The State of Coral Reef Ecosystems of the Marshall Islands

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INTRODUCTION AND SETTING

The reefs of the Marshall Islands are among the most pristine in the Indo-Pacific, having suffered minimal damage from bleaching, destructive fishing techniques, and sedimentation. However, signs of unsustainable resource exploitation are apparent, including the earlier extirpation of the largest giant clams, and the ongoing reduction of reef shark, grouper, and Napoleon wrasse populations. In addition, localized outbreaks of crown-of-thorns starfish (COTS) and coral disease, principally on the capital atoll of Majuro, are ongoing. Another concern is the growing, unregulated exploitation of reef fish for the local markets.

The Republic of the Marshall Islands (RMI) encompasses approximately 1,225 individual islands and islets with 29 atolls and five solitary low coral islands (Figure 13.1). Land makes up less than 0.01% of the area of the Marshall Islands, with a total dry land area of approximately 181.3 km^2. Most of the country is open ocean with a seafloor that reaches 4.6 km deep. Including the Exclusive Economic Zone (EEZ; shoreline to 200 miles offshore), the RMI covers 1,942,000 km^2 of ocean within the larger Micronesian region. Furthermore, there are 11,670 km^2 of semi-enclosed water within the lagoons of the atolls.

Scattered throughout the country are nearly one hundred isolated submerged volcanic seamounts. Seamounts with flattened tops, or guyots, are thought to have formed millions of years ago but were unable to keep pace with subsidence or persist as islands or atolls.

The average elevation of the Marshall Islands is about 2 m above sea level. Humidity is around 80% with considerable salt spray. The air temperature averages 27.8ºC with an annual range of 24-32ºC. Rainfall tends to be seasonal, ranging from 4 m a year in the south to as little as 0.6 m a year in the north. In extremely dry years, there may be no precipitation on some atolls. Tropical storms (typhoons) are relatively rare, but can be devastating when they occur.

The atolls vary in size from Kwajalein, the world's largest atoll with 16.4 km^2 of dry land and a lagoon of 2,174 km^2, to Bikar with 0.5 km^2 of land and 37.4 km^2 of lagoon, and Namdrik with 2.7 km^2 of land and 8.4 km^2 of lagoon. Individual islands range from tiny sand-spits and vegetated islets that are inundated during storms and extreme high tides to much larger islands such as Kaben Island at Maloelap Atoll, and Wotho Island, the main island at Wotho Atoll, both of which are over 8 km^2. Lagoons within the atolls typically have at least one deep-pass access; however, some, such as Namdrik Atoll, have no natural passes.

The atolls and islands of the Marshalls formed when fringing reefs began to establish and grow around emergent volcanoes. The ancient volcanic peaks then gradually sank and shrank, while fringing reefs continued to grow, eventually becoming coral atolls after the volcanoes disappeared entirely beneath the sea. The five solitary islands of the RMI were formed in much the same way, but the peaks were small enough that no interior lagoon developed.

For the most part, the atolls of the Marshalls are not circular, nor do they have uniform islets. They are much larger than those in the Indian Ocean and are surrounded by more numerous islets. The islets are more prevalent on the windward side and encircle a deep lagoon. The lagoons of RMI atolls also differ from others in that they are typically deeper (to about 60 m) and have greater circulation.

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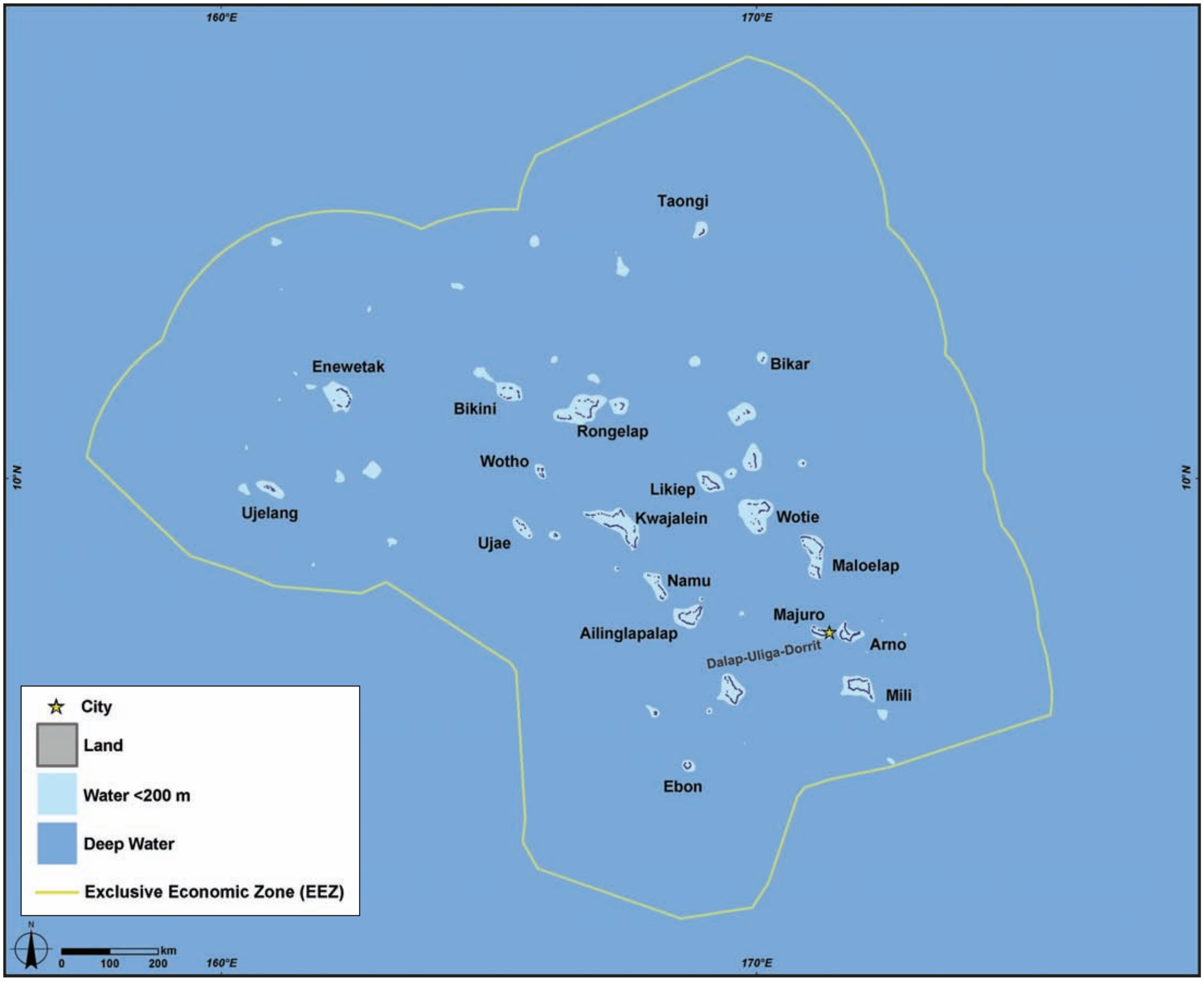

Figure 13.1. Locator map for the Marshall Islands. Map: A. Shapiro.

The islets are extremely young geologically and likely formed when sea level dropped about 2 m to its present level around 4,000 years ago, with more recent land creation resulting from the action of large waves which cast large reef blocks, coral rubble, and sand on top of shallow reefs. Vegetation, birds, crabs, and other animals then colonized the emergent islands, and eventually the Micronesian ancestors of the present day Marshall Islanders arrived on sailing canoes. In contrast, the atoll reefs are 50 million years old or more, and up to 1.5 km thick atop their volcanic foundation.

ENVIRONMENTAL AND ANTHROPOGENIC STRESSORS

Climate Change and Coral Bleaching

Low lying coral reef islands, such as the Marshalls, are at great risk from climate change, particularly from sea level rise, which could result in total submergence. It was suggested during an inter-governmental meeting that such countries could be considered for United Nations Environmental Programme protection as 'endangered species' (South Pacific Regional Environmental Programme, 1989).

It has been projected that air temperatures in the Marshall Islands will continue to rise on all atolls, with the highest increases in the northern areas (Crisostoma, 2000). This could decrease total rainfall, causing severe droughts while also impacting freshwater supplies. A slight change in temperature would increase both the intensity and frequency of storm events, which have a greater impact on low-lying islands.

The average sea temperature around the Marshall Islands is about 29°C, near the upper limit for coral survival of about 31°C. An increase of just 1°C could trigger massive coral bleaching. Some of the very shallow flat reefs on the lagoon side of Majuro Atoll bleached during a time of particularly elevated temperatures and calm conditions, coinciding with the period of spring tide; this occurred during the new moons of Sept-Nov 2002 and resulted in high reef flat mortality. Similar anecdotal observations for the same time period (in 2002) came from local inhabitants in Jaluit Atoll. Considerable bleaching, restricted to certain species of *Acropora,* was later seen on Jaluit, both in 2003 and 2004. However, local residents did not recall any other similar reef flat events in the RMI. No sign of coral bleaching was recorded during recent surveys of several atolls (Pinca, 2001; Beger and Pinca, 2003a; Pinca et al., 2004a,b), but reef flat bleaching was recorded in February 2005.

Diseases

Coral disease is visible on some reefs of the Marshall Islands (Figure 13.2), most notably a rapidly spreading "white" syndrome affecting Acropora spp. (see below). Two rare diseases also occur: a single Favid colony showing signs of red band disease was located on Arno, and some *Platygira sinensis* colonies have slowly progressing lesions bordered by a bright green algal margin. Coralline lethal orange disease, or CLOD, which is caused by an orange bacterium fatal to coralline algae, is common along the southern and eastern shores of Majuro.

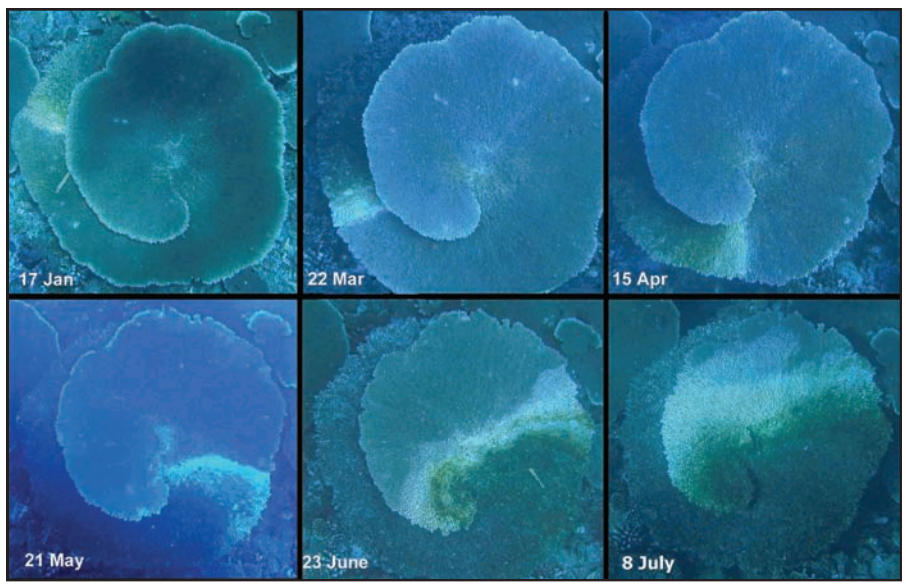

Figure 13.2. The rapid progression of a coral disease on a table coral in the Marshall Islands. Photo: D. Jacobson.

The white syndrome affecting table corals (*Acropora* spp.) is ubiquitous, particularly on the leeward shore of Majuro; this is a region with high human population density and where a shallow outfall bathes the reef shelf with untreated sewage. This disease is typically found on *A. cytherea*, *A. clathrata* and similar species; small digitate or caespitose species as well as branching colonies are not affected. Disease signs usually progress steadily at a rate of 2 cm per day. This disease can kill a 2 m colony in 10 months, as a narrow white band sweeping radially along the colony edge like the hand of a clock. Disease mortality on Majuro has been quantified at a leeward ocean site near the airport over a 12-month period. Based on surface area, 16% annual mortality occurs, in contrast to approximately 20% of annual growth. Mortality is density-dependent; in a local patch of particularly dense *A. cytherea* tables, mortality exceeded 30% over a 7 month interval as the disease spread to neighboring colonies. 2003-2004 mortality was much higher than in the few previous years, suggesting this disease outbreak had a recent inception (i.e., the year 2000). A disease "hot spot" is located far to the west at Laura, which experienced at least 50% mortality. Microbiological characterization of pathogens is ongoing (B. Willis, pers. comm.) and involves at least one virulent bacterium and a large histophagous ciliate whose aggregations appear as macroscopic yet minute spots within corallites. This disease is rare on outer atolls: barely detectable on Jaluit, and uncommon on the western shore of Arno, nearest to Majuro. It is also absent on the pristine northern shore of Majuro. Identical disease signs have been sighted on Pohnpei and Kosrae as well. Disease vectors are unknown, and new infections appear in every season and month.

Tropical Storms

Although major typhoons are not common in the Marshall Islands (Figure 13.3), they can be devastating when they hit. In 1991, Typhoon Zelda hit the southern atolls. It was quickly followed in early 1992 by Typhoon Axel, which scoured the south-facing reefs of Majuro, covering the land, including the airport, with coral debris and rubble. Shortly thereafter, Typhoon Gaye ravaged much of the northern atolls, including Wotho. In late 1997, Paka changed from a tropical storm to a typhoon while in the Marshalls and caused considerable damage to Ailinglaplap (N. Vander Velde, pers. comm.).

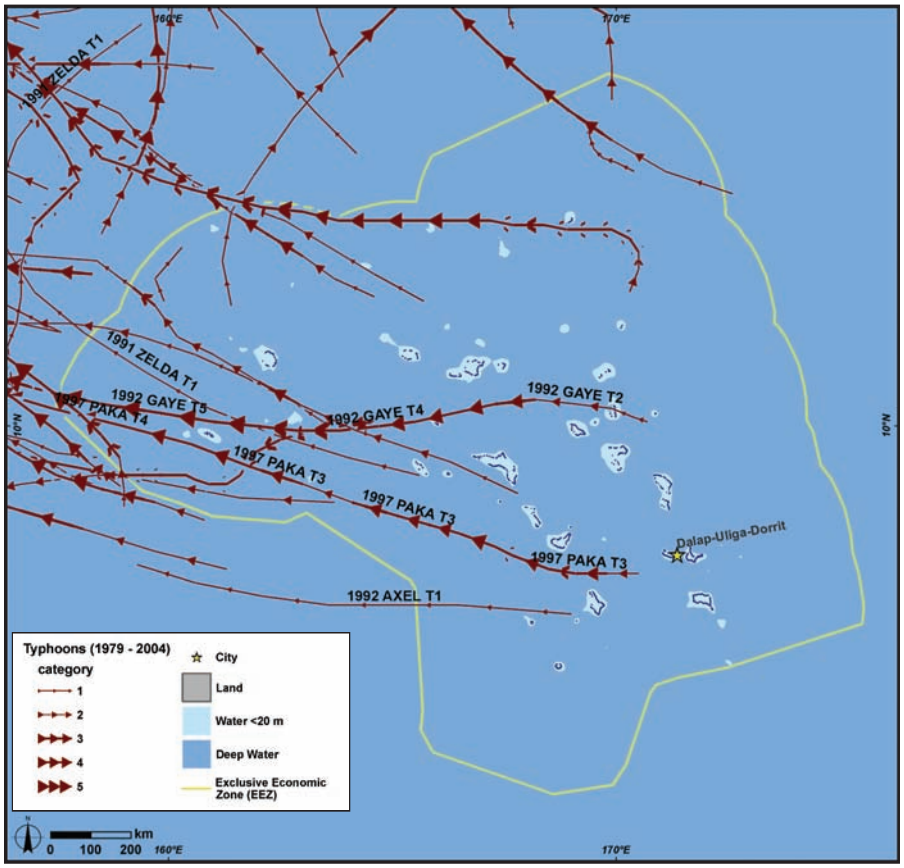

Figure 13.3. The path and intensity of typhoons passing near the Marshall Islands from 1979-2004. Many Pacific typhoons are not named or the names are not recorded in the typhoon database. Map: A Shapiro. Data: Unisys, http://weather.unisys.com/hurricane.

Coastal Development and Runoff

The human population has increased significantly in the Marshall Islands over the past century (Figure 13.4), doubling in size between 1973 and 1999 (RMI Embassy, http://rmiembassyus.org/statistics/statistics.html, Accessed 01/31/05). Although little data on the extent or impact of coastal development exists, population density on the heavily populated islands of Kili and Majuro in 1999 was 2,150 and 6,314 people per mi^2 respectively (1999 Census of Population, RMI).

In Majuro and other outer atolls, such as Likiep, eutrophication has been observed near human settlements.

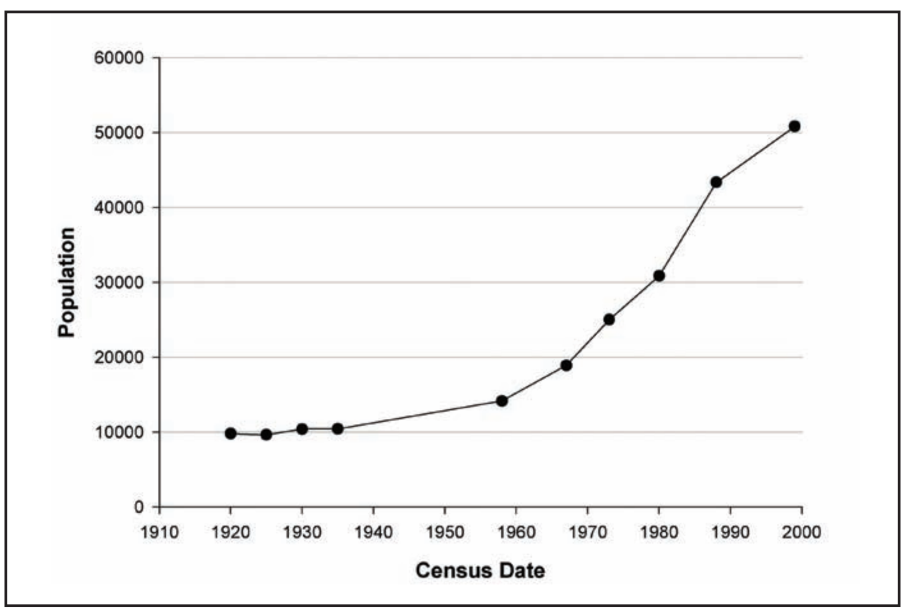

Figure 13.4. The population in the Marshall Islands doubled between 1973 and 1999. Source: RMI Embassy, http://rmiembassyus.org/statistics/statistics.html, Accessed 01/31/05.

Coastal Pollution

Little information on this threat is available, but obvious biotic affects appear down-current from the sewage outfall on Majuro. Table corals are unusually fragile, and the substrate is dominated by a slimy black encrusting algae, a eukaryotic red form. The more typical *Halimeda* spp. of algae are entirely absent. Such a biotic shift will reduce coral recruitment. Within the lagoon, a correlation between a eutrophic algae, *Dictyota* spp., and the most populated regions of Majuro is apparent. A particular *Zooanthus* spp. is also restricted to this eastern lagoon region where eutrophication is apparent.

Tourism and Recreation

The number of visitors to the Marshall Islands has fluctuated in the past two decades, but is generally fairly modest. The highest number of visitors to Majuro occurred in 1996, when arrivals totaled 7,563 persons; in 2003, there were 7,195 visitors (Marshall Islands Visitors Authority, http://www.spc.int/prism/country/mh/stats/toutism/travelers.htm, Accessed 01/31/05). Despite the low numbers of visitors, visitor expenditures did contribute an estimated $4 million to the Marshall Islands' economy in 2000 (U.N. Economic and Social Commission for Asia and the Pacific database, http://unescap.org/stat/data/apif/index.asp, Accessed 01/31/05) when 5,246 people visited.

Fishing

Subsistence and artisanal fishing play an important role in the Marshall Islands, especially in the outer atolls, where they provide the local population with a major source of animal protein. According to RMI Embassy statistics, nearly 3,400 households were engaged in subsistence fishing in 1999 (RMI Embassy, http://rmiembassyus.org/statistics/pdf/demographics/SubActbyAtoll99.pdf, Accessed 01/31/05). In most places, fishing was the most common subsistence activity, with more households participating in fishing than other subsistence activities such as growing food, producing copra, breeding livestock, or making handicrafts.

In addition to the subsistence harvest, a major commercial fishery exists in the RMI, and sale of fishing rights in the EEZ generates between $1-3 million per year. The Marshall Islands Marine Resources Authority (MIMRA) maintains statistics on total annual catch and method of catch, which are shown in Figure 13.5 (http://www.spc.int/prism/country/mh/stats/economic/fish_catch.htm, Accessed 01/31/05). However, most of the commercial fishing activity is focused on offshore tuna stocks and is not likely to impact reef ecosystems. MIMRA also operates the National Fisheries and Nautical Training Center, which educates approximately 75 Marshallese students per year, providing skills that prepare them to work in commercial fisheries enterprises.

Little information was available to characterize the threat to reef ecosystems from fishing. However, some industrial fishing impacts were noted in Rongelap in the form of longlines that were found entangled on corals at four outer reef sites at the leeward site of the atoll. Long-line shark fishing activities were occurring in RMI at the time, but were permitted only 5 miles off the coast. The lines may have been evidence of illegal shark fishing on the reefs, as longline shark fishing is no longer allowed nearshore.

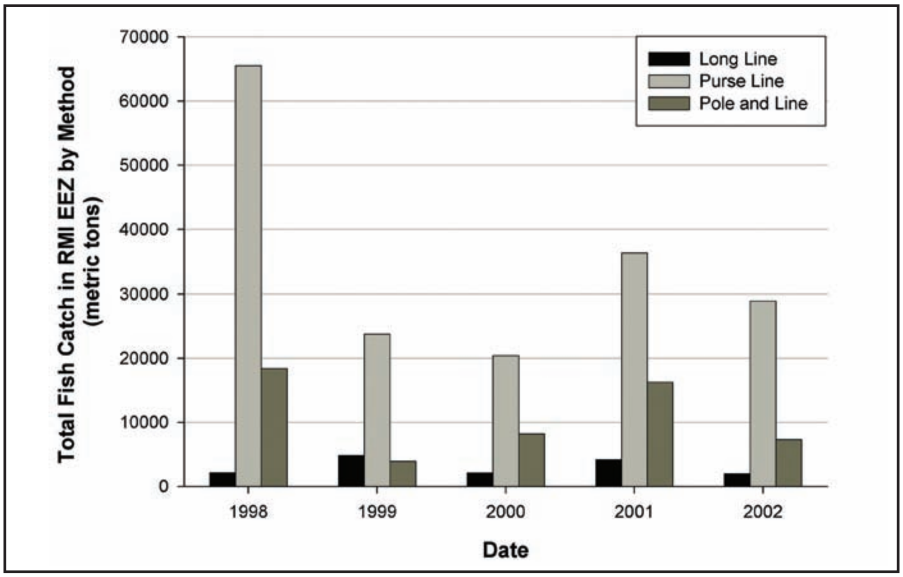

Figure 13.5. Total annual catch and method of capture in the Marshall Islands' commercial fishery, which targets offshore tuna stocks. Data on reef species and subsistence catch were not available. Source: MIMRA database.

Trade in Coral and Live Reef Species

Harvesting live rock and other coral reef products can have serious implications for reef communities. In the Marshall Islands, many species are exported for the aquarium trade (Figure 13.6), and seashells are frequently used in handicrafts, but little quantitative information on the amount of material removed from the reefs is available. However, a clam and live coral farm and a pearl farm are exporting sustainably-produced organisms for the aquarium market.

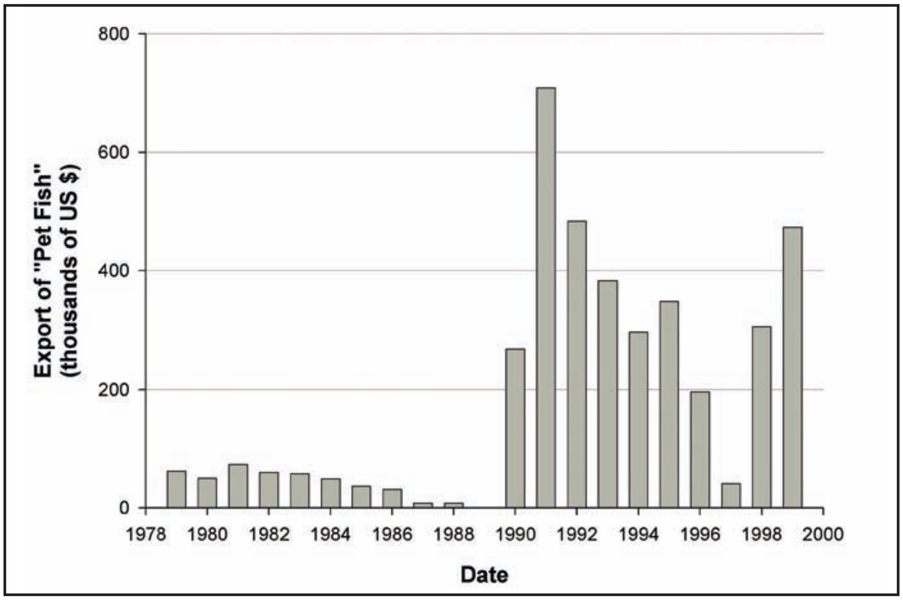

Figure 13.6. The value of 'pet fish' exported for the aquarium trade from 1979-2000. Source: RMI Division of Statistics; MIMRA database.

Ships, Boats, and Groundings

No information on this threat is available.

Marine Debris

Plastic, glass and metal trash and fishing and packaging debris are found along both lagoon and ocean shores on Majuro. Human-produced debris is found on outer atolls as well, but the amount produced by human settlement is much higher at the capital atoll and around its city. The most common pieces of debris produced by the city are plastic diapers, plastic bags, glass bottles and metal cans that accumulate on the bottom of the lagoon around town or remain trapped in coral branches.

Aquatic Invasive Species

Invasive and non-native species are a subtle, but potentially more permanent threat, especially on land. Many terrestrial invasive species have been documented and some of these, such as ironwood (*Casuarina equisetifolia*), can impact coastal areas by out-competing the native vegetation that protects the shoreline. Fouling marine invertebrates have been introduced, especially in ports where they probably arrived on ship hulls. Non-native algae and fishes have been documented, but the full impact of their presence has not been studied. Indications are that invasive species have a high potential to damage coral reefs (NBTRMI, 2000; N. Vander Velde, pers. comm.).

Security Training Activities

The most destructive series of anthropogenic events involving RMI islands, atolls, and lagoons occurred half a century ago. On March 1, 1954, a thermonuclear test bomb, code-named "Bravo," was detonated on Bikini Atoll. Within seconds, a mile-wide 15-megaton blast vaporized entire islands and created a huge crater in the reef. Fish, corals, and other marine and terrestrial animals were destroyed when millions of tons of water and debris were thrown high into the air and then fell back to the lagoon (Simon, 1997; Walker et al., 1997; Robison and Noshkin, 1999; Niederthal, 2001). This test was part of a series of thermonuclear and hydrogen bomb tests that were conducted from 1946–1958 on Bikini and nearby Enewetak Atolls. Winds spread the airborne radiation to nearby atolls, including inhabited Rongelap and Utrik and uninhabited Rongerik and Ailinginae.

Unfortunately, the complete picture of nuclear testing on the Marshalls' biodiversity is neither simple, nor necessarily what it seems to casual observers. For example, Delgado (1999) observed in his book Ghost Fleet that there was "no tangible evidence of the testing" on Bikini. Maragos (pers. comm.) counters, stating that "the 2 km wide and 50 m deep crater in the reef at the Bravo test site is certainly evidence of lasting impacts along with the islands that were evaporated by the Bravo blast." Although a half-century has passed, the full extent of the impact on the biota from radioactive materials introduced during the nuclear testing program is unknown (NBTRMI, 2000). Analysis to compare fish diversity data between two surveys in 1984 and 2002 produced no clear results because of the ambiguous nature of the old data (Beger et al., 2003). As Kenchington and Salvat (1988) stated, “radioactive wastes may have long-term and largely unpredictable effects upon the genetic nature of the biological community.” Risks from the consumption of large amounts of locally grown food are still acknowledged to exist, even though returning residents are again eating the crabs.

Offshore Oil and Gas Exploration

Oil and gas exploration activities are not known to occur.

Other

Evidence of damage from COTS, *Acanthaster planci*, is apparent on the reefs of the Marshall Islands (Figure 13.7), with densities along the south western lagoon shore of Majuro exceeding 1000 per km^2. *Acropora* species (tabulate and branching) have been decimated (over 90% mortality) in 2004 and 2005. Currently (Spring 2005) slow-growing massive species, particularly *Porites lobata*, *Pavona duerdeni*, and *Lobophyllia* sp., as well as *Pocillopora eydouxi*, are being killed in an area previously targeted by starfish eradication dives. The only unaffected species is *Porites rus*, which is clearly increasing its dominance. Smaller reef flat *Acropora* spp. are also unaffected. Following a wave of *Acropora* mortality, dead coral surfaces have become colonized by a thick carpet of *Dictyota* algae, even in regions previously dominated by *Halimeda* and lacking *Dictyota*. Another COTS ‘hot spot’ at Majuro Atoll is in Calelin Pass near Irooj Island. Feeding scars on *Porites* colonies are also evident in the far eastern lagoon, near Rita. Along the southern ocean fringing reef, COTS are abundant only in the far western district of Laura.

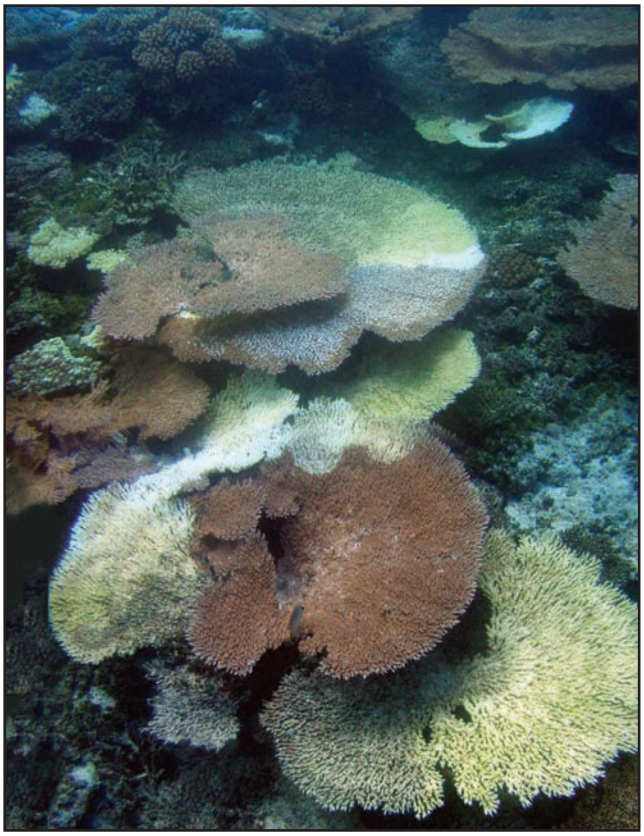

Figure 13.7. Crown-of-thorns starfish, *Acanthaster planci*, damage *Acropora* corals in Majuro lagoon, a region where *Acropora* mortality is over 70%. Photo: D. Jacobson.

This COTS outbreak may be the first to occur since a major eradication effort in 1970. A major outbreak also occurred 15-20 years ago on Enewetak atoll. Even now, *Acropora* is entirely absent on the ocean side of the inhabited Enewetak island, although luxuriant stands of *Acropora* survive in a small refugium in a reef flat quarry pool on the north end of the island.

Another predator of coral, the corallivorous gastropod, *Drupella* spp., is locally common (especially near the densely populated district of Delap) and can cause large feeding scars on *Acropora* spp. Several dozen snails can be found hiding during the day under the base of a single colony.

CORAL REEF ECOSYSTEMS—DATA GATHERING ACTIVITIES AND RESOURCE CONDITION

In addition to the outer island surveys on Rongelap, Bikini, Ailininae, Mili, Arno, Namu and Likiep scientists at the College of the Marshall Islands (CMI) have been paying close attention to local ecosystem indicators in the capital atoll of Majuro (i.e., bleaching, coral and coralline algal disease, COTS outbreaks, and pollution-associated changes in macroalgae). Permanently-marked transects are being installed in transitional sites to photographically monitor long-term changes. One of these sites has been extensively photo-mapped (over a 15 x 130 m area) to closely monitor the incidence of coral disease. In addition, a project involving manta tows over several km of leeward shore on Majuro is planned to map the distribution and abundance of schooling food fish species (i.e., rabbitfish, parrotfish, and surgeonfish).

WATER QUALITY

Coastal construction of ports, docks, airfields, causeways, and roads has affected water quality in the RMI, most notably in the capital atoll, Majuro. Development projects often require sources of fill material and expansion of land areas that lead to dredging and filling of adjacent reef areas (Maragos, 1993). While underway, construction along the shoreline introduces sediments, increases turbidity, and can change the circulation patterns in lagoons.

BENTHIC HABITATS

Pioneering studies on coral reefs in the Marshall Islands encompassed several atolls before 1955 (Tracey et al., 1948; Hiatt, 1950; Ladd et al., 1950; Wells, 1951 and 1954; Emery et al., 1954). A two-volume report on the natural and biological resources of Enewetak Atoll is perhaps the most comprehensive treatment of any of the Marshall Islands (Devaney et al., 1987). In 1988, Maragos coordinated coastal resource inventories and atlases of Arno, Kwajalein, and Majuro Atolls. There were additional marine biodiversity surveys of the northern RMI islands and atolls involving marine biologists and cultural specialists (Titgen et al., 1988; Thomas et al., 1988; AAA Engineering and Drafting and University of Hawaii Sea Grant Program, 1989; AAA Engineering and Drafting et al., 1989; Manoa Mapworks, 1989; Maragos, 1994.

In 2001, Pinca led a systematic survey of coral reef resources at Likiep Atoll with community support through the CMI and MIMRA (Pinca, 2001). Similar surveys followed at Rongelap and Bikini in the summer of 2002 (Pinca et al., 2002) and at Milli, Rongelap, and Ailininae Atolls in the summer of 2003 (Beger and Pinca, 2003a,b; Pinca et al., 2004a,b). Surveys of Majuro and Namu Atolls occurred in November 2004 (S. Pinca, pers. obs.).

During these systematic surveys, four transects parallel to the shoreline were laid at four different depths (5, 10, 15, and 20 m) and divers on each transect recorded data on percentage cover of substrate type, coral life-forms and target species of corals, seaweed groups, abundance and size of target fish species, and abundance of commercial invertebrates. In addition, the 15 m transect was replicated three times to give an indication of the variability at this depth. Sites were selected on both the ocean and lagoon side of atolls, including pinnacles and patch reefs. Biodiversity of fish and corals were recorded during 60-minute vertical swims from 30 m to the surface. In 2001 in Likiep, and in 2004 in Arno, manta tows were also used to assess broad changes in the benthic communities of coral reefs.

The results of these assessments confirm that coral cover is generally high in the Marshall Islands (Figure 13.8), with peak areas at the leeward ocean sides of the atolls. High values of hard coral cover vary between 57 and 68% (calculated as an average across sites in all four depth categories). Local coral cover at a single site reached as high as 79% of total substrate cover in Rongelap. Although coral cover was generally lower at lagoonal sites, a very high concentration of rare branching *Acropora* species were found in these environments. The lowest coral cover was generally recorded on the leeward lagoon side. However, many patch reefs and pinnacles with high coral cover and diversity are present inside the lagoons. The most common coral species or species groups are *Porites lobata-australiensis*, *Isopora palifera/cuneata*, and *Porites rus*. *Acropora* spp. were predominantly found inside the lagoon, as branching and tabulate growth forms, while non-*Acropora* encrusting, foliose, and *Millepora* spp. were more common at the oceanic sites. At some sites, blue corals (*Heliopora coerulea*) represented more than 20% of total coral cover (e.g., on the west side of Likiep Atoll). On the windward ocean side, where the mechanical energy of the wave action is much stronger than on the leeward side, the most abundant corals were the encrusting forms and *Millepora* spp. (fire coral). Fire coral was growing here in smaller colonies and was predominantly an encrusting form, compared to the fire coral on the leeward side, which grew in a branching and taller form.

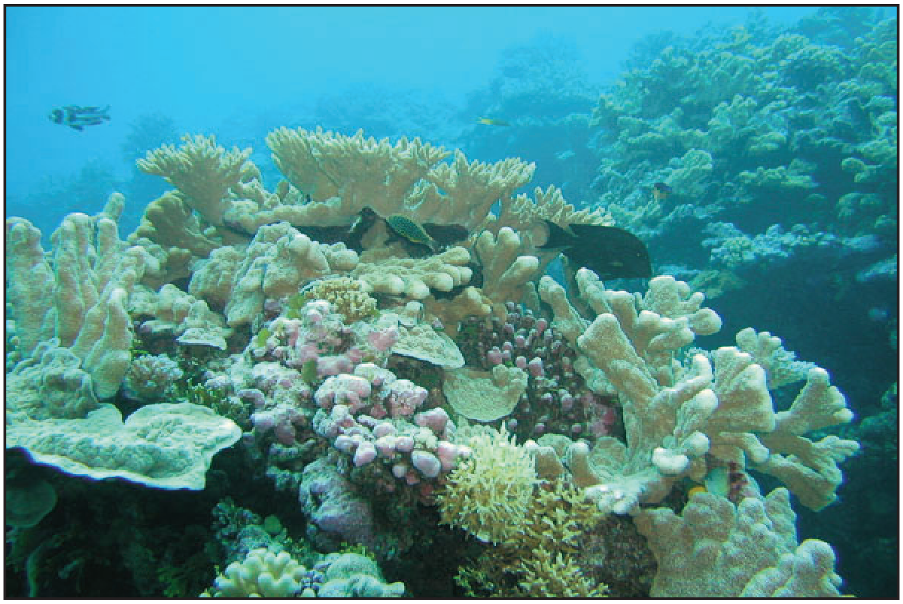

Figure 13.8. The upper forereef at Rongelap Atoll is an area of high coral cover and diversity in the Marshall Islands. Photo: S. Pinca.

Range extensions (when a species is found that had not been previously recorded at RMI) for several species of corals and fish were established during the 2002 and 2003 expeditions. A new species of coral (*Acropora rongelapensis*) was described in 2003 from Rongelap (Richards and Wallace, 2004).

Soft corals were rare in most atolls in the RMI. However, in Mili, *Sarcophyton* spp. and *Lobophyton* spp. were relatively abundant, as were gorgonians of the genus *Melithea*.

Fleshy seaweeds (especially *Microdyction* spp. and *Halimeda* spp.) and coralline algae were abundant and coexisted with healthy hard corals. Seaweed cover was higher at the west ocean and south ocean sites in Mili and east, south, and north ocean sites in Rongelap. Coralline algae dominated west ocean sites in Likiep. Two hundred and twenty-two species of macroalgae, three species of seagrass, and five species of mangroves have been identified in the Marshall Islands.

In 2001, a total of 18 sites around the six islands of Likiep Atoll were sampled by Pinca (2001). The general ecological health of coral reefs in Likiep Atoll was very good, although there are sharp differences among the six islands surveyed. The islands differ both ecologically (associations of different species of organisms, both corals and fish), as well as in the degree of integrity (status of corals, quantity and structure of fish populations). Some inhabited islands show initial signs of eutrophication by the presence of blue-green algae on the lagoon sand bottom in front of the villages. Also, a live-fish fishing enterprise that catches groupers and other reef fish was present in fall 2001, although its impacts have not been quantified.

ASSOCIATED BIOLOGICAL COMMUNITIES

In 2002 and 2003, a total of 45 sites in Rongelap Atoll were surveyed (Pinca et al., 2002; Beger and Pinca, 2003a; Pinca et al., 2004b), including sites at pinnacles and patch reefs inside the lagoon, as well as ocean and pass sites. A very high diversity and richness of fauna exist in Rongelap atoll, with particularly abundant and large fish, abundant megafauna such as sea turtles, rays, and sharks, as well as large and abundant giant clams. This atoll has been uninhabited for the past 50 years due to the evacuation of local people following radioactive fallout from the nuclear tests at Bikini Atoll. Coastal managers and marine biologists analyzed the results from the 2003 surveys and recommended specific sites to be preserved for their pristine health and high biodiversity.

A total of 20 sites were surveyed at Mili Atoll during a two-week period in 2003 (Pinca et al., 2004a), including nine sites on the ocean side of the atoll, two pass sites, and nine lagoon and pinnacle sites. The team worked directly with local landowners and government officials to propose that a few islands be dedicated as a marine sanctuary in the northeast corner of the atoll. The reefs were found in mostly pristine condition, with a large number of fish, coral, soft corals, and algae present. Sharks were not very abundant, and local anecdotal evidence suggested that illegal shark fishing by foreign large-scale fishing operations was to blame (Figure 13.9). Beaked whales, spinner dolphins, sharks, and large-size fish were found in the area proposed for a marine sanctuary. The proposed sanctuary area includes a variety of important habitats, such as ocean walls, passes, pinnacles, and lagoonal reef habitats.

Figure 13.9. Fins harvested from hundreds of sharks lay drying in the sun. While fishing for sharks is not illegal for Marshallese fishers, illegal shark fishing is suspected in some areas of the Marshall Islands, such as at Mili Atoll. Photo: S. Pinca.

The highest abundance of fish was found at the northern and southern ocean sides of the atolls of Likiep and Mili, and at the southeast lagoon, pass and slope areas of Rongelap (Pinca, 2001; Beger and Pinca, 2003a; Pinca et al., 2004a,b). Surgeonfish, snapper, wrasse, fusilier, parrotfish, and grouper are the most abundant food fish families. Seven of the 860 species of reef fishes recorded in the Marshall Islands are endemic. A total of 373 fish species were recorded at Mili Atoll in 2003. The richest areas were the central pinnacles in the southern lagoon and the ocean area that is being considered for designation as a marine protected area (MPA). The number of fish species at each site varied from 95 to 162 with an average of 124 fishes. Rongelap Atoll had a total of 397 species with the richest area being the tip of Jabwan at Rongelap Island, on the main pass, where the highest fish species numbers were counted both in 2002 (179 species) and in 2003 (205 species). The number of fish species counted at each site during a single visit varied from 91 to 205. On average, sites harbored 124 species of fish.

Passes generally support more species of fishes, since they combine aspects of outer and lagoonal habitats. Sheltered sites in the lagoon support lower fish abundances, but they harbor many unusual species. Humphead wrasses (*Cheilinus undulatus*) were observed in the eastern part of Rongelap Atoll, where they were found at the edge of the drop-off and on lagoon pinnacles near and in passes. They were slightly less abundant in Likiep, and least abundant in Mili Atoll.

The after-effects of some of the 67 nuclear tests in the northern Marshalls between 1946-1958 on fish have also been studied. Noshkin and Robison (1997) summarized the results from all available data on the radionuclide concentrations in flesh samples of reef and pelagic fish collected from Bikini and Enewetak Atolls between 1964 and 1995. Although they found that 239 + 240Pu (plutonium) and 241Am (americium) had not significantly accumulated in the muscle tissue of any species of fish, a variety of other radionuclides had accumulated in all species of fish (Noshkin et al., 1986). Over the years, many of those radionuclides have diminished by radioactive decay and natural processes (Noshkin and Robison, 1997). The authors report that fish collected in the 1980s and 1990s show only low concentrations of a few remaining long-lived radionuclides. By the 1990s, 207Bi (bismuth) remained below detection limits in muscle tissue of all reef fish except goatfish. Levels of 137Cs (cesium) diminished to detection limits in mullet and goatfish at many islands, and 60Co (cobalt) was undetected or at low concentrations.

Giant clams (*Tridacna* spp.) are significantly more abundant at leeward ocean sites. Four species of giant clams were recorded for Mili, where the highest total number is found at the south pass. Five species were recorded in Rongelap, where the highest numbers were represented by *Tridacna maxima* at the west pass.

Similarly, all five species of giant clam were recorded at pinnacles inside the lagoon. Sea urchins are most abundant at the windward ocean sites and relatively in low abundance elsewhere. Sea cucumbers are present in very high numbers on the lagoon side of the East Likiep Atoll.

RMI atolls support substantial populations of megafauna such as green sea turtles, whales, rays, and sharks. A high number of sharks are often observed around RMI atolls, on the reef flat and slope, and inside and outside the lagoon. Every dive is accompanied by either gray reef sharks (*Carcharhinus amblyrhynchos*), the most abundant species overall, or white tip sharks (*Triaenodon obesus*), and silvertip sharks (*Carcharhinus albimarginatus*) in deeper waters. Nurse sharks (*Nebrius ferrugineus*) appear to be rare and were only seen at three sites in Rongelap Atoll. A tiger shark was also observed by the main pass of this atoll, in shallow water. A few black tip sharks (*Carcharhinus melanopterus*) are also encountered, especially in shallow waters. Zebra sharks (*Stegastoma varium*) were seen in Rongelap and Namu atoll.

Manta rays (*Manta birostris*) were spotted in Rongelap, including at patch reef sites inside the lagoon; and eagle rays (*Aetobatus narinari*) are frequent in Majuro, as well as in all outer atolls visited.

CURRENT CONSERVATION MANAGEMENT ACTIVITIES

The primary agencies involved in protecting coral reef ecosystems are MIMRA and RMI Environmental Protection Authority (RMI-EPA). In 2000, the National Biodiversity Strategy and Action Plan (NBSAP, http://www.biodiv.org/doc/world/mh/mh-nbsap-01-en.pdf, Accessed 01/25/05) and the National Biodiversity Report (NBTRMI, 2000) were approved by the Cabinet. Both address the need for conservation and management of natural resources. The NBSAP recommends strengthening the concept of 'mo', a traditional system of taboo identifying certain areas as 'pantries' that could be harvested only periodically. The NBSAP also addressed the need for sustainable fishing practices and retention of local knowledge.

The Marine Science Program at the CMI (MSP-CMI) is studying the status of marine resources to help each atoll population manage its resources and plan fishing and other activities in a sustainable manner, with the specific purpose of conserving particularly rich or threatened zones (Pinca, 2003a). The MSP-CMI collaborates with MIMRA, RMI-EPA, Marshall Islands Visitor Authority, and Ministry of Internal Affairs to design community-based fishery management plans (Pinca, 2003b). During the past outer atoll surveys, MSP-CMI, together with the Natural Resources Assessment Surveys (NRAS, http://www.nras-conservation.org, Accessed 3/15/05) team, combined local marine survey expertise with international scientific expertise to conduct underwater surveys assessing reef health and fishing impacts.

The need to protect Marshallese marine resources stems from both a precautionary effort to conserve pristine reefs and a direct demand from local fishers who report a decline in target species for both commercial and local use. Lower abundance of clams, fish, lobsters, and cowry shells have been reported by local populations from the outer atolls. Marine reserves and other management measures are still in their infancy, but several atolls (Jaluit, Arno, Likiep, Mili, and Rongelap) are spearheading this effort. Selection of conservation sites and practices is based on biodiversity and conservation theories. Ecological observations like the ones collected by NRAS indicate where healthy and productive ecosystems are, where conservation is more urgent and more efficient for repopulation of scarce species, and where the recruitment of important species takes place, since it is important to protect both nursery and spawning areas. To help identifying source and sink areas of propagules, a study that models the water circulation at Rongelap Atoll is underway (Peterson et al., in review). The processes for MPA designation involve consulting with the community, identifying their expectations and preferences, and incorporating the results of research conducted by local and foreign scientists. Conservation will hopefully also help protect fishing grounds from illegal fishing operations. With outstanding diversity and coral cover, Likiep, Rongelap, and Mili Atolls provide refuge for a suite of marine organisms. Because of the difficulty of enforcing fishing regulations in remote locations, these atolls and other atolls such as Ailinginae, Bikini, and Jaluit are likely to experience illegal fishing.

Proposed MPA sites near Likiep include Jeltonet (east of the atoll), Liklal (north), and Lukonor (west) on the ocean side. In Mili, the northeast area around Reiher's Pass was proposed as a sanctuary by the community. In order to conserve the high biodiversity of this area, a reserve network in Mili Atoll has also been discussed. In Rongelap, Jabwan Point is recommended for sanctuary designation.

OVERALL CONCLUSIONS AND RECOMMENDATIONS

In general, the reefs of the Marshall Islands are in good condition. While the two atolls used for the nuclear testing program have experienced unique stresses, the reefs of the RMI as a whole have escaped the extensive damage seen in other parts of the world. Reefs surveyed at various locations in 2001, 2002, and 2003 were found to be in a very healthy condition, with a large number of fish, healthy corals, and algae. One could argue that because no humans inhabit atolls affected directly or indirectly by nuclear testing, the reefs at these atolls have recovered to support seemingly natural equilibrium populations that largely remain unexploited to date. Abundant megafauna such as sea turtles, whales, rays, and Napoleon wrasses were also recorded.

Training for local personnel to manage and monitor the reef areas is essential to the success of any community-based solution to conservation and sustainable development. Training and capacity building activities for local people are being undertaken at CMI, and conservation and management workshops are planned for the future. Local inhabitants are demonstrating interest in becoming park rangers and are requesting specific training. A certificate program in marine resource management, which includes reef ecology and monitoring techniques, was offered by RMI in 2004 and will be replicated in 2005.

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