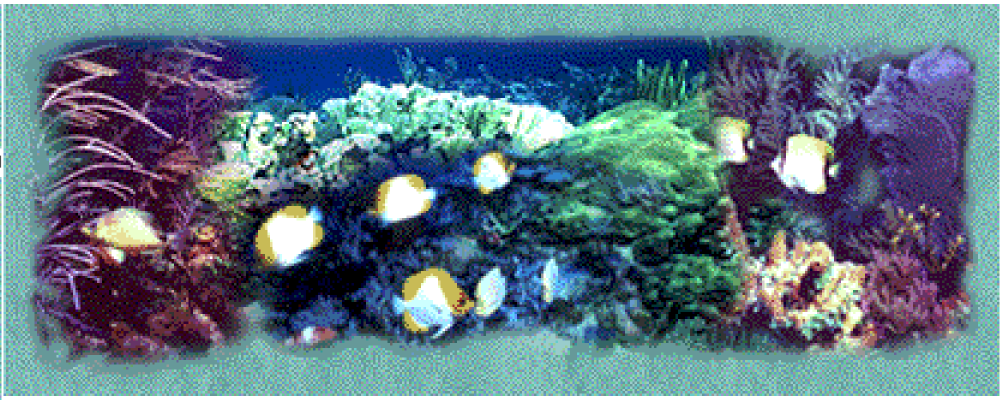
STATE OF THE COASTAL ENVIRONMENT

THE EXTENT & CONDITION OF U.S. CORAL REEFS



The United States has substantial coral reef holdings in the Atlantic and Pacific Oceans. In the Atlantic, off the coast of Florida, is the planet's third largest barrier reef system; other coral reef systems are found off Puerto Rico and the U.S. Virgin Islands. Many other notable systems are found throughout the Pacific, including significant coral reefs located off of Hawaii. Recent declines in coral reef health, and disturbances caused by hurricanes, diseases, and predator outbreaks, have captured the attention of governments and the public worldwide. Scientists have only recently begun the extensive studies necessary to determine whether and why coral reefs are in decline, and to understand the direct and indirect effects of human activities on reefs and reef resources.

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INTRODUCTION

Coral reefs are spectacular products of life in our oceans. They are massive structures built largely by colonial invertebrate animals that secrete skeletons of calcium carbonate. The skeletons remain after the animals die, forming a foundation for the next generation. A wide range of diverse organisms contribute to reef building, including algae, molluscs, sponges and worms, but hard corals are the most important. Surprisingly, the living and growing part of the reef is only a thin, fragile layer that sits atop the calcium carbonate foundation. Sometimes hundreds of meters in thickness, the foundations can survive millions of years. In contrast, the living coral reefs are quite fragile and can be easily damaged by natural or human disturbances.

Coral reefs are located off the coasts of more than 100 countries (Birkeland, 1997a) and large numbers of people depend on them for their livelihood. Reefs provide numerous recreational opportunities, are linked ecologically to adjacent coastal ecosystems such as mangroves and seagrasses, support substantial biodiversity, and protect shorelines from wave damage. Tourism and fishing are major economic activities in coastal communities with access to coral reefs. For example, visitors spend about $1.2 billion annually in the Florida Keys (English et al, 1996) where the reef tract is a primary attraction, and coral reefs in Hawaii are central to a $700 million marine recreational industry (Grigg, 1997). The value of reef fisheries off the Florida Keys and Hawaii is estimated at $48.4 and $20 million, respectively (Adams, 1992; Grigg, 1997). Worldwide, the potential sustainable yield of fish, crustaceans, and molluscs from reefs represents approximately 10% of the world's annual fisheries take–worth tens of billions of dollars (Smith, 1978; IUCN, 1993; Jameson et al., 1995).

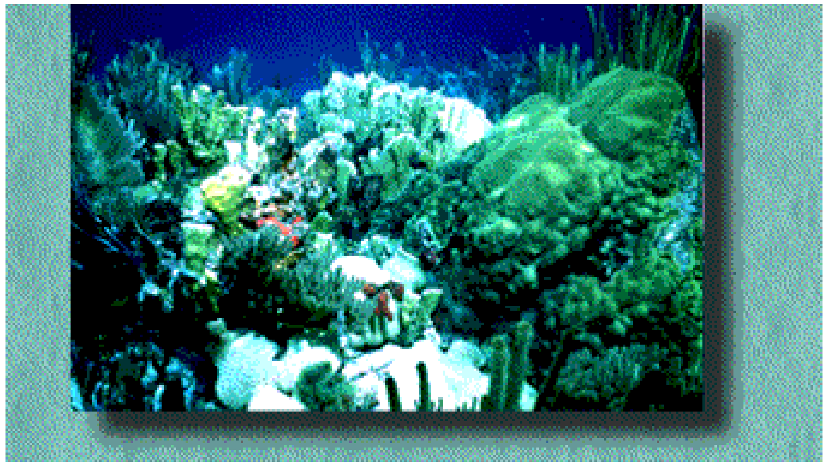


Photo 1. Coral reefs provide habitats and recreational opportunities, as well as shoreline protection from storms.

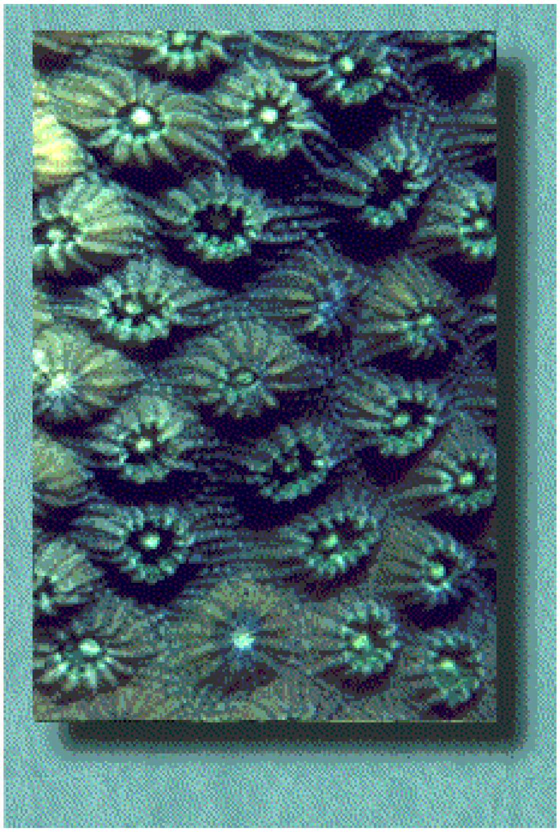
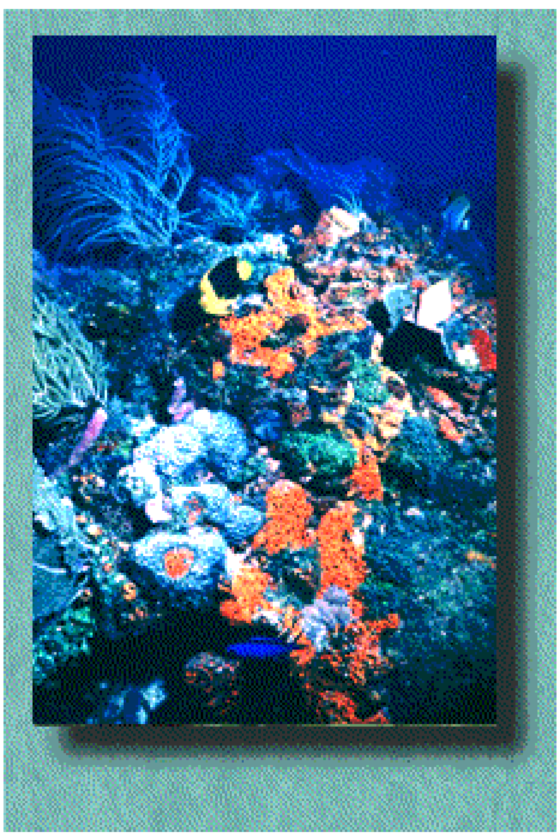


Photo 2. The living portion of a coral reef is only a thin, fragile layer of coral polyps.

Healthy coral reefs are typically bathed in waters that are warm, shallow, clear and relatively free of nutrients. The actual physical conditions that limit the geographic distribution of coral reef growth in the oceans are subtle. Temperature is clearly important at the global scale, with average annual minimum temperatures more important than summer maximums. Regional and local effects of sedimentation, changes in salinity due to flooding and river flow, and nutrients are also important, however. When conditions are suitable, healthy reefs are characterized by a dominant assemblage of benthic organisms, mostly corals, which are especially efficient at growth and reproduction when nutrient concentrations are low. This efficiency gives the corals an advantage over other benthic organisms that grow more quickly, but require higher concentrations of dissolved nutrients or plankton.



Natural factors and human disturbances can cause coral reefs to deteriorate (for a review, see Maragos et al., 1996). Natural factors include severe storms, changes in water temperature, rising sea level, population explosions of predators, and disease-induced die-offs of species that are beneficial to the reef. Human disturbances result from overfishing, specimen collecting, anchoring, ship groundings, sedimentation from land-based stormwater runoff and coastal development, and wastewater discharge. Reefs recover from natural disturbances differently than they do from human impacts. For example, large waves generated by storms cause severe short-term damage to reefs that does not appear to have negative long-term consequences. Indeed, cycles of disturbance and recovery from storm damage help to shape the dynamics of healthy coral reefs. When storm damage is combined with injury caused by pollution or overfishing, however, harm can be more severe and long lasting. In some cases, coral reefs may not recover (Hughes, 1994).

A major challenge for countries with coral reefs off their coasts is to balance the need of their growing economies that depend on coral reef resources with the need to protect and manage the reefs in a way that sustains their value. The U.S. has recently implemented a comprehensive management plan for its coral reef resources that includes marine reserves and special preservation areas in the Florida Keys National Marine Sanctuary. Additionally, the U.S. has sponsored workshops in the Pacific and Caribbean to support local education, outreach, and coral reef training projects (Crosby et al., 1995; Crosby and Maragos, 1995).
(top)

Photo 3. Corals thrive in warm, clear, shallow waters that are typically low in nutrients.

NATIONAL PICTURE

Estimates of total coral reef coverage, worldwide and nationally, are based on data sets of extremely rough scale, and many areas are not yet characterized. For example, in a recent estimate of shallow coral reefs (based on charts) for areas located in major geographic regions only five percent of reefs were mapped at a scale of 1:100,000 or better (Table 1, Spalding and Grenfell 1997). A second estimate is presented in Table 1 based on available platforms suitable for reef growth in water less than 30 meters deep(Smith 1978). Additional estimates range from 100 to 3,930 x 10^3 sq km (Kleypas, 1997), which suggests the great difficulty scientists have in making even first order attempts to define regional and global reef area. Differences in estimates for similar regions mostly reflect biases based on methodology and a general lack of information.

Photo 4. Accurate global estimates of coral reef areas are difficult to obtain because reefs are defined and mapped by a variety of methods.

Table 1. Comparisons of global and regional reef areas.

Region	Area (10^3 km^2)		Percent Area	
	Shallow[1] (>30 m)	Shallow and Deep[2]	Shallow[1] (>30 m)	Shallow and Deep[2]

Red Sea	17	27	4.4	6.7
Arabian Gulf	3	12	1.9	1.2
Indian Ocean	36	146	23.7	14.1
Southeast Asia	68	182	29.5	26.7
Northern Pacific	17	76	12.3	6.7
Southern Pacific	91	77	12.5	35.7
Caribbean	20	57	9.2	7.8
Northern Atlantic	2	32	5.2	0.8
Southern Atlantic	1	8	1.3	0.4
TOTAL	255	617	100	100

1. from Smith, 1978
2. from Spalding & Grenfell, 1997

Shallow reef types can be placed into four general categories: (1) fringing reefs, which are common throughout the Caribbean and the Indo-Pacific, are coral assemblages found along coastlines that extend a short distance from shore; (2) bank/barrier reefs are similar to fringing reefs, but are located further offshore and can be hundreds of meters wide at the reef crest with a shallow lagoon between the land and the reef; 3) atolls, nearly all of which are in the Indo-Pacific, are circular-shaped reefs that surround a central lagoon; and (4) patch reefs, which come in various sizes and shapes, are usually found in clusters. A variety of forces determine the sizes and shapes of coral reefs, including currents, turbulence related to average wave heights and directions, and underlying bathymetry.
(top)

Coral Reefs in the United States

The only emergent coral reefs found off the continental U.S. are located in the Florida Keys, from south of Miami to the Dry Tortugas. Averaging less than 1 km in width for shallow reef habitats, the system covers at least 360 sq km. This estimate does not include additional coral-covered hard grounds in deeper waters, coral habitats that extend further north and an extensive series of patch reefs in the Upper and Lower Keys. As the northernmost extension of the Caribbean reef system, the Florida reef tract accounts for a significant portion of coral reef holdings in the region. Unfortunately, figures are not yet available for coral coverage in the U.S. Virgin Islands and Puerto Rico, though compilations are under way.

In the Pacific, coral reef areas were summarized (Hunter, 1995) for depths between 0 and 100 meters indicated as reef or hard bottom on charts, although not all hard bottom is coral reef habitat (Table 2). The Hawaiian Islands include the largest areal coverage of U.S. coral reefs in the Pacific. The calculations for Hawaii must be considered preliminary, because coral coverage estimates for much of the northwestern region are based on the assumption that existing hard bottom contains corals. The rest of U.S. holdings in the Pacific represent a small fraction of the total, but a number of small U.S. territorial islands in the Pacific have significant reef habitats in their waters, including the islands of Howland, Baker, Jarvis, Johnston, Palmyra, Kingman, Wake, and Midway. Few surveys of these reefs exist beyond local territorial waters, although most also have reefs that extend out 200 nm, the limit of the U.S. Exclusive Economic Zone (EEZ).

Photo 5. The Florida reef tract accounts for nearly one-third of U.S. coral reef holdings in the Caribbean.

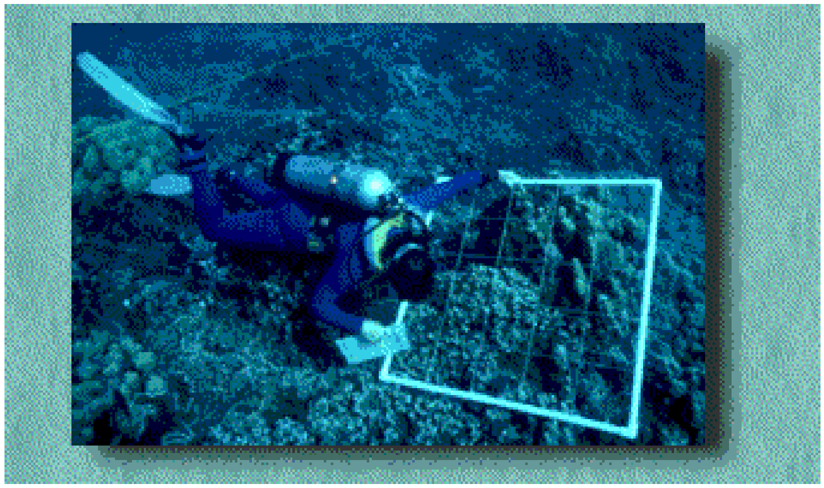


Photo 6. This diver is gathering information about the coral reef as part of a long-term monitoring program.

It is difficult to generalize about the condition of coral reefs in the U.S. because of their broad geographic distribution and the lack of long-term monitoring programs that document environmental and biological baselines. However, two points are clear. First, coral reefs are threatened (if not already damaged) wherever they are close to large concentrations of people; second, while there is widespread agreement that coral reefs are in decline (D'Elia, 1991; Ginsburg, 1993; Jameson et al., 1995; Maragos et al., 1996), data are available to evaluate the status and trends of coral reefs at only a few sites. Large-scale preliminary assessments (e.g., Reef Check, which is part of the 1997 International Year of the Reef) are planned and under way to provide basic information about the condition of coral reefs worldwide. However, great uncertainty exists about whether or not the assessments can be maintained long enough to provide scientists and managers with the monitoring data to evaluate the status and trends of this important coastal resource. In general, it is clear that degradation has outpaced our comprehension of the problems at many locations (Jameson et al., 1995).

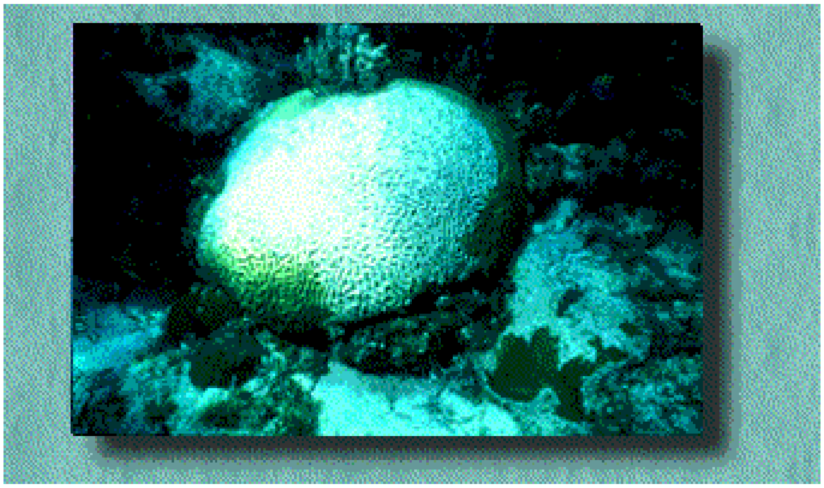


Photo 7. Though it is difficult to generalize about the condition of U.S. coral reefs, this bleached brain coral is an example of a stressed coral.

The status of the Nation's most important coral reefs are summarized by state or territory below.

Table 2. Summary of coral reef areas under U.S. jurisdiction (Hunter, 1995; this paper).

Region	**Reef Area (km^2)**		
	0-3 nm	3-200 nm	Total Area
U.S. Virgin Islands	200[1]	Estimates under way	Estimates under way
Puerto Rico	500[1]	Estimates under way	Estimates under way
Florida Keys	143	182	325
Texas/Louisiana	0	2	2
American Samoa	271	25	296
Guam	69	110	179
Main Hawaiian Islands	1,655	880	2,535
Northwestern Hawaiian Islands	2,430	9,124	11,554
Northern Mariana Islands	45	534	579
Other			
Johnston	130	75	205
Howland	5	0	5
Baker	10	0	10
Jarvis	8	0	8
Palmyra	396	4	400
Kingman Reef	39	10	49
Wake	32	0	32

Regional Totals	5,933	10,946	16,879

Abbreviation: nm=nautical mile

1. Very rough estimate by authors.

(top)

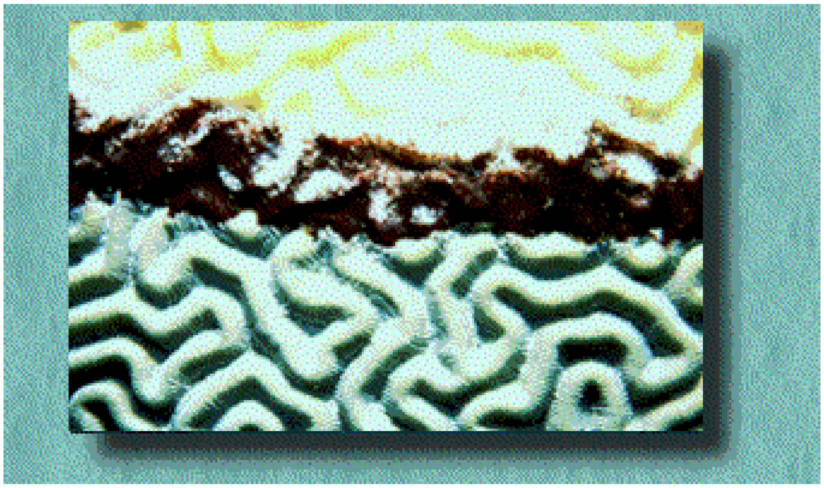


Photo 8. Declines in coral reefs of the Florida Keys have been observed in the last 15 years. This Florida brain coral suffers from blackband disease.

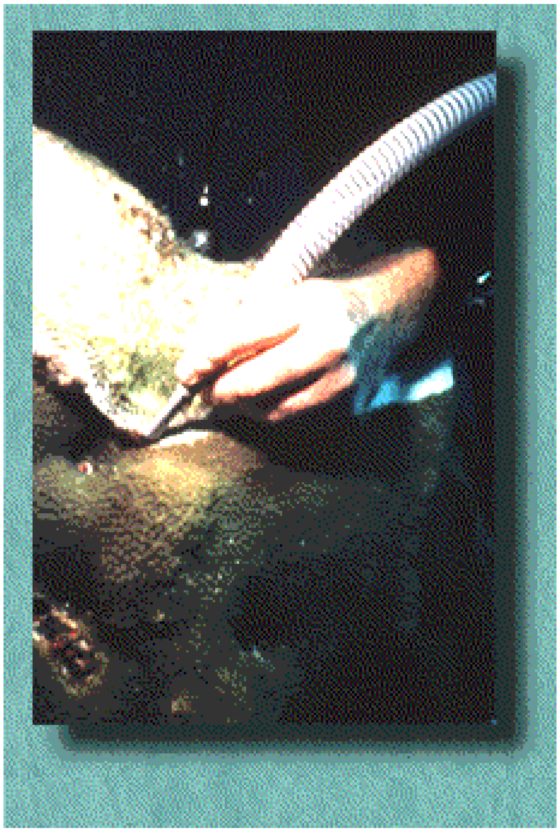


Photo 9. A diver works to remove

Most Important U.S. Coral Reefs

Florida . The coral reefs immediately off the Florida Keys are part of the world's third largest barrier reef ecosystem, stretching 360 sq km from south of Miami to the Dry Tortugas (Figure 1). Tremendous controversy surrounds even basic statements about the condition of these reefs, and has for well over 100 years. For example, in the 1850s, the U.S. government was concerned about the number of ships grounding on reefs in Florida, so the famous Harvard biologist L. Agassiz was dispatched to determine whether or not anything could be done to "get rid of" the reefs (Halley et al., 1997). Following the Agassiz expedition to Florida, it was concluded that the reefs were permanent structures, and that lighthouses would help protect shipping. The government shifted its position significantly and built the lighthouses, many of which survive to this day. The government's current position toward the coastal environment is evident in the 1991 Congressional designation of the Florida Keys National Marine Sanctuary, with a comprehensive management plan that went into effect in 1997. Importantly, a major water quality and benthic monitoring program is in place to provide managers with information about the condition of coral reef resources in the sanctuary and the effectiveness of various management strategies. A sense of urgency accompanies efforts to protect and manage coral reefs in the Keys because multiple threats and stresses may be related to the declines observed in the last 15 years (see Case Study).

blackband disease.

Photo 10. Monitoring programs are in place to provide information about water quality near coral reefs.

***Hawaii*.** Over 80% of reefs in Hawaii lie among the northwest Hawaiian Islands, stretching 1,300 miles from Kauai to Kure Atoll. The condition of reefs off of these islands are presumed to be good because of their remoteness; reef fish standing stocks also appear to be high. The main Hawaiian Islands contain a large area of coral reefs (880 sq km) located in federal waters. In general, coral reefs in state waters are overfished and some reefs are degraded due to coastal development. A recent review of coral reef health in Hawaii concluded that 90% of coral reefs in the main Hawaiian Islands are healthy; the best developed reefs are in state waters located in embayments sheltered from damage caused by storms and open ocean swells (Grigg, 1997). Embayments, however, are also sites of reef degradation due to coastal pollution (see Case Study). The biodiversity of reef corals in Hawaii is low with 47 species, compared to over 500 species in the Indo-West-Pacific region (Maragos, 1995). Storm damage and habitat depths are major factors that affect species diversity and the community structure of reefs in Hawaii (Grigg and Dollar, 1980; Grigg and Maragos, 1974; Grigg, 1983), with human-caused problems important in selected areas (Grigg, 1997).

Photo 11. Ninety percent of coral reefs in the main Hawaiian Islands are healthy, although they are generally overfished.

***Texas/Louisiana*.** In the Gulf of Mexico, well developed coral reefs are found approximately 110 miles south of the Texas/Louisiana border. These reefs were designated as the Flower Garden Banks National Marine Sanctuary in 1992. Formed atop salt domes located beneath the sea floor, they encompass a 56 sq mi protected area. In contrast to many other coral reef sites, this reef community has shown no significant declines during an ongoing 25-year monitoring period. The remote location of the Flower Gardens helps to protect the reefs from most fishing and diving pressures. Strict regulation of anchoring and offshore oil development in the area has helped minimize injuries to the reefs. However, divers are making extra efforts to visit these spectacular reefs because of their good condition. With over 10,000 dives made at the site annually, managers are concerned that unforeseen challenges will soon develop (Gittings et al., 1993).

Puerto Rico. With a land area about the size of Rhode Island, Puerto Rico is comprised of six main islands that occupy a central position in the Caribbean West Indies. The largest island has a 500-km coastline and is mountainous. Flooding from rivers and runoff to coastal plains and nearshore marine areas create sediment problems for most reefs around the island. Well developed shallow reefs are located off the east coast, surrounding the islands of Culebra and Vieques; coral cover is between 20% and 35%. Along the south shore from the west to La Parguera, coral cover is low; starting at La Parguera, the offshore reefs on the shelf break are well developed and quite spectacular, with coral cover approaching 50% to 60%. This contrasts with the inshore reefs where local extinctions, warm sea surface temperatures, hurricanes, coral bleaching, and competitive displacements of corals by sponges have decreased coral cover and increased seaweed biomass (Vicente, 1993). Estimates of the reef area are not available. Based on a coastline that includes reef or coral-covered hard bottom in most areas, however, approximately 500 sq km is a reasonable approximation for territorial waters. Reefs in the Jobos Bay National Estuarine Research Reserve, located off La Parguera, are in poor condition due to sewage disposal and coastal erosion; coral cover averages less than 5%. Most reefs are located outside the reserve. The west shelf consists of a large carbonate platform with coral cover between 15% and 30%; nutrients and sediments from coastal erosion are major problems. Fisheries management plans are in development for the island, but most reefs are already overfished.

Virgin Islands. The U.S. Virgin Islands are approximately 1,000 mi southeast of Miami and 45 mi east of Puerto Rico. Shallow bank/barrier reefs are the most common reef types surrounding the islands, but fringing reefs and deeper reefs with well developed spur and groove formations are also common. In general, the amount of living coral on these reefs has declined, and the amount of algae has increased in the last two decades. Hurricanes in 1989 and 1995, and white band disease, which affected branching elkhorn and staghorn corals, produced the most damage to reefs (Rogers, in prep.). However, sedimentation from runoff and overfishing through the use of fish traps are also problems. With a coastline of 188 km, reef area in territorial waters can be estimated at less than 200 sq km. The total reef area is undoubtedly much larger, but is difficult to determine due to the island's 200-nm EEZ and the absence of any ground-truthed data. Fishing is an important commercial and recreational activity in the Virgin Islands, with the value of the fishery estimated at over $5 million in 1993 (Meyers, 1994). Several major hurricanes in 1995 and 1996 significantly damaged commercial fishing (Tobias, 1997). Protected areas in St. Croix include Buck Island Reef National Monument and Salt River Submarine Canyon, established in 1961 and 1992, respectively. Two hurricanes caused serious damage to reefs at Buck Island in 1979; at around the same time, white band disease reduced the cover of live elkhorn coral from 85% to 5% (Gladfelter, 1982; Rogers et al., 1982). Three small marine reserves and wildlife sanctuaries are located off the southeast coast of St. Thomas. In St. John, the Virgin Islands National Park and Biosphere Reserve occupies about two-thirds of the island and surrounding waters. White band disease has seriously affected coral reefs throughout the Virgin Islands. Indeed, next to overfishing, white band disease has probably caused the most damage to coral reefs throughout much of the Caribbean basin (see Long-term recovery section, below). Currently, various coral diseases appear to be increasing in prevalence throughout the islands, which may reflect a trend throughout the Caribbean.

Photo 12. Coral reefs are an important part of tourism in the Northern Mariana Islands. Most of the economy depends on tourism.

Guam **.** Located about 3,700 miles west-southwest of Honolulu, Guam is a U.S. territory with a locally elected government. It is the southernmost island, approximately 212 sq mi in size, of the 750-km Mariana Islands archipelago, which also includes the Commonwealth of the Northern Mariana Islands. Nearly all coral reefs surrounding Guam are located within territorial waters, within 3 nm of shore, and they are generally overfished and degraded as a result of various human activities, especially coastal development.that leads to sedimentation. The commercial fish catch declined over 70% in the last 15 years, from 103 to 28.4 metric tons (Birkeland, 1997b), worth less than $100,000 today (estimate based on value of $1.50 per pound). Species richness appears to be greater around Guam than in the Northern Marianas, but is less than that in Palau, the Philippines, and Australia's Great Barrier Reef. This may be due to the fact that the major currents move away from the island, from east to west (Birkeland, 1997b). The only reefs in federal waters are located on four offshore submerged banks ranging from 5 to 60 m in depth, and are not readily accessible. Two barrier reef lagoons exist that are extensively modified. Apra Harbor, one of two extensively modified barrier reef lagoons, has been degraded by sewage and problems associated with sediment from coastal development. Several marine reserves were recently established.

Northern Mariana Islands . A 685-km chain of 16 volcanic islands about 100 miles northeast of Guam, the Northern Mariana Islands include well developed fringing reefs along most islands, though the east coasts tend to be rocky with steep cliffs. While reefs are currently under federal jurisdiction, control over nearshore reefs is likely to be local in the future. Tourism provides the main source of income to a population of nearly 60,000, who live primarily on three southern islands. Over 700,000 tourists, largely Japanese, visited the islands in 1996. The condition of the coral reefs varies due to physical disturbances from storms and outbreaks of crown-of-thorns starfish; overfishing and pollution are lesser problems, except on Saipan, where the population is larger and coastal development is extensive. Because the region is sparsely populated, human-caused disturbances are few; local damage results from typhoons and/or lava and ash from active volcanoes (Birkeland, 1997b). Several of the northern islands are protected as wildlife conservation areas, and their remoteness limits visitors. One fisheries reserve was initiated in 1994, and several marine reserves were established in 1997.

Photo 13. The crown of thorns starfish is a venomous creature that feeds on coral. It inverts its stomach to cover and digest the live coral, leaving only the skelaton behind.

American Samoa . The land area of American Samoa, the only U.S. territory south of the equator, is relatively small (76 sq mi) and includes five volcanic islands and two coral atolls. The volcanic islands are generally surrounded by fringing reefs that are partially exposed at low tide. At the seaward margin of the reef, the bottom slopes abruptly to deep water. The nearshore reefs on the main island of Tutuila have seen two recent major hurricanes, a crown-of-thorns outbreak in the late 1970s, and a coral bleaching event in 1994. As a result, significant damage occurred, but the reefs are recovering; coral cover increased two- to threefold during 1994-1995 in places, but is still sparse in many areas. Harbor dredging and discharge from tuna canneries have degraded the reefs in Pago Pago Harbor on Tutuila Island; recovery of these reefs is unlikely due to increases in sediment from terrestrial sources, occasional oil spills, and other water quality problems associated with the dense population around the harbor. The more remote islands are in good condition, with far more live coral cover and species richness than Tutuila Island. Rose Atoll, located over 240 km east of Pago Pago, is one of the world's most isolated and least disturbed atolls (and protected as a National Wildlife Refuge). A major ship grounding there in 1993 caused substantial physical and chemical damage to the reef; over 100,000 gallons of diesel oil were spilled (A. Greene, pers. comm.). The Rose Atoll grounding demonstrated that remoteness and refuge status do not guarantee protection; shipwrecks can happen anywhere, anytime. Another protected area is the Fagatele Bay National Marine Sanctuary, which was designated in 1986. While only 0.25 sq. miles, it contains nearly 200 species of coral. The crown-of-thorns starfish destroyed most living coral in the sanctuary in the late 1970s. Hurricanes in 1991 and 1992, and an unusually hot summer in 1993, caused additional damage. Despite these destructive events, corals in the sanctuary are recovering. The National Park of American Samoa, established in 1993, includes approximately 400 underwater hectares on three islands, and is one of the few places where the rare coral *Heliopora coerulea* is relatively abundant.

(top)

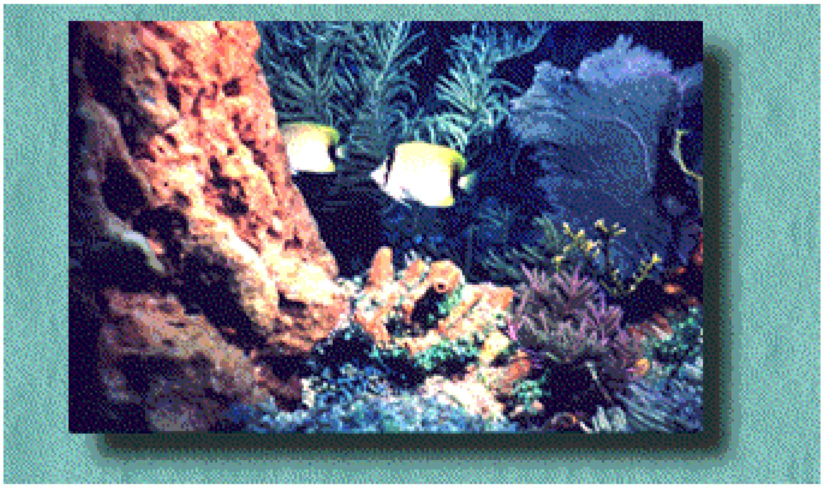


Photo 14. American Samoa is home to the Fagatele Bay National Marine Sanctuary, which contains nearly 200 species of coral.

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REGIONAL CONTRASTS

Caribbean vs. Pacific Island Territories and Possessions

Coral reefs in the Caribbean and Pacific look and may function differently. Why? The answer to this question helps explain why Caribbean reefs appear to be in worse condition than their Pacific counterparts.

Diversity

Coral reefs are known for their high species diversity (for a review, see Maragos et al., 1996). Recent estimates suggest that while nearly 100,000 species are known to occur on coral reefs, the number may be underestimated by a factor of 10 (Reaka-Kudla, 1997). This diversity, however, is not distributed evenly across all oceans. For example, over 350 species of reef-building corals and over 1,500 species of fish are recognized on the Great Barrier Reef in Australia, while only 62 hard corals (Levy et al., 1996) and approximately 500 fishes (Starck, 1968) are found along the reef tract in Florida.

The difference in diversity between the Caribbean and Pacific probably does not result from long-term environmental degradation (Budd et al., 1993), but instead reflects complex processes associated with the closing of the Isthmus of Panama nearly 3.5 million years ago, and the smaller size of the Caribbean (Coates et al., 1992). Interestingly, more than 50% of coral genera that no longer exist in the Caribbean are still present in the Pacific. Whatever the causes, low-diversity systems tend to suffer more dramatic changes in population and community structure. This may not bode well for reefs in the Caribbean, Gulf of Mexico, and Florida.
(top)

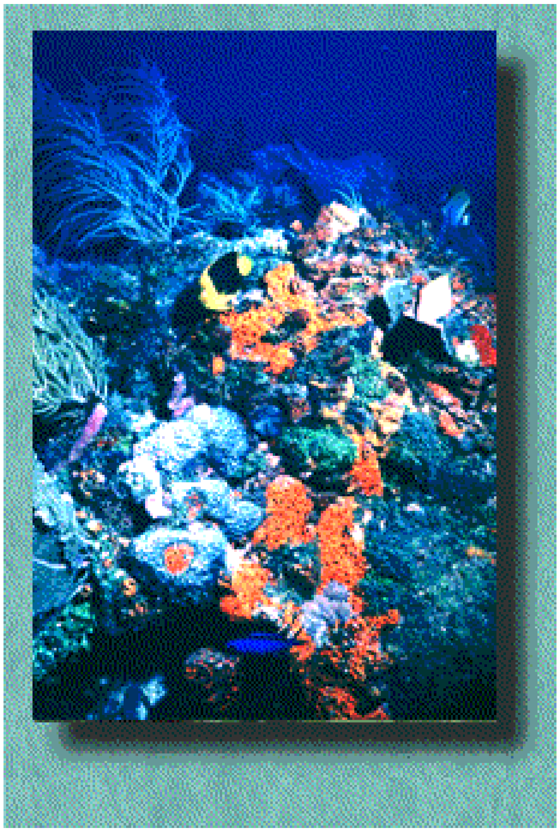

Photo 15. Nearly 100,000 different plant and animal species are thought to occur on coral reefs worldwide, although this number may be an underestimate.

Long-term Recovery

A problem scientists have when trying to evaluate the relationships among biodiversity, community structure, stress, and recovery, is that research careers are relatively short compared to the processes that are likely to drive the ways that coral reefs look and function. This means that events that look dramatic in the short term may actually be relatively insignificant over longer time periods. For example, Caribbean reefs prior to the 1980s contained two common species of fast-growing branching corals of the genus *Acropora* (commonly known as elkhorn and staghorn corals), which were subsequently devastated by white band disease. The corals were major framework builders, and they are now largely gone from many reefs throughout the Caribbean and Florida. Even so, they grow fast (10-cm linear extension rate per year) and reproduce readily by fragmentation as well as by sexual activity. It is possible that under the right set of conditions, a quick (meaning 10 or 20 years) recovery could occur if the species remain disease-free. There was also a Caribbean-wide die-off of the long-spined black sea urchin, a major seaweed grazer, in the early 1980s. The die-off resulted in a shift to more macroalgae and less coral on the reefs (Carpenter, 1990).

Photo 16. Boat groundings, such as this one, can severely damage coral reefs.

Scientists today are faced with the problem of trying to place the recent demise of the Caribbean acroporid corals, urchin die-offs, and wide-scale overfishing in long-term perspective. Will the Caribbean reefs recover to a state previously familiar to marine biologists before the current declines occurred, will they continue to decline, will they remain stable in their present configuration, or are new surprises in store? These are among the biggest questions faced by coral reef scientists and managers working in the Caribbean.

The situation is only a little less complicated in the Pacific. Some reefs in the Pacific have suffered multiple infestations of crown-of-thorns starfish and significant storm damage, only to recover in relatively rapid fashion. The repeated cycles of devastation and regrowth have not been seen to occur in the Caribbean reefs. The fact that Pacific reefs, in general, have nearly 100 fast-growing species (compared to two major examples in the Caribbean) may help explain the faster recovery of the Pacific reefs (Kojis and Quinn 1993). In addition, the Pacific is significantly larger than the Caribbean, and there may be important relationships between recovery and

the spatial extent of damage in a region. Problems in the Pacific tend to be reef-specific or regional, leaving vast areas undamaged. In the Caribbean, significant disease epidemics have influenced the entire basin.
(top)

Water Chemistry and Pollution

There is reason to believe that the chemistry of the water is different in the Caribbean and the Pacific. At the regional scale, continentally derived nutrients and sediments readily reach coral reefs in the Caribbean. Further, the dispersal of fresh water from the great rivers of South America (e.g., the Amazon and the Orinco) affects salinity, nutrients and phytoplankton all the way to Puerto Rico (Muller-Karger et al., 1988). Also, Mississippi River outflow can be detected off the Florida Keys during major flood events (Lee et al., 1994). While the vastness of the Pacific reduces this effect, poor land use practices can lead to significant sedimentation of coral reefs in localized areas. The subtleties of chemistry and freshwater flow, when combined with differences in species diversity, suggest that both regional and local factors affect the ability of coral reefs to grow and survive during periods of stress. Local factors that are increasingly important include a suite of potentially damaging human influences.

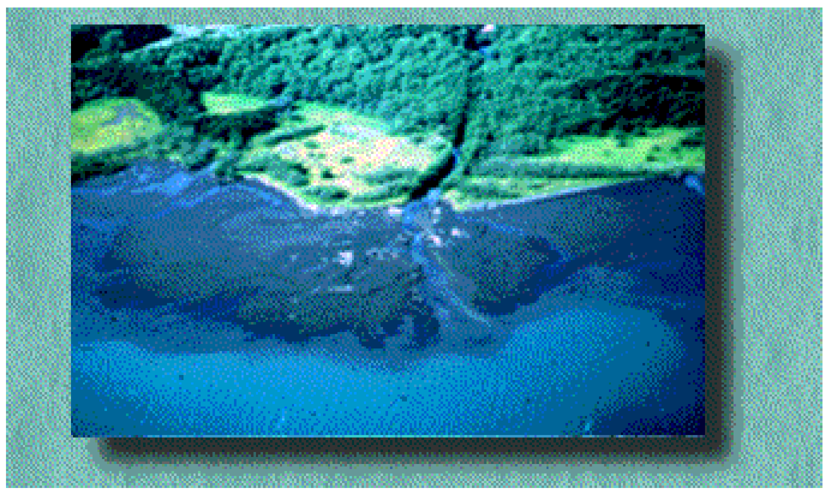

Photo 17. A delta of sediment overlying coral habitats in Hawaii.

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CASE STUDIES

The following two case studies are among the best known examples of coral reef ecosystems changing through a combination of natural and human-caused disturbances. In Florida, the relative importance of natural and human stresses is still under debate. In Hawaii, the effects of coastal development and sewage disposal practices seem clear, but scientists still have difficulty predicting what will happen on the reefs.

Florida Keys: Why Coral Reefs Look the Way They Do in Florida

Coral reefs in the Florida Keys are generally not in good condition, though some areas remain quite spectacular. This can be attributed to both human and natural factors. The human assault includes thousands of ship groundings since colonial times, over-harvesting of fish, collecting of coral and sponges, and sewage-polluted nearshore waters.

Natural factors are also implicated in the decline. In the early 1980s, an epidemic killed almost all the long-spined black sea urchins in the Caribbean and south Atlantic; the urchins were the "sheep" of the reef, grazing on algae that competes with corals for space. Now that the urchins are few in number, it is difficult to determine whether or not the sewage

Photo 19. Florida's reefs are overfished, with populations of most species of snappers and groupers below critical levels.

pollution that is a problem near shore, or the absence of urchins, is responsible for the increased seaweed on the reefs. Causing further problems is a second disease epidemic that killed a significant amount of branching coral throughout the Caribbean and is still present in the Keys. Unusually cold weather has killed corals on several occasions as well.

Photo 18. A diver prepares to repair a brain coral damaged by a careless boater.

Degraded water quality is a serious concern in the Florida Keys, but little evidence ties nearshore sewage pollution to the condition of the offshore reefs. It is significant that the Florida reef tract is located adjacent to a major warm water current, the Gulf Stream, which brings massive amounts of clear and clean water to the reefs on a regular basis. Florida's reefs are also overfished, with most species of snappers and grouper below critical population levels (Ault et al., 1997). In many ways, it is surprising that reefs exist in Florida. Urchin die-offs, disease, coral bleaching, weather extremes, rising sea level, overfishing, and perhaps the average annual position of the Gulf Stream all affect the condition of these coral reefs. A major challenge to scientists and managers working in the Keys, and worldwide, is to understand the relative effects of natural system variability and human-caused damage. Why? Because the latter is manageable; the former is not.
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Kaneohe Bay, Hawaii: No End to the Story

Kaneohe Bay is one of the best known coral reef systems in the world (Hunter and Evans, 1993). Anecdotal information suggests that corals flourished on its fringing reefs (Agassiz, 1889) and coral gardens were abundant in the south bay at the turn of the century (Mackaye, 1915). But all is not well with the bay. It is known that freshwater stream discharge and runoff from agriculture and other land uses have affected the bay for centuries. Recently, the human population grew from about 5,000 in 1940 to just under 30,000 in 1960, reaching more than 66,000 in 1990 (State of Hawaii, 1992). Between the 1950s and the 1970s, up to 7.5 million gallons per day of treated sewage (but without nutrient removal) were discharged into the bay.

In the 1970s, the green bubble alga, *Dictyosphaeria cavernosa,* smothered extensive amounts of living coral, especially in the central bay (Banner, 1974). Phytoplankton bloomed in the southern part of the bay during the same time period. During 1977 to 1978, the sewage was diverted to a deep ocean outfall. A decrease in nutrients, phytoplankton, and turbidity occurred immediately in the bay, but reef recovery was slower. Coral recovery was significant by 1983. However, seven years later, additional

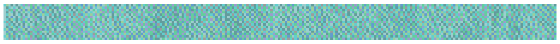

Photo 20. Nutrient pollution from a sewage outfall caused algae to overgrow this coral in Kaneohe Bay, Hawaii.

Photo 21. Marine debris is a type of pollution that damages coral reefs.

coral recovery had not occurred. Importantly, algae had increased twofold at some sites. Possible explanations for the increase in algae include nutrient release from sediments following long-term enrichment, freshwater runoff and sedimentation, cesspool discharge to groundwater, municipal sewage bypasses, and discharges from boats. Data from this period suggest that water column nutrients in the bay stayed the same or declined (Hunter and Evans, 1993), which makes it difficult to explain patterns of recovery, stasis and decline. Subsequent to sewage abatement in 1979, a major rain storm and flooding in 1988 caused a massive coral mortality event. Unlike a previous flood event in 1965, recovery was relatively quick, which suggests coral reefs can recover from natural disturbances, but not under polluted conditions (Jokiel et al., 1993)

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Conclusion

The factors that affect the dynamics of chemistry and biology of the Florida reef tract and Kaneohe Bay are complicated, as revealed by the continuing problems after diversion of a major sewage outfall in the bay. Problems in the bay are different from those in the Florida reef tract, however, because the bay is a relatively closed system and the reef tract in Florida is open, bathed by the fast-moving waters of the Gulf Stream. Pollution problems tend to be worse in systems that are not well flushed. Whatever the final outcome in Hawaii and Florida, the next chapter of the coral reef story will undoubtedly hold more surprises.

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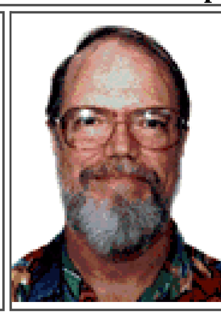
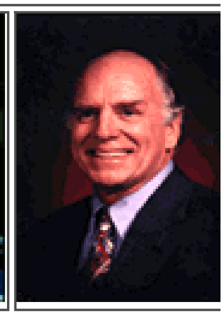
EXPERT INTERPRETATION

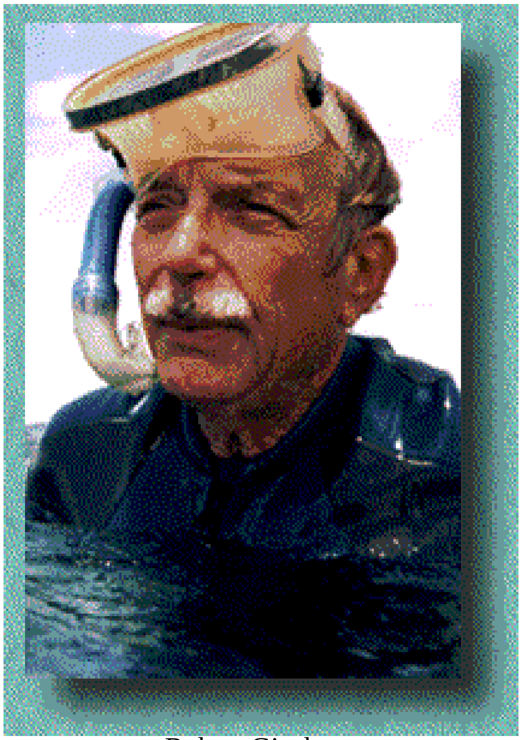
The four individuals below are experts in the topic of coral reefs. Here they voice their opinions on two questions relevant to that topic.

Question 1 – There is a widespread appreciation that coral reefs are equivalent in many ways to tropical rain forests. However, we are losing rain forests at an unprecedented rate as human populations expand and demands for resources increase; will coral reefs suffer the same fate?

Question 2 – We know that the condition of coral reefs can change over time, due both to nature and human influences, but how do we determine if coral reefs are healthy?

Experts

			
Robert Ginsburg	**Michael Ham**	**Cynthia Hunter**	**John Ogden**



Robert Ginsburg

Professor of Marine Geology, Rosenstiel School of Marine and Atmospheric Science, University of Miami

Professor Ginsburg is known worldwide for his research and teaching on coral reefs. For the past several decades, he has been studying shallow water carbonate sediments and coral reefs in the western Atlantic, particularly in Florida, Belize and the Bahamas. He has long taken a leading role in international science as the organizer and chairman for two international conferences on reefs, as the originator of a program of Global Sedimentary Geology and, most recently, as organizer of the 1997 International Year of the Reef.

Response to Question 1

Response to Question 2

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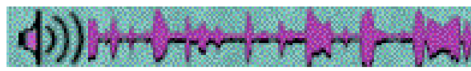
Question 1. There is a widespread appreciation that coral reefs are equivalent in many ways to tropical rain forests. However, we are losing rain forests at an unprecedented rate as human populations expand and demands for resources increase; will coral reefs suffer the same fate?

Click here for audio response

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The wholesale destruction of rain forests for timber and agriculture is not matched by a similar "clear-cutting" of coral reefs, except in a few locations where coral is the only building material or ingredient for making lime. Instead, the main anthropogenic impacts on reef health are pollution from land-based runoff of sediment and/or nutrients and overfishing. **Pollution from land is localized to nearshore reefs adjacent to large populations, but overfishing is global.**

Can overfishing be reduced? In many developing countries, reef fish and shellfish are the main sources of food and/or income for inhabitants of the coastal zones. The increasing worldwide markets for fish and shellfish has encouraged the expansion of wide-ranging commercial fishing. Locally, even recreational fishing can rival or exceed commercial and subsistence harvesting. These pressures on limited stocks of reef fish and shellfish have already led to serious declines in many parts of the world. The loss of key elements in the tightly integrated reef ecosystem could initiate declines in the whole system. Regulated, sustainable harvesting of reef resources is an admirable goal, but given the history of fisheries declines from over-exploitation-cod, herring, tuna, conch-it may not be realistic. Perhaps it is only when stocks are all but exhausted that fishers and governments can join in regulating exploitation.
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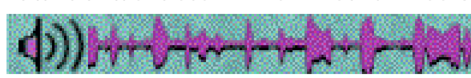
Question 2. We know that the condition of coral reefs can change over time, due both to nature and human influences, but how do we determine if coral reefs are healthy?

Click here for audio response

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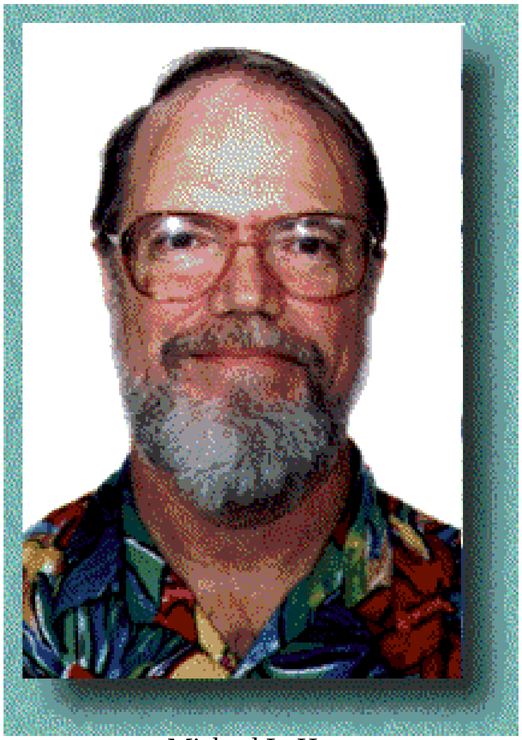
Assessing the health of coral reefs is like assessing the health of cities. For both, identifying the extremes is relatively easy. For example, an unhealthy city would have a high incidence of tuberculosis **and** other communicable diseases, a longevity under 40 years, and high infant mortality. A reef city could be considered unhealthy if its coral community has more **standing** colonies dead than alive, new coral recruits are missing or rare, and an abundance of fleshy algae and/or other smothering epibionts.

Coral condition is tightly coupled with the health of the other components of the reef ecosystem, most noticeably fish. Overfishing will initially be signaled by the loss of top predators (groupers and snappers). Even more intense overfishing would remove herbivores. **These losses of fish can result in declines in the coral communities and the overgrowth by fleshy algae.** Healthy reefs will show none of these declines.

Using these guidelines, it is clear that many reefs near centers of large populations are seriously degraded. What is not known, yet urgently needed, is the state of health of reefs remote from centers of population. Determining the extent of declines in remote reefs would indicate **the global and regional extent of overexploitation, diseases or other impacts.** (top)



Michael L. Ham

Administrator, Guam Coastal Management Program

Mr. Ham has been the administrator of the Guam Coastal Resource Management Program for the past 13 years. Earlier he had been a coastal resource planner for three years with the same program. Mr. Ham has also had experience at the local level, where for three years he worked on issues of beach access, endangered species, flood plain management, and coastal hazards for the township council in Malibu, California.

Response to Question 1

Response to Question 2

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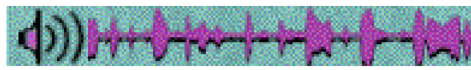
Question 1. There is a widespread appreciation that coral reefs are equivalent in many ways to tropical rain forests. However, we are losing rain forests at an unprecedented rate as human populations expand and demands for resources increase; will coral reefs suffer the same fate?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I believe coral reefs are in a more serious situation, in many ways, than the rain forests. People are just now beginning to understand the plight of the reefs, while the rain forests have been in the public consciousness for a decade or more. Also, we humans feel a closer affinity to land resources, and most of us have walked in a forest. We can imagine its problems. Reefs don't have that advantage. Finally, the rain forests are under stress from direct and definable sources for the most part. Coral reefs suffer from nearly every human activity, and the impacts are unseen by nearly all. Land-based pollution, ocean-borne pollution and air-borne pollution all find their way to the reefs. Reefs are the repositories of mans' errors.
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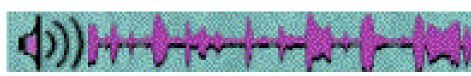
Question 2. We know that the condition of coral reefs can change over time, due both to nature and human influences, but how do we determine if coral reefs are healthy?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We must first understand what "healthy" means on each reef. Coral coverage and variety vary from reef to reef, and we cannot judge one reef by the realities of another. To understand what nature intended for a particular reef, we should learn to observe the resource itself. The disappearance of fishes and other life from our reefs tells us our reefs are not healthy. Changes in dominant species should serve as a warning. We must learn to control, and develop the will to control, the actions of humans near the reefs. If we are not controlling our own communities and the by-products of our communities, our coral reef communities cannot possibly be healthy.
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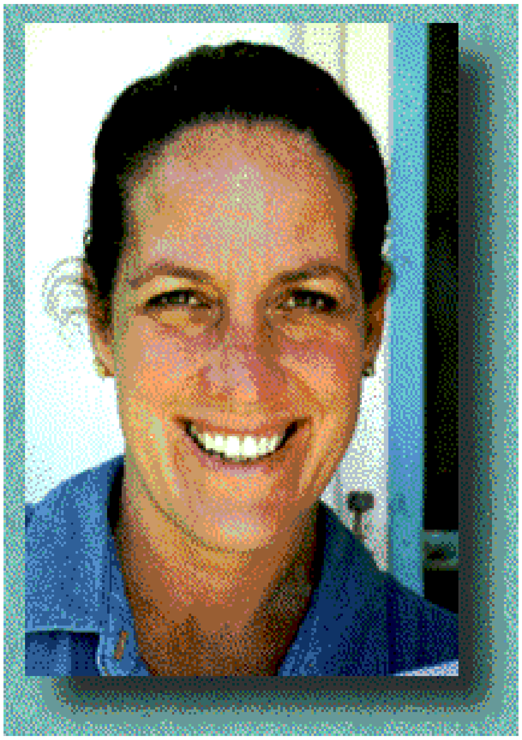

Cynthia Hunter

Post-doctoral Research Fellow, Botany Department, University of Hawaii

Dr. Hunter has been working on various aspects of coral biology and coral reef ecology on Pacific reefs for the past 15 years. Her research interests include the genetics, reproduction and population structures of corals and their algal symbionts, as well as the long-term dynamics of coral and algal interactions on reefs. Currently, her work focuses on the impacts of disease and tumors on Hawaiian reef corals.

Response to Question 1

Response to Question 2

(top)

Question 1. There is a widespread appreciation that coral reefs are equivalent in many ways to tropical rain forests. However, we are losing rain forests at an unprecedented rate as human populations expand and demands for resources increase; will coral reefs suffer the same fate?

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Tropical rain forests make up approximately 6% of the earth's total land area, or about 9 million sq. km. Best estimates of the total area of coral reefs are an order of magnitude smaller, at 617,000 sq. km. Current rates of habitat loss are about 154,000 sq. km. (0.5%) per year for rain forests. Researchers have estimated that 10% of coral reefs worldwide have been destroyed by human activities; a further 30% of reefs are currently considered to be significantly degraded or threatened. Therefore, although they are much less extensive in area, coral reefs have suffered an overall rate of loss or degradation on a global basis that is as high or higher than that of tropical rain forests.

The major threats from human activities to the continued existence of rain forests and coral reefs are also similar and often linked: overharvesting and habitat degradation through destructive harvesting methods and/or poor land management practices. Rain forests are lost largely to clear-cutting for timber, cattle grazing, agriculture, mining and road construction. Coral reefs are damaged primarily through overfishing and excessive sedimentation as a result of soil erosion (often because of upland deforestation). These threats stem mainly from rapidly increasing human population size, poverty, and consumptive economics. That areas of highest human population growth rates overlap or abut tropical forests and reefs suggests that anthropogenic pressures on these ecosystems should be expected to increase. Support for greater public education and awareness, improved and sustainable land use practices and participatory management strategies involving all shareholders are necessary to protect these ecosystems.
(top)

Question 2. We know that the condition of coral reefs can change over time, due both to nature and human influences, but how do we determine if coral reefs are healthy?

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Reliably ascertaining the "health" of a particular coral reef is a difficult proposition and one with which reef researchers continue to grapple. Certainly, a number of "symptoms" can be used to assess reef decline. However, the causes of such symptoms and whether they are human-induced or natural processes on reefs, are often much more difficult to determine. In addition, stresses to reefs vary from place to place and in their short- or long-term impacts on reefs.

Specific indicators of reefs in decline may include overgrowth of living corals by macroalgae, smothering of corals by sediments or microbial mats, coral bleaching and high incidence of disease in corals or other species. Negative indicators of reef health also include damage resulting from ship groundings, oil spills, improper anchoring, and destructive fishing practices (e.g., ghost nets, traps, or gear; and, in many parts of the world, use of explosives, bleach, or cyanide). Lowered fisheries productivity as evidenced by smaller catch abundance, catch size, or a shift in catch species composition is a more general indicator of declining reef condition. Such a loss of productivity may result directly from over fishing or reflect a change in the productive nature of the reef habitat.

Damage to reefs from episodic events such as storms or predation by corallivorous animals (e.g., crown-of-thorns starfish, *Drupella* snails) is generally followed by relatively rapid recovery, *except* in cases where there are compounding stresses (e.g., depletion of grazing species that reduce algal overgrowth, sedimentation, pollution). Coral reef health is a relative term. We need to collect data on reefs from a wide range of habitats and locations with varying degrees of anthropogenic influence. Compilation of such information on reef status on a global basis is currently in progress and will be used to assess further trends and to identify areas of special concern for reef resource managers and users.
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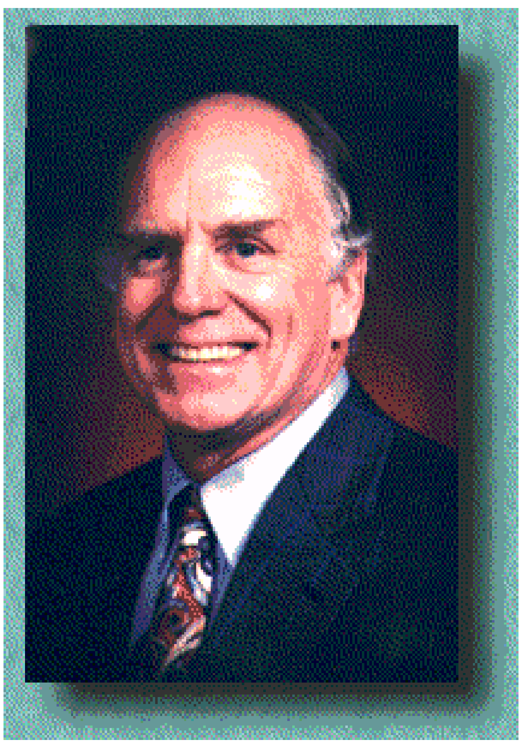

John C. Ogden

Director, Florida Institute of Oceanography and Professor of Biology, University of South Florida

For the past 20 years, Professor Ogden has engaged in the study of the ecology and management of coral reefs. He was director of the West Indies Laboratory from the mid-1980s until 1988. From 1981 to 1986, he was director of the Hydro Lab Saturation Diving Program, National Underseas Research Center, in St. Croix, U.S. Virgin Islands. He is also president of the International Society for Reef Studies, and he is involved in the conservation of tropic and subtropical marine biodiversity through numerous governmental and nongovernmental organizations.

Response to Question 1

Response to Question 2

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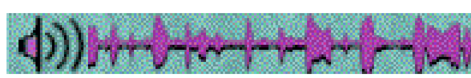
Question 1. There is a widespread appreciation that coral reefs are equivalent in many ways to tropical rain forests. However, we are losing rain forests at an unprecedented rate as human populations expand and demands for resources increase; will coral reefs suffer the same fate?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There is a tragic link of destruction between human disturbance in rain forests and coral reefs. Tropical deforestation damages coral reefs by de-stabilizing the forest soils, which, with rainfall, run off into coastal waters smothering reefs with sediments. In addition, soil nutrients fertilize algae, which overgrow corals. Through this and other disturbances, notably over-fishing, coral reefs have suffered a fate similar to rain forests in that most reefs close to relentlessly growing coastal human populations have already been seriously damaged or destroyed. We cannot yet survey coral reefs as we can rain forests over large regions using aerial photography and satellite imagery.

Coral reefs must be examined one at a time by divers using a variety of underwater sampling and survey techniques. The global status of coral reefs, particularly those in remote locations, is one of the questions being addressed by the International Coral Reef Initiative and the International Year of the Reef through concerted actions of governments and citizens.
(top)

Question 2. We know that the condition of coral reefs can change over time, due both to nature and human influences, but how do we determine if coral reefs are healthy?

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Seen at one point in time, coral reef ecosystems are highly variable in structure and functioning. This variability depends upon a variety of natural and human-induced factors which we often cannot easily see, such as (1) geological history; (2) physiographic setting; (3) the impact of the last typhoon or hurricane; (4) major pollutants; and (5) the extent of fishing. The great challenge is to be able to discriminate damage caused by human disturbance, which we presumably can "manage," from damage caused by natural disturbances. The only way that this can be done is by long-term monitoring. Nested within the world's major coral reef management plans is monitoring of coral reef structure, functioning (e.g., reproduction, recruitment, productivity), and associated physical variables (e.g., temperature, salinity, currents). Thus, just as in human medicine, the diagnosis of "health" of a coral reef is an individual concept and utterly dependent upon repeat visits.
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Text References

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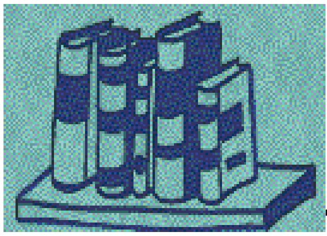

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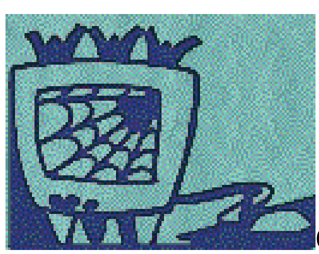

On-line References

The following references were accessed via URL on the World Wide Web during October 1997.

Note: Coral reefs are currently a popular topic, as evidenced by the many thousands of addresses returned from a World Wide Web search. The on-line references presented here are intended to provide supplementary information related to the text of this essay. These references also supply links to many additional sites.

Geology, Biology, and Ecology of Coral Reefs

Springer Science Online. Coral Reefs: Journal of the International Society of Reef Studies.

http://link.springer.de/link/service/journals/00338/index.htm

Offers an on-line version of Coral Reefs, Journal of the International Society for Reef Studies, where coral reef scientists publish papers on both modern and ancient coral reefs. The journal also publishes review articles and perspectives on major scientific problems concerning coral reefs.

University of North Carolina at Wilmington's National Undersea Research Center and The Aquarius Underwater Web Site.

http://www.uncwil.edu/nurc/

http://www.uncwil.edu/nurc/aquarius/

Provides information about the Center's science programs, including work in Florida that represents the largest coral reef research program in the country, located in Key Largo, Florida. Provides summaries of coral reef research projects supported by the Center. Aquarius, a highly sophisticated underwater laboratory owned by NOAA, operates in the Florida Keys National Marine Sanctuary. Research conducted from the laboratory addresses management concerns related to deep reefs in Florida.

The University of Stuttgart. Jurassic Reef Park.

http://www.uni-stuttgart.de/UNIuser/igps/edu/JRP/JRP_english1.html

This well designed site answers the question, "Why should you care about reefs from ancient Jurassic times, 160-135 million years ago?" Comparisons and conclusions are made that have relevance to understanding what the future may hold for reefs that exist today.

Status and Trends

Jameson, S.C., J.W. McManus, and M.D. Spalding. 1995. State of the Reefs: Regional and Global Perspectives. International Coral Reef Initiative.

http://www.ogp.noaa.gov/misc/coral/sor/

Provides detailed information on the regional status and trends of reef health for the tropical Americas, Middle East, Indian Ocean, East Asia, and the Pacific. Also included is a complete list of references cited in the text.

Eakin, C.M., J.W. McManus, M.D. Spalding, and S.C. Jameson. 1996. Coral Reef Status Around the World: Where are we and where do we go from here?

http://www.ogp.noaa.gov/misc/coral/8icrs/

This is a paper that was presented at the 8th International Coral Reef Symposium, held in Panama. Information is presented about threats to reefs, reasons that our knowledge is limited about the regional and global status of reefs, and efforts under way to develop monitoring networks and data distribution in meaningful ways. Good information is also presented about the full range of global estimates for coral reef coverage.

Internet Data Bases and Information Sources

National Oceanic and Atmospheric Administration's Ocean Chemistry Division Atlantic Oceanographic and Meteorological Laboratory. NOAA's Coral Health and Monitoring Program.

http://coral.aoml.noaa.gov

Includes coral health bulletins, updates about the International Coral Reef Initiative and the Global Coral Reef Monitoring Network, near real-time satellite images of coral reefs, searchable literature abstracts, the on-line Coral Researchers Directory, archives of the List-Server for coral reef researchers, current and historical data from the SEAKEYS program and the National Ocean Data Center, and links to other sites.

International Center for Living Aquatic Resources Management. ReefBase: A Global Data Base on Coral Reefs.

http://www.cgiar.org/iclarm/reefbase/

This is an extensive site with a variety of data bases. For example, it is possible to search for coral reef papers using keywords, determine the location of marine-protected areas throughout the world, identify via maps and listings the location of coral reefs, view pictures of coral reefs, order products, and much more.

The Pew Charitable Trusts. SeaWeb: A project of the Pew Charitable Trusts.

http://www.seaweb.org

This site is a public education effort with a wide variety of resources related to life in the sea. Features include the latest news and views, media presentations, and specific products generated by SeaWeb on many ocean issues. Interesting background articles are available on such topics as marine reserves, aquaculture, problems associated with overfishing, and change in the oceans.

Reefnet. Reefnet Internet Information Service.

http://www.reefnet.org

An internet service to help increase understanding of coral reef ecosystems. Of particular note are articles that describe exciting work and recent discoveries by scientists and conservationists, including background information about how individuals began their careers, interviews about their work, and well written accounts of what it is like to work as a marine scientist.

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GLOSSARY

algae: a diverse group of photosynthetic organisms that lack roots, stems, leaves, and vascular tissues. Examples range from unicellular phytoplankton to multicellular seaweeds that are meters in length.

atoll: a circular or horseshoe-shaped coral reef that surrounds a lagoon, common in the Pacific.

bathymetry: measurements of ocean depths to determine the shapes and contours of the sea floor.

benthic: pertaining to organisms that live on rock or sediment beneath a body of water.

biodiversity: in an ecosystem, variability among living organisms from all sources, sometimes measured by the total number of species or other taxonomic groupings, and their relative abundances.

calcium carbonate: the mineral produced by corals that forms their hard skeleton.

coralline algae: algae that secrete calcium carbonate in their tissues. Hard, encrusting, red coralline algae are significant reef builders in some areas.

embayment: an inlet or bay that has reduced or restricted water exchange with the larger body of water to which it is connected.

genus (*pl.* genera): a taxonomic category that includes groups of closely related species.

ground truthing: measurements conducted on the ground or at sea to calibrate observations made from satellites or aircraft.

grounding: a ship's striking a shoal or reef.

habitat: the living place or "home" of a particular organism or biological community.

invertebrates: a collective name for all animals that lack a vertebral column. Corals are invertebrates.

mangrove: tropical or subtropical trees and shrubs of the genus *Rhizophora* that are variously salt tolerant and can form dense systems of roots and branches at the land-sea interface, ultimately building land.

mollusc: a taxonomic division of the animal kingdom that includes snails, slugs, octopuses, squids, clams, mussels, and oysters.

monitoring: periodic measurements of the same parameters, physical or biological, designed to detect change over time.

nutrient enrichment: an increase in the amount of nutrients added to an ecosystem, above normal levels; pollution occurs when damaging amounts of nutrients are added.

nutrients: chemicals required to support growth and reproduction, such as nitrogen, phosphorus, iron, and potassium. Phytoplankton acquire nutrients directly from seawater.

phytoplankton: planktonic algae, including unicellular, chlorophyll-containing algae that passively drift with water currents; plankton are eaten by zooplankton and other filter feeders, but can sometimes build up huge populations, called blooms, that can be damaging to marine life and the environment.

planktonic: aquatic algae and animals that passively float, or weakly swim, in a body of water.

runoff: water that appears in streams, streets, or other impervious surfaces, usually after rain events, and reaches nearshore environments; runoff can contain substantial amounts of contaminants from urban and agricultural land uses, e.g., sewage pollution, fertilizer from lawns and agriculture, pesticides.

sediment: solid or fragmented material that comes from weathering rock, accumulates, and forms layers on the sea floor, e.g., sand, gravel. silt, mud.

shelf break: nearshore bathymetry characterized by rapid and substantial increases in depth that are continuous with the deeper parts of the ocean.

spur-and-groove formation: a coral reef formation characterized by fingerlike projections of coral accumulation (spurs) separated by sand (grooves) that form in the direction of prevailing waves.

status and trends analysis: a monitoring program designed to evaluate the current condition of physical and biological features found in an ecosystem and to detect changes that may occur over time.

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STATE OF THE COASTAL ENVIRONMENT

THE EXTENT & CONDITION OF U.S. CORAL REEFS

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Many of the photos were gathered from NOAA archives or were generously provided from personal collections of NOAA staff members.

Others were contributed from outside of NOAA, and we gratefully thank the following institutions and individuals:

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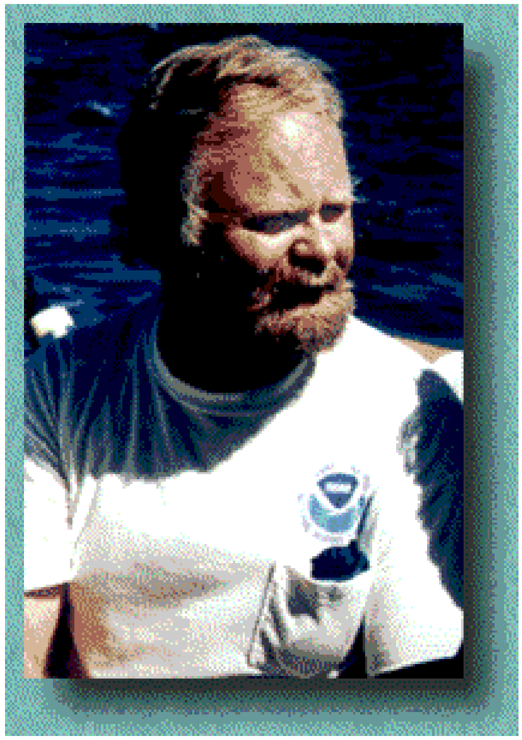
About the Authors

Dr. Steven L. Miller is with the University of North Carolina at Wilmington (UNCW) and is Associate Director of NOAA's National Undersea Research Center, located at UNCW. He has a B.A. in Biology from Brown University and a Ph.D. from the University of Massachusetts in Amherst. His research focuses on coral reef ecology, water quality issues, seaweeds, and long-term studies in the Florida Keys National Marine Sanctuary (FKNMS). He is currently involved in research programs to evaluate the recovery of reefs damaged by major ship groundings, and coral reef monitoring in marine protected areas in the FKNMS. His educational and public outreach efforts include the world's first underwater web site that features NOAA's Aquarius underwater laboratory (http://www.uncwil.edu/nurc/aquarius), frequent presentations, and writing to increase public understanding of important marine science issues. Dr. Miller works and lives in Key Largo, Florida. He is also Recording Secretary for the International Society for Reef Studies.

Dr. Michael Crosby is the National Research Coordinator for the Office of Ocean and Coastal Resource Management (OCRM), NOAA in Washington, D.C. Prior to joining NOAA in May 1991 as the Chief Scientist for the Sanctuaries and Reserves Division of OCRM, he held numerous faculty positions with the Baruch Institute for Marine Biology and Coastal Research at the University of South Carolina, the Department of Marine Science at Coastal Carolina University, the graduate program at the University of Charleston, and Salisbury State University. Currently, Dr. Crosby is the lead Principal Investigator on a U.S. Man and the Biosphere Program multidiscipline, multiyear research project entitled "Ecological and socioeconomic impacts of alternative access management strategies in marine and coastal protected areas"; Project Coordinator and Co-Principal Investigator on a U.S. AID project to develop a cooperative research and monitoring program for the binational Red Sea Marine Peace Park; and the Co-Chair of the U.S. Coral Reef Initiative.



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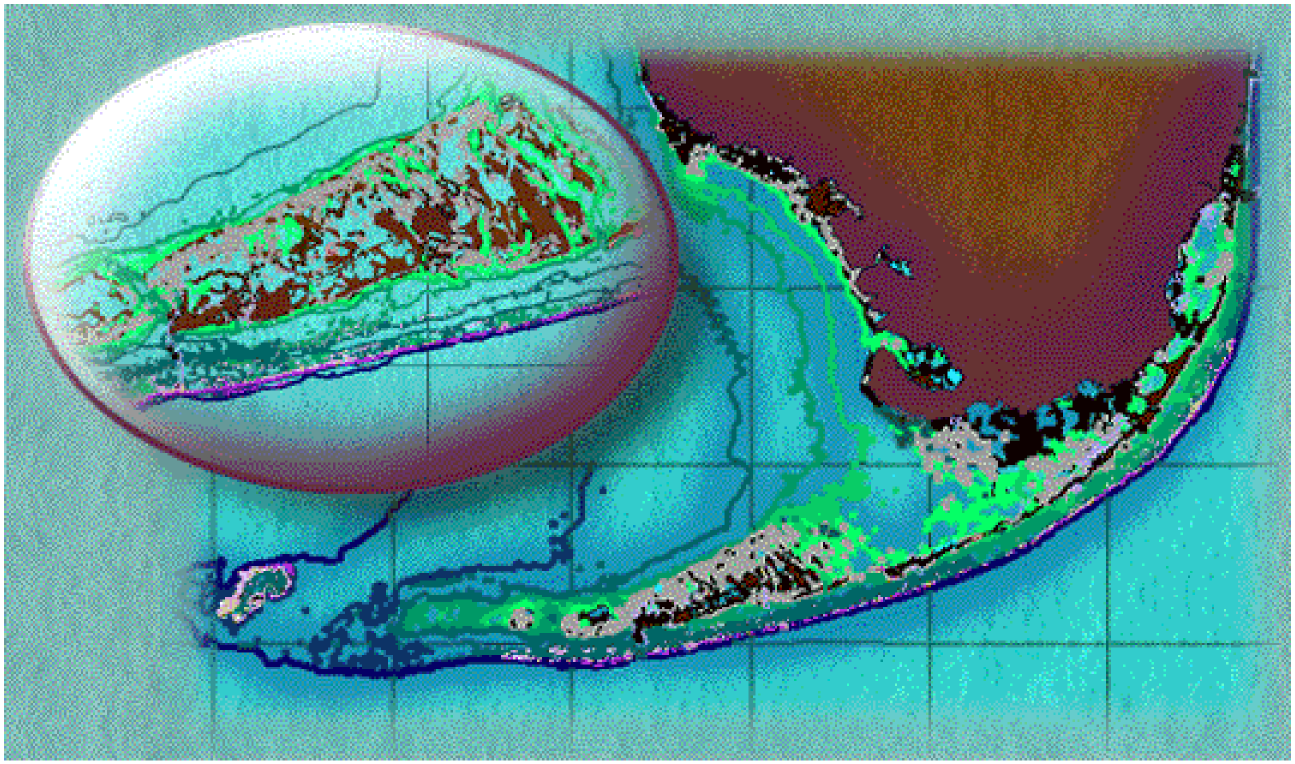

Figure 1. Southern Florida and Florida Keys ecosystem. Brown areas are land, thin magenta line is the coral reef system.