BASELINE MARINE BIOLOGICAL SURVEYS OF THE PHOENIX ISLANDS, JULY 2000

BY

DAVID OBURA,[1] GREGORY STONE,[2] SANGEETA MANGUBHAI,[4]
STEVEN BAILEY,[3] AUSTEN YOSHINAGA,[3] CAT HOLLOWAY,[5]
ROBERT BARREL[5]

ABSTRACT

Rapid assessment surveys were conducted during a 21-day marine biological expedition to the Phoenix Islands, Republic of Kiribati, from 29 June to 11 July 2000. This study includes new data on the biological diversity and abundance of the region and research and management recommendations. We conducted surveys and over 300 research SCUBA dives among the remote Phoenix Islands: Nikumaroro (Gardner), McKean, Manra (Sydney), Kanton (Aba-Riringa), Enderbury, Orona (Hull) and Rawaki (Phoenix), only excluding Birnie Island due to time limitations.

Corals, benthic and mobile invertebrates, fishes, algae, sea turtles, sea birds, and marine mammals were surveyed at each site. Deep-sea life was sampled during seven deployments of an autonomous digital video camera system to 1,000 m depth at Kanton, Manra, and Orona. Coral reef and fish communities were surveyed using rapid assessment methods, small benthic fishes were collected using rotenone as a stunning agent, marine algae were collected by hand primarily during SCUBA dives, and a deep-drop collecting net was deployed to sample deep-sea animals.

The reefs show evidence of the extreme isolation of these islands, pounded on three sides by the large ocean swells of the Pacific with only a narrow protected side to the west providing protection for anchorage. Coral species diversity of the islands was moderately high. While lacking in some corals dominant in other major reef areas, the reefs have interesting species assemblages, with prolific growth of some species normally subdominant in other reef areas. The reefs were in an excellent state of health, at the time of these surveys free from the bleaching that has plagued reefs in other parts of the Pacific recently and with no evidence of any coral diseases. Our data include new distribution records for species of algae, coral and fishes.

---

[1]CORDIO-East Africa, P.O. Box 10135 Bamburi, Mombasa, Kenya. Corresponding author: dobura@cordioea.org;
[2]Senior Vice President for Ocean and Exploration and Conservation
New England Aquarium, Central Wharf, Boston, MA 01220, USA
[3] New England Aquarium, Central Wharf, Boston, MA 01220, USA
[4]World Wide Fund for Nature - South Pacific, Private Mail Bag, GPO Suva, Fiji; 4) NAI'A Cruises, PO Box 332, Pacific Harbour, Fiji.
[5] NAI'A Cruises, PO Box 332, Pacific Harbour, Fiji

Fish communities were abundant and diverse and included pelagic fishes such as tuna and oceanic mackerels. Significant populations of grey reef, whitetip reef, and blacktip reef sharks were also observed indicating a healthy coral reef ecosystem. Reef macropredators (trevally, Napoleon wrasse) were also abundant. The deep-sea camera recorded images of deep-water sharks including six-gilled and Pacific sleeper sharks. Marine mammal sightings include bottlenose dolphins, Pacific spinner dolphins, beaked whales (*Mesoplodon* spp.), and unidentified whales. Sea birds observed on Rawaki, McKean, Enderbury, and Orona Islands included tens of thousands of nesting spectacled terns (grey-backed), sooty terns, white fairy-terns, brown noddies, blue-grey noddies, masked boobies, brown boobies, red-footed boobies, red-tailed tropic birds, great frigate birds and lesser frigate birds. Green sea turtle nesting sites were identified on Nikumaroro, McKean and Phoenix Islands. The observations on Rawaki Island are the first confirmed green turtle nestings for that island.

INTRODUCTION

This multidisciplinary scientific expedition to the Phoenix Islands was part of the Primal Ocean Project, which documents ecologically healthy regions of the ocean that resemble prehuman, or preexploitation, conditions. The program documents key aspects of the marine environments at uninhabited and undisturbed locations. For this study, we surveyed some of the most remote coral atoll islands in the Pacific Ocean. The Phoenix Islands (Figure 1), which are part of the Republic of Kiribati, are rarely visited and our expedition provided the first comprehensive, systematic survey of the reefs and adjacent marine biomes. We used a combination of methods to identify and quantify the abundance and distribution of marine mammals, the diversity and condition of the coral reefs and coral fish, and the distribution and diversity of marine algae. We also recorded observations of seabirds and turtles throughout the expedition. This paper provides a summary of the results for the year-2000 expedition, and recommendations for follow-up research and conservation management.

The Phoenix Islands are in the eastern Kiribati Group of Micronesia at approximately 4 degrees latitude south of the equator and 175 degrees west longitude, 1,850 miles southwest of Honolulu, Hawaii, 3,250 miles northwest of Sydney, Australia, and 1,000 miles northeast of Suva, Fiji. (Figure 1). They first found fame as the finest sperm whaling grounds of the South Sea whale fishery in the early 1800s (Towsend, 1935) and were featured in the famous tale, *Moby Dick*, as the location of the final confrontation between Captain Ahab and the white whale (Melville, 1851). The islands were entirely uninhabited until the late 1800s when British and American governments discreetly fought to claim control of the group by installing entrepreneurs to plant coconuts and establish guano mines. Coconut planters came and quickly went from a few of the islands and they were again uninhabited until 1938.

In 1937, British delegates surveyed the Phoenix Islands as potential places to resettle Gilbertese and Ellice Islanders as an escape from their overpopulated (and overmined) homelands. Upon seeing Gardner Island and its thick coverage of buka trees for the first time, the Gilbertese villagers immediately recognized the place from their dreams and myths: this was Nikumaroro, the legendary home of the fierce and powerful

Polynesian goddess of ocean navigation, *Nei Manganibuka*. Hence, the current correct name for Gardner Island is Nikumaroro. In 1938, modest colonization of Nikumaroro, Orona and Manra Islands began idealistically and passionately, largely as a result of the untouched beauty of the atolls and the incredible abundance of fish the settlers and surveyors found (Bevington, 1937). Apparently, blacktip sharks gathered in dozens around their ankles as they waded along the shore. Turtles, lobsters, crabs and large pelagic fishes were easily caught and the lagoons teemed with a common type of mullet and triggerfish. However, fresh water was difficult to catch and gather from wells and many families opted to leave in the 1940s; by the 1960s, the settlement scheme was entirely abandoned. Only Kanton Island has any inhabitants now, fewer than 50 people.

Previous research on these islands included a visit by the research vessel Bushnell in 1939 that resulted in a taxonomic collection of fishes (Shultz, 1943), studies on seabird (Clapp, 1964), turtles (Balazs, 1982) and the corals from McKean island in the early 1970s (Dana, 1975). It was not until 1972-73 that detailed marine surveys were conducted, of a comprehensive study of Kanton Atoll (Smith and Henderson 1978), including work on lagoon circulation and biogeochemistry (Smith and Jokiel 1978), coral taxonomy and biogeography (Maragos and Jokiel, 1978) and lagoon and leeward reef coral distributions and assemblages (Jokiel and Maragos, 1978). In additon to these primarily scientific interests, others have been attracted to the Phoenix Islands: the Waikiki Aquarium of Hawaii collected baby black tip sharks from Kanton in the 1980s and the TIGHAR expedition searching for Amelia Earhart's plane wreckage in 1997, dived the island of Nikumaroro (Holloway, 1999).

We chose these islands for our study because of their isolation, their long history of being uninhabited and the opportunity to provide biological information for the purpose of management and conservation.

METHODS

The 120' M/V NAI'A departed Fiji on June 24, 2000 and after a five-day crossing arrived at the Phoenix Islands on June 29, 2000. We began our survey with Nikumaroro Island, followed by McKean, Kanton, Enderbury, Enderbury, Manra, and Orona Islands and then returned again to Nikumaroro for the final two days of the expedition (Fig. 1). Birnie Island was excluded due to travel and time constraints. We spent between one and two days at each island and transited between islands at night. Upon arrival, we sought a station on the leeward side of each island from which skiffs could be launched safely. Next, we made three or four dives each day seeking maximum diversity of underwater habitats ranging from the shallow surf zone to depths of 140 feet. Most of our time was spent on the leeward sides of the islands due to wind and swell making operations difficult on the windward sides. Landings at each island were made to search for turtle nests and to assess the populations of seabirds. We departed the Phoenix Islands for Fiji on Tuesday, July 11, 2000. Specific methods for each area of research are described below:

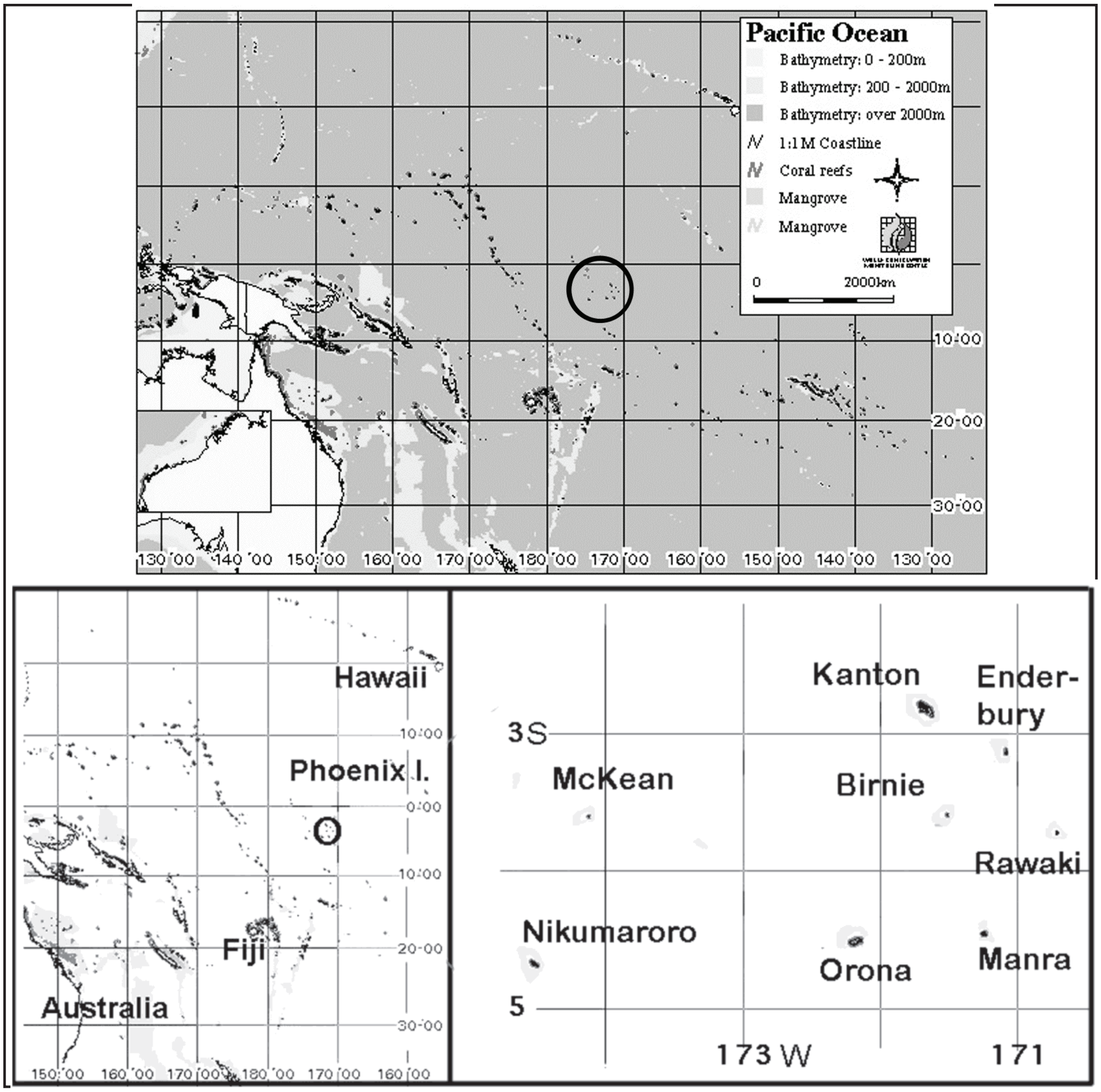

Figure 1. Left. The location of the Phoenix Islands in the Pacific Ocean. Right. The Phoenix Islands, showing all eight islands in the Republic of Kiribati.

Corals and Benthic Cover

Three methods were used for rapid surveying of reefs for coral diversity and condition, as well as benthic cover. Rapid assessment methods were chosen in order to cover as much area as possible during the several dives in each study area.

Coral Species Diversity - timed surveys. Coral species were identified at each site by recording new coral species observed in 2.5 minute intervals during each dive, giving information on species diversity, as well as community structure. Identification was done using Veron (1986). Small fragments of unidentified corals were collected, bleached for two days in domestic bleach, then dried and sealed in airtight plastic bags for transportation. Preliminary identifications were made at the Australian Institute of Marine Science (Doug Fenner) and the Museum of Northern Queensland (Dr. Carden Wallace).

Coral and benthic cover - video transects. Video records of the benthos using a fixed camera-to-subject distance provided reliable images for scoring benthic cover of major algal and benthic invertebrate groups, many of the latter to genus or species level. Sample quadrats were selected during playback of the material. The video tape of benthic cover was stopped at four-second intervals, sampling five fixed points on the screen, with 100 points defining a single "transect". As far as possible, five transects were analyzed for each site, though some sites had fewer transects due to the low video-time recorded.

Coral condition. The incidence of coral stress indicators (i.e., bleaching, epiphytism, partial mortality, seastar predation) was also noted for each site. These were recorded in repeated 10-minute samples during each dive.

Benthic Invertebrates

Important benthic invertebrate resource species were sampled in ten-minute intervals during dives. The identity (at species level where possible) and number of individuals were recorded for the following invertebrate groups: sea cucumbers, lobsters, clams and crown-of-thorns seastars.

Fishes

Fish populations were studied using four different methods designed to sample: a) abundance of large predatory fishes, b) abundance of ecologically important fish families, c) diversity of representative ornamental fishes, and d) diversity and taxonomy of small cryptic fishes. The first two methods consisted of identifying and counting fish in situ. In the first method, 18 selected species of large predatory fishes were counted during all dives (Table 1). The second method counted fishes at the family level, selecting families common to coral reefs and with important ecological roles (Table 2). The third method assessed relative diversity of representative ornamental reef fish families. Species counts were taken for the following three groups: butterfly fishes (Chaetodontidae), angel fishes (Pomacanthidae) and clown fishes (Pomacentridae; Amphiprioninae).
In the fourth method, small benthic fishes were collected with rotenone, an organic fish toxicant. The only previous systematic fish collections made in this region were in 1939 during the *U.S.S. Bushnell* expedition (Shultz, 1943). Most of those collections were made with nets and traps because SCUBA technology was not yet available. Due to the fishing method used in collecting fishes, these collections focused on larger benthic and pelagic species. The small cryptic fish fauna that lives on the bottom and in crevices was not sampled as extensively; thus it was decided a significant contribution could be made by collecting the smaller cryptic fishes using SCUBA gear and hand-catching.

Collections were made at various depths. Sites were selected that contained a rubble bottom, which would provide suitable habitat for the target species, and had currents and structure likely to retain the rotenone. Rotenone was mixed on board the NAI'A into a paste with seawater to a consistency that would allow fine cloud dispersion; the paste was transported underwater in a plastic bag. Once on site, the rotenone bag was opened and mixed with seawater by scooping an amount sufficient to create a consistency

Table 1. Large fish species counted at each site for relative fish abundance

Scientific Name	Common Name
TUNA AND PELAGICS	
Gymnosarda unicolor	Dogtooth Tuna
Euthynnus affinis	Mackerel Tuna
Scomberoides lysan	Double-spotted Queenfish
Elegatis bipinnulata	Rainbow Runner
JACKS	
Caranx sexfasciatus	Bigeye Trevally
Caranx melampygus	Bluefin Trevally
Caranx lugubris	Black Trevally
REEF PREDATORS	
Sphyraena qenie	Chevron Barracuda
Cheilinus undulatus	Napoleon Wrasse
Epinephelus fuscoguttatus	Flowery Cod
Plectropomus laevis	Footballer Trout
Aprion virescens	Green Jobfish
Lutjanus bohar	Red Bass
Macolor macularis	Midnight Seaperch
SHARKS AND RAYS	
Carcharhinus melanopterus	Blacktip Reef Shark
Carcharhinus amblyrhynchos	Grey Reef Shark
Triaenodon obesus	Whitetip Reef Shark
Manta birostris/alfredi (complex)	Manta Ray

Table 2. Common fish families surveyed for abundance at each site.

Family	Common name
Serranidae	Groupers
	Fairy Basslets
Lutjanidae	Snappers
Scaridae	Parrotfishes
Acanthuridae	Surgeonfishes Unicornfishes
Balistidae	Triggerfishes

reminescent of heavy cream. This solution was then released out of the bag onto the rubble substrate where it primarily settled, depending on currents and surge. The mixture would envelop an area of substrate that was on average 4 m^2. Sometimes, depending on current and surge, the rotenone would be lifted into the water column and interact with those fishes. After 2-4 minutes, the effects of the rotenone would irritate the fish out of their burrows and eventually incapacitate them, at which point they were collected in small plastic jars. The majority of fish specimens were collected in a catatonic state in the immediate vicinity of the substrate. Due to the loose and extremely porous nature of the rubble, researchers would often dig down into rubble to a depth of 0.5 m on average to retrieve samples. Specimens were picked up and placed in clear plastic jars with screw-on lids. Specimens were fixed when back on board in 10% neutral buffered formalin (NBF) then transferred to 10% NBF-soaked gauze prior to transport. Thirty-five percent of the collections were photographed prior to fixing.

While in the field, the specimens were generally identified by personal familiarity or using references (Schultz, 1943; Randall et al., 1990; Myers, 1991). Definitive analysis of all specimens is being conducted at the ichthyology departments of the Museum of Comparative Zoology at Harvard University, Cambridge, MA, USA and the National Museum of Natural History at the Smithsonian Instititue, Washington, DC, USA. The expertise of some of the world authorities on particular fish families has been enlisted; among those are the Royal Ontario Museum (Ottawa), Natural History Museum (London), and J.B.L. Smith Institute of Ichthyology (South Africa).

All specimens will have their ultimate disposition at either the National Museum of Natural History, Smithsonian Institution or the Museum of Comparative Zoology, Harvard University, depending on their contribution to an already existing comprehensive collection for that species or family. All information and data concerning these specimens will be made available to the Kiribati Government and for scientific requests, following standard museum procedures.

Algae

Marine algae were collected by SCUBA diving, reef walking and snorkeling. Collections were stored and logged at the end of each day according to habitat and water depth, temperature and visibility, and then preserved in 5% formaldehyde in seawater. Specimens were catalogued by phyla on board the research vessel and then delivered to Professor Robin South of the Marine Studies Programme (USP) of the University of the South Pacific, Suva, Fiji for final analysis, including sorting, microscopic examination and preparation as slides and whole mounted specimens. For large specimens, herbarium or liquid-preserved specimens will be prepared and, where necessary, anatomical sections were retained on microscope slides. Photomicrograph records are stored at the USP laboratory. All species were analyzed and housed in the Phycological Herbarium, the University of the South Pacific Herbarium in Suva, Fiji. A list of recorded species has been compiled and a formal record of the collection is being published separately by South et al. (2001).

Marine Mammals

Sighting watches were kept from the bridge of the NAI'A during most daytime transits. Observer height-of-eye was 6 meters above waterline, and normally two observers, one on each side of the vessel, scanned the waters in an arc from the bow to 90 degrees on each side. For each marine mammal sighting the following information was recorded: date, time, species, number of animals, behaviors, latitude and longitude, distance at first sighting, distance when abeam of NAI'A, water depth, weather conditions (sea state, cloud cover, wind), observers, and comments.

Turtles and Birds

Turtles and birds were counted opportunistically throughout the cruise. Each island was surveyed for turtle-nesting sites by walking the beaches and from boats.

Deep-Sea Camera Survey

The National Geographic Society provided a deep-sea digital video camera (“rope-cam”) for use on this expedition. The camera had an operating depth of up to 2,000 meters and had an automatic recording system with a preset on-off schedule once it reached depth. The camera was lowered over the side with bait to attract animals and was then recovered using block and tackle and a tow skiff. A single deployment took up to seven hours. The camera’s operating program had the camera switched on for two minutes and then off, or “sleeping,” for 13 minutes. The “sleeping” periods allowed the deep-sea animals time to return after usually being frightened away by the bright lights on the apparatus. There were seven camera deployments, each resulting in one hour of recorded bottom time. A full description of the methods can be found in Stone et al. (1998).

Deepwater Net Tow

In addition to the deep camera system there was one deployment of a deepwater net to a depth of 1000 meters. The net was a four mm mesh with a square frame that measured one metre square. The sample of deepwater fishes and other organisms was analyzed along with the shallow-water fish collections.

The above methods cover a range of spatial and temporal scales of measurement, and application at site and island-specific levels. Table 3 gives a summary of how they were collected, and their reporting in the results section.

GENERAL RESULTS

Thirteen days of surveys were completed in the Phoenix Islands, with nine days of ocean crossings (Table 4). Forty-two research SCUBA dives were completed at 29 survey locations within the island group, nearly 75% of which were at leeward locations due to inaccessibility of rougher waters on the windward sites (Table 5). Additional spot-checks were conducted, for example in the lagoon at Orona, but without detailed collection of data so are not shown in the table.

Results are presented in two formats. First, for those data that can be summarized for the entire expedition, we present summary information below. This includes fish collections, marine mammal sightings, algae, and deep-camera results. Following this, island-specific results are presented for coral and fish assemblages, bird populations and turtle sightings.

Table 3. Tabulation of methods, scales of observation and reporting

Method	Observations	Spatial scale	Results
Fish collection/ Deepwater Net Tow	Collection.	Tallied by site and aggregated by island	Overall
Algae	Collection.	Tallied by site and aggregated by island	Overall
Marine Mammals	Above-water observation and counts.	From vessel during crossings and at islands, from diving skiffs.	Overall
Deep-Sea Camera Survey	Video record.	Spot deployment at 7 locations off 4 islands	Overall
Corals and Benthic Cover	Underwater observations, quantitative.	Individual-site records from marked locations around each island	Island-specific
Benthic Invertebrates	Underwater observations, quantitative.	Individual-site records from marked locations around each island	Island-specific
Fishes	Underwater observations, quantitative.	Individual-site records from marked locations around each island	Island-specific
Turtles	Above-water and underwater counts for turtles, beach walks for nests	Individual-site records and total counts by island.	Island-specific
Birds	Beach and island walks to count nests and birds.	Total counts by island.	Island-specific

Table 4. Itinerary of Expedition.

Date	Locations
June 25 to 29, 2000	Ocean crossing – Fiji to Phoenix Islands
June 29 and 30, 2000	Nikumaroro (Gardner) Island
July 1, 2000	McKean Island
July 2, 3,and 4, 2000	Kanton (Aba-Riringa) Island
July 5, 2000	Enderbury (Enderbury) Island
July 6, 2000	Phoenix Island
July 7, 2000	Manra (Sydney) Island
July 8 and 9, 2000	Orona (Hull) Island
July 10 and 11, 2000	Nikumaroro (Gardner) Island
July 12 to 15, 2000	Ocean crossing – Phoenix to Fiji

Table 5. Number of sites sampled at each island in the major reef types in the Phoenix islands – leeward, windward, lagoon and channel.

Island	Leeward	Windward	Lagoon	Channel	Total
Enderbury	3	1			4
Kanton	5	1	1	1	8
Manra	2	1			3
McKean	2				2
Nikumaroro	4	2			6
Orona	2	1			3
Rawaki	3				3
Total	21	6	1	1	29

Fish Collection

Fishes were collected at all islands during the expedition. Eighteen collections were made with rotenone, five were live or incidental collections and one was made with a deep-drop net to 1000 m. Fifteen collections were on the protected leeward sides of the islands, five were made on the exposed windward side, and three were made inside lagoons. Further details of collections are in Tables 6-7 and the content of each collection is listed within each island's description.

Table 6. Number of fish collections, fish species and fish specimens at each island.

Island	Collections	Species	Specimens
Nikumaroro	5	31	96
McKean	2	20	43
Kanton	7	31	80
Enderbury	3	18	54
Enderbury	1	11	31
Manra	2	20	71
Orona	4	32	79

Table 7. Characteristics of fish collections by depth and substrate (depth in meters).

Depth range	# Collections	Substrate	# Collections
< 5	1	Sand (fine sediment)	3
6-10	8	Rubble	11
11-15	6	Sand/Rubble mix	5
16-20	2	Water column	3
21-25	4	Coral top	2
26-30	1	Other	1
31-50	1		
> 50	1		
Totals	24		25*

* one collection included specimens caught at two locations.

Twenty eight families and 85 species are currently represented in the collection. The Pomacentridae, with eight species, are the most diverse family, while 10 other families have just one species. The most often collected species was *Chromis acares* (Midget chromis: Pomacentridae) from 13 of 24 collections, while 34 species were sampled only once.

The team was provided with a species list compiled by the Kiribati Ministry of Natural Resource Development's Fisheries Division. It is currently comprised of 393 species with a scientific name, common name and Kiribati indigenous name listed for each one. Presently this report is able to add 37 additional species (Table 8). Of those 37 species it is believed that two represent zoogeographic range extensions (see Table 60). Some of the species listed as additions in Table 8 are quite common at most collection

Table 8. Additions to Kiribati Ministry of Natural Resource fish species list.

Family	Genus/species	Common name
Moringuidae (Spaghetti Eels)	*Moringua ferruginea*	Rusty spaghetti eel
Muraenidae (Moray Eels)	*Gymnothorax chilospilus*	(none)
	Gymnothorax buroensis	Buro moray
	Uropterygius supraforatus	(none)
Congridae (Conger and Garden Eels)	*Conger cinereus cinereus*	Moustache conger
Cyclothonidae	*Cyclothone pallida*	(none)
	Cyclothone alba	(none)
Ophidiidae (Cusk Eels)	*Brotula multibarbata*	Reef cusk eel
Bythitidae (Livebearing Brotulids)	*Dinematichthys iluocoeteoides*	Yellow pygmy brotula
Antennariidae (Frogfishes)	*Antennarius nummifer*	Spotfin frogfish
Exocoetidae (Flying fishes)	*Cheilopogon suttoni*	Sutton's flyingfish
Scorpaenidae (Scorpionfishes)	*Scorpaenodes guamensis*	Guam scorpionfish
	Scorpaenodes hirsutus	Hairy scorpionfish
	Taenianotus triacanthus	Leaf fish
	Pterois antennata	Spotfin lionfish
Serranidae (Fairy Basslets and Groupers)	*Suttonia lineata*	(none)
Grammistidae	*Pseudogramma polyacanthum*	(none)
Pseudochromidae (Dottybacks)	*Pseudoplesiops revellei*	Revelle's basslet
Cirrhitidae (Hawkfishes)	*Cirrhitops hubbardi*	(none)
	Paracirrhites nisus	(none)
	Paracirrhites xanthus	(none)
Apogonidae (Cardinalfishes)	*Gymnapogon urospilotus*	Lachner's cardinalfish
Pomacanthidae (Angel fishes)	*Centropyge flavicauda*	White-tail angel fish
	Centropyge flavissima	Lemonpeel angel fish
Pomacentridae (Damselfishes)	*Chrysiptera brownriggii*	Surge damselfish
	Plectroglyphidodon johnstonianus	Johnston damselfish
Tripterygiidae (Tripletails)	*Enneapterygius tutuilae*	(none)
	Enneapterygius nigricauda	(none)
Gobiidae (Gobies)	*Amblygobius phalaena*	Brown-barred goby
	Callogobius plumatus	Feather goby
	Callogobius sclateri	Pacific flap-headed goby
	Paragobiodon modestus	Warthead goby
	Priolepis nocturna	(none)
Acanthuridae (Surgeon and Unicornfishes	*Acanthurus nigricans*	White cheek surgeonfish
	Acanthurus nigrofuscus	Brown surgeonfish
	Zebrasoma scopas	Brown tang
	Zebrasoma veliferum	Sailfin tang

sites. *Cyclothone alba* and *C. pallida*, the two species of fish that were collected in the one deep water net tow, share the distinction with their close relation *Vinciguerria* as the genera that have the greatest abundance of individuals of any verterbrate genus in the world (Nelson, 1994). The cyclothonids occur in virtually all marine waters including Antarctica.

The number of specimens remaining to be identified is considerable. Table 9 outlines the task by illustrating the progress to date on more than 400 of those fishes. An additional 350 (primarily labrid and anthiid) specimens have only been grossly classified to family level. The collection methods focused the effort on interstitial fishes. Consequently, the majority of the specimens collected are species that do not achieve a size that facilitates classification using strong visual characteristics.

Table 9. Unidentified fishes collected during expedition.

Family	Genus (if known)	Species or description	Collection #	Status of inquiry
Synodontidae	*Synodus*	sp.1	10	pending
Antennariidae	*Histrio*	‘xtreme small’	11	pending
Bythitidae	*Dinemichthys*	‘yellow’	10,16,18,20	pending
Holocentridae	*Myripristis*	sp.1	7	pending
Holocentridae	*Sargocentron*	sp.1	5,18,20	pending
Scorpaenidae	(scorpaenid)	sp.1	5,16,18,21	pending
Scorpaenidae	*Scorpaenodes*	sp.1	4,6,10	pending
Scorpaenidae	*Scorpaenopsis*	sp.1	10	pending
Scorpaenidae	*Scorpaenopsis*	sp.A	16,22	pending
Scorpaenidae	*Sebastapistes*	sp.1	22	pending
Caracanthidae	*Caracanthus*	sp.1	18	pending
Serranidae	*Cephalopholis*	sp	1	pending
Apogonidae	*Apogon*	sp.1	4,8,10,20,22	pending
Apogonidae	*Apogon*	sp.2	10	pending
Tripterygiidae	*Enneapterygius*	sp.1	22	pending
Tripterygiidae	*Helcogramma*	sp.1	8	pending
Acanthuridae	*Naso*	sp.1	21	pending

Additionally: the Labridae portion of the collection (approximately 75 specimens) has not been examined; the Anthiinae (approximately 200 specimens) analysis is commencing; 12 other families have not yet received any cataloguing.

Algae Collection

A total of 69 taxa of subtidal benthic marine algae, including nine new records (Rhodophyceae) for Micronesia, were collected and identified (Table 10). The collections were made from Nikumaroro, McKean, Kanton, Enderbury, Enderbury, Manra, and Orona islands. These samples included seven Cyanophyceae, 29 Rhodophyceae, five Phaeophyceae and 28 Chlorophyceae. Together with previous studies (Doty, 1954; Degener and Gillaspy, 1955; Degener and Degener, 1959; Dawson, 1959), this brings to 107 the total number of species reported from these islands. The flora is representative of that of neighboring areas of Micronesia, although one species, *Cladophora boodleoides*, is reported only for the second time from the South Pacific Ocean. For a complete report of these specimens see South et al. (2001).

Table 10. Marine Algae Collected. Each ✓ represents a specimen. Two or more ✓ represents more than one sample of same species. Sites: A/B: Nikumaroro. C: McKean. D: Kanton. E: Enderbury. F: Enderbury. G: Manra. H: Orona. Confirmed = ✓

Species	A/B	C	D	E	F	G	H
Antithamnionella elegans (Berthold) Price & John					✓		
Asparagopsis taxiformis (Delile) Trevisan						✓	
Avrainvillea sp.			✓				
Blennothrix lyngbyacea (Kützing) Anagnostidies Komárek					✓		
Bryopsis pennata Lamouroux			✓✓				
Bryopsis sp.			✓				
Caulerpa cupressoides (Vahl) C. Agardh				✓✓✓	✓		
Caulerpa serrulata (Forsskal) J. Agardh				✓			✓
Ceramium flaccidum (Kützing) Ardissone			✓				
Ceramium sp.		✓	✓				
Cladophora liebetruthii Grunow					✓		
Codium arabicum Kützing							✓
Coralline algae				✓			
Crouania attenuata (C. Agardh) J. Agardh			✓				
Cyanophyta	✓✓✓	✓	✓✓	✓			
Dasya sp.						✓	
Dictyopteris repens (Okamura) Børgesen			✓	✓✓			
Dictyosphaeria cavernosa (Forsskål) Børgesen		✓		✓✓✓			
				✓			
Dictyosphaeria versluysii Weber van Bosse					✓✓		
Dictyosphaeria sp.				✓			
Galaxaura filamentosa Chou			✓				
Gelidiopsis intricata (C. Agardh) Vickers					✓		
Gelidiopsis sp.				✓			
Griffithsia heteromorpha Kützing					✓		
Halimeda copiosa Goreau & Graham			✓	✓			
Halimeda cuneata Hering					✓		
Halimeda cylindracea Decaisne						✓	✓
Halimeda macroloba Decaisne							✓
Halimeda micronesica Yamada		✓					
Halimeda taenicola Taylor					✓		
Halimeda sp.		✓✓	✓✓	✓✓✓		✓	✓
Herposiphonia dendroidea Hollenberg					✓		
Hypnea sp.	✓			✓✓			
Hypoglossum caloglossoides Wynne & Kraft					✓		
Jania micrarthrodia Lamouroux					✓		
Jania sp.				✓			
Lithothamnion proliferum Foslie						✓	
Neomeris annulata Dickie			✓✓✓	✓			✓✓
Polysiphonia sp.		✓					
Porolithon sp.		✓				✓	
Rhipilia geppii Taylor					✓		
Rhipilia orientalis Gepp & Gepp					✓		
Rhipilia sp.	✓✓	✓	✓	✓			
Rhipiliopsis sp.				✓			
Spermothamnion sp.				✓			
Turbinaria ornata (Turner) J. Agardh							✓
Turf algal assemblage	✓✓✓						✓
Valonia aegagropila C. Agardh				✓✓			
Not algae				✓		✓	✓

Deep-Sea Video Survey

Ropecam deployments were successful and documented several deep-sea sharks around the islands. Sharks repeatedly ate all the bait on the camera system and violent encounters were evidenced by bending and actually biting off the bait pole. On the last deployment, the bait pole was bitten off and the outer camera port was missing, causing flooding of the camera housing. Due to this damage, there were no further deployments. Either the port failed due to structural problems or a shark may have shaken the entire camera system and banged it against some rocks. Table 11 lists the types of animals seen during deployments.

Table 11. Deep-sea ropecam results

Date	Island	Position	Depth (m)	Comments
7-02-00	Nikumaroro	04° 48.6' S 171° 43.7' W	1,000	Camera out of focus
7-03-00	Kanton	02° 47.8' S 171° 44.1'W	1,000	Six-gill shark (Hexanchus sp.) and cat shark images (Scyliorhinoidei)
7-04-00	Kanton	02° 48.2' S 171° 44.1 W	1,200	Camera malfunction: ran continuously
7-05-00	Enderbury	03° 07.4' S 171° 06.6'W	1,100	Eels, sergestid shrimp
7-07-00	Manra	04° 28.0' S 171° 16.1' W	1,000	Pacific sleeper shark (Somiosinae)
7-08-00	Manra	04° 29.3' S 171° 13.4' W	1,100	Sergestid shrimp, unidentified fish, six-gill and unidentified Somniosinae sharks
7-09-00	Manra	04° 29.2' S 172° 13.4'W	1,300	Camera retrieved with missing lens port; camera destroyed by water damage; remaining system OK

Cetacean Sightings

Surprisingly few cetaceans were seen during the marine mammal watches which covered over 1,500 nautical miles of ocean as well as cruise tracks in between the islands. Odontocetes were the most common suborder observed and bottlenose dolphins (*Tursiops truncatus*) the most common species. Most notable was the lack of any identified large whales, such as sperm whales (*Physeter macrocephalus*) or any mystecetes. All cetacean sightings are listed in Table 12.

ISLAND RESULTS

This section lists results by island, covery underwater and terrestrial survey results. In total, 42 dives group dives totaling approximately 400 man-dives and 10 shore-visits were carried out.

Nikumaroro (Gardner) Island

Site Descriptions. Nikumaroro was the first and last island on the trip itinerary, with 12 dives made on four days, at eight unique sites (seven leeward and one windward, Table 13). The lee of the island consisted of only the farthest western portion of the island, the remaining north, south and eastern sides being pounded by heavy surf and exposed to storms and swell from the east and south. The return visit on July 10 and 11 was done to verify data collected during the initial familiarization and training dives.

All survey sites had a consistent topography characteristic of oceanic atolls. A sloping consolidated platform extended from the wave zone down to between 10 and 15 meters depth, below which the bottom sloped steeply in some places forming a vertical wall. The shallow platform varied from flat to a spur and groove formation, often with very deep-cut grooves and bowls with vertical walls. In shallow water, the substrate tended to be hard and consolidated, giving way to large amounts of rubble forming the majority of the steep slope in deeper water fed from rubble generated in shallow water, and transported downwards in the grooves. The deeper slopes were not sampled with video transects as extensively as slopes < 20 m deep due to diving safety constraints.

Table 12. Marine Mammal Sightings.

Date	**Position**	**Species**	**#**	**Comments**
6-24-00	17° 03.7'S 178° 15.0'W	*Tursiops truncatus*	5	Bow-riding
6-29-00	05° 34.7'S 173° 59.0'W	*Tursiops truncatus*	2	Bow-riding
7-1-00	03° 03.7'S 173° 36.0'W	Unidentified Whale	1	Blow seen only (sperm?)
7-2-00	02° 49.0'S 171° 43.0'W	*Tursiops truncatus*	10	Bow-riding
7-2-00	02° 49.0'S 171° 43.0'W	Dolphin species	?	Divers heard dolphins during night dive
7-3-00	02° 49.0'S 171° 43.0'W	Dolphin species	?	Divers heard dolphins during night dive
7-4-00	02° 49.0'S 171° 42.0'W	*Tursiops truncatus*	4	Jumping
7-5-00	03° 07.0'S 171° 05.0'W	*Tursiops truncatus*	50+	Bow-riding and porpoising
7-8-00	04° 29.9'S 172° 13.1'W	*Mesoplodon* spp.	1	Surfaced once 20m from boat
7-10-00	04° 41.6'S 174° 30.0'W	*Tursiops truncatus* (20) *Stenella longirostrus* (10)	30	Mixed school bow-riding and jumping
7-11-00	04° 43.2'S 174° 34.5'W	Unidentified whale	1	Blow seen
7-11-00	10° 57.6'S 178° 22.1'W	Unidentified whale	1	Blow seen 200m from boat (humpback?)

Table 13. Dive and survey sites at Nikumaroro Island.

Date	Time	Name	Lat. (S)	Long. (W)	Exposure
29-Jun-00	8:00 am	Landing	04°40.54	174°32.59	Leeward
29-Jun-00	11:20 am	NAI'A Point	04°39.15	174°32.86	Leeward
29-Jun-00	2:45 pm	Amelia's Lost Causeway	04°40.27	174°32.85	Leeward
29-Jun-00	5:15 pm	Norwich City	04°39.61	174°32.94	Leeward
30-Jun-00	7:55 am	North Beach	04°39.10	174°32.53	Leeward
30-Jun-00	11:50 am	SW Corner	04°40.87	174°32.41	Leeward
30-Jun-00	3:20 pm	Windward Wing	04°39.00	174°32.68	Windward
10-Jul-00	10:45 am	Kandy Jar	04°39.30	174°32.88	Leeward
10-Jul-00	1:40 pm	NAI'A Point	04°39.13	174°32.85	Leeward
10-Jul-00	4:40 pm	Landing	04°40.53	174°32.59	Leeward
11-Jul-00	7:05 am	Landing	04°40.53	174°32.59	Leeward
11-Jul-00	9:45 am	Landing	04°40.52	174°32.59	Leeward

Bottom Cover: Coral cover tended to be higher on the shallow platform and decreased on the steep deeper slope giving way to rubble and *Halimeda*. Video transects were recorded at four sites, one windward and three leeward sites (Fig. 2).

Leeward sites had 25-40% coral cover, in some places exceeding 75% on the shallow platforms. Coralline algae, *Halimeda* and rubble were the three other dominant cover categories. Coralline algae tended to dominate in shallower water, associated with good coral growth, while *Halimeda* and rubble dominated the deeper, unconsolidated slopes. Rocky spurs along the deeper wall tended to have higher coral cover with algal turf and coralline algae, with soft corals (gorgonians) becoming more abundant at 30 m and deeper.

The windward site had a very distinct crest at 15 m depth from the shallow platform to the steeply sloping reef edge. Both platform and slope were smoother and less accidented than the leeward slopes. Coral cover on the platform was estimated at 70% and the lower cover on the slope was 30%, comparable to the leeward sides. The steep slope was dominated by *Halimeda* with plates of *Porites*. In contrast to the leeward side, very little loose rubble was found with the majority of bare surfaces covered by encrusting coralline algae in shallow water. At depth large coraline rocks were jammed together to form a relatively stable, steep incline.

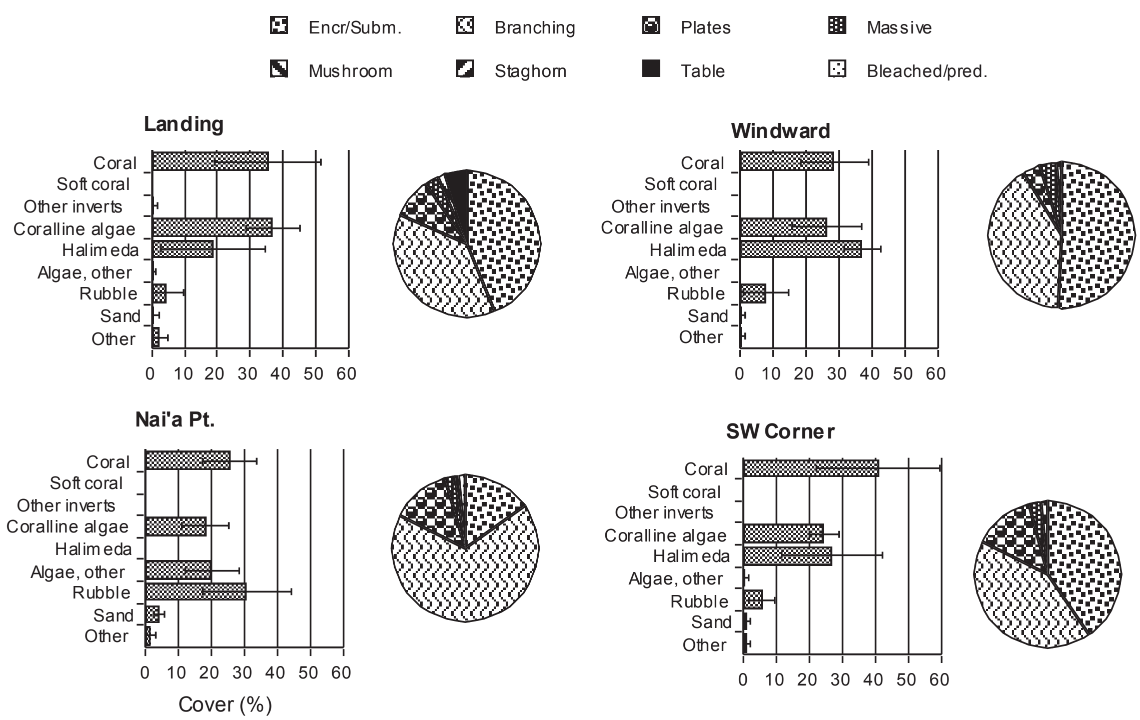

Figure 2. Benthic cover (bar charts) and relative abundance of coral growth forms (pie charts) at Nikumaroro Island. The bar charts show the mean and standard deviation of bottom cover in percentages. The pie charts show the proportion of the total coral cover contributed by the growth forms listed in the legend.

Corals. At the four sites sampled by video transect (Fig. 2), encrusting/submassive and branching corals were the most common growth forms, dominated by *Pocillopora*, *Pavona* and a variety of faviids. Plating corals were third, mostly at deeper depths (*Porites lutea*) or as minor components of the shallow coral fauna (*Echinopora*, *Echinophyllia*, *Montipora*). Leeward sites had very characteristic open-branching and submassive corals revealing the influence of water energy by the amount of fresh rubble. At the windward site, branches were more robust and closely packed, with less fresh rubble and greater substrate cementation by coralline algae.

Five dive sites were sampled for coral species, yielding 61 species. The 10 most frequently observed species are listed in Table 14 and were common to both leeward and windward sites. *Pocillopora* colonies showed the highest rates of partial and full bleaching (Table 15). *Porites* and *Fungia* showed low levels of any threat while *Acropora* was rare and seldom observed. On average, seven coral colonies with evidence of poor condition were observed in each 10 minute sample.

Table 14. The 10 most abundant coral species at Nikumaroro Island.

Family	Species
Acroporidae	*Montipora efflorescens*
Agariciidae	*Pavona minuta, Pavona varians*
Faviidae	*Echinopora lamellosa, Favia rotumana, Favia stelligera, Favites pentagona, Leptastrea purpurea*
Pectiniidae	*Oxypora lacera*
Pocilloporidae	*Pocillopora verrucosa*

Table 15. Frequency of coral threats observed at Nikumaroro Island. Number indicates the number of corals observed with each condition during 10-minute samples in each dive. Four coral genera were sampled for four categories of threat – algal growth, partial bleaching, full bleaching and seastar predation.

Site	NAI'A Pt. 1	2	Landing	Windward	SW corner	Average
Number of samples	5	4	5	5	4	4.6
Acropora						
Algal Growth	0	0	0	0	0	0
Fungia						
Bleached	0	0	0	1	0	0.2
Partly Bleached	0	0	0	0	1	0.2
Pocillopora						
Algal Growth	2	0	0	0	0	0.4
Bleached	1	1	1	3	4	2
Partly Bleached	3	1	2	10	0	3.2
Starfish Predation	1	0	0	0	0	0.2
Porites						
Bleached	0	0	1	0	0	0.2
Partly Bleached	0	0	1	1	0	0.4
Starfish Predation	1	0	0	0	0	0.2
TOTAL	8	5	2	15	5	7

Invertebrates. Clams in the genus *Tridacna* were the most frequent key invertebrate (Table 16) with no sightings of any sea cucumbers or *Acanthaster planci* (crown-of–thorns seastars) during the surveys. One *A. planci* was observed during a break in the survey schedule at 24m at North Beach. The low abundance of invertebrates was particularly striking, especially in view of the unexploited nature of the reefs.

Table 16. Number of key invertebrates observed at Nikumaroro Island, in replicate 10-minute samples.

Site	Landing	Nai'a Pt.	SW corner	Windward
Number of samples	5	5	4	5
Sea cucumbers				
Bohadschia argus	0	0	0	0
Holothuria atra	0	0	0	0
Holothuria leucospilota	0	0	0	0
Lobster	0	0	0	0
Clams (*Tridacna* sp.)	5	1	1	2
Acanthaster planci	0	0	0	0

Fishes. Large indicator predatory fishes were abundant at all sites at Nikumaroro (Table 17). Of the tuna and pelagics, rainbow runners were the most abundant, and dogtooth tuna were observed on every dive. Bigeye jacks were the most abundant of the carangids, forming large schools aggregated with barracuda on the windward site and at Nai'a Point. Chevron barracuda were present in large schools at two sites and large Napoleon wrasses were seen on all but one dive. Red bass were ubiquitous and highly curious, often circling within 30 cm of divers. Sharks were common and also highly curious at all sites, dominated by blacktip reef and grey reef sharks. They would usually approach divers directly, circle around a few times, then swim off only to return. Mildly aggressive behavior was observed occasionally, but never any escalation to strong aggression. One manta ray was recorded during surveys.

Of the ecologically important fish families, triggerfishes (invertivores) and surgeonfishes (herbivores) were ubiquitous and common at all sites (Table 18) in loose schools that would often break up as individual fish swam away. Snappers and parrotfishes were also common but their greater mobility often resulted in their not being counted during samples. Groupers were patchily distributed and not recorded at half of the sites sampled.

Nikumaroro had a high species richness of butterfly fishes and angel fishes (21 and 7 respectively, Table 19) recorded over 11 dives.

Sea Birds. There were no large aggregations of birds observed on this island indicating there may not have been any significant nesting occurring at the time of the survey. Species observed flying near the island included, 200-300 mostly sub-adult brown boobies (*Sula leucogaster)*, 50-70 great frigate birds (*Fregata minor*) of both sexes, 40-50 sooty (*Sterna fuscata*) or spectacled (*Sterna lunata*) terns, 20 masked boobies (*Sula dactylatra*), 20-30 brown noddies (*Anous stolidus*), and several little white fairy-terns (*Gygis microrhyncha*).

Table 17. Numbers of large indicator fish species at Nikumaroro Island.

Scientific Name	Common Name	Amelia LC	Land-ing	NAI'A Pt. (1)	NAI'A Pt. (2)	North Beach	SW Corner	Windward (1)	Windward (2)
TUNA AND PELAGICS									
Gymnosarda unicolor	Dogtooth Tuna	5	2	2	4	2	1	3	7
Euthynnus affinis	Mackerel Tuna	0	0	3	0	4	0	0	7
Scomberoides lysan	Double-spotted Queenfish	6	8	0	3	3	0	15	2
Elegatis bipinnulata	Rainbow Runner	11	0	10	20	22	6	20	8
JACKS									
Caranx sexfasciatus	Bigeye Trevally	30	50	200	50	30	0	50	100
Caranx melampygus	Bluefin Trevally	50	10	12	20	12	8	20	26
Caranx lugubris	Black Trevally	16	20	20	10	15	6	40	20
REEF PREDATORS									
Sphyraena qenie	Chevron Barracuda	1	0	2	2	250	0	300	300
Cheilinus undulatus	Napoleon Wrasse	4	2	4	6	2	1	6	0
Epinephelus fuscoguttatus	Flowery Cod	1	0	3		0	0	2	1
Plectropomus laevis	Footballer Trout	0	0	0	0	0	0	0	1
Aprion virescens	Green Jobfish	1	2	2	1	1	0	1	1
Lutjanus bohar	Red Bass	12	0	30	10	30	7	30	10
Macolor macularis	Midnight Seaperch	9	0	2	0	7	6	25	12
SHARKS AND RAYS									
Carcharhinus melanopterus	Blacktip Reef Shark	8	4	2	20	4	0	12	1
Carcharhinus amblyrhynchos	Grey Reef Shark	8	14	8	30	5	3	6	16
Triaenodon obesus	Whitetip Reef Shark	0	1	3	7	1	0	3	5
Manta birostris/alfredi	Manta Ray	0	1	0	0	0	0	0	0

Table 18. Average abundance of key fish families in 10-minute samples at Nikumaroro Island.

Site	Amelia's LC	Kandy Jar	Landing (1)	Sites (2)	NAI'A Point	North Beach	Norwich City	Windward
Epinephelinae (Groupers)	0	0	2.5	0	3.5	3	0	1
Lujanidae (Snappers)	31	60	40.5	18	60.5	0	18.5	29.3
Scaridae (Parrotfishes)	0	11	14.5	10	6.5	0	4.5	5.3
Acanthuridae (Surgeon and unicornfishes)	23	30	18	33	21	21	31	34.3
Balistidae (Triggerfishes)	12	6	19	6	10.5	8	10	20

Table 19. Abundance and list of butterfly fishes (Chaetodontidae), angel fishes (Pomacanthidae) and anemone fishes (Pomacentridae; Amphiprioninae) species recorded at Nikumaroro Island.

Family	#	Species
Chaetodontidae (Butterfly fish)	21	*Chaetodon auriga, C. bennetti, C. ephippium, C. kleinii, C. lunula, C. meyeri, C. ornatissimus, C. punctatofasciatus, C. quadrimaculatus, C. reticulatus, C. semeiom, C. trifascialis, C. lunulatus, C. ulietensis, C. vagabundus* *Forcipiger flavissimus, F. longirostris* *Heniochus acuminatus, H. chrysostomus, H. monoceros, H. varius.*
Pomacanthidae(Angel fish)	9	*Apolemichthys arcuatus, A. griffisi* *Centropyge bicolor,C. flavicauda, C. flavissimus, C. loriculus, C. multifasciatus, C. nigriocellus, Pygoplites diacanthus*
Amphiprioninae (Anemone fish)	2	*Amphiprion chrysopterus, A. periderion*

Marine Turtles. Fifteen to 20 green sea turtle (*Chelonia mydas agassizi*) tracks were identified on the southwestern beach of this island (the only beach that researchers had time to survey). The tracks were fresh and may have represented nesting behavior within the past month. During the 11 dives on Nikumaroro, a total of one hawksbill (*Eretmochelys imbricata bissa*) and 12 green turtles were observed in situ.

Marine Mammals. A mixed group of bottlenose and spinner dolphins was oberved one mile to the east of Nikumaroro. The group swam in the bow wave of the vessel and both genera were photographed swimming within two meters of each other.

McKean Island

Site Descriptions. McKean was the second island on the trip itinerary with only two dives conducted on a single day, both on the leeward side (Table 20).

Table 20. Dive and survey sites at McKean Island.

Date	Time	Name	Lat. (S)	Long. (W)	Exposure
1-Jul-00	9:00 am	Guano Hut	03°35.86	174°07.69	Leeward
1-Jul-00	11:45 am	Rush Hour	03°35.52	174°07.65	Leeward

The lee (west) of the island appeared to have underwater shelves extending north and south. The first dive was on the southern shelf and slope, while the second dive was along the northern end of the lee side off the beach. The bottom topography was similar to that seen at Nikumaroro, except that the crest of the deep slope was closer to 20-24m, and the shallower slope was a more complex system of coral bommies and rocky patches surrounded by sand and rubble. The shallowest sections formed a steep solid wall, with “bowls” as observed at Nikumaroro. Visibility was lower and temperatures slightly cooler, suggesting upwelling and mixing of deeper water on this smaller island.

Bottom Cover. Coral cover was low at McKean, average 20%, with higher abundance of algae (mainly turf and incipient fleshy algae), rubble, and some coralline algae (Fig. 3). Very little *Halimeda* was observed while carpeting soft corals (*Sinularia*, *Lobophytum*) occupied 10% of the bottom. The greater abundance of algal turf was clear compared to Nikumaroro. Upwelling of nutrient-rich water may be a cause as well as fertilization from the guano deposited over hundreds of years by nesting sea birds on the island.

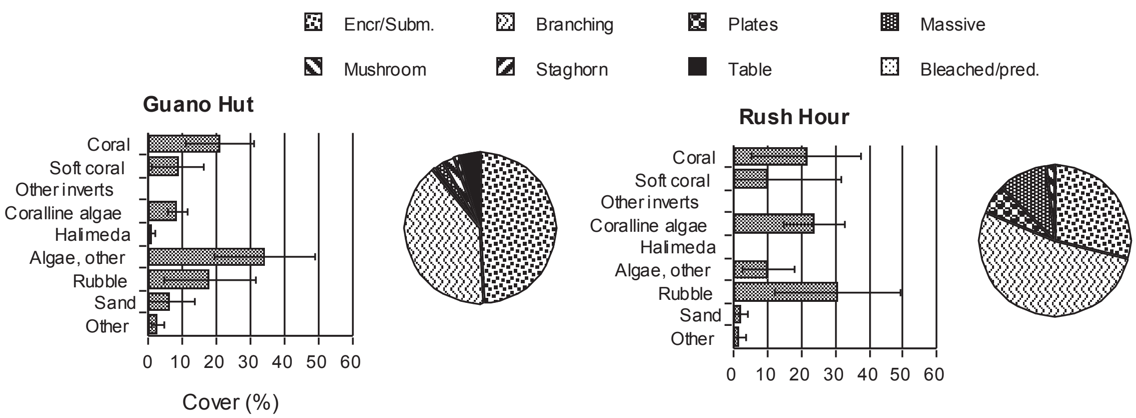

Figure 3. Benthic cover and relative abundance of coral growth forms at McKean Island.

Corals. As at Nikumaroro, branching and encrusting/submassive growth forms predominated, followed by massive corals in third place, due to the bommies that provided significant topography to the site (Fig. 3). Only one site (Guano Hut) was sampled for coral species, yielding a low number of 19 species. The coral fauna at the second site (Rush Hour) was apparently more diverse, however the coral fauna at this small island appears more depauperate than at the larger island of Nikumaroro. Very little evidence of coral stress was observed, with only one partially bleached *Fungia* recorded (Table 21).

Invertebrates. Sea cucumbers were found at only very low densities though giant clams (Tridacnids) were common at the second site, with an average of 23 recorded in a 10-minute sample (Table 22).

Fishes. The population of large predatory fishes at McKean was essentially similar to that of Nikumaroro, though with fewer schooling jacks and some missing species (Table 23), either because they were not there or because the low number of dives missed some of the rarer species. The shark population at Guano Hut was noticeably more active and aggressive than so far observed with rapid circling and aggregation by grey reef sharks at the start and throughout the dive.

Surveys for key fish families noted the low presence of herbivores at Guano Hut and high abundance of triggerfishes (Table 24). Though not recorded in the surveys, large parrotfishes were observed feeding in shallow waters < 15 m. The species diversity of butterfly fishes and angel fishes was significantly lower than at Nikumaroro (Table 25). As for corals, it is not possible to say explicitly whether smaller island area or lower sampling effort contribute to this low diversity of fishes.

Table 21. Frequency of coral threats observed at McKean Island. Number indicates the number of corals observed with each condition during 10 minute samples in each dive. Four coral genera were sampled for four categories of threat: algal growth, partial bleaching, full bleaching and seastar predation.

Site	Guano Hut	Rush Hour	Average
Number of samples	4	4	4
Acropora			
Algal Growth	0	0	0
Fungia			
Bleached	0	0	0
Partly Bleached	1	0	0.5
Pocillopora			
Algal Growth	0	0	0
Bleached	0	0	0
Partly Bleached	0	0	0
Seastar Predation	0	0	0
Porites			
Bleached	0	0	0
Partly Bleached	0	0	0
Seastar Predation	0	0	0
TOTAL	1	0	0.5

Table 22. Number of key invertebrates observed at McKean Island, in replicate 10-minute samples.

Site	Guano Hut	Rush Hour
Number of samples	4	5
Sea cucumbers		
Bohadschia argus	0	0
Holothuria atra	0	0
Holothuria leucospilota	2	0
Lobster	0	0
Clams (*Tridacna* sp.)	1	23
Acanthaster planci	0	0

Sea Birds. Large aggregations of birds were nesting on this island. Nearly the entire island was surveyed, allowing us to assess the bird populations with some certainty. Bird nesting sites were found throughout this island, with the large aggregations estimated at 2,000-4,000 spectacled or sooty terns, 2,000- 3,000 small white fairy-terns, 5,000-10,000 brown boobies, 10,000-20,000 great frigate birds, 1,000-2,000 brown noddies, and 5,000-10,000 masked boobies. Also present in lesser undetermined numbers were red-footed boobies (*Sula sula*). Probable petrel burrows were also observed, but no birds were seen. Several unidentified shorebirds, probably migrants, were also seen.

Marine Turtles. Due to the relatively small size of this island, researchers surveyed all sandy beach edges. Two recent green sea turtle tracks and nests were

Table 23. Numbers of large indicator fish species at McKean Island.

Scientific Name	Common Name	Guano Hut	Rushhour
TUNA AND PELAGICS			
Gymnosarda unicolor	Dogtooth Tuna	1	3
Euthynnus affinis	Mackerel Tuna	0	6
Scomberoides lysan	Double-spotted Queenfish	4	5
Elegatis bipinnulata	Rainbow Runner	15	12
JACKS			
Caranx sexfasciatus	Bigeye Trevally	0	0
Caranx melampygus	Bluefin Trevally	24	16
Caranx lugubris	Black Trevally	10	17
REEF PREDATORS			
Sphyraena qenie	Chevron Barracuda	0	0
Cheilinus undulatus	Napoleon Wrasse	3	6
Epinephelus fuscoguttatus	Flowery Cod	2	4
Plectropomus laevis	Footballer Trout	0	0
Aprion virescens	Green Jobfish	2	4
Lutjanus bohar	Red Bass	20	25
Macolor macularis	Midnight Seaperch	0	0
SHARKS AND RAYS			
Carcharhinus melanopterus	Blacktip Reef Shark	2	2
Carcharihinus amblyrhynchos	Grey Reef Shark	20	9
Triaenodon obesus	Whitetip Reef Shark	1	2
Manta birostris/alfredi	Manta Ray	0	0

Table 24. Average abundance of key fish families in 10-minute samples at McKean Island.

Site	Guano Hut	Rush Hour
Epinephelinae (Groupers)	4	6
Lujanidae (Snappers)	40	18
Scaridae (Parrotfishes)	0	0
Acanthuridae (Surgeon and Unicornfishes)	0	14
Balistidae (Triggerfishes)	23	12

Table 25. Abundance and list of butterfly fishes (Chaetodontidae), angel fishes (Pomacanthidae) and anemone fishes (Pomacentridae; Amphiprioninae) species recorded at McKean Island.

Family	#	Species
Butterfly fishes	7	*Chaetodon auriga, C. ephippium, C. lunula, C. meyeri, C. ornatissimus, C. quadrimaculatus* *Forcipiger flavissimus*
Angel fishes	4	*Apolemichthys arcuatus* *Centropyge flavissimus, C. loriculus* *Pomacanthus imperator*
Anemone fish	1	*Amphiprion chrysopterus*

identified on the southern beach of this island. The tracks were fresh and may have represented nesting behavior within the past month. During three SCUBA surveys, a total of two green turtles and one hawksbill turtle were observed in situ.

Marine Mammals. There were no marine mammals observed at McKean.

Kanton (Aba-Riringa) Island

Site Descriptions. Kanton was the third and largest island on the trip itinerary and the first with a large lagoon. Twelve dives were made on nine unique sites (Table 26), of which four were on the leeward side, one windward, and two in the lagoon. As the largest island of the Phoenix group, and in the form of a true atoll with a large lagoon, Kanton had the largest variety of habitats to be surveyed. The lee of the island was the largest so far visited but, as with Nikumaroro, this only comprised the farthest western portion of the island. The lagoon of Kanton measured over 10 x 4 kilometers in length and width with the only opening at the leeward side through a channel artificially widened by blasting.

Table 26. Dive and survey sites at Kanton Island.

Date	Time	Name	Latitude	Longitude	Exposure
2-Jul-00	9:55 am	British Gas	02°49.20	171°43.15	Leeward
2-Jul-00	1:50 pm	Satellite Beach	02°47.47	171°43.81	Leeward
2-Jul-00	4:30 pm	President Taylor	02°49.03	171°43.15	Leeward
2-Jul-00	6:20 pm	British Gas	02°49.20	171°43.15	Leeward
3-Jul-00	7:50 am	Weird Eddie	02°48.86	171°43.34	Channel
3-Jul-00	11:50 am	Six Sticks	02°48.39	171°43.51	Leeward
3-Jul-00	2:45 pm	Coral Castles	02°48.22	171°42.61	Lagoon
3-Jul-00	6:45 pm	Six Sticks	02°48.37	171°43.50	Leeward
4-Jul-00	7:50 am	Nai'a Fly'a	02°48.91	171°43.24	Channel
4-Jul-00	12:10 pm	Steep To	02°50.32	171°42.47	Windward
4-Jul-00	3:00 pm	House of Cards	02°47.53	171°42.29	Lagoon
4-Jul-00	6:45 pm	Six Sticks	02°48.36	171°43.49	Leeward

The leeward sites showed a more highly developed reef community structure than at the islands visited so far with a broader shallow slope at 10-20 meters and greater development of a coral community. In 0 - 10 m of water the bottom was mostly made up of a solid wall and rock platform cut by deep surge channels. From 20 m and deeper the reef sloped steeply, as in previous islands visited, with a high proportion of rubble and large boulders.

At its entrance, the lagoon experiences very high tidal flows with extensive coral gardens extending a radius of approximately 2 km from the channel. Starting at about 4 km inside of the channel, the lagoon is crossed by four north-south reef ledges (Pacific Islands Pilot 1984, Jokiel and Maragos 1978) that reduce water flow and suppress coral growth. Surveys were restricted to the coral gardens zone which was characterized by highly developed *Acropora* tables and staghorn thickets growing over a sandy bottom with dunes and rocky spires.

Bottom cover. Coral communities were more highly developed on the Kanton reefs than at previous islands surveyed. The high end of coral development was represented by Satellite Beach with > 50% coral cover and approaching 100% on a 10 m scale of small patch reefs (Fig. 4). British Gas and Six Sticks represented the more average conditions with 30-40% coral cover and relatively high abundance of rubble, sand and turf and fleshy algae. Coralline algae and *Halimeda* were less abundant than at previous islands. Coral Castles in the lagoon, dominated by large tabular and staghorn *Acropora* colonies covering sandy and rocky substrates, had the highest coral cover of all sites on the expedition at > 80%. In the lagoon, coralline and other algae were only present underneath the canopy cover of coral colonies making identification on the video difficult.

Vertical and steep slopes also had more highly developed coral communities than seen at the previous islands. At Steep To, for example, on the windward side, the shallow slope was developed into a wall with deep canyons and caves supporting abundant and diverse coral and invertebrate growth. At Satellite Beach, the deeper steep slope had strong growth of small and medium-size corals on the rubble bottom, giving a high coral cover and diversity.

Corals. The coral community was morphologically more diverse at the Kanton outer sites (Fig. 4), generally dominated by the same branching and encrusting/submassive corals as found previously (**Table 27**) . At Six Sticks there was a significant presence of massive and staghorn corals in the genera *Leptastrea/Favia* and *Acropora*,

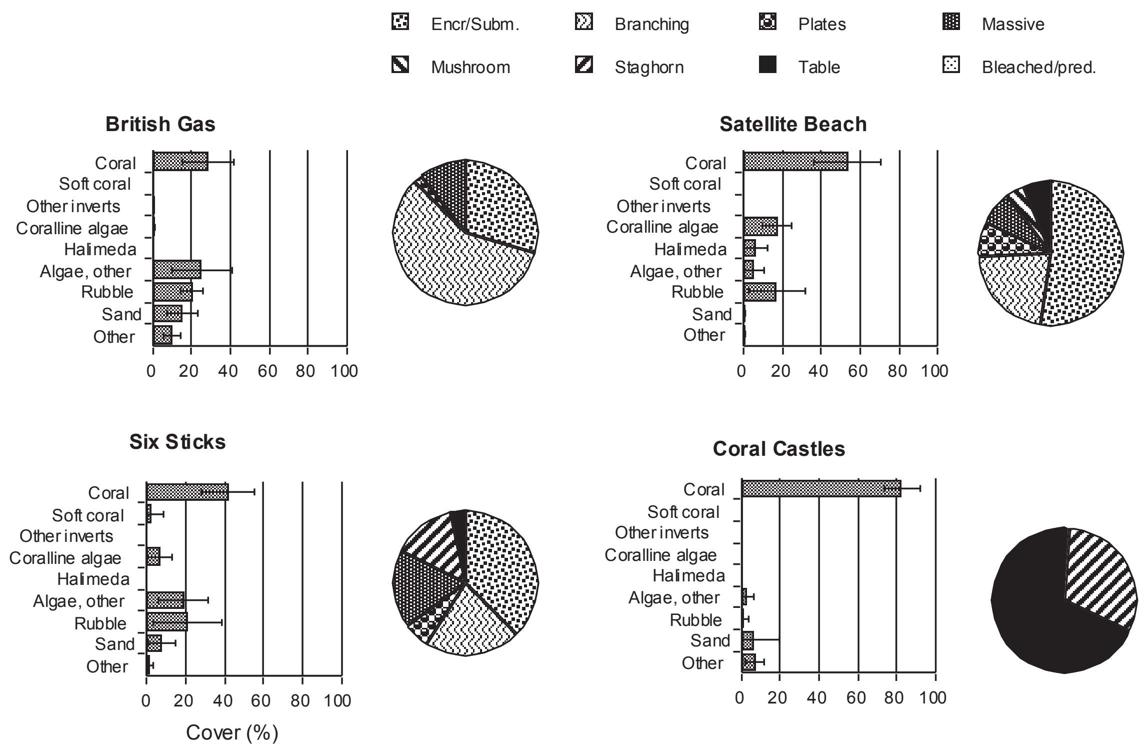

Figure 4. Benthic cover and relative abundance of coral growth forms at Kanton Island. See Figure 2 for legend.

Table 27. The 10 most abundant coral species at Kanton Island.

Family	Coral species
Acroporidae	*Acropora cytherea, Montipora efflorescens*
Agariciidae	*Pavona varians, Pavona explanulata*
Faviidae	*Leptastrea purpurea, Favia stelligera, Echinopora lamellosa*
Fungiidae	*Halomitra pileus*
Milleporidae	*Millepora platyphylla*
Pocilloporidae	*Pocillopora verrucosa*

respectively. The dominance of *Acropora* in the lagoon at Coral Castles is clearly shown by the dominance of table and staghorn morphologies. The lagoon sites surveyed are among the most highly developed *Acropora* communities we have seen anywhere in the world.

Six sites were sampled for coral species presence, yielding 73 species. Kanton had the highest single-site and island-wide number of coral species of all the islands, with 76% of all coral species recorded. Further evidence of the health of coral communities at Kanton was the near absence of signs of threat to corals, with only algal overgrowth recorded for two coral colonies in the four sites surveyed (Table 28).

Table 28. Frequency of coral threats observed at Kanton Island. See caption to Table 15 for details.

	Satellite Beach	British Gas	Six Sticks	Steep To	Average
Number of samples	5	3	3	3	3.5
Acropora					
Algal Growth	0	1	0	0	0.25
Fungia					
Bleached	0	0	0	0	0
Partly Bleached	0	0	0	0	0
Pocillopora					
Algal Growth	1	0	0	0	0.25
Bleached	0	0	0	0	0
Partly Bleached	0	0	0	0	0
Seastar Predation	0	0	0	0	0
Porites					
Bleached	0	0	0	0	0
Partly Bleached	0	0	0	0	0
Seastar Predation	0	0	0	0	0
TOTAL	1	1	0	0	0.5

Invertebrates. As at Nikumaroro, invertebrates were noticeably absent with only a few giant clams (genus *Tridacna*) noted on fore reef slopes,and a lobster in the complex canyons and caves at Steep To (Table 29).

Fishes. The general fish fauna at Kanton was similar to that at previous islands, with regular occurrence of dogtooth tuna, barracuda, red bass and sharks at all sites. Exceptionally abundant fish populations were recorded around the channel leading into the lagoon at the sites NAI'A Fly'a, President Taylor and Weird Eddie (Table 30,

Table 31). Schooling trevally were present in massive schools, congregating there with 1,000s-strong schools of parrot fish on the turn of the tides. Intense spawning activity was noted of the parrot fish, *Hipposcarus longiceps*, at the mouth of the channel on the new moon at the onset of the ebbing tide. A large school of snapper was recorded on the fore reef at the site British Gas (Table 31), consisting largely of *Lutjanus gibbus*, commonly seen throughout the islands. Manta rays were observed in the area of the channel mouth and patrolling the reef margin to the north.

Table 29. Number of key invertebrates observed at Kanton Island, in replicate 10-minute samples.

Site	**British Gas**	**Satellite Beach**	**Six Sticks**	**Steep To**
Number of samples	3	5	3	3
Sea cucumbers				
Bohadschia argus	0	0	0	0
Holothuria atra	0	0	0	0
Holothuria leucospilota	0	0	0	0
Lobster	0	0	0	1
Clams (*Tridacna* sp.)	0	2	1	1
Acanthaster planci	0	1	0	0

Table 30. Numbers of large indicator fish species at Kanton Island.

Scientific Name	Common Name	British Gas	NAI'A Fly'a	Satellite Beach	Weird Eddie
TUNA AND PELAGICS					
Gymnosarda unicolor	Dogtooth Tuna	0	7	4	6
Euthynnus affinis	Mackerel Tuna	0	0	0	0
Scomberoides lysan	Double-spotted Queenfish	1	0	0	11
Elegatis bipinnulata	Rainbow Runner	20	14	8	18
JACKS					
Caranx sexfasciatus	Bigeye Trevally	0	1000	0	700
Caranx melampygus	Bluefin Trevally	19	25	57	25
Caranx lugubris	Black Trevally	7	20	7	50
REEF PREDATORS					
Sphyraena qenie	Chevron Barracuda	10	16	1	100
Cheilinus undulatus	Napoleon Wrasse	9	7	7	4
Epinephelus fuscoguttatus	Flowery Cod	2	2	7	2
Plectropomus laevis	Footballer Trout	0	0	0	0
Aprion virescens	Green Jobfish	1	2	0	0
Lutjanus bohar	Red Bass	20	17	40	35
Macolor macularis	Midnight Seaperch	0	0	0	0
SHARKS AND RAYS					
Carcharhinus melanopterus	Blacktip Reef Shark	0	0	0	0
Carcharhinus amblyrhynchos	Grey Reef Shark	5	5	13	2
Triaenodon obesus	Whitetip Reef Shark	1	4	2	2
Manta birostris/alfredi	Manta Ray	0	2	0	2

Table 31. Average abundance of key fish families in 10-minute samples at Kanton Island.

Site	British Gas	President Taylor	Satellite Beach	Weird Eddie
Groupers	2	4	3	8
Snappers	1,000	110	65	11
Parrotfishes	7	800	18	8
Surgeonfishes	21	18	12	18
Triggerfishes	7	5	3	16

Despite its larger size, Kanton had a lower diversity of buttefly fishes and angel fishes than Nikumaroro (15 compared to 21, and five compared to seven, respectively, Table 32). This may, however, be due to repeat sampling at Nikumaroro at the end of the trip when more closely targeted observation for absent species may have yielded better survey results.

Table 32. Abundance and list of butterfly fishes (Chaetodontidae), angel fishes (Pomacanthidae) and anemone fishes (Pomacentridae; Amphiprioninae) species recorded at Kanton Island.

Family	#	Species
Butterfly fishes	15	*Chaetodon bennetti, C. ephippium, C. kleinii, C. lunula, C. meyeri, C. ornatissimus, C. quadrimaculatus, C. trifascialis, C. lunulatus, C. ulietensis, C. vagabundus* *Forcipiger flavissimus* *Heniochus acuminatus, H. singularis, H. varius*
Angel fishes	5	*Apolemichthys griffisi* *Centropyge flavissimus, C. loriculus, C. multifasciatus* *Pomacanthus imperator*
Amphiprioninae (Anemone fishes)	2	*Amphiprion chrysopterus, A. periderion*

Sea Birds. More than 20,000 brown noddies were seen returning to land at dusk and continued to be heard returning after dark. A small undetermined number of spectacled or sooty terns, as well as small white fairy-terns, were also seen from the water.

Marine Turtles. No beach surveys for nesting sites were conducted at this island. During nine SCUBA surveys, a total of one hawksbill and 34 green turtles were observed in situ.

Marine Mammals. Bottlenose dolphins were observed five times along the southwestern side of the island; two sightings occurred during night dives. All sightings consisted of groups of 10 – 15 individuals.

Enderbury Island

Site Descriptions. Enderbury was the fourth island on the trip itinerary with four dives made on a single day at four unique sites (one windward, three leeward, Table 33). Similar to McKean Island, Enderbury is a small island with no lagoon, a small west-facing leeward side, and rocky platforms extending north and south from the leeward edge. The Southern Ocean site was the most windward facing point surveyed so far on the expedition at the extreme southeastern point of the island and facing straight into the south and easterly wind and swells.

Table 33. Dive and survey sites at Enderbury Island.

Date	Time	Name	Lat. (S)	Long. (W)	Exposure
5-Jul-00	7:45 am	Southern Ocean	03°08.79	171°04.51	Windward
5-Jul-00	12:15 pm	Obs Spot	03°08.45	171°05.71	Leeward
5-Jul-00	3:45 pm	Shark Village	03°06.22	171°05.44	Leeward
5-Jul-00	7:00 pm	Bird Beach	03°07.29	171°05.74	Leeward

The survey sites were similar to locations surveyed on previous islands. The leeward site was even more dramatic in its depth profile, with a sharp reef edge at about 15m. Above this was a gently sloping platform dominated by rubble (Fig. 5), to an extent not seen before on the trip. The rubble bottom was interrupted in places by the underlying rocky substrate, increasingly at shallow depths. The deeper slope was steep, almost entirely composed of large rubble pieces jammed together. The influence of ocean swell and wave-induced breakage of corals was clear in the amount of old and fresh rubble, with strong transport of the rubble down the reef slope.

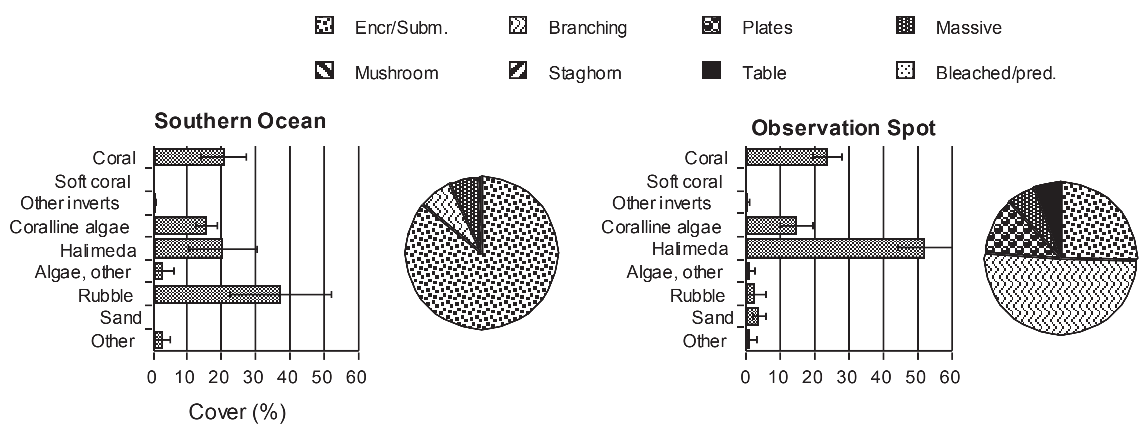

Figure 5. Benthic cover and relative abundance of coral growth forms at Enderbury Island. See Figure 2 for legend.

Bottom Cover. Both leeward and windward slopes were dominated by coral rubble (Figure 5), clearly produced by breakage from the existing corals, and, from observation on the beach and the island, from the rock that makes up the island. Algal cover on the rubble and rock surfaces was predominantly coralline algae and *Halimeda*. There was little evidence of soft coral and other invertebrates, perhaps due to the highly mobile rubble.

Corals. Coral cover at both survey sites was relatively low, at 20-25%, and clearly contributed to the abundant rubble. The dominance of encrusting/submassive corals at the windward site attests to the continual breakage of branching and plating forms. Few large coral colonies and many small ones were seen, indicating frequent breakage preventing growth to large size. Coral diversity was moderate, with 47 species recorded from 2 dives. Species in the genus *Pavona* were particularly abundant (Table 34), often found in areas of high physical disturbance and opportunistic growth. Coral condition and threats were not surveyed as at previous sites but little stress was seen and the only major influence noted was physical breakage, as mentioned above.

Table 34. The 10 most abundant coral species at Enderbury Island.

Family	Coral species
Agariciidae	*Pavona clavus, P. maldivensis, P. minuta, P. varians*
Faviidae	*Favia stelligera, Leptastrea purpurea, Favites pentagona*
Fungiidae	*Halomitra pileus*
Pocilloporidae	*Pocillopora verrucosa*
Poritidae	*Porites lutea*

Invertebrates. Invertebrate surveys were not conducted due to injury to the collector. Observations recorded the presence of *Tridacna* clams in moderate numbers (see previous results), three species of holothurian including *Bohadschia argus*, and the seastar *Linkia* spp.

Fishes. Overall, the fish populations at Enderbury had a larger component of pelagic species than the other islands and fewer coral reef species. In terms of the large fishes, more rainbow runner and black trevally were recorded than previously (Table 35). Most noticeably, the abundance of sharks, particularly grey reef sharks, at the windward point was significantly larger than previously seen at other islands. Red bass was also present in larger numbers. Triggerfishes were more abundant than previously noted with large numbers of the planktivorous black and blue durgons, *Odonus niger* and *Melichthys niger*, respectively (Table 36).

The populations of butterfly fishes, angel fishes and anemone fishes at Enderbury were noticeably less diverse than all the other islands, including McKean, with only three butterfly species seen (Table 37).

Sea Birds. Large aggregations of birds were nesting on this island including, in just one area, 10,000-15,000 great and lesser frigate birds and 30,000+ spectacled or sooty terns. In addition, smaller numbers of other birds were observed including masked and brown boobies, red-tailed tropic birds (*Phaethon rubricauda*), brown noddies, little white fairy-terns, and several shorebirds (one plover and one possible yellowlegs). Birds of all ages, of various species, were observed, as were eggs.

Marine Turtles. All beaches were carefully walked on this island, without evidence of turtle nesting. During three SCUBA surveys, a total of five green turtles were observed in situ.

Marine Mammals. No marine mammals were seen at Enderbury.

Table 35. Numbers of large indicator fish species at Enderbury Island.

Scientific Name	**Common Name**	**Obs. Spot**	**Shark Village**	**Southern Ocean**
TUNA AND PELAGICS				
Gymnosarda unicolor	Dogtooth Tuna	1	1	3
Euthynnus affinis	Mackerel Tuna	3	4	0
Scomberoides lysan	Double-spotted Queenfish	0	0	0
Elegatis bipinnulata	Rainbow Runner	30	46	18
JACKS				
Caranx sexfasciatus	Bigeye Trevally	0	0	0
Caranx melampygus	Bluefin Trevally	0	20	30
Caranx lugubris	Black Trevally	50	30	60
REEF PREDATORS				
Sphyraena qenie	Chevron Barracuda	0	20	0
Cheilinus undulatus	Napoleon Wrasse	0	2	2
Epinephelus fuscoguttatus	Flowery Cod	0	0	0
Plectropomus laevis	Footballer Trout	0	0	0
Aprion virescens	Green Jobfish	0	2	0
Lutjanus bohar	Red Bass	45	30	60
Macolor macularis	Midnight Seaperch	0	0	0
SHARKS AND RAYS				
Carcharhinus melanopterus	Blacktip Reef Shark	1	0	2
Carcharhinus amblyrhynchos	Grey Reef Shark	18	30	20
Triaenodon obesus	Whitetip Reef Shark	4	6	3
Manta birostris/alfredi	Manta Ray	0	0	0

Table 36. Average abundance of key fish families in 10-minute samples at Enderbury Island.

Site	Obs. Spot	Shark Village	Southern Ocean
Groupers	0	6	6
Snappers	29	18	0
Parrotfishes	3	8	0
Surgeonfishes	11	12	21
Triggerfishes	26	32	50

Table 37. Abundance and list of butterfly fishes (Chaetodontidae), angel fishes (Pomacanthidae) and anemone fishes (Pomacentridae; Amphiprioninae) species recorded at Enderbury Island.

Family	#	Species
Butterfly fishes	3	*Chaetodon quadrimaculatus, C. punctatofasciatus, Forcipiger flavissimus.*
Angel fishes	4	*Apolemichthys griffisi Centropyge flavissimus, C. loriculus Pomacanthus imperator*
Amphiprioninae (Anemone fishes)	1	*Amphiprion chrysopterus*

Rawaki (Phoenix) Island

Site Descriptions. Rawaki Island was the fifth island on the trip itinerary with four dives made on one day, at three leeward sites (Table 38). Phoenix Island was slightly larger than Enderbury and McKean Islands, but with similar terrestrial habitats and more nearly circular. As with the others, the lee of the island comprised only the farthest western portion of the island with a long sandy beach bordered at the north and south by a rocky platform with heavy surf from the windward sides. The survey sites sloped gently from the beach margin, consisting of a sandy bottom with large coral bommies bearing high densities of coral heads. At 15-20m, the sandy bottom flowed into large and steep sandy canyons with the coral bommies coalescing into rocky and hard-substrate spurs, sloping steeply into deep water.

Table 38. Dive and survey sites at Rawaki Island.

Date	Time	Name	Lat. (S)	Long. (W)	Exposure
6-Jul-00	7:45 am	Stillwater	03°43.39	170°42.91	Leeward
6-Jul-00	10:45 am	Deepwater	03°43.18	170°43.00	Leeward
6-Jul-00	2:10 pm	Clearwater	03°43.60	170°42.79	Leeward
6-Jul-00	4:50 pm	Stillwater	03°43.39	170°42.91	Leeward

Bottom Cover. Excluding the sandy bottom between the coral bommies, the three dive sites at Rawaki Island had among the highest cover of live coral of all the fore-reef slopes visited comparable to Six Sticks at Kanton Island. The rocky platforms and spurs of Stillwater and Deepwater had coral cover of over 60% (Fig. 6) with coralline algae as the next dominant cover category in shallow water and rubble on the steep slopes in deeper water.

Corals. Unlike other sites, branching corals were not dominant at Rawaki Island with highest cover contributed by encrusting/submassive colonies at one site and plates at the other two (Fig. 6). Massive corals were also significant in abundance, reflecting the origin of the coral bommies that form the main reef substrate of the sites. Two sites were sampled for coral species yielding 38 species, a relatively low number compared to the other islands surveyed. The high abundance of massive corals recorded at Rawaki Island (Fig. 6) is reflected in the abundance of small and medium-sized massive colonies of 5 faviid species (Table 39).

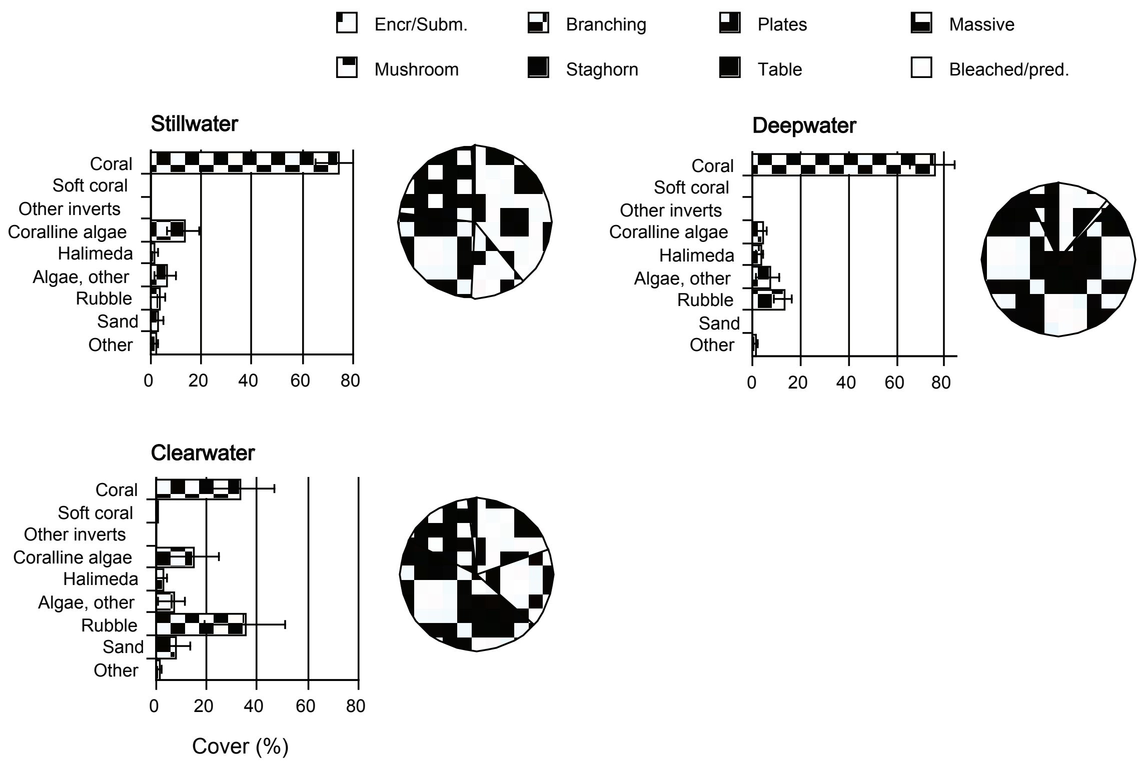

Figure 6. Benthic cover and relative abundance of coral growth forms at Rawaki Island. See Figure 2 for legend.

Table 39. The 10 most abundant coral species at Rawaki Island.

Family	Coral species
Acroporidae	*Acropora cytherea, Montipora efflorescens*
Faviidae	*Cyphastrea chalcidicum, Favia rotumana, Favia stelligera, Leptastrea purpurea, Montastrea annuligera*
Agariciidae	*Pavona varians*
Pocilloporidae	*Pocillopora eydouxi*
Poritidae	*Porites lutea*

Coral condition and threats were not quantified but little stress was seen. The only major influence noted was a high proportion of rubble in shallow water at Deepwater where surf refracted around the southern point causing breakage of corals. The elevation of coral heads on large bommies above the bottom likely has a large effect in reducing scouring damage by sand and rubble during storms.

Invertebrates. Invertebrate surveys were not conducted.

Fishes. Rawaki Island survey sites had a relatively low abundance of pelagic species, tuna, groupers and sharks. The dominant large fishes seen were the black trevally and red bass (Table 40). The dominance of large coral bommies at the sites were reminiscent of high-current patch reefs of mainstream Indo-Pacific reef systems potentially influencing the predatory fish fauna in a similar way towards an abundance of jacks and snappers as dominant predators. No data were recorded on the abundance of the key fish families.

Table 40. Numbers of large indicator fish species at Rawaki Island.

Scientific Name	Common Name	Rawaki	
		North West	South West
TUNA AND PELAGICS			
Gymnosarda unicolor	Dogtooth Tuna	1	0
Euthynnus affinis	Mackerel Tuna	0	0
Scomberoides lysan	Double-spotted Queenfish	0	0
Elegatis bipinnulata	Rainbow Runner	8	6
JACKS			
Caranx sexfasciatus	Bigeye Trevally	0	0
Caranx melampygus	Bluefin Trevally	6	9
Caranx lugubris	Black Trevally	20	40
REEF PREDATORS			
Sphyraena qenie	Chevron Barracuda	2	2
Cheilinus undulatus	Napoleon Wrasse	2	8
Epinephelus fuscoguttatus	Flowery Cod	0	0
Plectropomus laevis	Footballer Trout	0	0
Aprion virescens	Green Jobfish	1	3
Lutjanus bohar	Red Bass	50	50
Macolor macularis	Midnight Seaperch	0	0
SHARKS AND RAYS			
Carcharhinus melanopterus	Blacktip Reef Shark	0	0
Carcharhinus amblyrhynchos	Grey Reef Shark	2	4
Triaenodon obesus	Whitetip Reef Shark	3	2
Manta birostris/alfredi	Manta Ray	0	0

Rawaki Island had a representative assemblage of butterfly fishes (nine species compared to highs of 15 at Kanton and 21 at Nikumaroro where sampling was more intensive), and a full complement of angel fishes and anemone fishes (five and two species respectively, Table 41).

Table 41. Abundance and list of butterfly fishes (Chaetodontidae), angel fishes (Pomacanthidae) and anemone fishes (Pomacentridae; Amphiprioninae) species recorded at Rawaki Island.

Family	#	Species
Butterfly fishes	9	*Chaetodon auriga, C. ephippium, C. lunula, C. meyeri, C. ornatissimus, C. ulietensis, C. unimaculatus, C. vagabundus Forcipiger flavissimus.*
Angel fishes	5	*Apolemichthys griffisi* *Centropyge flavissimus, C. loriculus, C. multifasciatus* *Pomacanthus imperator*
Amphiprionine (Anemone fishes)	2	*Amphiprion chrysopterus, A. periderion*

Sea Birds. The large numbers of birds nesting on this island created a strong guano odor that reached the boat offshore. Several spirals comprising 120 frigate birds each were seen over the water and the land. Tens of thousands of mostly great frigate birds were seen in one area, interspersed with occasional brown and masked boobies, as well as occasional red-footed boobies on their tall stick nests. Nests contained eggs or nestlings. A few juvenile lesser frigate birds were noted. The small area visited contained groups of mixed male-female great frigate birds as well as a group of 5000+ males; there was also a large area of same-age chicks alone. Present were a few little white fairy-terns on the wing and a few blue-grey noddies (*Procelsterna cerulea*) nesting. Also nesting were brown noddies with eggs and chicks. Two nesting red-tailed tropic birds were found in this area and one large juvenile. Several all-dark, unidentified petrels were found nesting under large rocks. Five shorebirds, probably migrants, were seen, of which three were whimbrels (*Numenius phaeopus*).

Marine Turtles. All beaches were carefully walked on this island and five green turtle nest sites were found. At the top of one nest a desiccated baby green sea turtle carcass was collected. During three SCUBA surveys, a total of three green turtles were observed in situ.

Marine Mammals. No marine mammals were seen at this island. (There were dozens of living rabbits observed on this island).

Manra (Sydney) Island

Site Descriptions. Manra was the sixth island visited on the expedition with four dives made at four unique sites. Two windward and twp leeward sites were visited; the first windward site (Northern Exposure) exposed to strong currents and refracted waves at the northern tip of the island and the second (Wild Side) on the southern tip of the island exposed to storms and swell from the south and east (Table 42).

Table 42. Dive and survey sites at Manra Island.

Date	Time	Name	Latitude	Longitude	Exposure
7-Jul-00	7:45 am	Harpoon Corner	04°27.15	171°15.93	Leeward
7-Jul-00	11:40 am	Northern Exposure	04°26.02	171°14.50	Windward
7-Jul-00	11:40 am	Northern Lee	04°26.05	171°14.70	Leeward
7-Jul-00	3:05 pm	Wild Side	04°27.64	171°13.42	Windward

The topography of the survey sites conformed to previous ones. The north windward point resembled closely the north windward sites at Nikumaroro (Windward Wing) with high cover of tightly packed branching and submassive corals, coralline algae and rubble on a shelf to about 15m, dropping sharply onto a rubble slope. The south windward slope resembled the similar site at Enderbury (Southern Ocean), with a shallow shelf dominated by the rubble of branching and plating corals broken by ocean swell and a sharp drop off onto a steep rubble wall. The leeward sites had the typical shallow shelf with a moderate cover of corals mixed with rubble and mixed algae turning into large coral bommies on a sandy bottom adjacent to a beach with a steep slope of rocky and rubble spurs between sand chutes.

Bottom Cover. The leeward sites showed typical coral communities for the Phoenix Islands with ≈ 30 % coral cover and 20 % coralline algae, followed by a mixture of fleshy algae, rubble and sand (Fig. 7). As with the other small, round islands, Manra had a beach on its leeward shore resulting in high supply of sand to the shallow subtidal platform, development of coral bommies, and steeply sloping sand chutes at 15-20m. The northern windward slope had a similar coral cover with comparable abundance of coralline algae and rubble indicating high levels of breakage by waves. The deep slope here was not as steep as most slopes so far encountered and was dominated by rubble tumbling down from the shallow platform above. The coral community at the southern windward site showed extreme influence of swell and storm damage with large expanses of recent partially living coral rubble, including many plates of the fast growing genus *Montipora* with coralline and turf algae on the dead parts of the rubble.

Corals. The coral communities at Manra were dominated by submassive and branching corals, typical of most survey sites (Fig. 7). The leeward site had a significant abundance of massive coral heads and the northern windward site had significant quantities of mushroom coral. Forty-three coral species were recorded in two dives with the abundance of submassive, massive and mushroom corals illustrated by the top 10 corals all being in the families Faviidae (massive/submassive) and Fungiidae (mushroom corals, Table 43).

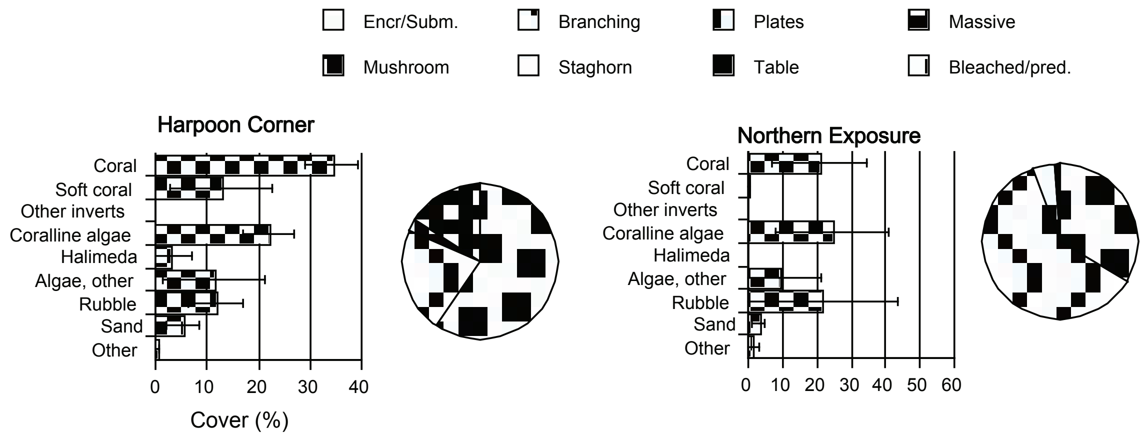

Figure 7. Benthic cover and relative abundance of coral growth forms at Manra Island. See Figure 2 for legend.

Table 43. The 10 most abundant coral species at Manra Island.

Family	Coral species
Faviidae	*Cyphastrea chalcidicum, Echinopora lamellosa, Favia rotumana, Favia stelligera, Favites pentagona*
Fungiidae	*Fungia danai, Fungia fungites, Fungia scutaria, Halomitra pileus, Herpolitha limax*

Fishes. Large predatory fishes were abundant at all survey sites in particular at or adjacent to the windward slopes (the Northern Lee site was around a point from Northern Exposure, which was not sampled for fishes). Northern Lee and Wild Side had high abundances of trevally, red bass and grey reef sharks, similar to populations encountered at the windward site at Nikumaroro and Enderbury (Table 44). Though not sampled quantitatively, Northern Exposure also had high abundances of sharks, trevally and barracuda.

The abundance of key fish families was moderate at the leeward sites surveyed in Manra with prominence of planktivorous triggerfishes(Table 45). The species diversity of butterfly fishes was high compared to those of other similar islands, reflecting the high diversity of coral species and complex topography of the coral bommy habitats. (Table 46)

Sea Birds. None noted.

Marine Turtles. All beaches were carefully walked on this island and 31 green turtle nest sites were found. During three SCUBA surveys, a total of 17 green turtles were observed in situ.

Marine Mammals. No marine mammals were seen at this island.

Table 44. Numbers of large indicator fish species at Manra Island.

Scientific Name	Common Name	Harpoon Corner	Northern Lee	Wild Side
TUNA AND PELAGICS				
Gymnosarda unicolor	Dogtooth Tuna	0	4	2
Euthynnus affinis	Mackerel Tuna	0	0	0
Scomberoides lysan	Double-spotted Queenfish	0	0	0
Elegatis bipinnulata	Rainbow Runner	20	6	20
JACKS				
Caranx sexfasciatus	Bigeye Trevally	0	0	50
Caranx melampygus	Bluefin Trevally	2	20	40
Caranx lugubris	Black Trevally	11	40	20
REEF PREDATORS				
Sphyraena qenie	Chevron Barracuda	200	100	10
Cheilinus undulatus	Napoleon Wrasse	2	4	4
Epinephelus fuscoguttatus	Flowery Cod	0	0	0
Plectropomus laevis	Footballer Trout	0	0	0
Aprion virescens	Green Jobfish	2	1	3
Lutjanus bohar	Red Bass	9	20	70
Macolor macularis	Midnight Seaperch	0	0	0
SHARKS AND RAYS				
Carcharhinus melanopterus	Blacktip Reef Shark	0	1	3
Carcharhinus amblyrhynchos	Grey Reef Shark	3	11	17
Triaenodon obesus	Whitetip Reef Shark	6	2	4
Manta birostris/alfredi	Manta Ray	0	0	0

Table 45. Average abundance of key fish families in 10-minute samples at Manra Island.

Site	Harpoon Corner	Northern Lee
Groupers	7	0
Snappers	7	8
Parrotfishes	2	6
Surgeonfishes	27	15
Triggerfishes	45	40

Table 46. Abundance and list of butterfly fishes (Chaetodontidae), angel fishes (Pomacanthidae) and anemone fishes (Pomacentridae; Amphiprioninae) species recorded at Manra Island.

Family	#	Species
Butterfly fishes	13	*Chaetodon bennetti, C. ephippium, C. meyeri, C. ornatissimus, C. quadrimaculatus, C. reticulatus, C. unimaculatus* *Forcipiger flavissimus, F. longirostris* *Heniochus acuminatus, H. monoceros, H. varius, H. singularis.*
Angel fishes	4	*Apolemichthys griffisi* *Centropyge flavissimus, C. loriculus* *Pomacanthus imperator*
Anemone fishes	2	*Amphiprion chrysopterus, A. periderion*

Orona (Hull) Island

Site Descriptions. Orona Island was the last island to be visited on the expedition before the final return to Nikumaroro. Seven dives and one snorkel survey (Lagoon Look 1) were conducted at six unique sites (Table 47). Orona is an atoll with a large lagoon second in size to Kanton but with several spill-overs and shallow channels allowing exchange between the lagoon and surrounding ocean. The lagoon was deep with 10 – 20 m basins dotted with shallow rubble patches on very fine white sand. Towards the main channel it had good development of bommies and rocky/rubble patches, with a low diversity of corals and high abundance of small *Tridacna* clams.

Table 47. Dive and survey sites at Orona Island.

Date	Time	Name	Lat. (S)	Long. (W)	Exposure
8-Jul-00	7:50 am	Algae Corner	04°30.58	172°13.56	Leeward
8-Jul-00	12:10 pm	Lagoon Look 1	04°30.37	172°08.32	Leeward
8-Jul-00	12:20 pm	Lagoon Look 2	04°29.83	172°09.31	Leeward
8-Jul-00	12:30 pm	Lagoon Look 3	04°29.49	172°10.15	Leeward
8-Jul-00	3:10 pm	Dolphin Ledge	04°28.90	172°10.45	Leeward
9-Jul-00	7:50 am	Aerials	04°32.05	172°12.39	Windward
9-Jul-00	11:00 am	Dolphin Ledge	04°28.89	172°10.45	Leeward
9-Jul-00	3:30 pm	Dolphin Ledge	04°28.89	172°10.45	Leeward

The outer reef sites were similar in topography to other sites visited, on windward and leeward sides, with two notable exceptions. Algae Corner on the western tip of the island did not have a deep wall or steep slope, the bottom deepening gradually from rocky and rubble patches as found in other sites to a rubble slope tailing off into deeper water. Dolphin Ledge, at the entrance to the lagoon channel on the north-western leeward shore was characterized by deep (3 - 5m vertical relief) and narrow surge channels in shallow water and leading into the lagoon giving way to a fine-rubble bottom steeply sloping at 15 – 20m into deep water. Unlike any other sites visited on the entire expedition Algae Corner and the shallow surge channels at Dolphin Ledge showed evidence of eutrophication, to be discussed below.

Bottom Cover. The survey sites at Orona Island had a number of unique characteristics in comparison to all the sites so far surveyed. Algae Corner showed evidence of high nutrient levels, currently and/or in the recent past by a high cover of filamentous wispy brown algae on all surfaces including rock, rubble, *Halimeda* and other algae (Fig. 8). Coral cover was extremely low at < 5%, though coral heads typical of a healthy reef were abundant though dead. Their varied appearance, levels of degradation and epiphytic algal covering suggested there was chronic mortality over an extended period of time. Nutrient enrichment was also apparent in the shallow surge channels at Dolphin Ledge at the entrance to the lagoon shown by the presence of small tufts of brown algae. This site also had a large iron anchor and chain extending from < 5 m down the slope and off the into the deep and evidence of shipwrecks on the beach. Iron enrichment causes characteristic “black turf” growths on remote atoll reefs, documented on Rose Reef and Tabuaeran in the

Line Islands (J. Maragos, pers. comm.), and this may have played a role in the degradation of Algae Corner. Additionally, we recorded observations by the residents of Orona in 2002, that there was a high incidence of ciguatera in fish from this site, probably related to eutrophication and algal growth.

The Aerials survey site was similar to other windward sites with large quantities of recent coral rubble, covered with coralline algae, and healthy coral populations though at a low cover of 20%. Dolphin Ledge had a very high proportion of fine, interlinked coral rubble on the bottom with many small living corals cemented onto this mobile substrate. Nevertheless, coral recruitment and growth were robust and diversity high.

At inner leeward lagoon sites, 10 coral species were identified typical of high-silt environments (e.g., *Favia* spp., *Cyphastrea chalcidium*, *Acropora lovelli*), growing loose on fine calcareous silt in aggregated patches with abundant *Tridacna* clams. Towards the center and windward side of the lagoon the sandy bottom became coarser with coral growth developing around dead bommies and small patch reefs. Coral diversity increased progressively towards the lagoon channel, with increasing presence of outer-reef species.

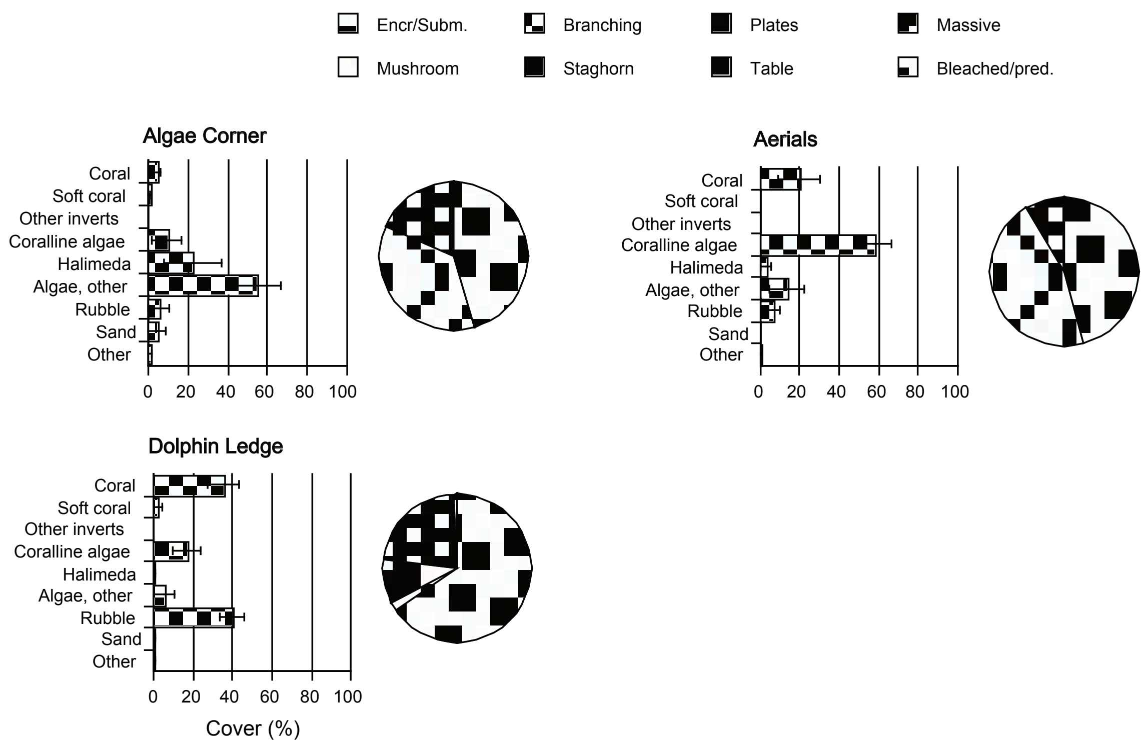

Figure 8. Benthic cover and relative abundance of coral growth forms at Manra Island. See Figure 2 for legend.

Corals. Coral species diversity was moderate at Orona with 49 species recorded from four dives. As at Manra, faviid species were particularly abundant (Table 48) along with the encrusting and submassive agariciids and *Montipora* plates. Threats to corals were reported for Dolphin Ledge, with overgrowth of *Pocillopora* colonies by algae as the main condition observed, linked to other signs of eutrophication (Table 49).

Table 48. The 10 most abundant coral species at Orona Island.

Family	Coral species
Faviidae	*Favia rotumana, Favia stelligera, Goniastrea edwardsi, Echinopora lamellosa, Leptastrea purpurea, Cyphastrea chalcidicum*
Agariciidae	*Pavona varians, Pavona clavus, Leptoseris mycetoseroides*
Acroporidae	*Montipora efflorescens*

Table 49. Frequency of coral threats observed at Orona Island. See caption to Table 15 for details.

Site	Dolphin Ledge
Number of samples	4
Acropora	
Algal Growth	0
Fungia	
Bleached	0
Partly Bleached	0
Pocillopora	
Algal Growth	6
Bleached	1
Partly Bleached	0
SeastarPredation	0
Porites	
Bleached	0
Partly Bleached	0
Seastar Predation	0
TOTAL	7

Invertebrates. Key invertebrate populations were sampled at Orona, at Dolphin Ledge, and in the lagoon. Dolphin Ledge had similar low densities of invertebrates as recorded at other outer reef sites (Table 50). The short survey conducted in the lagoon on a dense aggregate of corals and clams revealed very high densities of *Tridacna* sp. with numbers over 50 m^{-2} counted.

Table 50. Number of key invertebrates observed at Orona, in replicate 10-minute samples.

Site	Dolphin Ledge	Lagoon
Number of samples	4	1
Sea cucumbers	0	0
Bohadschia argus	0	0
Holothuria atra	0	0
Holothuria leucospilota	0	0
Lobster	0	0
Clams (*Tridacna* sp.)	1	523
Acanthaster planci	0	0

Fishes. The large fish fauna of Orona was typical of other sites visited though with generally lower tuna and pelagic fish numbers. Algae Corner had lower populations of schooling predators with large schools of barracuda, abundant red bass and abundant grey reef sharks at Aerials and Dolphin Ledge (Table 51). Herbivores were present in high abundance at Algae Corner, with larger numbers of parrotfishes than recorded before (Table 52). The diversity of butterfly fish species at Orona was relatively high reflecting the larger number of dives made and vibrant coral community. The diversity of angel fishes and anemone fishes was similar to most of the other islands, except for McKean and Enderbury (Table 53).

Table 51. Numbers of large indicator fish species at Orona.

Scientific Name	Common Name	Aerials	Algae Corner	Dolphin Ledge
TUNA AND PELAGICS				
Gymnosarda unicolor	Dogtooth Tuna	1	2	0
Euthynnus affinis	Mackerel Tuna	0	0	0
Scomberoides lysan	Double-spotted Queenfish	0	3	0
Elegatis bipinnulata	Rainbow Runner	2	2	7
JACKS				
Caranx sexfasciatus	Bigeye Trevally	0	0	0
Caranx melampygus	Bluefin Trevally	35	9	8
Caranx lugubris	Black Trevally	25	20	30
REEF PREDATORS				
Sphyraena qenie	Chevron Barracuda	100	0	200
Cheilinus undulatus	Napoleon Wrasse	3	3	4
Epinephelus fuscoguttatus	Flowery Cod	1	0	0
Plectropomus laevis	Footballer Trout	0	0	0
Aprion virescens	Green Jobfish	0	2	2
Lutjanus bohar	Red Bass	20	8	30
Macolor macularis	Midnight Seaperch	0	0	0
SHARKS AND RAYS				
Carcharhinus melanopterus	Blacktip Reef Shark	2	3	3
Carcharhinus amblyrhynchos	Grey Reef Shark	25	13	17
Triaenodon obesus	Whitetip Reef Shark	0	2	1
Manta birostris/alfredi	Manta Ray	0	0	0

Table 52. Average abundance of key fish families in 10-minute samples at Orona Island.

Site	Aerials	Algae Corner	Dolphin Ledge
Groupers	4	4	1
Snappers	0	100	12
Parrotfishes	3	75	4
Surgeonfishes	6	25	8
Triggerfishes	20	38	10

Table 53. Abundance and list of butterfly fishes (Chaetodontidae), angel fishes (Pomacanthidae) and anemone fishes (Amphrionae, Pomacentridae) species recorded at Orona Island.

Family	#	Species
Butterfly fishes	1 7	*Chaetodon auriga, C. ephippium, C. kleinii, C. lunula, C. meyeri, C. ornatissimu* *punctatofasciatus, C. quadrimaculatus, C. reticulatus, C. lunulatus, C. ulietensis,* *Forcipiger flavissimus, F. longirostris* *Heniochus acuminatus, H. chrysostomus, H. monoceros, H. varius*
Angel fishes	5	*Apolemichthys griffisi, Centropyge bicolor, C. flavicauda, C. flavissimus, C. lori*
Anemone fishes	2	*Amphiprion chrysopterus, A. periderion*

Sea Birds. In one area, tens of thousands of adult sooty terns were seen nesting beneath bushes with many chicks. No juvenile sooty terns were observed, however. A few frigate birds, little white fairy-terns, brown noddies, and an occasional brown booby and masked booby were seen.

Marine Turtles. Only a small portion of these beaches were surveyed and 12 probable green turtle nest sites were found. During six SCUBA surveys, a total of 13 green turtles were observed in situ.

Marine Mammals. No marine mammals were seen at this island

Island Results – Overall Synthesis

Bottom Cover. Taking all survey sites together, the dominant bottom cover was hard coral (36.0%) followed by coralline algae (18.0%), rubble (16.7%), turf and fleshy algae (11.6%) and *Halimeda* (10.4%). Other benthic categories had total covers of > 3%. The dominance of coral and coralline algae indicates healthy reef ecosystems dominated by calcifying organisms and active reef framework growth. The high abundance of rubble is testimony of the dramatic influence of wave energy from open ocean storms and swell. The level of exposure to storms is indicated by the dominance trends among benthic categories (Table 54):

1. Windward sites were characterized by coralline algae (which are more resistant to high wave energy than corals), rubble and *Halimeda* growth;
2. The single lagoon site surveyed had the highest cover of hard coral;
3. Leeward sites had higher abundances of hard and soft corals and turf and turf and fleshy algal cover.

A cluster analysis of mean benthic cover shows these relationships by grouping, in the top basal branch of the tree (Fig. 9) two subbranches of sites dominated by coralline algae and *Halimeda* on the one hand (Group 1, Table 55) and hard coral on the other (Group 2). The lower half of the tree contains a main group with nine sites with high cover of rubble (Group 4) and two outliers, of single sites with unusually high algae cover (Algae Corner) and sand (British Gas). The cluster analysis emphasizes the principal characteristics of coral reef sites in the Phoenix Islands where robust and dynamic growth of corals and coralline algae, indicating healthy reef growth, is offset by high levels of physical disturbance that produces rubble. This illustrates the dominant controlling force of water energy on the island reefs.

Table 54. Mean and standard error of benthic cover categories by exposure.

	Windward (17)		Lee (78)		Lagoon (5)		Comparison
Cover type	m	se	m	se	m	Se	
Coral	24.1	2.2	35.4	2.3	85.8	4.9	Lag > Lee > Wind
Soft coral	0.1	0.1	2.3	0.8	0.0	0.0	Lee > Wind/Lag
Turf/Fleshy Algae	6.0	2.1	13.4	2.0	2.9	1.5	Lee > Wind > Lag
Coralline Algae	29.6	4.0	16.7	1.3	0.0	0.0	Wind > Lee > Lag
Halimeda	17.3	4.0	9.5	1.8	0.0	0.0	Wind > Lee > Lag
Rubble	20.6	4.5	16.8	1.8	1.1	1.1	Wind/Lee > Lag
Sand	1.0	0.4	3.9	0.6	6.3	6.0	Lag/Lee > Wind
Other	1.3	0.5	1.8	0.3	4.0	0.7	Lag > Lee/Wind

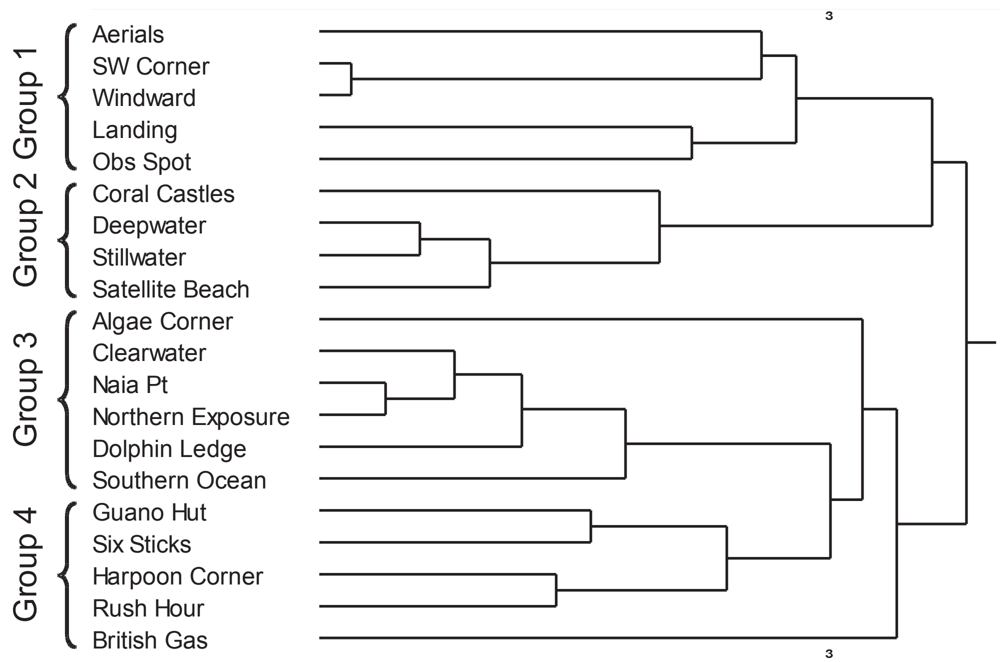

Figure 9. Cluster analysis of mean bottom cover. See table 55 for statistics on clusters.

Corals. The dominant growth form of corals throughout the islands was encrusting/submassive (38.8%) followed by branching (26.7%) and massive (14.8%, Table 56). The dominance of encrusting/submassive growth forms further emphasizes the importance of physical disturbance in the islands. Similarly, the breakdown of growth forms shows greater dominance of the resistant encrusting/submassive forms in windward sites (59.5%), its somewhat lower abundance at leeward sites and a corresponding increase in more delicate plate forms (17.4%), and the dominance of fragiles table and staghorn corals (70.7% and 18.6%, respectively) in protected lagoon sites.

Table 55. Cluster group statistics on benthic cover categories (means and standard deviation) for Figure 9. Sites included in each group are indicated.

Cluster	1		2		3		4		5	
# sites	5		4		1		9		1	
	m	Sd	m	sd	m	Sd	M	sd	m	sd
Coral	29.7	8.6	**71.9**	13.5	4.3		28.7	7.5	28.6	
Coral. algae	**32.0**	16.3	8.4	8.1	8.4		17.3	7.4	0.6	
Halimeda	**27.6**	18.7	2.5	2.7	19.6		3.0	6.6	0.0	
Algae-other	3.1	5.8	5.0	1.5	**59.2**		13.5	9.7	25.2	
Invertebrates	0.2	0.3	0.0	0.0	0.0		0.0	0.1	0.2	
Other	1.1	0.9	1.7	1.6	0.0		1.4	0.9	9.8	
Rubble	5.3	1.9	8.4	7.6	4.2		**27.8**	9.4	20.2	
Sand	1.1	1.5	2.1	2.9	4.3		4.1	2.9	**15.4**	
Soft coral	0.0	0.0	0.0	0.0	0.0		4.0	5.0	0.0	
Sites:	Aerials, Landing, Obs Spot, SW Corner, Windward		Coral Castles, Deep-water, Satellite Beach, Stillwater		Algae Corner		Clearwater, Dolphin Ledge, Guano Hut, Harpoon Corner, Naia Pt, Northern Exposure, Rush Hour, Six Sticks, Southern Ocean		British Gas	

Table 56. Percent contribution of coral morphologies (including dead and bleached/predated corals) in video transects by exposure.

	Wind	Lee	Lagoon	Overall
Encrusting/Submassive	59.5	38.8	1.2	38.8
Branching	32.7	27.7	0.6	26.7
Plates	1.6	17.4	-	14.8
Massive	4.9	11.6	-	10.2
Table	-	1.8	70.7	5.6
Staghorn	-	1.2	18.6	2.0
Mushroom	0.8	1.1	-	0.9
DeadCoral	-	0.1	8.6	0.5
Bleached/predation	0.2	0.1	-	0.1

Considering coral species diversity (Fig. 10), the larger islands of Nikumaroro, Kanton and Orona contributed more species than the smaller islands indicating the importance of the larger area of reef on these islands for support of biodiversity. This is consistent with classic island biogeography theory (MacArthur and Wilson 1967) wherein larger islands can support greater species and functional guild diversity.

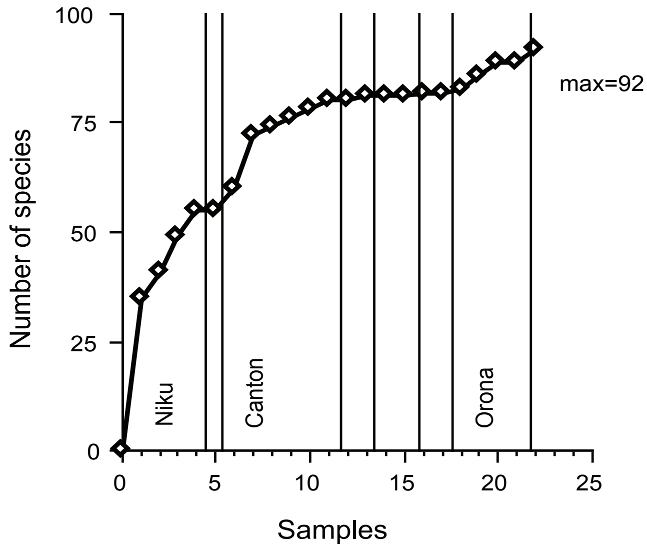

Figure 10. Coral species accumulation curve in successive sampling dives. Ninety-two coral species were recorded in 22 dives. The vertical lines indicate sampling of new islands with Nikumaroro, Kanton and Orona having the most samples and showing noticeable addition of new species at each new island.

In all, field identifications listed a tentative total of 99 coral species, from the timed species surveys, video transects, still photos and coral collection. Of these, 70 species were confirmed and definite identifications and 29 were at various stages of uncertainty (see Obura, this volume, for corrected numbers). These were collected in a total sampling time of 480 minutes (eight hours) spread over 22 dives. This, and individual island coral species richness, are tabulated with species numbers compiled for other islands and island groups in the South Pacific (Table 57).

The coral species diversity of individual sites appears to have been reasonably sampled in about six timed intervals (i.e.15 minutes) indicated by the flattening of most species accumulation curves at 4-6 intervals (Fig. 11). Nevertheless, sites at which longer surveys were possible from 11 to 16 intervals (i.e. 27 – 40 minutes) recorded continual increases in the species accumulation curves (i.e. Kanton – Satellite Beach and British Gas; Nikumaroro – Landing).

The Phoenix islands, located at the intersection of the equator and 180^{o} east and west fall outside of the sharp decline in biodiversity recorded for scleractinian corals in the Central and South Pacific (Veron and Stafford-Smith, 2000). While the low number of coral species, compared to those in American Samoa, Guam and the Marshall Islands is expected (Table 57), it is instructive to note that the low sampling time at individual islands (Table 57) and the increasing species accumulation curves (Figs. 10, 11) suggest significantly more coral species could be recorded with more intensive surveys at each island.

Due to the rapid survey nature of the study, firm species identifications were not possible for all coral species seen and a number are classified as uncertain and unidentified (Table 5). More intensive collection of coral skeletons will likely produce a larger number of uncertain specimens, unidentified species and unknown species. Several

Table 57. Coral species number reported for other South and Central Pacific islands and island groups, extracted from the references shown, compared with species richness for individual islands and the entire Phoenix group from this study. Data from this study are highlighted in bold, and sampling effort at each island in number of minutes dedicated to coral species surveys.

Island and Island groups	Species richness	Source
American Samoa	222	Lovell *et al.* 2000
Palmyra Atoll	168	Brainard et al. 2004
Guam	159	Lovell *et al.* 2000
Kingman Reef	155	Brainard et al. 2004
Marshall Islands	138	Lovell *et al.* 2000
Kiribati (Tarawa and Abaiang Atolls)	127	Lovell *et al.* 2000
Rose Atoll	111	Brainard et al. 2004
Phoenix Islands (480 min)	**96**	**This study**
Howland Island (US Phoenix Islands)	91	Brainard et al. 2004
Baker Island (US Phoenix Islands)	88	Brainard et al. 2004
Palmyra Atoll	82	Lovell *et al.* 2000
Kanton	82	Maragos and Jokiel 1978
Kiritimati Island (Line Islands)	82	Brainard et al. 2004
Tabuaeran Atoll (Line Islands)	77	Brainard et al. 2004
Kanton	77	Maragos and Jokiel
Kanton (130 min)	**73**	**This study**
Tabuaeran I. (Fanning I.)	71	Lovell *et al.* 2000
Nikumaroro (218 min)	**61**	**This study**
Main Hawaiian Islands	59	Brainard et al. 2004
Northwestern Hawaiian Islands	57	Brainard et al. 2004
Commonwealth of Northern Mariana Islands	53	Lovell *et al.* 2000
Hawaii	51	Lovell *et al.* 2000
Orona (80 min)	**49**	**This study**
Jarvis Island	49	Brainard et al. 2004
Enderbury (43 min)	**47**	**This study**
McKean (Phoenix Islands)	46	Lovell *et al.* 2000
Johnston Atoll	46	Brainard et al. 2004
Swains Island	44	Brainard et al. 2004
Manra (40 min)	**43**	**This study**
Wake Atoll	39	Lovell *et al.* 2000
Rawaki (40 min)	**38**	**This study**
Johnston Atoll	29	Lovell *et al.* 2000
McKean (20 min)	**19**	**This study**
Northern Hawaiian Islands	13	Lovell *et al.* 2000

species identified in the field were reclassified where reference specimens were available, suggesting that some of the uncollected species may be wrongly identified and could even be unknown or new species.

Threats to corals were quantified during surveys but were negligible compared to the influence of physical disturbance from waves. The most common evidence of coral stress was the presence of partially bleached colonies of *Pocillopora* spp. (*verrucosa*, *meandrina*, *eydouxi* and *damicornis*); however this was at low levels that can be considered normal for healthy coral communities. No evidence of a recent bleaching event was seen though it is possible that dead colonies from the worldwide bleaching event of 1997-98 could not be recognized due to their age and colonization by algae.

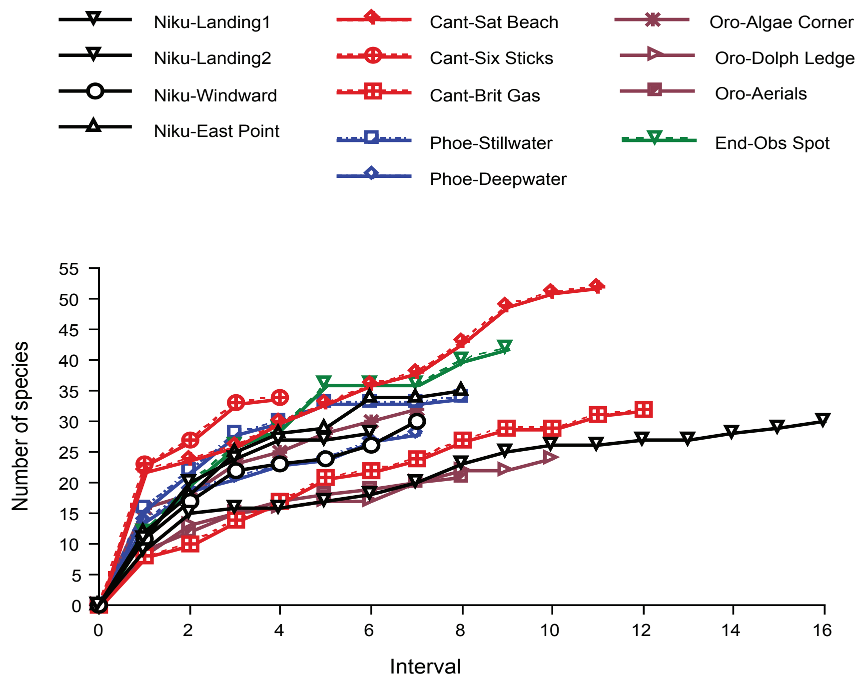

Figure 11. Coral species accumulation curves within dives at the sites shown. Intervals are 2.5 minutes, the curves show the number of new species seen in each interval over previous ones (see methods). The longest sample dive was 16 intervals (40 minutes) at Nikumaroro Landing.

The presence of harmful invertebrates was also noted with only one *Acanthaster planci* being observed during survey periods (with only four more counted during the expedition). The corallivorous snail *Drupella* was not noted and the only significant coral predator seen was the cushion star *Culcita*, though in low numbers and no impact on coral abundance.

Invertebrates. Mobile invertebrate densities were exceedingly low in the Phoenix Islands. Low numbers of holothurians were noted in the order of 1 – 5 per dive and often none during sampling intervals. Only one lobster was recorded during sampling and low numbers seen at other times during the expedition, including during night dives. As indicated above, invertebrates that potentially threaten corals were also low in abundance. Clams in the genus *Tridacna* were observed in low numbers at all survey sites with 1 – 5 being recorded in sampling intervals. *Tridacna squamosa* and *T. maxima* were observed but not *T. gigas*. Abundances were higher in sthe Orona lagoon but highly patchy and separated by large sandy expanses.

Reasons for the low abundance of invertebrates were not immediately clear. Further area-based transect surveys need to be done to obtain more accurate data as well as to differentiate between the three main influences that may explain the low abundances. These are: a) isolation of the Phoenix groups from source populations may reduce larval influx to levels below those needed to maintain abundant populations; b) the area of suitable habitat, e.g., of lagoon (only two islands have true lagoons) or shallow fore-reef, is relatively low and may hinder high rates of population growth; and c) predation by the large fish populations on larval, juvenile and/or adult invertebrate life stages may prevent accumulation and dense populations.

Fishes. Most of the survey sites had a diverse mix of reef and pelagic predatory fishes schooling in large numbers. Sites clustered into two main clusters with the largest comprising the two subgroups 1 and 2 (Table 58) characterized by variable numbers of most species, abundant bigeye and blue jacks in large mixed schools and moderate numbers of barracuda. The second main cluster was comprised of sites with massive abundances of individual species with rainbow runners and grey reef sharks superabundant in group 3 (all Enderbury sites and Nai'a Pt. On Nikumaroro), bigeye jacks in group 4 (the two Kanton channel-mouth sites) and a massive resident aggregation of barracuda at the Nikumaroro Windward site, sampled on two separate occasions.

Table 58. Abundance of large fish species in five clusters of sites (mean and standard error). Groups 1 and 2 contain the majority of sites, with variable numbers of fish species. Fish are listed by common names and preceded by their group code (see methods results for scientific names and groups in full).

Cluster	1		2		3		4		5	
N Rows	8		9		4		2		2	
	m	se	m	se	m	se	m	se	m	se
tun-Dogtooth	2.1	0.6	1.4	0.4	2.3	0.8	6.5	0.5	5	2
tun-Mackerel	1.1	0.8	0.4	0.4	1.8	1	0	0	3.5	3.5
tun-Queen	2	0.9	1.6	0.9	0.8	0.8	5.5	5.5	8.5	6.5
tun-Rainbow runn.	12.8	1.8	8.1	2.6	**28.5**	**6.4**	16	2	14	6
jac-Bigeye jack	35	24.5	8.9	6.1	12.5	12.5	**850**	**150**	75	25
jac-Blue jack	28.4	6.4	12.2	3.3	17.5	6.3	25	0	23	3
jac-Black jack	17.1	3.8	20.8	3.4	37.5	11.1	35	15	30	10
rf-Barracuda	3.3	1.5	94.7	33.7	5.5	4.9	58	42	**300**	**0**
rf-Napoleon wrasse	5.6	0.8	2.6	0.3	2.5	1.3	5.5	1.5	3	3
rf-Flower cod	2.4	0.8	0.1	0.1	0	0	2	0	1.5	0.5
rf-Footballer trout	0	0	0	0	0	0	0	0	0.5	0.5
rf-Jobfish	2	0.5	1.2	0.3	0.8	0.5	1	1	1	0
rf-Red Bass	33.4	6.8	19.3	5.2	36.3	10.7	26	9	20	10
rf-Seapearch	1.4	1.1	1.4	1	0	0	0	0	18.5	6.5
sha-Black Tip	2.1	0.9	1.9	0.6	5.8	4.8	0	0	6.5	5.5
sha-Grey Reef	10.5	2	10.3	2.6	**24.5**	**3.2**	3.5	1.5	11	5
sha-White Tip	1.9	0.4	1.8	0.6	5	0.9	3	1	4	1
sha-Manta	0	0	0.1	0.1	0	0	2	0	0	0
Sites:	British Gas, Satellite Bch., Wild Side, Guano Hut, Rush Hour, Nai'a Pt., Amelia's Landing, Deepwwater		Harpoon Crnr, Northern Lee, SW Corner, Landing, North Bch., Dolphin Ledge, Aerials, Algae Crnr, Stillwater		Obs. Spot, Shark Vill., Southern Exp., Nai'a Pt.		Weird Eddy, Nai'a Flya		Windward 1 and 2	

A dendrogram of the large predatory fishes (Fig. 12) indicates that there are two clusters of fish. The upper group is made up of the low-abundance species with the bigeye jack as the outlier due to its superabundance at some sites. The lower group comprises the more abundant and uniform species with barracuda as the outlier also due to superabundance at one site.

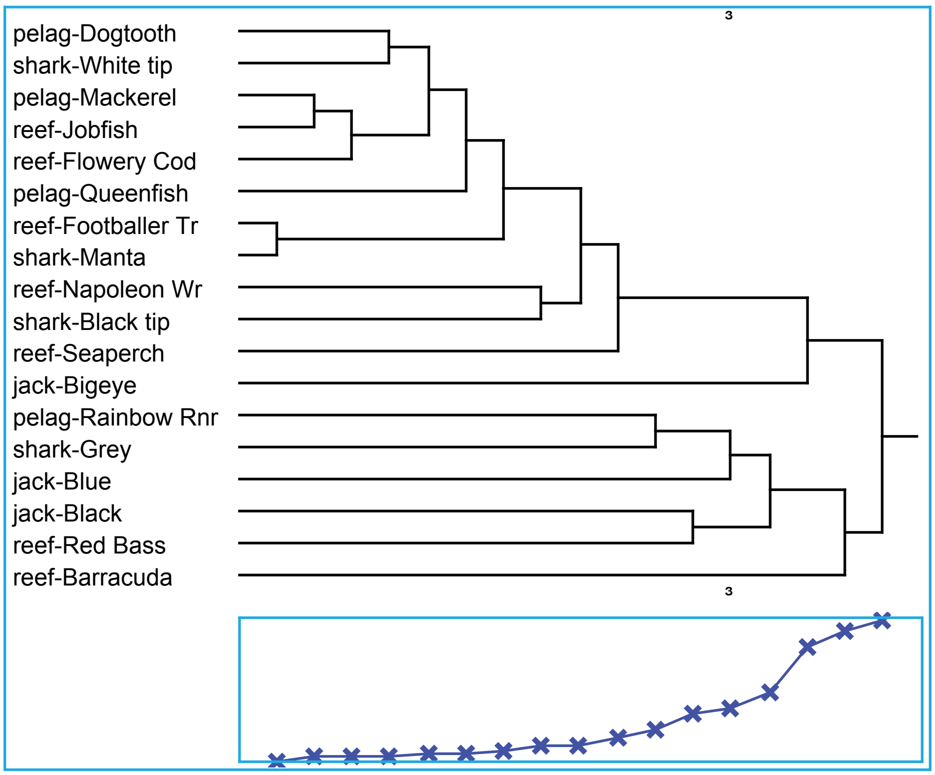

Figure 12. Cluster analysis of mean large fish abundance at each site. Two main groups are indicated as the two main forks of the base tree. Each group has outliers represented by Bigeye jack (above) and Barracuda (below).

Data on dominant fish family abundance indicates overall similarity among sites with 12 out of 22 sites grouped together with low-to-moderate abundances of all families (group 1, Table 59). The second cluster group is characterized by higher abundance of surgeonfishes, the predominant herbivorous finfish family observed on the reefs. All of these sites are leeward sites on Nikumaroro, protected from wave action. The three sites in group 3 were characterized by high abundances of all fish families and were characterized by high water flow (Southern Ocean), abundant herbivorous food (Algae Corner) and high topographic complexity (Harpoon Corner). The two outlier sites in “groups” 4 and 5 comprised two sites adjacent to the mouth of the lagoon on Kanton where parrotfishes and snappers were superabundant.

The species diversity of anemone fishes and scorpionfishes did not show any differences among the islands, principally due to the low species diversity within each group and their ubiquitous spread among islands. Similarly with butteflyfishes, though species diversity was higher (23 species) than with these groups, it is likely that differences in species number between islands was affected greatly by sampling effort and uncertainties in species recognition. Lower numbers of species were recorded on the smaller islands, however more systematic species surveys would need to be done to confirm this trend.

Table 59. Abundance of dominant fish families (mean and standard devaition) and cluster analysis grouping of sites.

Cluster	1		2		3		4		5	
N Rows	12		5		3		1		1	
	m	sd	m	sd	m	sd	m	sd	m	sd
Groupers	·	2.4	0.3	0.6	5.7	1.5	4.0		2.0	
Snappers	25.2	22.0	31.4	17.1	35.7	55.8	**110.0**		**1,000**	
Parrotfishes	5.9	5.7	6.2	4.5	25.7	42.7	800.0		7.0	
Surgeonfishes	13.0	6.3	**30.3**	**4.4**	24.3	3.1	18.0		21.0	
Triggerfishes	18.3	10.7	10.8	5.8	44.3	6.0	5.0		7.0	
Sites:	Satellite Bch. Weird Eddie, Obs Spot, Shark Village, Aerials, Dolphin Ledge, Guano Hut, Rush Hour, Landing, NAI'A Point, North Beach, Northern Lee		Amelia, Kandy Jar, Landing, Norwich City, Windward Wing		Southern Ocean, Algae Corner, Harpoon Corner		President Taylor		British Gas	

A number of fish species collected during this study qualify for species range extensions and new records for the Phoenix Islands (Table 60). At least two species had not been described in the Phoenix Islands group but were common, the hawkfishes *Paracirrhites nisus* and *P. xanthus*. They were particularly prominent, nestling in the branches of *Pocillopora* coral colonies and on other surfaces. The data on fish diversity was greatly increased through surveys in 2002, reported in Allen and Bailey (this volume).

Table 60. Fish species range extensions and new records for the Phoenix Islands (2000).

Family	Genus/species	Justification
RANGE EXTENSIONS		
Cirrhitidae (Hawkfishes)	*Paracirrhites nisus*	(Randall, pers. Com)
	Paracirrhites xanthus	Closest record is the Tuamotu Islands group(Randall, 1982-2000.)
NEW RECORDS		
Muraenidae (Moray Eels)	*Gymnothorax chilospilus*	recorded from the Society Islands (Randall, 1985)
Serranidae (Fairy Basslets and Groupers)	*Suttonia lineata*	recorded from the Hawaiian, Line and Society Islands, Fiji, Vanuatu and Guam (Randall, pers. Com.)
Gobiidae (Gobies)	*Priolepis nocturna*	reported from numerous sites in the west and the Marquesas Islands (Randall, 1985).

DISCUSSION

Prior to 2002 the Phoenix Islands were a diverse and healthy example of central Pacific atoll coral reef communities. The fact that these islands and lagoons have been excluded from long term human impacts makes them excellent examples of this habitat type in its near pristine state. For these reasons we believe it is of global significance and deserves further study and a management plan that will ensure the long-term health and sustainability of the ecosystem.

This is the first comprehensive marine biological survey of the Phoenix Islands and these results provide a foundation for understanding these ecosystems and cataloguing the fauna and flora of the region. These data are particularly valuable because all but one of the Phoenix Islands are completely uninhabited (Kanton has less than 50 people) and all are remote from major human settlements and near shore anthropogenic impacts. Phoenix Island reefs provide a model of what atoll reefs in this part of the Pacific Ocean are like with minimal human disturbance. These data are useful at both the regional and global level because they provide biological benchmarks for understanding change and for rebuilding reef systems elsewhere that have been degraded.

Coral reefs of the Phoenix Islands were notable for their moderate coral cover (20-40%) and evidence of high physical breakage by wave energy on the southern, eastern and northern shores of the islands. Fish populations were abundant with large schools of jacks, barracuda, snappers, surgeonfish, and parrotfish, and abundant sharks at locations featuring high currents and topographic complexity. Both coral and fish communities showed differentiation between windward, leeward and lagoon habitats. Invertebrate populations were notably low with low numbers of clams (*Tridacna* spp.), pearl oyster (*Trochus* spp.), holothurians (beche de mer) and lobster. This is potentially due to the isolation of the islands from larval sources, the minimal area available for lagoon-dependent species and high predation by fish on larval, juvenile and/or adult life stages.

Overall, coral reefs appeared in near-pristine condition with no evidence of human influence. This pilot expedition identified several “significant sites” based on ecological parameters which stood out as either providing unique or sensitive habitat, or unique species assemblages (Table 61).

These surveys were also valuable for identifying new species and providing an inventory of the biodiversity of this region. The occurrence of new coral and fish (Allen and Bailey 2003) species, reported in Obura (this volume) and Allen and Bailey (this volume) underscore the significance of these reef systems for biodiversity. Additionally, range extensions were recorded for a number of algae (South et al. 2001), coral and fish species. The surveys conducted on this expedition were for rapid assessment of biodiversity and effort at most islands amounted to only one day of diving. There is therefore a strong rationale for continuing inventories of marine life at all these islands. This is emphasized for corals by the increasing coral species accumulation curves (Figs. 10, 11) which suggest an additional 30% more species may be identified given more sampling effort (and see Obura, this volume). It is likely that other new species of coral and fishes remain to be discovered. We also did not survey Birnie Island at all and this site should be considered a priority for any future surveys.

Table 61. Significant sites

Dive Site/Island	Significant pattern	Importance
Coral Castles (Kanton lagoon)	Maximum coral cover, dominance of table and staghorn Acropora	Delicate climax community of low-energy reefs. High vulnerability to disturbance.
Satellite Beach (Kanton), Deepwater, Stillwater (Phoenix)	High coral cover, diverse coral communities	Biodiversity and ecological complexity
Algae Corner (Orona)	Lowest coral cover, highest algal cover – evidence of chronic stress from low water quality	Impact of lagoon and land-based factors on coral communities, vulnerability
Nikumaroro, Kanton, Orona Islands	Highest coral diversity due to large area effect	May contain key source and refuge sites for corals and other reef species during stressful events.
Orona and Kanton lagoons	Only true lagoons with coral and other communities	Rare habitats with extreme isolation from neighbouring island groups.
Kanton lagoon mouth and adjacent sites	Superabundant fish populations aggregate in and beside channel mouth, for feeding, spawning, etc.	Critical ecological role in feeding and reproduction, high vulnerability to destructive- and over-exploitation.
Windward Wing (Kanton)	Largest barracuda aggregations seen in islands	High vulnerability to fishing.
Enderbury	Largest aggregations of sharks, in particular grey reef sharks	Special circumstances enhancing shark populations?
Rawaki	Green turtle nesting sites	First record of Green Turtles nesting at this island.

With respect to fishes, at the time of writing there are two range extensions, three new records and many additions to the Kiribati Government's official fish list. It is possible that new species will be identified. For fishes, a high priority in the Phoenix Islands region is to add significantly to our knowledge of the cryptic fishes found in the coral rubble habitat. The expedition's intent was to focus primarily on the Blenniidae, Tripterygiidae and the Gobiidae, but the results reveal that at least 27 families of fish rely on, or have some association with, the thick layers of accumulated coral rubble substrate common on the leeward side of these islands. Further sampling is necessary to improve coverage of depth zones to include more shallow (< 3m) and deeper (50 – 300m) sites. For the latter, this may need Nitrox and Trimix diving gases for the 33 – 75m range and rebreathers for the 75 – 125m range. Further sampling of coral communities is also necessary as shown by the species accumulation curves (Figs. 10, 11) and coral species taxonomy is in a state of flux. Recent publication of additional references (Veron and Stafford-Smith 2000) is likely to improve greatly future coral taxonomic work at Phoenix Islands.

Sea birds, turtles and dolphins were found mostly near islands probably because their food, small fishes and coastal invertebrates, are also found there as opposed to the deep-water in-between islands. The expedition found turtle nests on Phoenix Island which had not been previously recognized as a nesting ground.

A very surprising result was the almost total lack of large whales, in particular sperm whales. The Phoenix Islands are located in the heart of the famous 19th century sperm-whaling ground. In these waters, whalers from North America came and hunted sperm whales in tremendous numbers in the 19th century (Townsend, 1935). Our data indicate that populations of sperm whales in the Phoenix Islands are negligible today, at least at the time of year we surveyed. These data are of concern and support the need for the currently proposed International Whaling Commission South Pacific Sanctuary, which would protect all large whales in the region.

Deep-water camera deployments and images provided the first data on deep-sea fauna for the Phoenix group. These are new sighting records for six-gilled sharks and help to build our understanding of their worldwide distribution. The Phoenix Islands are located in extremely deep ocean waters (> 5,000m) and our sampling program was relatively shallow (1,000m). It is likely that many new gains in our knowledge of the biodiversity of these waters will be gained from deep-sea sampling and imaging. The "ropecam" provided a low cost method for viewing animals in this biome but remotely operated vehicles and deep-sea submersibles will provide a more thorough method for surveying these regions (Stone et al., 2000).

We note that a previous management plan for the Phoenix Islands (Garnett, 1983) pertained only to the terrestrial ecosystems and did not include the marine aspects. Conservation and management of the marine ecosystems of this area can yield long-term benefits to Kiribati.

The coral reefs of this island group are of national, regional and global significance and provide a rare opportunity in the South Pacific for conservation and biodiversity research. The importance of protecting Kiribati's biodiversity has been highlighted by the government's signing of the Convention on Biological Diversity in 1994 and the recent drafting of the country's National Biodiversity Strategy and Action Plan in 2000. To date, the only management plan produced for nature conservation in the Line and Phoenix Islands by Garnett (1983) has a terrestrial focus and does not extend sufficiently to cover the marine environment.

CONCLUSIONS

Recommendations are split into two components, that outline opportunities for further research and the need to embed this in an integrated management framework that includes the whole island group.

Research

The findings of the scientific expedition to the Phoenix Islands, detailed in this report, provide a strong justification for the development and implementation of a more focused research strategy. This will be aimed at obtaining more substantial inventories of the species of flora and fauna in the island group as well as quantifying their marine resources. The information from more extensive research will provide invaluable data to the Kiribati Government on its marine resources and will provide the information required to make sound decisions about the conservation, management and wise use of these nationally significant reefs. The pristine state of the reefs and their global significance will be of great interest to the wider scientific community.

The following components are recommended for a future research strategy:

1. Birnie Island was not surveyed during the expedition due to time restraints and should be visited to complete our understanding of the habitat and diversity found in the Phoenix Island group.
2. More extensive and quantitative coral, invertebrate and reef-fish surveys should be conducted at each of the eight atolls to obtain baseline inventories and abundance estimates of the species of flora and fauna present. An annual monitoring program based on these baseline surveys should be designed and capacity developed within Kiribati institutions to implement this.
3. More comprehensive assessments of reef resources should be undertaken focusing on major food fish and invertebrate species.
4. Collections of relevant faunal groups (algae, corals, small fishes) should be expanded to improve taxonomic knowledge of the island group's flora and fauna.
5. Greater attention needs to be paid to windward and lagoon reefs to increase their sampling with respect to leeward reef sites.
6. A strategy for deep-water research around these islands should be developed, incorporating remotely operated vehicles (ROVs) as well as the "rope-cam" method used here.

Management Plan for Marine Conservation

The findings of the scientific expedition to the Phoenix Islands unequivocally support the recommendation for the establishment of a conservation and management plan for the Phoenix group that recognizes both the need to protect biodiversity and allows for the wise use of the marine resources in the area. A precedent for conservation management is provided in north Tarawa where the Kiribati government in collaboration with the South Pacific Regional Environment Programme (SPREP) has established the country's first Marine Protected Area.

An Integrated Coastal Area Management (ICAM) framework provides the most broad-based approach to marine biodiversity and resource conservation. This approach incorporates the following key concepts for management of a remote and near-pristine region such as the Phoenix Islands:

1. Managing threats to ecosystem health and function through management of resource use and human coastal populations;
2. Incorporating and integrating multiple objectives of management such as resource use and biodiversity protection;
3. Preservation of options for future decisions through an explicit multiobjective management framework.

As a complement to ICAM, management models that explicitly recognize the biodiversity, resource, cultural, historical, and potential tourism value of the individual islands and the island group are useful. These, such as the World Heritage Site (IUCN) and Biosphere Reserve (UNESCO-MAB) models, are internationally recognized and can provide significant leverage for funding and implementation by the Kiribati Government.

Full development of an Integrated Management Plan may take 5-10 years for which the Kiribati government may need external support, institutional capacity building, and a commitment to implementation that prevents short-term opportunistic uses of the islands that may be detrimental in the medium-to-long term.

The results presented in this report, together with our experience of marine ecosystem management and conservation in other parts of the world, indicate five key components for an integrated management framework for the Phoenix Islands:

1) Multiple-Use Management. This is appropriate for the larger islands, Kanton and Orona, where multiple marine (and terrestrial) habitats occur, and there is already some level of current human habitation and resource use. This spatial and utilization complexity requires a multiple-use framework that can follow a classic ICAM model as well as the Biosphere Reserve concept of the UNESCO Man and the Biosphere program. Our recommendations include:

a) The identification of representative windward, leeward and lagoon sites for complete protection, e.g., Satellite Beach, Coral Castles, comprising up to 50% of their total areas;
b) The identification of key vulnerable sites such as the lagoon mouths to protect spawning aggregations of fishes; and
c) For the remainder of the islands, establishment of management regulations for existing sites being used (for habitation, fishing, copra, etc.) based on sustainable use principles.

2) Fully Protected Marine-Terrestrial Sanctuaries. Marine Protected Areas (MPAs) are viewed by the tropical scientific and fisheries management community as the only fully effective tool for managing fish stocks in multispecies coral reef fisheries. MPAs address the critical features of fishery stock management that include brood-stock protection, minimum viable population size, habitat protection and enforcement. As the first component of an integrated plan for multiple-use management, a representative network of multiple protected sites is necessary to conservation management in the Phoenix Islands. The current existence of two fully protected areas, the terrestrial bird sanctuaries of McKean and Birnie Islands, provides a precedent for expansion of this concept to other islands and, in particular, for integration across terrestrial and marine environments. Additionally, as recognized by the World Heritage Site designation for which a site is under consideration in Kiribati (Christmas Island or Millenium Island), both biodiversity and cultural/historical features can be central features of a protected area.

Our results suggest the following islands as potential MPAs, in addition to the representative sites on Kanton and Orona mentioned in the section above. None of the following sites have any current exploitative uses while they all have current biodiversity value as well as potential tourism value through diving and visitation. Through full protection they may collectively have sufficient value for World Heritage Site protection:

a) McKean, Birnie – extend terrestrial bird sanctuary protection to cover the marine environment;
b) Nikumaroro – the cultural significance of Nikumaroro to the I-Kiribati people, and its potential archeological and historical importance as a possible site of Amelia Earhardt's plane crash, give it conservation value in addition to biodiversity reasons;
c) Phoenix – has potential for sanctuary status as it has the same characeristics as McKean and Birnie islands (i.e. bird populations, turtle nesting, marine habitats, unsuitability for human habitation), with additional importance of name for island group.

3) Preserving Future Options. The near-pristine nature of the Phoenix Islands group and their potential value for income generation through conservation advocates a strict application of the precautionary principal in the development of a management framework for the islands. This can be applied in two stages:

a) In the form of a provisional moratorium on all new activities pending development of the integrated management plan for the island group. This will prevent degradation by opportunistic and degrading activities while the management plan is being developed;
b) As a central component of the management plan, the reservation of significant areas of the island group based on the potential for future uses, not identifiable at present, that rely on a nondegraded and pristine habitat.

Based on components *1)* and *2)* above, this designation can be applied as follows:

a) To the remaining islands, Enderbury and Manra, this is analogous to ascribing them sanctuary status as in *2)* above but with flexibility for future uses that are not degrading;
b) On Kanton and Orona, to the additional sites not currently being used, but not in the 50% protection zones. This will effectively reserve options for future uses not conceived during the establishment of the Integrated Management Plan.

4) High Seas Issues. The high seas, or pelagic environment, are a critical link in the life cycles of coral reef organisms, as well as harboring species independent of reef environments. In Kiribati, the high seas of the EEZ are a highly significant resource for the country. With respect to the Phoenix Islands, the high seas contained within the boundaries of the island group are important in three areas relevant to conservation management of the islands and reefs:

a) Management of fisheries of reef-associated species such as sharks, jacks and mackerel;
b) Evaluation of the relevance of the Phoenix Islands for the South Pacific Whale Sanctuary. Few marine mammals were recorded in this study, potentially emphasizing the long-term effects of unrestricted utilization over a century ago;
c) The flow of ocean currents and eddies among the islands may have a critical role in the maintenance of reef populations and biodiversity through migration of fish, marine

mammals and turtles, and dispersal of larvae. Management of the Phoenix Islands high seas must incorporate this issue together with identifying needs for research in this area.

5) Financing And Economic Implications. The biological communities of the Phoenix Islands represent a significant part of the natural wealth of Kiribati and potentially an important income resource for the country. The trade-off of short-term and long-term benefits and costs of different ways of using this resource is critical to the conservation status and value of the islands as well as to the real benefits accrued to the people of Kiribati in this and future generations (Mangubhai 2002). Comparative analysis of financial and economic options, including resource extraction, tourism and conservation options, must be carried out during preliminary stages of establishing an integrated management plan in order to justify objectives of the plan and empower its enforcement.

The findings of this report, and our experience in other small-island marine ecosystems, strongly advocate a focus on biodiversity conservation and management. To provide immediate as well as long-term benefits to the people of Kiribati, conservation has to be backed up by innovative financing and investment through low-impact tourism (eco-tourism, dive tourism) and global investment in key-site biodiversity conservation. Key features for this type of financing would include:

a) Development of an integrated conservation management plan that meets international criteria through mechanisms such as World Heritage Sites, Biosphere Reserve and Integrated Coastal Area Management;
b) Promotion of the Phoenix Islands as near-pristine coral reefs for dive and visitor-based low-impact tourism (ecotourism) based on live-aboard dive boats and a small number of exclusive cottage-style resorts;
c) Promotion of the cultural and historical importance of the Phoenix Islands, for example, the I-Kiribati people, Amelia Earhardt's plane crash, 19th century whaling and the Second World War;
d) Improvement of appropriate infrastructure, which would include airstrip and marina facilities on Kanton, reservation of a small number of sites for ecotourist concessions, quality infrastructure for a limited population on Kanton to service government needs and a small scale, high quality tourism industry;
e) Fishery and resource-use regulations that are biologically sound and ban export-based extraction for consumption outside of the Phoenix group.

ACKNOWLEDGMENTS

We thank the Kiribati Government for their cooperation in conducting this research and to Kandy Kendall for her vision and help initiating this project. We thank Mr. Kaburoro Ruaia of the Ministry of Natural Resources Development in Kiribati for his help and cooperation on many aspects of this project. Funding for the expedition was generously provided by the expedition team members, NAI'A Cruises, the New England Aquarium, the Oak Foundation, the National Geographic Society's Committee for Research and Exploration, the Pew Fellowship in Marine Conservation and the Environment, and the Worldwide Fund for Nature, South Pacific Program. We also thank the other dive team members for their tireless efforts collecting data during this grueling and intensive trip: Bruce Thayer, Mary Jane Adams, Craig Cook and Alex Morrison. We thank the captain and crew of NAI'A for delivering us to the Phoenix Islands and helping with all aspects of our work. A very special thanks goes to Tuake Teema from the Kirbati Government for providing background and technical advice on the Phoenix Islands. We thank Emory Kristoff and the National Geographic Society for loaning us the deepwater camera system and their forgiveness when the housing flooded on the last deployment.

The complex process of fish identification was greatly aided by the following individuals: Karsten Hartel and Anne Everly, Museum of Comparative Zoology, Harvard University; Jeff Williams and David Smith, National Museum of Natural History, Smithsonian Institution; John Randall, Bishop Museum, Hawaii; Tony Gill, Natural History Museum, London; Ofer Gon, JLB Smith Institute of Ichthyology, South Africa; Rick Winterbottom, Royal Ontario Museum, Ottowa; Mary Jane Adams, Pasadena, Ca. We also thank Doug Fenner, Australian Institute of Marine Science, and Dr. Carden Wallace, Museum of North Queensland for assistance with coral identifications. Thanks to Bruce Collete and Victor Springer of the National Museum of Natural History, Smithsonian Institution for pre-cruise technical assistance, and to Aaron Dunning for help preparing this report. Publication of this report was made possible by the Oak Foundation.

REFERENCES

Allen, G.R., and S. Bailey.
2002. *Chrysiptera albata,* a new species of damselfish *(Pomacentridae)* from the Phoenix Islands, central Pacific Ocean. *Aqua, J. Ichthyol. Aquatic Biol.* 6(1):39-43.

Baker, C.S.
2000. *New Evidence for Stock Boundaries of Humpback Whales in the Proposed South Pacific Whale Sanctuary*. Report to the Annual Meeting of the International Whaling Commission Scientific Committee, Adelaide, July 2000. Paper no. SC/52/IA20.

Balazs, G.H.
1982. *Status of Sea Turtles in the Central Pacific Ocean*. Pp 243-251. In: K.A. Bjorndal (ed.) Biology and Conservation of Sea Turtles. Smithsonian Press, Washington, DC 583 pp.

Brainard, R, Maragos, J, Schroeder, R, Kenyon, J, Vroom, P, Godwin, S, Hoeke, R, Aeby, G, Moffitt, R, Lammers, M, Gove, J, Timmers, M, Holzwarth, S, Kolinski, S.
2004. *The State of Coral Reef Ecosystems of the U.S. Pacific Remote Island Areas*. USCR.

Clapp, R.
1964. Smithsonian Biological Survey. 01-18-14-90-81
Dawson, E.Y.
1959. Some marine algae from Kanton Island. *Atoll Research Bulletin* 65: 1-6.
Degener, O., and I. Degener.
1959. Kanton Island, South Pacific. (Resurvey of 1958). *Atoll Research Bulletin* 64: 1-24.
Degener, O. and E. Gillaspy.
1955. Kanton Island, South Pacific. *Atoll Research Bulletin* 41: 1-51.
Doty, M.S.
1954. Distribution of the algal genera Rhiplia and Sargassum in the Central Pacific. *Pacific Science* 8(3): 367-368.
Garnett, M.C.
1983. A management plan for nature conservation in the Line and Phoenix Islands. Part 1: Description; Parts and 3: Policy and Recommendation. Report prepared for Government of Kiribati. 449pp.
Holloway, C.
1999. The search for Amelia Earhart. *Skin Diver*. November, 1999; pp 57-61.
Jokiel, P., and J. Maragos
1978. Reef corals of Canton atoll: II. Local distribution. *Atoll Research Bulletin* 221: 71-97
Maragos, J., and P. Jokiel
1978. Reef corals of Canton atoll: I. Zoogeography. *Atoll Research Bulletin* 221: 55-69
Lovell, E.R., T. Kirata, and T. Tekinaiti
2000. National Coral Reef Status Report Kiribati. Report prepared by the International Ocean Institute, South Pacific and Kiribati Fisheries Division for the International Coral Reef Initiative and the South Pacific Regional Environment Program. 35pp.
Mangubhai, S.
2002. Viable long-term options for isolated atolls of the Phoenix Islands, Republic of Kiribati. Global Marine Programs, New England Aquarium, Boston
Melville, H.
1851. *The Whale* (Moby Dick). Harper & Brothers, New York. 287pp.
Myers, R.F.
1991. *Micronesian Reef Fishes: Practical Guide to the Identification of the Inshore Marine Fishes, Tropical Central and Western Pacific*, 2nd Ed. Coral Graphics, Guam, 298 pp.
Nelson, J.S.
1994. *Fishes of the World*. Third Ed. John Wiliey & Sons, Inc., New York, 600 pp.
Randall, J.E. (ed.)
1982-2000. *Journal of Indo-Pacific Fishes* No. 1-24. Bishop Museum, HI.
Randall, J.E., G.R. Allen and R.C. Steene
1990. *Fishes of the Great Barrier Reef and Coral Sea*. University of Hawaii Press, Hawaii, 507 pp.

Shultz, L.P.

1943. Fishes of the Phoenix and Somoan Islands collected in 1939 during the Expedition of the U.S.S. "Bushnell". Smithsonian Institution, United States National Museum, Bulletin 180. 315 pages.

Smith, S. V., and R. S. Henderson (eds.).

1978. An environmental survey of Canton Atoll Lagoon, 1973. *Atoll Research Bulletin* . No. 221 192 pp.

Smith, S. V., and P. L. Jokiel.

1978. Water composition and biogeochemical gradients in the Canton Atoll lagoon. *Atoll Research Bulletin*. 221, p. 17-53

South, G.R., P.A. Skelton, A. Yoshinaga.

2001. Subtidal Benthic Marine Algae of the Phoenix Islands, Republic of Kiribati, Central Pacific. *Botanica Marina*. 44: 559-570

Stone, G., A. Clarke, S. Earle (eds.).

2000. Deep Ocean Frontiers. *Marine Technology Society Journal*. 33(4). pp 93.

Stone, G., E. Kristof, J. Coccia, R. M. Cole, T. Tucker, R. Zimmerfaust.

1998. Deep-Sea Research with a Ropecam Video System in Kaikoura Canyon, New Zealand. *Marine Technology Society Journal*. 32(2).

Townsend, C.H.

1935. The distribution of certain whales as shown by logbook records of American whaleships. *Zoologica*. N.Y. 19(1):1-50.

Veron, C.

1986. *Corals of Australia and the Indo-Pacific*. Australian Institute of Marine Science, Townsville, Australia.

Veron, C., Stafford-Smith.

2000. *Corals of the World*. Australian Institute of Marine Science, Townsville, Australia.