Vietnam is directly to the west, and the islands of Indonesia are to the south and southwest. This region is considered to be the center of tropical marine biodiversity.

The Philippines is an archipelago consisting of some 7,000 islands, the major ones being Luzon in the north and Mindanao in the south. In between are strewn the islands of the Visayans, the largest of which are Samar, Leyte, Bohol, Cebu, Negros and Panay. Other important islands are Mindoro which is counted politically as part of Luzon, and Palawan, a long landmass that stretches along a northeast-southwest axis into the Sulu Sea. The total reefal area lining the Philippine coastline is estimated to be about 25,000 km², which is equivalent to almost 10% of the country's land area (Gomez et al. 1994).

DESCRIPTION OF THE REEFS

Most reefs of the country are fringing reefs of varying width and length. As such, they experience strong influences from the adjacent landmasses. A few reefs of the atoll type are found in the Sulu Sea.

The fringing reefs are characterized by a reef flat which may range from hundreds of meters to several kilometers wide. The reef flat is typically inhabited by a mixture of any of the following: seagrass communities, macroalgae, hard coral, soft coral, and various invertebrates. There are usually extensive patches of rubble and sand. After the reef flat is the typical reef crest which is the site of the most vigorous hard coral development, down to the upper reef slope. Many Philippine fringing reefs typically extend to depths of about 20 m, after which the sandy sea bed commences. Apart from terrestrial run-off, the most important physical influence on Philippine reefs is perhaps that generated by the reversing monsoon system.

More than 70 genera and 400 species of scleractinian corals have been recorded from the Philippines (Gomez et al. 1994). In addition, there are about a thousand associated species of fish. Because of exploitation that has assumed severe proportions due to the rapid growth of human populations dependent on reef resources, a number of species have become locally extinct. The most dramatic case is perhaps that of the giant clams (Tridacnidae). Many species of fish are also threatened.

Use of Coral Reef Resources

The fraction of the Philippine population inhabiting the coast shares a distinct characteristic with peoples of most other third world countries in that the dependence on coral reef resources is subsistence in nature. Coastal communities in the Philippines derive their main form of livelihood from exploitation of the sea. The primary value of coral reefs has been as a source of food. Organisms consumed are notably finfish, followed by molluscs and crustaceans, echinoderms, and macroalgae.

Harvest of reef organisms for food takes place mainly in the form of small artisanal fisheries. Fishermen use small outrigger boats to ply nearshore waters. Traditional fishing methods consist of nets, trawls or hook-and-line devices.

Another notable use of coral reef resources in the Philippines has been the extraction of sand, rock and even live coral for use as building material, such as for houses, port structures, or even roads. In the 1970s, international trade in hard corals for ornamental purposes flourished. Legal measures have since been adopted to halt this trend, although with varying degrees of success. Recently, a more conservation-conscious industry revolving around reef use has evolved in the form of ecotourism. This activity, however, is limited to the more affluent stratum of society or to foreign tourists who can afford the relatively expensive undertaking of hiring boats and diving on reefs, usually with SCUBA equipment.

The main economic benefit from coral reef resources derives from fishing. The estimated annual yield of various fishery products is estimated to range from 5 to 37 tons/km^2 (Alcala and Gomez 1985). Since the extraction of reef material for construction purposes is discouraged, this is not a significant source of revenue. Tourism is a growing industry, but it is still limited to major island destinations and tourist resorts, and the fraction of coastal populations that derive income from this activity is still low.

The social benefit from coral reefs derives from economic activities sustained by the existence of reef resources. Thus, the sea is a major arena for transportation, commerce and recreation. Coral reefs, however, provide a benefit also for their sheer aesthetic value which again underlies recreational activities of both locals and visitors.

Natural and Anthropogenic Disturbance to Coral Reefs

The Philippines lies within the influence of the reversing monsoon system (northeast during September to February, and southwest during June to September). The country is also situated within the typhoon belt, experiencing an average of 20 typhoons a year, which is more important in terms of physical impacts on reefs.

Typhoons probably constitute the most important natural disturbance to reefs occurring on a regular basis. Strong bottom surge generated by typhoon waves can inflict extensive physical damage manifested in the breakage of fragile colonies, the shifting of sessile organisms over great distances (after which they may or may not survive), and the smothering of the benthos by sediment. It should be understood, however, that the present profile of Philippine reefs is the net result of adaptation to regular typhoon stress over geologic time.

Other less frequent natural disturbances are represented by earthquakes and volcanic eruptions. Though these are relatively rare events, they exert massive effects when they do occur. Tectonic uplift or subsidence associated with earthquakes has caused reef areas to either be exposed or submerged in deeper water. For example, much of northern Luzon consists of limestone, indicating that fossil reefs constitute a significant portion of the present-day land area.

Volcanic eruptions, such as the violent episode involving Mt. Pinatubo in the Philippines in 1991, sent debris into coastal waters which smothered benthic organisms and disrupted fish associations. If large areas are covered, these represent new substrata for recolonization of benthic organisms, including corals and associated reef species.

Anthropogenic impacts on reefs may be considered more serious, with deleterious consequences over the longterm. Because significant qualitative and quantitative alterations to reefs are inflicted over relatively short time periods, reef organisms may not have developed mechanisms for adaptation or recovery (as is the case with some natural forms of disturbances). The most serious recent threat to Philippine reefs is that associated with severe land degradation (as in deforestation, poor agricultural practices) which releases large amounts of sediment into coastal waters. Many reefs throughout the Philippines show signs of smothering by fine sediment of terrestrial origin.

The next serious impact on reefs comes from destructive fishing practices. The use of explosives in fishing has spread in recent times throughout the Philippine archipelago. The application of poisons such as cyanide is also significant, although the extent of its use is more difficult to document than blast fishing.

In more localized areas, reefs are impacted by activities associated with coastal development such as the construction of ports, resort development, shipping, and related problems, such as the indiscriminate discharge of sewage into coastal waters.

PRESENT CONDITION

The status of Philippine reefs in recent years has been summarized by Gomez (1991; Table 1). The bulk of the data derives from a nationwide survey which commenced in the mid-

Table 1. Status of Philippine coral reefs based on surveys by three projects (Gomez 1991).

Source	No. of transects (stations)	Excellent (75-100%)		Good (50-74.9%)		Fair (25-49.9%)		Poor (0-24.9%)	
		No.	%	No.	%	No.	%	No.	%
Yap & Gomez (1985)	632	35	5.5	153	24.2	242	38.3	202	32.0
ASEAN-Australia project	103	4	3.9	32	31.1	46	44.7	21	20.4
ASEAN-US project	40	0	0.0	18	45.0	17	42.5	5	12.5

1970s and terminated in the early 1980s (Yap and Gomez 1985; Table 1). Subsequent surveys of Philippines reefs, though employing different techniques, were conducted in the late 1980s under the auspices of either one of two ASEAN (Association of Southeast Asian Nations) programs: the ASEAN-Australia "Living Coastal Resources" program (with funding from the Australian International Development Assistance Bureau), and the ASEAN-U.S. "Coastal Resources Management" project (with funding from the United States Agency for International Development). A discussion of the differences in techniques used in the earlier and later surveys, and implications regarding interpretation, are given in Gomez et al. (1994).

In Table 1, data on coral cover is summarized and reefs are classified according to their condition (Yap and Gomez 1985). Results from a total of 775 individual transects representing various stations throughout the country are reported. Of these, a range of 0-5% are considered to be in excellent condition, 24-45% appear to be in good condition, 38-44% are in fair condition, and 12-32% are in poor condition. The percentages quoted do not add up to 100% because the results are from three independent survey projects. The majority of Philippine reefs are seen to be in fair to good condition, although this breakdown does not distinguish causal factors (eg., no distinction is made between natural and anthropogenic disturbance).

In Gomez et al. (1994), an attempt was made to analyze in a semi-quantitative manner the contributions of various impacts, both natural and anthropogenic, to the condition of selected reefs in the country. Causes of disturbance, on the basis of visual observation, were listed and each arbitrarily assigned a rank to denote its relative importance on each reef (only a subset of the reefs in Table 1 were used for the analysis). These ranks were then correlated with values of hard coral, dead coral and total live coral for each reef; the correlation analysis was performed on the pooled data set.

Gomez et al. (1994) did not include smothering by silt or sediment in the analysis of impact on reefs. Barring this omission, their list of natural and anthropogenic impacts provides a fairly good indication of the type of disturbances typically afflicting Philippine reefs. Because the ranks assigned could not provide relative weights or importance of the different factors among different reefs (but merely an ordering of the impacts according to relative importance within the same reef), some of the results of the correlation analysis turned out counter-intuitive, such as significant negative correlation between the amount of live coral cover and the level of management effort!

Nevertheless, the results provide some worthwhile indications, and point to directions for further research, particularly for well-planned ecological experiments to test the hypotheses posed by the results of the correlation analysis.

In terms of natural impacts on reefs, the analysis points out the following as the most significant:

1. impacts of strong waves
2. algal overgrowth and presence of large seaweeds
3. population abundance of invertebrate grazers

The above ranking is not necessarily in relative order of importance, because this changes from one locality to another. Note that algal overgrowth could be a consequence of human impact, specifically, eutrophication due to increased levels of nutrient inputs, or lack of grazing by herbivorous fishes.

The most significant anthropogenic impacts highlighted by the same analysis are:

1. intensity of fishing (based on numbers of fisherman)
2. mariculture
3. dredging
4. mining of coral and sand

Again, these factors are not ranked in order of relative importance as their effects vary in degree among different reefs. Curiously, blast fishing did not merit a high score in the correlation analysis, even though observations of blast fishing show this to be widespread. One reason for blast fishing not being more evident in the analysis could be that its effects are not immediately apparent. A few days after the occurrence of a blast, visual evidence of the impact is diminished by shifting of coral rubble and overgrowth by algae.

SCIENTIFIC IMPORTANCE AND RESEARCH

Until the early 1970s, research on coral reefs concentrated mainly on the taxonomy of scleractinian corals, as exemplified by the work of Francisco Nemenzo, Sr. In the mid-70s, the first nationwide coral reef surveys were launched by the Marine Science Institute (then known as the Marine Sciences Center) with financial support from the Ministry of Natural Resources. These surveys continued throughout the 1980s, as described in the preceding section.

The surveys yielded broad descriptions of the composition and distribution of coral reef organisms, with emphasis on the sessile components, as well as observations of impacts and their probable causes (see preceding section). In addition, work was initiated in the early 1980s on the growth and transplantation of scleractinian corals, with a view to utilize the results of research in possible schemes to rehabilitate damaged reefs. Such studies were conducted by both the Marine Science Institute and the Marine Laboratory of Silliman University in Dumaguete City, Negros Oriental.

Also in the early 1980s, investigations were begun on the recruitment of coral and other reef organisms. Recruitment studies have continued up to the present time. These have been accompanied by studies on the basic biology of scleractinian corals, such as reproduction and metabolism (in addition to growth). More recently, studies on primary production and respiration have been extended to other reef components in the effort to understand broad spatial and temporal patterns of energy dynamics.

Much of the current work is centered around the main island of Luzon and its southern flank, notably Puerto Galera on the island of Mindoro. The bulk of the research is conducted around the reefs of Bolinao in Pangasinan (northwestern Luzon) where the Bolinao Marine Laboratory of the Marine Science Institute is situated.

Research efforts are proceeding along the following lines:

1. Understanding the dynamics of ecosystem recovery and recruitment, with a view toward improving efforts to protect and rehabilitate reefs;
2. Understanding what constitutes reef ecosystem "health," including developing objective and quantifiable indices to measure and monitor reef health.

These research areas fit well with priorities elsewhere in the world regarding the response of reefs to longterm global change, and the need to protect marine biodiversity.

Financial support available for coral reef research from local sources, including the national government and the university, ranges from inadequate to almost nonexistent. The level of expertise and knowledge achieved to date are largely due to a vigorous infusion of funding from international sources. In order that the Philippines maintain its momentum in the coral reef research, national support should be strengthened in the longterm.

MANAGEMENT

Perhaps the most notable example of success in coral reef management is that achieved by the Marine Laboratory of Silliman University with the institution of the Sumilon Island marine reserve in the central Philippines (Alcala and Russ 1990). Protection of a portion of the reef surrounding the island was brought about through action of the local community with guidance from university personnel. Fish catch in the adjacent open-access areas was observed to increase significantly, possibly a result of out-migration of fish from protected areas.

Elsewhere in the country, laws governing the management of marine reserves are not enforced. Numerous problems abound. For example, in the "Hundred Islands National Park" (declared in 1940) in Pangasinan in northwestern Luzon, which is a famous tourist attraction, rampant blast fishing occurs, as well as indiscriminate collection of reef organisms, mostly for the tourist trade. Many of the reefs are also silted over due to sediment runoff resulting from poorly planned construction and development on the islands.

An attempt is currently underway to replicate the Sumilon Island success story in Bolinao through a collaborative project on "Community-Based Coastal Resources Management" funded by the International Development Research Centre of Canada (IDRC). It is being implemented by the Marine Science Institute, the College of Social Work and Community Development (both units of the University of the Philippines), and the Haribon Foundation, a non-governmental environmental organization. Project personnel have undertaken an environmental awareness campaign, which is an attempt at the village level to initiate legislative action to protect certain reef areas as marine reserves.

Perhaps the greatest obstacle to marine environmental protection in the Philippines is still a lack of appreciation of the need for environmental conservation, from the highest levels of government to certain elements of the public and private sectors. This, despite all the publicity surrounding the Earth Summit and the resulting Chapter 17 of Agenda 21, to which the Philippines government was signatory.

In Bolinao, marine scientists are waging an environmental battle against a cement plant complex that is proposed to be constructed only 300 m from the Institute's Bolinao Marine Laboratory, and on the shores of the only extensive reef complex in the entire Lingayen Gulf. The proposed cement plant complex is planned to be among the largest in Asia. The proponents are a Taiwanese-Japanese consortium, and most of the cement production is intended to feed the construction needs of a "fantasy city" to be built by Taiwanese financial interests on the island of Fuga in the northern Philippines.

Another example of environmental havoc is on the island province of Marinduque, where the main river system was recently swamped by tons of toxic mine tailings from the Marcopper mining complex. Marcopper is a Canadian firm which has been operating for decades without close environmental monitoring. The surrounding marine habitat has been obliterated to a distance of several kilometers from the shore.

In the coral reef literature, much concern has been voiced about environmental damage caused from human activity such as blast fishing, poor land management practices, dredging and over-exploitation of living resources. Much of the blame has been placed on coastal subsistence communities. However, the two recent examples cited above highlight new sources of concern: a lack of awareness or concern on the part of the national government, and inadvertent or deliberate failure to act to protect the environment in cases where large business interests place profit above all considerations of environmental conservation.

These are critical issues prevalent not only in the Philippines but also in other third world developing countries. An important step in the struggle to save the world's coral reefs is recognition by the international community of such problems, and decisive action to address them.

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TAIWAN

ASSESSMENT OF THE PRESENT HEALTH OF CORAL REEFS IN TAIWAN

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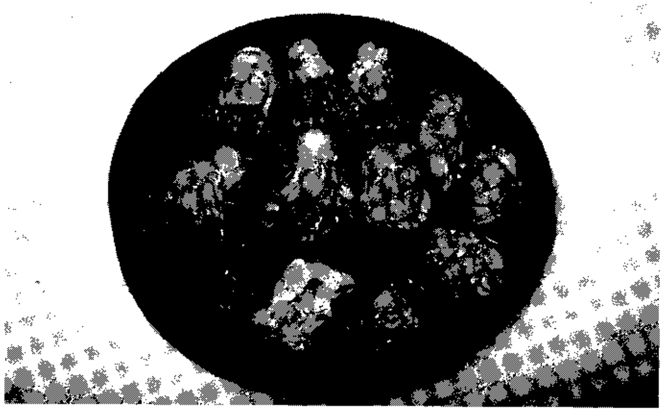
Taiwan is located on the edge of the Asian continental shelf. Tectonically, Taiwan is situated in a continental-arc collision zone between the Asian Plate and the Philippine Sea Plate. The neotectonics of the island during the Holocene has been evident by its substantial uplift. To the east, the submarine topography drops steeply from 4,000 m. In contrast, the west coast is characterized by a gentle sloping topography. The north and northeast coasts are mainly sandstone rocky shores. The south coast of the island is surrounded by emergent fringing reefs.

Oceanographic conditions of Taiwan are greatly influenced by the Kuroshio and the seasonal monsoon. During the summer, the winds are gentle and from the southwest (monsoon). Also the Kuroshio is strong, bringing warm water and calm weather. During the winter, the northeast monsoon winds dominate, creating cool water temperature and rough seas. Typhoons hit the island during June and October every year, sometimes causing severe damage to coral reefs.



Corals are found in all the water around Taiwan except in the sandy area on the west coast. The main reef area is around the southern tip of the island, the Hengchun Peninsula where well-developed fringing reefs are found (Jones et al. 1972; Dai 1991a). These reefs are characterized by diverse and abundant scleractinians and alcyonaceans. Scleractinians dominate most of the area except on the two tips (Mao-bi-tou and O-luan-pi) where the current is relatively strong and alcyonaceans are the dominant. Coral reefs in southern Taiwan extend generally to 20 and 30 m. There are no extensive reefs found below 40 m where the majority of substratum is covered by sand (Dai et al. 1992). The depth limit of reef-building corals in southern Taiwan is between 70 and 80 m (Dai et al. 1992).

The north, northeast and east rocky coasts have flourishing or patchy coral communities but reef development is generally absent (Yang and Dai 1982; Randall and Cheng 1977, 1979). These coral communities are dominated by scleractinians (Figure 1).

Coral reefs and coral communities are also well developed around offshore islands including Lu-tao (Green Island), Lan-yu (Orchid Island), Hsiao-liu-chiu and Peng-hu (Pescadores). Lu-tao and Lan-yu, located southeast off Taiwan, are situated in the pathway of the warm Kuroshio current. These reefs are densely covered by abundant scleractinians and alcyonaceans (Chang et al. 1991); alcyonaceans (mainly Xeniidae) dominate the west and southwest coast while scleractinians dominate the north and east coast. Hsiao-liu-chiu, to the southwest, is an emergent reef island. The coral fauna of this island is dominated by stony corals (Yang et al. 1975). The Peng-hu Islands are a cluster of 64 islands located about 50 km west of Taiwan in the Taiwan Strait. Coral communities are dominated by stony corals which are widely distributed in the shallow subtidal areas of these islands (Chang et al. 1992, 1993). Tung-sha (Pratas) Island and Nan-sha (Spratly) Islands are typical tropical atolls to the south of Taiwan in the South China Sea. These reefs are densely inhabited by scleractinians and alcyonaceans (Dai et al. 1995; Dai and Fan 1996).

Species diversity of reef organisms on the coral reefs around Taiwan is relatively high. Approximately 300 species of scleractinian corals, 50 species of alcyonaceans, 20 species of gorgonians, 130 species of decapods, 90 species of echinoderms, 1,200 species of reef fishes and 150 species of algae have been recorded from coral reefs in southern Taiwan, Lutao and Lanyu. About 200 species of scleractinian corals and 1,000 species of fishes have been reported from Hsiao-liu-chiu and Penghu Islands. About 120 species of scleractinian corals and 800 species of fishes have been reported from the coastal areas in the north and northeast.

A total of 101 species of scleractinians in 34 genera, 28 species of alcyonaceans in four genera, three species of gorgonaceans and three species of hydrocorals were recorded from Tung-sha Island. Scleractinians dominate most coral communities at Tung-sha Island where *Acropora* and *Porites* are the most abundant and widely distributed genera. Distributions of alcyonaceans are relatively limited; they are found on the outer edge of the reef flat on the west and northwest sides of the island. Coral communities on the reef flat and seaward slope on the west and northwest sides of the island are highly developed for which high species diversity and coral cover of both scleractinians and alcyonaceans are found. Well developed coral communities also occur in the lagoon on the north side of the island in which many large *Acropora* and *Porites* colonies are found. Coral communities on the reef flat around the island are poorly developed possibly due to the influence of shallow water, high ultraviolet irradiation and drifting sand. The coexistence of corals and seagrasses in these areas constitutes a peculiar biological community.

A total of 163 species of scleractinians in 15 families and 56 genera, 15 species of alcyonaceans in three families and five genera, and six species of gorgonaceans in four families and five genera have been recorded from Taiping Island (Itu Aba Island) in the Spratlys of the South China Sea. The coral communities of Taiping Island are dominated by scleractinian corals with high species diversity and coral cover found on reef flats at depths between 1 and 3 m. Alcyonaceans and gorgonaceans are mainly distributed on the reef slopes at depths below 15 m. Wide reef flats and reef terraces exist on the east and west sides of the island indicating that reef development is better in these areas. Species diversity of coral communities is highest on the east side and lowest on the west side of the island. Dead coral skeletons and debris are widely spread on the reefs below 3 m deep and only small colonies are found. These observations indicate that coral communities of Taiping Island may have

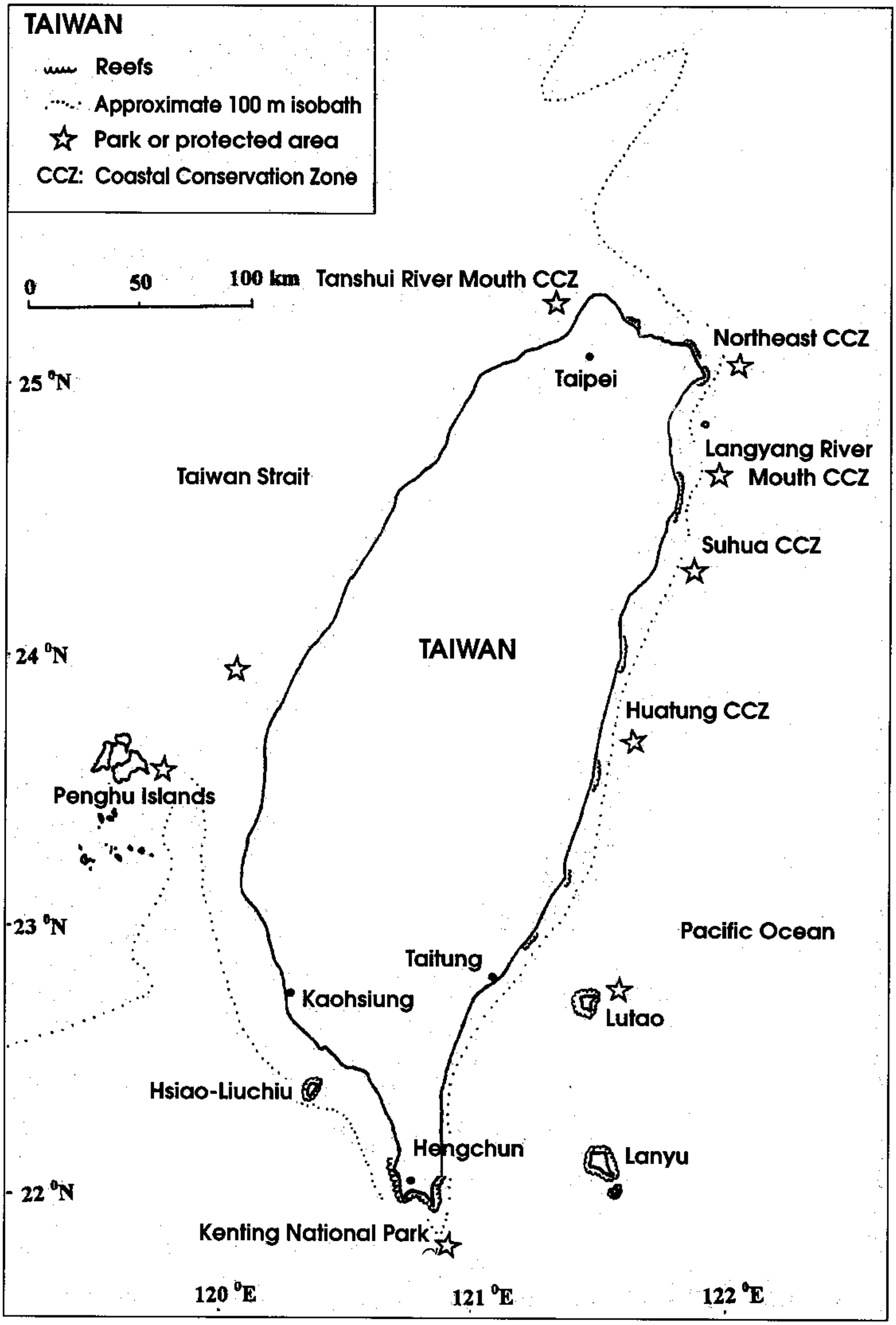


Figure 1. Map of Taiwan showing the distribution of reefs, parks and protected areas.

been heavily damaged by natural catastrophes or artificial destruction during the last decade. Possible sources of disturbance include typhoons and warming events.

Coral reefs in Taiwan are important for both fisheries and tourism (Table 1). Fish and invertebrates collected from waters adjacent to the reefs comprise a considerable portion of the total catch of nearshore fisheries. Most coral reefs are within National Parks or National Scenic Areas. These include the Kenting National Park in the south, the Northeast Coast National Scenic Area, the East Coast National Scenic Area, Penghu National Scenic Area, and the Lanyu National Park. These areas are major attractions for tourists and are popular for recreational fishing. Various marine recreational activities, such as SCUBA diving, snorkeling, glass bottom boat trips and recreational fishing, depend on coral reefs. Many local people rely on coral reefs for their subsistence.

PRESENT CONDITION OF CORAL REEFS IN TAIWAN

Coral reefs in Taiwan have suffered increasing threats during the past decade (Table 2). Tourist abuse, sedimentation from construction and dredging, explosive fishing, spearfishing, aquarium fish collection, coral collection, and various types of pollution are the most serious sources of impact to many reef systems.

In the last 10 years, coral reefs in southern Taiwan experienced several anthropogenic and natural disturbances of various magnitudes and significant changes in species composition, diversity and total coral cover have been observed. Thermal effluent from a nuclear power plant in Nanwan Bay caused coral bleaching on a local scale in 1987-90. Subsequent change in coral community structure included the disappearance from the shallow water of some pocilloporids. Seasonal blooms of the green alga *Codium* spp., possibly related to sewage pollution, occurred during spring months and induced injury to coral tissues. Increasing sedimentation from terrestrial runoff also caused severe damage to corals during the period 1989-95. Foliaceous corals were the most vulnerable species to both algal blooms and sedimentation. Typhoon disturbances during summer and autumn months also cause high coral mortality over large areas and branching corals are the most vulnerable species. In general, living coral cover has been reduced from approximately 50% to 30%. Some species of reef fishes, gastropods and crustaceans have become locally extinct.

Coral communities in northern and northeastern Taiwan have experienced heavy sewage pollution, sedimentation, aquarium fish collection and tourist abuse. Coral communities have been severely degraded and almost none are now pristine.

Coral reefs in Penghu have been heavily damaged by explosive fishing, ground trawling and sedimentation.

Coral reefs on the eastern coast of Taiwan have suffered increasing tourism and sedimentation related pollution. The reefs in two islets, Lu-tao and Lan-yu, are under heavy pressure of increasing tourist abuse and sedimentation. Although living coral cover of these islets remains high (>50%) at most localities, reef fish populations are very low due to intense aquarium fish collection and spearfishing.

Table 1. Status of Taiwanese coral reefs.

Locality	No. of site	Excellent	Good	Fair	Poor
North Taiwan	11	0	0	4	7
East Taiwan	12	0	3	1	8
South Taiwan	13	2	3	5	3
Penghu Is.	42	0	3	8	31
Lutao	6	2	3	1	0
Lanyu	5	2	2	1	0
Hsiao-Liuchiu	9	0	0	6	3
Tungsha I.	8	2	1	2	3
Taiping I.	7	0	3	2	2
Totals	113	8 (7%)	18 (16%)	30 (27%)	57 (50%)

Excellent = living coral cover 75-100%
Good = living coral cover 50-75%
Fair = living coral cover 25-50%
Poor = living coral cover 0-25%

*Source of data: From various marine biological surveys conducted by three groups of scientists at different localities in 1992-95.

Table 2. Environmental stress on Taiwanese coral reefs.

Locality	Explosive fishing	Aquarium fish collection	Sedimentation	Sewage pollution	Thermal pollution	Tourist
North Taiwan	+	++	+++	+++	+	+++
East Taiwan	+	++	+	—	—	++
South Taiwan	++	+++	+++	++	+	+++
Penghu Is.	+++	++	++	+	—	++
Lutao	+++	+++	+	—	—	+++
Lanyu	+++	++	+	—	—	+++
Hsiao-Liuchiu	+++	++	+++	++	—	++
Tungsha I.	++	—	—	—	—	—
Taiping I.	+++	—	—	—		—

+, ++, +++: indicate relative intensity of environmental stress.
—: no environmental stress has been observed

SCIENTIFIC IMPORTANCE AND RESEARCH

Taiwan borders the region of the west Pacific Ocean with highest coral diversity, which lies between the Philippines and eastern Australia. Because of its central position in the western Pacific and the influence of the Kuroshio current, Taiwan might be expected to serve as a "stepping stone" in the northward and eastward dispersal of reef organisms. Hence, studies of Taiwanese reefs is of scientific importance to develop a better understanding of the biogeography and evolution of reef organisms in the Pacific.

Taiwanese reefs have been studied by Yabe and Sugiyama (1941), Kawaguti (1942, 1943, 1953), Utinomi (1959), Jones et al. (1972), Randall and Cheng (1977, 1979), Yang et al. (1976, 1977, 1982), Yang and Dai (1982), and Dai (1988, 1991a, 1991b, 1993). Kawaguti (1953) listed 87 species and 35 genera from southern Taiwan. Jones et al. (1972) listed 52 genera and 173 species from the reefs of southern Taiwan. Subsequent investigations by Yang et al. (1976, 1977, 1982) increased the number to 245 species and 59 genera. Dai (1991a) re-examined the previous coral collections and provided a list of 230 species representing 58 genera of scleractinian corals, 9 species of non-scleractinian reef building corals, and 40 species of alcyonacean corals.

Marine biological communities have been surveyed in several areas pertaining to the establishment of National Parks or National Scenic Zones (Chang 1983; Chang et al. 1989, 1991, 1992, 1993; Chang and Jeng 1990).

Research on the basic biology and ecology of corals in Taiwan is sponsored by the National Science Council, the National Park Authority of the Ministry of Interior, and the Bureau of Tourism of Ministry of Communication. Research is mainly carried out by scientists at National Taiwan University, National Sun Yat-Sen University, and National Taiwan Ocean University.

MANAGEMENT

The National Park Law provides for the establishment of national parks. The coastal areas of the Kenting National Park are zoned into Ecological Protection Zones, Special Scenic Zones, General Use Zones and Control Zones. Only scientific activity is allowed in the Ecological Protection Zones and Special Scenic Zones. Limited activities are permitted in the Control Zones but no living resources are allowed to be removed. Most human activities, at levels that are ecologically sustainable, are permitted in the General Use Zones. Park management plans are to be revised every five years and the National Park Department within the Construction and Planning Administration of the Ministry of Interior is responsible for their administration.

Coastal resources are protected under the Coastal Area Environment Protection Plan which is administered by the National Park Department. Under the plan, seven coastal conservation zones (CCZ) have been established:

North-east Coast CCZ
Lang-Yang River Mouth CCZ
Su-Hua CCZ
Hua-Tung CCZ
Kenting National Park
Chan-Yun-Chia CCZ
Tan-Shui River Mouth CCZ

Except for the last two, which lie on the sandy west coast, all of the coastal conservation zones include reefs. They are managed by the Ministry of the Interior and Government of Taiwan Province. Activities permitted depend on the type of zone. In addition, 25 Fishery Conservation Areas have been established which include three on the north coast, 11 on the east coast, one at Lutao, one at Hsiaoliuchiu, one bordering the Kenting National Park, two at Penghu Islands, and six on the west coast. Nineteen include or are adjacent to coral reefs. These areas are managed in the same way as CCZ, but commercial fishing is strictly prohibited as their aim is to protect nursery areas. Within the conservation areas, environmental impact assessments are required before approval of any development project.

Efforts must be enhanced to survey coral reefs to provide information on their ecological and management status. The essential step for conservation and sustainable use of coral reefs is to understand natural and anthropogenic impacts. The present anthropogenic threats to reefs should be eliminated or mitigated. This involves confronting the underlying problems of ever-expanding tourism in coastal areas, unsustainable exploitation and the increasing discharge of contaminants into the environment. More immediate attention should be focused on obtaining an increased understanding of reef ecosystems and developing improved concepts which constitute protection and management. This includes resource management, environmental education and training, employment of simple survey and monitoring techniques and participation by stakeholders who actually use the resources of the coastal zone.

Currently, longterm monitoring projects on the ecology and dynamics of coral communities are being sponsored by the Kenting National Park and the Northeast Coast National Scenic Area Administration. Several research projects on the basic ecology and physio-biochemistry of corals, as well as other reef organisms, are being sponsored by the National Science Council. Education and training programs are being promoted by the Kenting National Park Headquarters and the National Museum of Marine Biology.

It is also recommended that at least part of the reef area in Penghu should be closed to allow recovery of the reef; dredging in the vicinity of the reefs should be banned; size restrictions should be introduced for commercial fish species; and an awareness program should be introduced as a high priority. Future work in the area should carefully document the distribution and composition of the reefs.

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THAILAND

STATUS OF CORAL REEFS IN THAILAND

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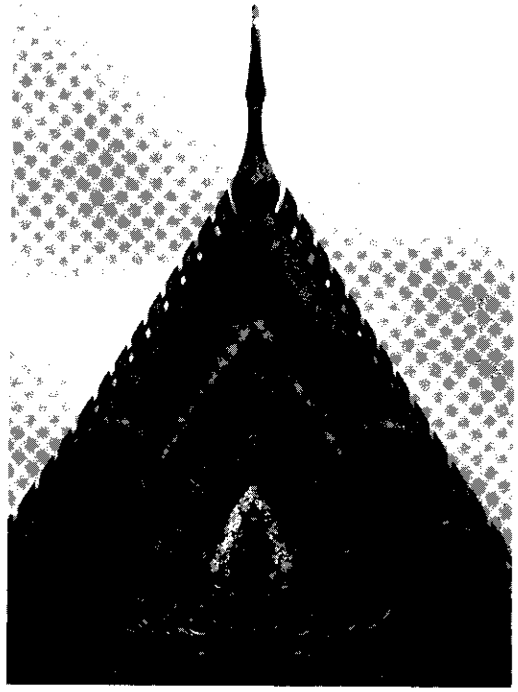
Thailand's coastal waters, located between 6°N and 13°N, offer good conditions for coral reef growth. The total coastline of the country is almost 2,600 kilometers. There are over 300 major reef groups in Thailand, covering an estimated area of 12,000 square kilometers (Figure 1). They could be divided into four distinct areas with different oceanographic conditions, that is, the inner part of the gulf of Thailand (Chonburi), the east coast of the gulf of Thailand (Rayong and Trad), the west coast of the gulf of Thailand (Prachuap Kirikhan, Chumporn and Surathani) and along the coastline on the Andaman Sea (Ranong, Phuket, Pang-Nga, Krabi, Trang and Satun).

Since 1984, Thailand has participated in the Living Coastal Resource (LCR) Project under the ASEAN-Australia Economic Cooperative Programme on Marine Science. Data gathered from the LCR project has enabled us to



describe the present condition of coral reefs in Thailand.

The majority of coral reefs in Thailand are either fringing reefs or coral communities growing on substrata other than limestone, such as boulders and granite. Sudara et al. (1991) described three types of coral communities in the Gulf of Thailand (i.e., coral communities, developing fringing reefs and young fringing reefs).

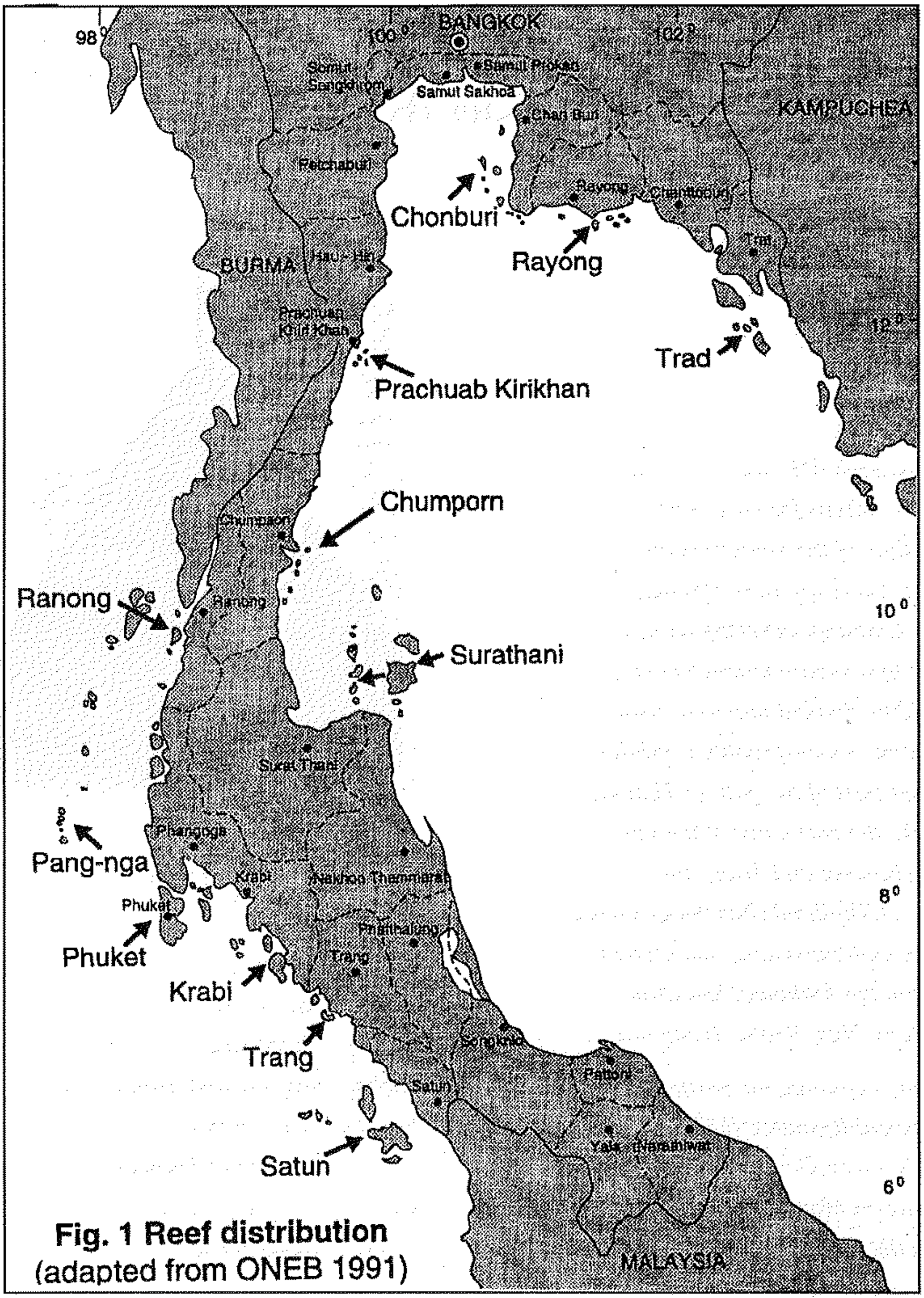


Fig. 1 Reef distribution
(adapted from ONEB 1991)

Figure 1. The distribution of the four major coral reef areas in Thailand. The inner part of the gulf near Bangkok has reefs only in Chonburi Province. The east coastline has reefs from Rayong Province to the Cambodian border. The west coastline area stretches south of Bangkok to the Malaysian border. The Andaman Sea contains reefs between the Burmese and Malaysian borders.

GULF OF THAILAND

The Inner Gulf

Since there are four major rivers which open into the inner part of the Gulf of Thailand, most of the coastal areas of the inner part of the gulf are dominated by mangroves. Several islands in the inner part of the gulf have scleractinian corals. The most inner island, Koh Sichang, has most interesting growth of coral. It is in the form of coral community rather than a reef formation. It may be that the terrestrial environment is always extending seaward. Sediment is considered an important factor, among others, that inhibits the growth, or in extreme situations, causes the death, of corals. Various activities of man in coastal areas result in heavy sedimention. The dominant species of coral is the massive form of *Porites lutea*. Sudara et al. (1991) reported that growth rate of *Porites lutea* around Khang Khao Island of Koh Sichang is correlated significantly with the amount of suspended solids.

It is interesting to recognize that among the coral communities in the inner part of the gulf, the long spine black sea urchin, *Diadema setosum*, is found in high numbers. The high abundance of the sea urchins may have caused a lack of seaweeds among the corals. It should be noted that coralline algae, an important component for coral reef development, is rare in this area.

Further down the eastern part of the inner gulf, there are islands along the west coast. After Koh Sichang there is the Pattaya group which consists of several islands. The coral communities on these islands have been damaged by over-use from tourism. Islands closer to shore are most impacted. The dominant species in this area are *Pavona* sp. and *Porites lutea*.

South of Pattaya, the area of Sattaheep is restricted by the Navy. The coral communities are in very good condition. On many islands within this area, corals are in perfect condition because the Navy patrols the islands for a turtle conservation project that has been going on for many years.

Farther south, water movement is directed toward the western part of the inner gulf. Along the coast in this section there are mangrove forests. No islands exist in this area of the inner gulf.

The East Coast of the Gulf

This is Rayong Province in the open gulf where many islands exist. At one time, all of these islands had very good coral growth but due to illegal dynamite fishing and increasing tourism, the coral reefs of many islands are now in a poor condition. Some totally lack live coral coverage; for example, Ao Praw and Koh Samet.

Farther along the east coast to Chantabury most of the coastline is mangrove. However, fringing reefs are found along the shore where there is no river runoff and on a few small islands.

From Rayong to Trat, there are many islands with coral reefs. Until recently the coral reefs in this area were in very good condition. Recent destruction has been caused by illegal dynamite fishing. Also, aquarium fish collection and live fish catch for consumption by using toxic chemicals are major causes of degradation. Within the last few years, certain coral reefs, such as Koh Kradad are now totally destroyed.

The West Coast of the Gulf

Coral reefs in the Gulf of Thailand are exposed to cyclonic storms. Approximately 20% of Thailand's major coral reef groups occur at shallow depths in the western Gulf of Thailand. Chumporm and Suratani are the only two provinces in this area with major reef groups.

From Prachuap Kirikhan Province in the north, a few islands exist with newly formed fringing reefs. Because these islands have bird sanctuaries, access is prevented. The coral reefs are also protected. The branching form of *Acropora* spp. is the dominant form.

At Chumporn, coral reefs are best developed on the eastside of islands. Fresh water and sediment from land inhibit reef growth on the west side of these islands. Some coral damage exists from illegal fishing activities. Conservation activities include the use of mooring bouys for boats.

Farther south to Surathani on Samui, Pha-Ngan and Tao, coral coverage is undergoing severe degradation due to tourism. Conservation activities are now beginning, including the use of mooring bouys and public campaigns. Sundra et al. (1991) have proposed a management plan for the coral reefs in this region. Based on the data of reef condition, present uses of the reefs and existing regulations, the coral reefs are classified into three categories: preservation area, common use or conservation area, and private development area.

The Andaman Sea

There are significant climatic and oceanographic differences between the Andaman Sea and the Gulf of Thailand which affect coral reefs. Coral reefs in the Andaman Sea are subject to semidiurnal tides and are exposed to predominant Southwest monsoons from May to October. Approximately 55% of Thailand's major coral reefs occur in the Andaman Sea. Within this region, there are significant differences in coral reef species composition and morphology. Reef conditions and coral coverage tend to vary with the degree of exposure to the monsoon, distance from the mainland, current and substrata. Fringing reefs predominate. The coral reefs in the Adang-Rawi group are a classic example. There are also some coral communities where corals grow on rocky shores and vertical granite walls. There is no substantial limestone reef development. This is the case for the Similan Islands and the Mu Ko Phi Phi group. The Surin Islands group (i.e., Pachumpba and Stok Islands) are considered to be the most extensive, pristine and perhaps best developed reefs in Thailand. Other coral reefs of major ecological significance in the Andaman Sea include Ko Kradan and Ko Ngai in Trang Province; and Ko Damhok, Damkwan, and Yong in Krabi Province. From the northern part, Surin and Similan Islands, which are now Marine National Parks, are becoming very famous spots for tourists and divers. Even though these islands can not be visited all year round due to heavy seas from the monsoon, their degradation is evident. Many shallow water reefs have been damaged from tourist activity. Growth of algae is also increasing. Conservation activities are now underway including the installation of mooring bouys and formulation of management plans for the parks.

Phuket once had good fringing reefs. However, now many coral reefs exist with only a small percentage of living coral cover. Tourism development seems to be the major factor causing the deterioration of coral reefs in this province.

Beautiful islands in Phuket, Pang-Nga, Kravi, Trang and Satun are now caught between the struggle of conservation and rapid tourism development. Many coral reefs are now in very bad condition. Some developers do have a conservation ethic and are trying to protect the coral reefs. However, many others still exploit their coral reefs resulting in rapid degradation.

USES OF CORAL REEFS

The coral reefs in Thailand waters support a variety of activities that can be classified as tourism and recreation; fisheries-related uses; and other uses, including research and education. In the last decade, there has been a marked change in reef use patterns, as small-scale or traditional fisheries have gradually been replaced by tourism activities. Local fishermen have converted their boats into tour boats and paid more attention to shell collections for souvenir trade. This shift in coral reef use is most notable in Trad, Surathani, Pang-Nga and Trang.

Tourism and recreation uses include diving, underwater photography, sightseeing from glass-bottom vessels and sport fishing. Coral reefs close to beach resorts are often used intensively for tourism-related activities. Provinces where tourism and recreation are the most important reef use include Chonburi, Rayong, Phuket and Krabi. Approximately half of all coral reefs located in Surathani and Pang-Nga are also used primarily for tourism-related activities. Coral reefs in several localities have received heavy tourism uses such as Pattaya, Ko Samet, Ko Samui, Patong and Ko Hae. Several coastal provinces, such as Trad, Surathani, Pang-Nga, Phuket and Kravi, are experiencing a rapid and steady growth in tourism, with dramatic increases in coral reef-dependent recreational activities.

Most coral reefs in Thailand are used for fisheries. Coral reefs located in rural areas are used for small-scale fisheries, and shell and ornamental fish collection. In such locations, coral reef fisheries and products are important sources of income and food. Trad, Chumporn, Ranong, Trang and Satun are all provinces where fisheries activities continue to be the dominant coral reef use. Coral reefs also support the fisheries sector by functioning as recruitment and nursery areas for stocks important to offshore fisheries.

Coral reefs in Thai waters are being more frequently used for education programs, especially in Marine National Parks and for Marine Science Institutes. Several Thai universities, including Chulalongkorn, Kasetsart, Burapa and Prince of Songkla, have on-going research programs at selected coral reefs.

Coral Reef Condition

The condition of coral reefs in Thailand ranges from very good to very poor (Figure 2). Over 60% of all major coral reef groups in Thai waters are either in poor or fair condition. Less than 36% are in good or very good condition. The wide spread degradation of coral reefs in Thailand is a recent event associated with the use of explosives and the introduction of bottom-trawlers in the early 1960s, and the expansion of beach resorts in the late 1970s. The provinces that still have significant areas of coral reef in good and very good condition are Trad, Pang-Hga and Trang. The provinces where coral reef deterioration is most severe due to human-related activities are Chonburi, Rayong, Surathani, Phuket and Satun.

The dominant cause of coral reef degradation is shifting in many locations. Coral reef blasting is reported to on the decline in several provinces but coral damage associated with trawling is on the increase (Sudara & Patimanukasem 1991). Sedimentation and wastewater pollution associated with rapid coastal development are recent and increasing problems in many provinces even along remote islands (Sudara et al. 1992).

Besides the impacts related to human activities, coral reefs are exposed to many natural events that bring about significant change in their structure and species composition. The major natural causes of coral reef damage are storms and monsoons which uproot and break coral branches. Sudara et al. (1992b) reported that typhoon Gay hit Southern Thailand in

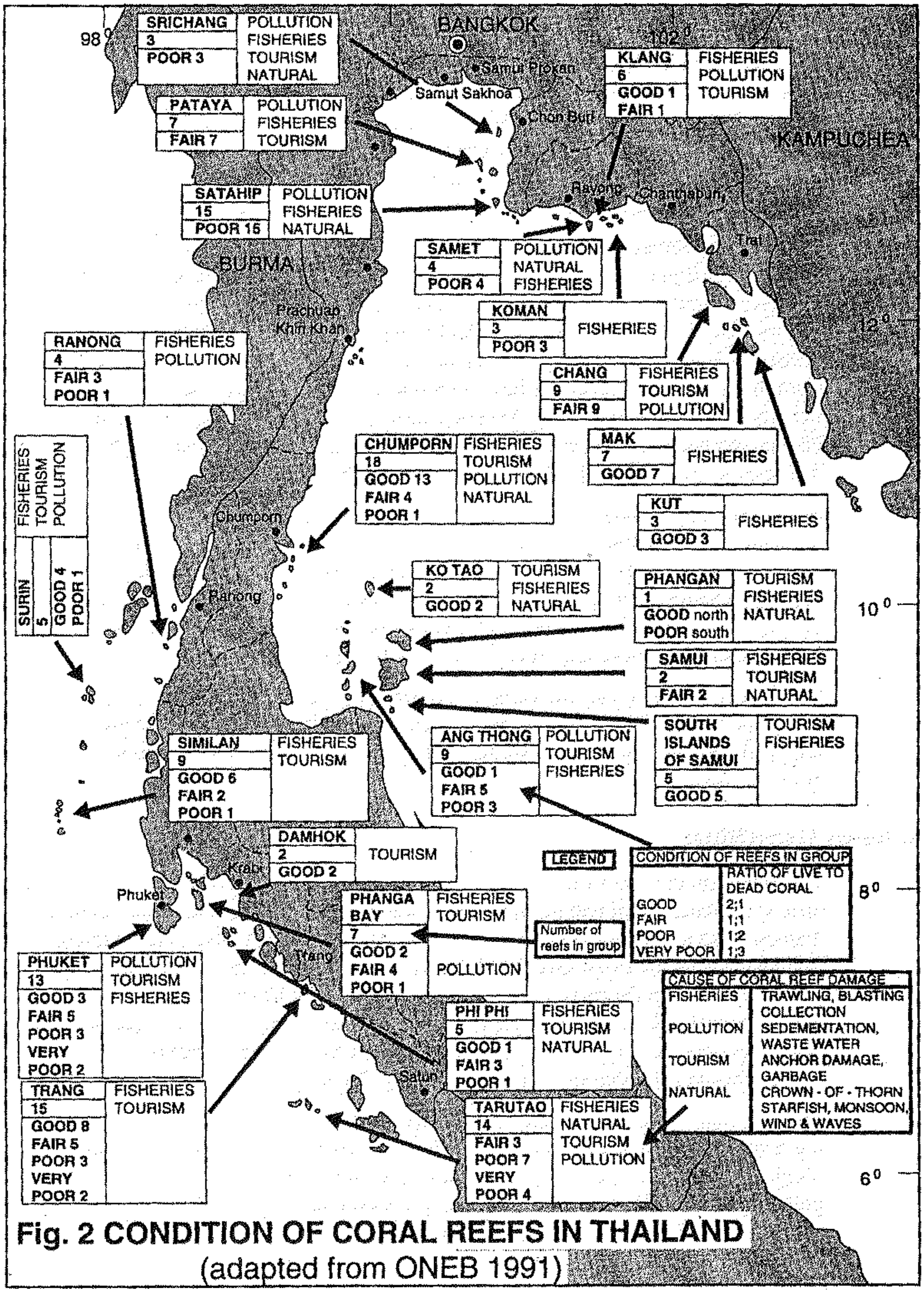


Figure 2. The condition of reefs in Thailand. The status of the 24 reef groups has been classified with the number of reefs divided into four categories: good, fair, poor and very poor. The major impacts are also included in the boxes.

November 1989 and caused significant damage to the terrestrial environment as well as coral reefs.

The crown-of-thorns starfish, *Acanthaster planci*, feed on live coral and can destroy large areas of the reef. Localized outbreaks of *Acanthaster planci* have been reported in the Gulf of Thailand and there has been a significant increase in outbreaks in the Andaman Sea since 1982. Extreme low tides and coral bleaching are additional natural phenomena which cause severe damage to coral reefs in Thailand.

Recovery of Coral Reefs

Aside from discriminating the stresses on the coral reefs, research on rate of recovery, growth, reproduction and recruitment of various populations of coral reefs have been very important in providing more insight into coral reef ecology. Growth rates of corals in the Gulf of Thailand have been well documented (Sudara et al. 1991). Species composition and recruitment of corals have also been investigated with settling plate experiments and field observations (Yeemin et al. 1992; Sudara et al. 1994). The most abundant juvenile corals are Acroporidae and Pocilloporidae. Sedimentation and the prevailing hydrological conditions seem to be major determinants of coral recruitment patterns. Differences in coral recruitment patterns among locations determine recovery rates of coral communities after severe environmental disturbances.

Coral Reef Management

Coral reef management in Thailand depends on the enforcement of laws and regulations that apply to all coral reefs, as well as additional measures applicable only to marine protected areas. Recently, central agencies, provincial governments and the private sector have undertaken non-regulatory actions aimed at improving coral reefs through restoration, preventive measures and education (ONEB 1991; Figure 3).

A set of urgent measures for coral reef protection was proposed to the cabinet for approval in 1990: (1) determine proper mooring sites and install mooring buoys on coral reefs that are frequently used by tour boats; (2) increase the effectiveness of measures aimed at reducing coral reef destruction through enhanced enforcement efforts and public education; and (3) direct the Navy and the Harbor Department to support urgent measures for coral reef management and to prevent and control coral reef destruction along coastal waters. (The Ministry of Agriculture will assign authority to Navy and Harbor Department Staff to act as enforcement officers for the Fisheries Act.)

Moreover, ONEB (1993) outlines Thailand coral reef management strategy policies which are as follows: (1) manage coral reefs according to their different ecological and economic values to maintain a balance of uses; (2) reduce degradation of coral reefs by increasing the effectiveness of existing laws and measures; (3) build and maintain strong public support for the management of Thailand's coral reefs; (4) make essential revisions and additions to existing laws, administrative directives, and institutions so that effective management is feasible; (5) monitor and evaluate progress in accomplishing the objectives of the National Coral Reef Strategy; and (6) support management through scientific research.

As stated in Sudara et al. (1991), in order to have a successful management plan, all obstructions have to be identified and awareness needs to be created at all levels. When the plan is implemented, a monitoring program has to be in place in order to provide feedback that will

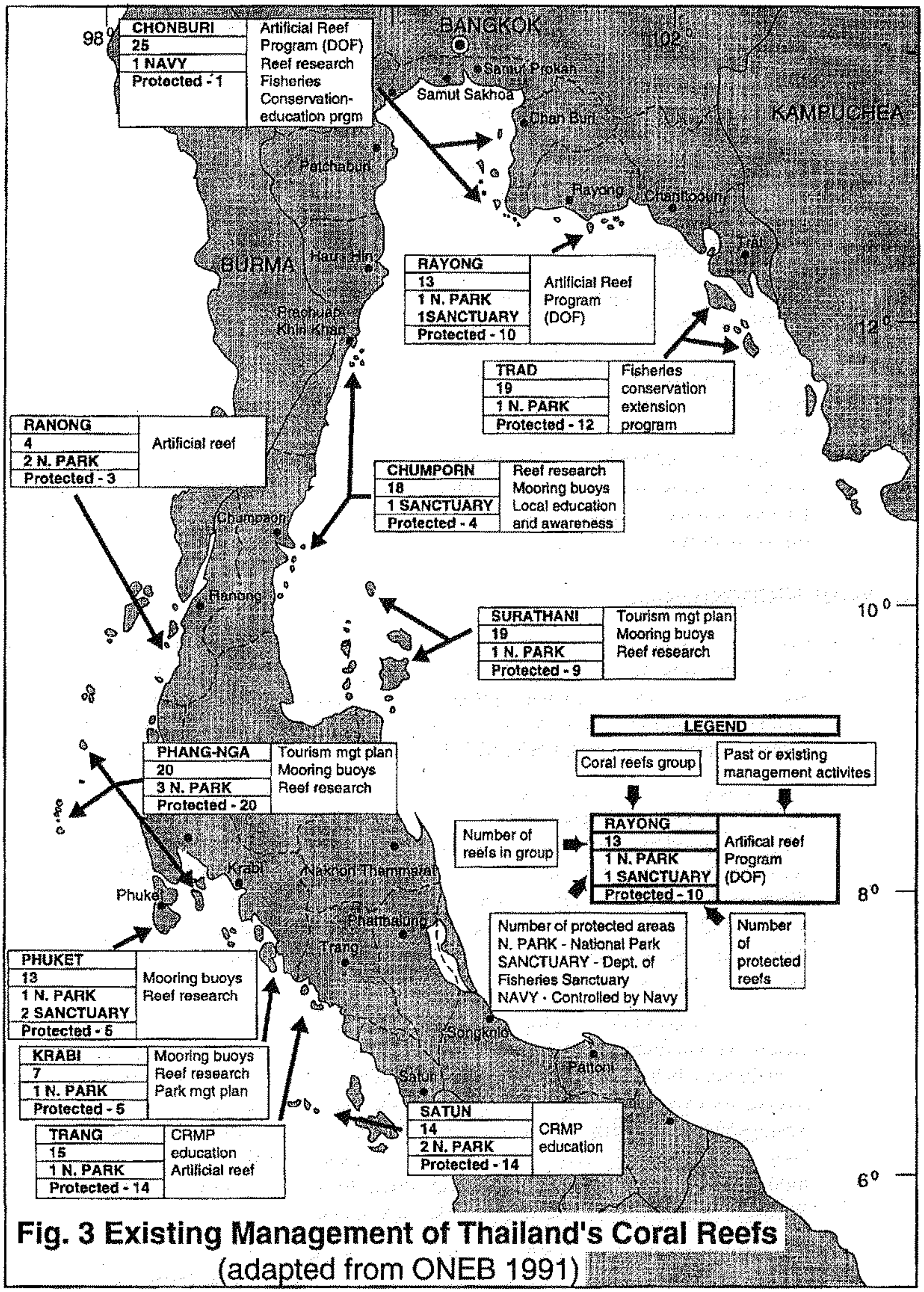


Figure 3. The current status of reef management in Thailand showing the existing parks and sanctuaries and the activities or special features of each managed area.

allow assessment of the effectiveness of the management scheme. A monitoring program will be successful only when local citizens and those in authority are actively involved.

CONCLUSIONS

Coral reef deterioration is widespread in Thailand, however, many pristine reefs still exist. Urgent action is required in order to preserve the remaining good coral reefs. Effective management of Thailand's coral reefs depend on an understanding of reef ecology and an awareness of the impact of human activities. The nationwide baseline data on reef condition from the ASEAN-Australia Living Coastal Resources Project has helped to understand and plan for effective management.

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