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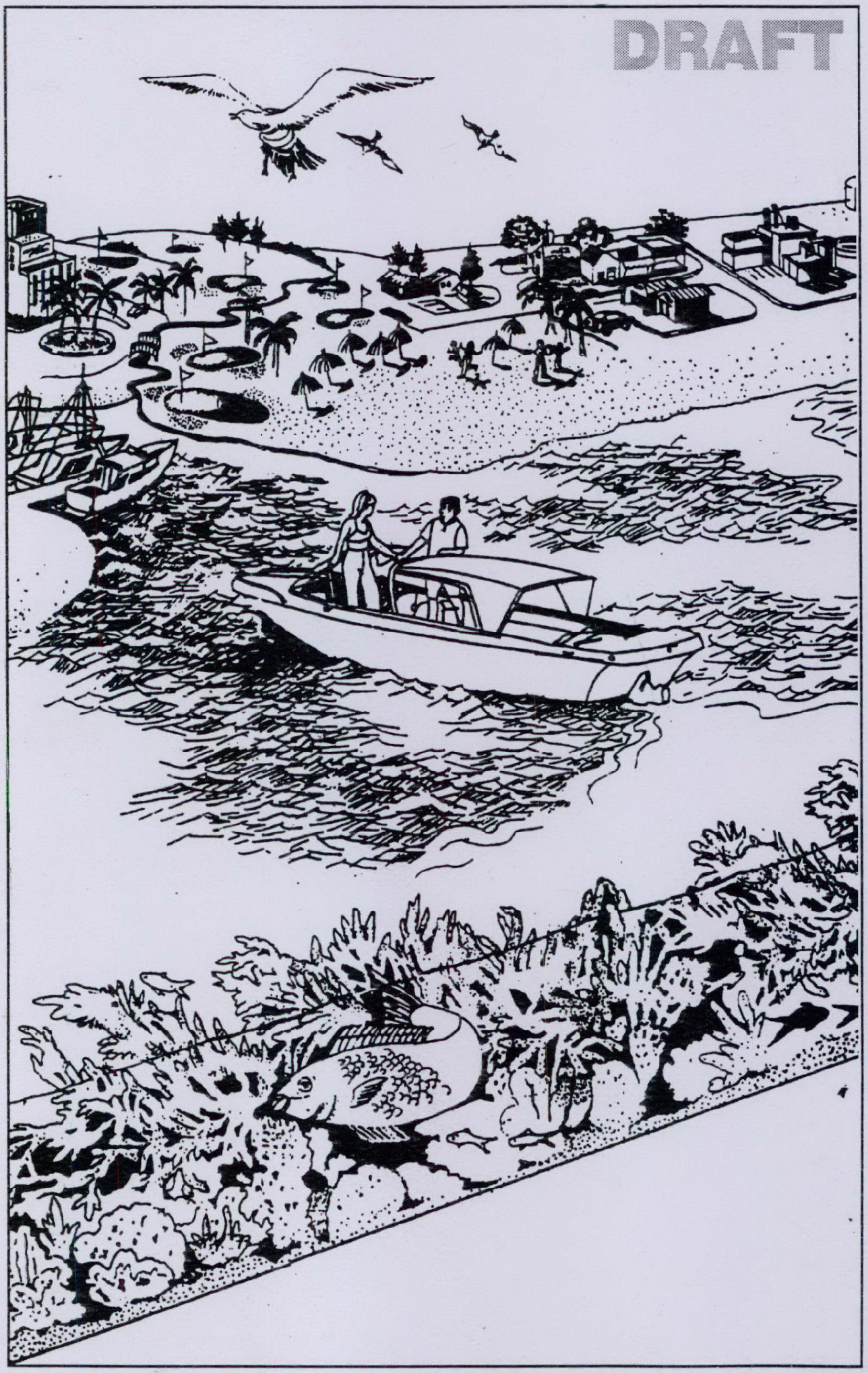
Watershed Management of Coral Reef Communities:

A Framework for Protection



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Introduction

Coral communities are some of the most diverse, and threatened, ecosystems in the world. Over the years, management plans have been designed and implemented to protect these ecological systems. The plans have primarily addressed direct impacts such as recreational activities like scuba diving and sportfishing, commercial fishing, boat anchoring, propeller damage, and discharge of municipal and industrial wastes. Unfortunately, the plans have not always effectively protected coral ecosystems. Coral reefs around the world are still experiencing stress and are declining.

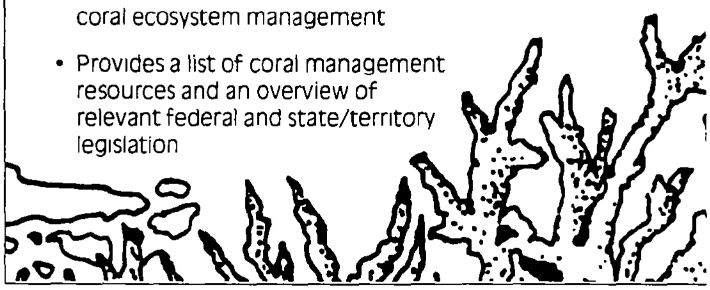
The ineffectiveness of some past management practices requires us to look at the way we approach coral reef protection. We need to broaden our management perspective to address the *indirect* impacts on coral communities as well as the direct impacts. These indirect impacts include the upland activities, such as agriculture and forestry, urbanization, and marina activities, that are affecting the offshore ecosystem. Individually and collectively, these impacts can have a detrimental effect on coral ecosystems. Runoff from agricultural lands carries pesticides, fertilizers, and sediment. Development elevates levels of stormwater runoff, which often contains high concentrations of oil and grease, nutrients, and sediment. Marinas are a source of waste material and petroleum products.

The best way to address the impacts of upland activities is to approach coral ecosystem management on a watershed-wide basis. A watershed is a geographic area in which water, sediments, and dissolved materials drain to a common outlet, such as a river, lake, bay, or ocean. Although the watershed approach to protecting ecosystems has been around for several years, it has traditionally been thought of in the context of protecting the water quality in rivers, lakes, and near coastal waterbodies. But the watershed approach can also be a critical component of preserving and protecting specific ecosystems like coral habitats. By investigating what is happening up in the coastal watershed and how pollutants are being transferred to coastal waters, such pollutants can be stopped or reduced at the source before they affect coral communities.

The purpose of this document is to describe some of the stresses to which coral ecosystems are exposed and introduce the watershed planning concept as a management tool for coral protection. Section 1 provides an overview of coral ecosystems, describes coral ecosystems in the United States, and describes some of the factors that need to be considered in coral reef management. Section 2 discusses the stresses to which coral communities are exposed and the impacts of these stresses. Section 3 describes the watershed planning and management process and provides a general outline for a watershed management and monitoring plan. Section 4 presents four case studies that illustrate successful ecosystem management on a watershed scale. The appendices contain a summary of federal and state/territory legislation related to coral protection and resources for additional information on reef management. A glossary is also included.

This Report:

- Provides a characterization of coral communities and describe coral ecosystems found in the United States and its island territories
- Introduces the concept of watershed management to protect coral ecosystems
- Presents case studies that illustrate watershed-wide coral ecosystem management
- Provides a list of coral management resources and an overview of relevant federal and state/territory legislation



Section 1

Understanding the Coral Reef Ecosystem

Characteristics of the Coral Ecosystem

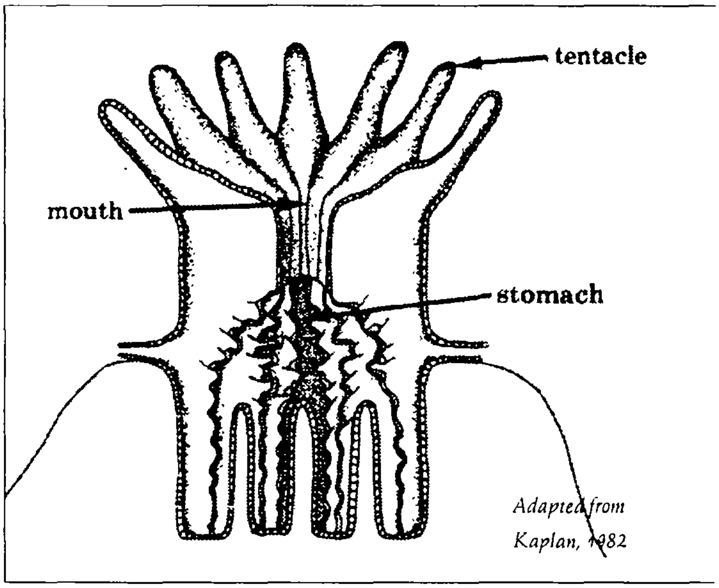
Coral ecosystems are unique, biologically diverse habitats that are recognized as valuable economic and environmental resources They are very sensitive habitats that are integral parts of larger coastal ecosystems An understanding of the biology, distribution, and economic, environmental, and social importance of these systems is critical to achieving responsible and effective management

Biology

A coral is an animal that consists of a single polyp or colony of polyps. A polyp is a tube-like body cavity that has rings of tentacles surrounding a single mouth. Polyps secrete calcium carbonate, commonly called limestone. The limestone serves as skeletal material that either is embedded in the living tissues or encloses the animal. Coral polyps live in symbiotic association with small, single-celled plants called zooxanthellae The coral depends on the zooxanthellae to produce oxygen while the zooxanthellae rely on the coral for food. The symbiosis is a response to the nutrient deficiency of clear tropical waters. The plant-animal relationship is reflected in the growth form of many corals, a number of which are plant-like in their structure and their orientation toward light.

There are generally two types or categories of corals—soft corals and hard corals. *Soft corals* deposit the limestone in their tissue, giving them a soft, fleshy texture; *hard corals* deposit the limestone both around and beneath each polyp, as well as under the tissue that connects the polyp colony. Hard corals form reefs (Sheppard, 1983).

Both hard and soft corals are very delicate organisms that can exist only within a narrow range of environmental conditions. Seawater temperature should range from 16 to 36 °C (61 to 75 °F), although most active coral growth occurs in a much narrower range (23 to 25 °C, 73 to 77 °F) Adequate sunlight, well-oxygenated water, and stable water salinities (35 parts per thousand, or ppt) are equally important for coral growth. These factors, combined with a need for wave action or vigorous water currents, generally restrict well-developed reefs to the windward sides of shorelines and the



A coral polyp

seaward sides of reef structures (Smith, 1948).

Coral reefs form largely in response to underlying geological features. Coral need a hard *substrate* on which to "anchor" and begin growing. As a result, coral reefs have been categorized or defined according to their form. Overall, there are five basic types of reef structures (Buck, 1991).

- *Fringing reefs* are formed by corals growing close to the shore and in shallow water. As fringing reefs develop, their crests extend seaward and toward the water's surface. They are characterized by a diversity of coral types.

- *Barrier reefs* are separated from land by a shallow, sand-floored lagoon These reefs form a series of ramparts along the coastline They contain two major areas or structures—the reef crest and the forereef. Both of these areas contain numerous zones that are inhabited by many distinctive corals. Some well-known barrier reefs include the Great Barrier Reef in Australia, the Florida Reef Tract, and the Barrier Reef in Belize.

- *Platform/patch reefs* are small circular or irregular reefs that are distinct from other reef sections. They form where the hard seabed rises close to the surface. In some locations, portions of these reefs may be exposed at low tide.

Table 1. Geographic Distribution of Shallow-water Coral Reefs

Geographic Area	*Percent of Total Global Coral Reef Coverage*
Caribbean and North Atlantic	14
South Atlantic	1
Indian Ocean	60
Pacific Ocean (South of the Equator)	13
Pacific Ocean (North of the Equator)	12

Source Buck, 1991

- *Bank reefs*, in contrast to platform/patch reefs, form on deeper seabeds and are never exposed

- *Atolls* are true coral islands typically found far from the mainland Atolls form circular reef structures, often with small islets formed from accumulated coral debris, and with central, calm-water lagoons Atolls are largely absent from the Atlantic and Caribbean, but there are more than 300 in the Indo-Pacific.

Coral reefs are home to many organisms, such as algae, mollusks, crustaceans, sponges, fish, and worms. All contribute to and play special roles in the construction of coral reefs. The result of this collaborative effort is a diverse and biologically productive system that has high levels of biological recycling and nutrient retention and serves as a habitat for a large variety of organisms.

Coral reef ecosystems are not biologically isolated communities They are systems that require nutrient inputs from adjacent areas, such as sea grass beds and mangrove forests, and from bacteria in reef sediments. They also respond to terrestrial factors such as freshwater flows into the coastal system Consequently, destruction or alteration of surrounding coastal systems, including uplands, can directly affect the health and productivity of coral reef communities.

Distribution

Corals and coral reefs are located in subtropical and tropical oceans and seas around the world. Most of the large reef communities are located in shallow waters. Deeper and colder waters usually support only small coral communities that do not form large reef structures

The shallow-water coral reefs have been more widely recognized than other reefs for their uniqueness and biological importance to the marine environment. Globally, these reefs cover approximately 241,000 square miles (Buck, 1991). They are located in most of the major oceans throughout the world. Table 1 illustrates the geographic distribution of shallow-water coral reefs as a percentage of total global coral reef coverage.

In the United States, shallow-water coral reefs are primarily found in southeast Florida and Hawaii. In addition, reefs can be found in the coastal waters of some of the U S. territories. The U.S. Virgin Islands, Puerto Rico, Guam, American Samoa, the Marshall Islands, and the Commonwealth of the Northern Marianas Islands all have reef ecosystems.

Less recognized, deeper-water coral *communities* and *assemblages* can be found both domestically and internationally. In the United States, deeper coral assemblages include Gray's Reef in Georgia and Flower Garden Banks in Texas. Internationally, assemblages of deeper corals have been found along continental shelves in Europe, the Gulf of Mexico, and West Africa

Economic, Environmental, and Social Importance

Coral reef ecosystems provide important economic, environmental, and social benefits to human communities worldwide. These benefits can be seen both directly and indirectly, but are all products of a healthy, viable coral reef ecosystem. Some of these benefits include fisheries, scientific and medical research, recreation and tourism, coastal protection, and environmental values.

Fisheries

Coral reef ecosystems provide habitat for a wide variety of organisms that have high commercial value. Fish, mollusks, oysters, and lobsters are all members of the coral reef community that are harvested for human consumption. Worldwide, reef-related fisheries yield an estimated 9 6 to 12 percent of the total annual catch of 77 million tons Some of the highly productive reef communities, like the Philippines, support annual harvests of 33 tons per square kilometer (km^2), or 85 6 tons per square mile (mi^2), and can yield 11,000 pounds per fisherman per year (White et al , 1994).

Scientific and Medical Research

The coral reef ecosystem serves as an ideal laboratory for students and scientists to study and learn about complex ecological and biological processes In addition, the diversity and uniqueness of the ecosystem also attract members of the medical community. The reef yields many biological treasures that are increasingly being recognized as natural sources of biomedical chemicals. These chemicals have been found to be useful for the treatment of many disorders, including cancer

Recreation and Tourism

The aesthetic attraction of coral reefs makes them a vital resource for tourism and recreation. People visit coral reefs for recreational activities like fishing, underwater photography, scuba diving, and snorkeling. Many nations, such as Maldives, have developed entire tourism industries around coral reefs In the United States, the Virgin Islands National Park receives about one million visitors each year, generating more than $23 million in revenue (Buck, 1991). The Florida Keys yield an estimated $30 million to $50 million per year from fishing, diving, and educational research activities (White et al., 1994).

Coastal Protection

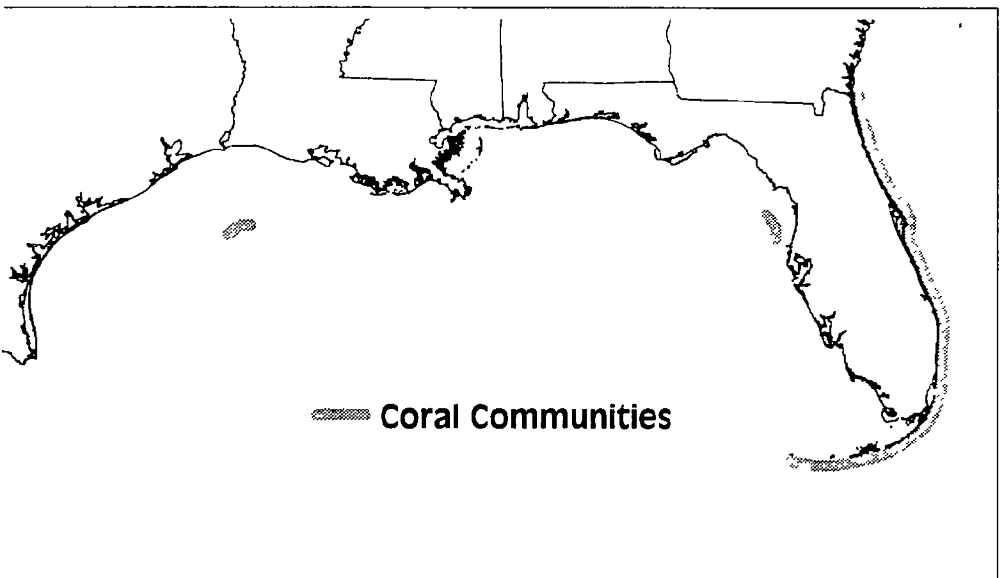
Coral reefs are also important for coastal protection. The reefs act as natural breakwaters or buffers that protect the coastline and help reduce erosion of beaches and shorelines. In the absence of these reefs, artificial structures would have to be constructed at an estimated cost of billions of dollars (Buck, 1991).

Environmental Values

Coral reefs contain a richness of species that rivals that of tropical rain forests. The reef ecosystem contributes significantly to the world's biodiversity (range of different species) and biological productivity. Many people value coral reefs as a source of enrichment and personal inspiration.

Reef Communities of the United States

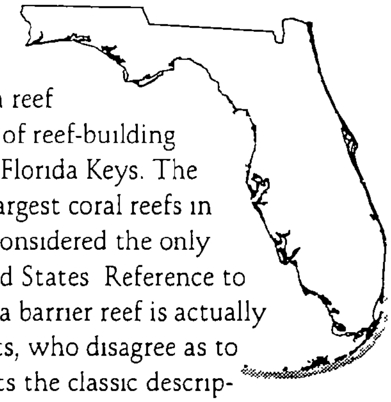
The coral communities of the continental United States largely exist at extreme latitudes for coral growth. Consequently, these coral communities can experience changes in physical parameters (especially temperature) more frequently than do reefs closer to the equator. The species richness and community development reflect this higher degree of physical stress. The distribution of coral communities in the continental United States is limited to the southeast coasts of Georgia, Florida, and the Gulf of Mexico



Southeast United States

Along the Atlantic coast, from the Georgia border to Fort Pierce, Florida, pretzel coral bank communities (*Oculina* sp) occur at depths of 49 to 165 feet. Although these coral assemblages are of relatively low diversity, they provide important structural habitat for many species, particularly fish (Jaap, 1984). From Fort Pierce to Palm Beach, Florida, pretzel coral communities are blended with tropical coral species A shift in dominance by tropical species occurs south of Palm Beach to Miami, although the building of three-dimensional reef structures occurs only farther south, near the Florida Keys The region of maximum coral reef development, the Florida reef tract, is restricted to the area south and west of Miami.

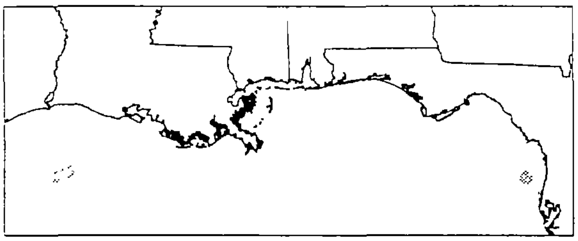
The Florida Reef Tract



Largely influenced by the warm waters of the Gulf Stream, the Florida reef tract is a bow-like band of reef-building corals that parallels the Florida Keys. The reef tract is one of the largest coral reefs in the world and is often considered the only barrier reef in the United States Reference to the Florida reef tract as a barrier reef is actually debated among scientists, who disagree as to whether it accurately fits the classic description (Jaap, 1984); however, the reefs are clearly large, elongated, and separate from the existing land mass of the Keys. The reef tract occurs atop a large limestone platform composed of marine sediments up to 23,100 feet deep and up to 150 million years old.

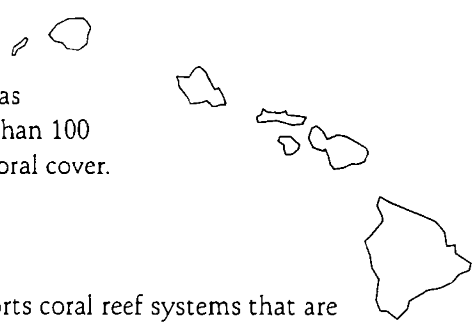
Several physical environments are associated with the reef tract: Hawk Channel, the body of water between the reef and the Keys, and a series of shallow-water embayments that include Biscayne Bay, Card and Barnes sounds, and Florida Bay. These environs support a variety of biological communities, such as deep reefs, reef crests, patch reefs, sea grasses, mangroves, wetlands, and uplands, all of which play a role in the development and survival of the reef. Impacts to these systems can affect the reef.

Because of the accessibility of the reef and the tropical allure of the Keys, the Florida reef tract began showing signs of stress, especially degradation of water quality, as early as the 1950s Continuing problems contributing to the decline of the reef included pollution, overfishing, physical impacts (e g , boat anchors, ship groundings, contact by divers), overuse, and use conflicts. The system also experiences adverse impacts from upland areas including the highly developed south Florida coast and the Everglades agricultural areas. Several management efforts have been initiated, the most recent being the passage of the Florida Keys National Marine Sanctuary Act (Causey, 1995). Details on this effort are provided in the case study in Section 4



Gulf of Mexico Systems

In the Gulf of Mexico, close to Florida, hard-bottom communities known as the "Middle Grounds" occur with a few coral species present, but without forming reef structures. Near Texas, the Flower Garden Banks form coral structures of limited size dominated by massive coral species. Twenty-one species of corals occur on the Flower Gardens, as well as more than 250 species of invertebrates and 175 species of fishes. The Flower Gardens are separated into East and West Banks, located approximately 12 miles apart. Both are located 100 miles southeast of Galveston, Texas. The East Flower Garden Bank is a pear-shaped dome, approximately 3.1 miles in diameter, rising to within 50 feet of the surface. The total area of live reef at the crest of the bank is about 250 acres. The West Flower Garden Bank is oblong in shape, is approximately 5 by 7 miles in area, and has a little more than 100 acres of live coral cover.



Hawaii

Hawaii supports coral reef systems that are part of the tropical central Pacific region The Hawaiian archipelago is the longest and most isolated chain of tropical islands in the world. The geography of the islands is varied and complex. The species richness of corals is low compared to that of the Caribbean and Indo-Pacific, a condition attributed to the change in ocean surface currents over geological time (Grigg, 1988). The number of coral species in Hawaii is less than 10 percent of the number in the Indo-West Pacific. However, the reef structures can be well developed and highly productive Coral growth is highest near the southeastern end of the island chain, where water temperature and sunlight are optimal. The coral species composition is remarkably uniform in spite of the large spatial variability, suggesting that most of the coral species that occur in Hawaii are *generalists*. (UNEP/IUCN, 1988).

The best-developed coral reefs in Hawaii are on the leeward (south and southwest) coasts, or in bays. Coral reefs are present along the Kona Coast and Kealakekua Bay on Hawaii Island, Molokini Lagoon on the south coast of west Maui, the north coast of Lanai, the southeast coast of Molokai, and Hanauma Bay and Barbers Point on Oahu Lagoons of the northwest Hawaiian Islands, including Midway and Kure, also support reefs (UNEP/IUCN, 1988). Many of the reefs are dominated by branching corals, such as *Porites* sp., *Pocillopora* sp., and *Montipora* sp , which can form large stands in structuring reef crests and flats. Research on reef fishes and invertebrates has shown low species diversity compared to the Indo-Pacific region, but there are several species unique to Hawaii (Hourigan and Reese, 1987; Kay and Palumbi, 1987).

Kaneohe Bay, on Oahu, is one of the most intensively studied reef systems in the Pacific. Before the 1960s the descriptions of coral reefs within the bay were limited; however, research has shown that these reefs have evolved under significant terrestrial influences from adjacent watersheds. Heavy coastal development has had significant adverse impacts on coral abundance and distribution within Kaneohe Bay.

Several reef systems in Hawaii are exhibiting signs of impacts from upland stresses. An example is Kuai, Hawaii's fourth-largest island, most of which is bordered by fringing reefs, many with wide reef flats. Several major streams on the island have headwaters in the massive rocks of a large central volcanic crater Fifteen streams feed into estuaries, and these contribute to 11 distinctive bays around the island High degrees of freshwater input, siltation, agricultural wastewater, and sewage discharge affect water quality, and algal responses to elevated nutrients have been implicated in the inhibition of coral growth (UNEP/IUCN, 1988)

Reef Communities of the Island Territories

Coral reefs also occur in the insular territories of the United States (the islands of the Caribbean and Indo-Pacific regions). The physical conditions under which reefs develop in both regions are similar; however, characteristics such as species diversity, age, reef morphology (structure), and zonation (geographic distribution) vary

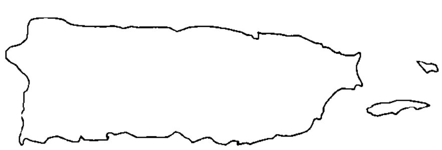
Species are less diverse in coral reefs of the Caribbean compared to regions in the Indo-Pacific. *The west Indo-Pacific is the world's center of coral species diversity* As examples, Caribbean coral reefs have only one-sixth the number of hard corals found on the Great Barrier Reef (Kojis, 1993); 3 species of an important reef-building coral, *Acropora*, occur in the Caribbean, compared to over 200 species on the Great Barrier Reef and up to 150 in other regions of the Indo-Pacific. The massive star coral, *Montastrea annularis*, is the most abundant and primary reef-building coral in the Caribbean, whereas there is no single species that dominates the Great Barrier Reef or reefs in many other Indo-Pacific locations. .

Caribbean reefs are also significantly younger than most Indo-Pacific reefs. Caribbean reefs have largely formed since the last ice age. Consequently, the depth of ancient reef structure is much less than that of the Indo-Pacific region.

The Caribbean

The general coral reef types observed in Puerto Rico and the U S. Virgin Islands include fringing reefs, fringing barrier reefs, submerged barrier reefs, and patch reefs

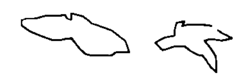
Puerto Rico



The coral communities of the north coast of Puerto Rico consist primarily of scattered hard coral colonies, soft corals, and poorly developed reefs in hard pavement areas along the coast (USEPA, 1992). The percent cover of living coral tissue is generally low and where quantitative observations have been made, has not exceeded 7 percent. Coral reefs are better developed along the eastern side of the north coast, with patch reefs formed east of San Juan to Ensenada Comezón, and fringing reefs off Punta Miquillo and Punta Picúa (Goenaga and Cintrón, 1979). Historically, coral coverage in this area has been low because of the discharge of sediments from the large rivers in the region and the heavy exposure to waves of the open Atlantic. Sedimentation from extensive dredging and pollution from sewage also destroyed well-developed reefs northwest of Boca de Cangrejos.

Coral reefs on the eastern and southern side of the island are occasionally well developed and form patch and fringing coral reefs. The estimated percent cover ranges from 6 to 100 percent (USEPA, 1992). The submerged-shelf edge along the south coast also supports well-developed reefs. However, many of the reefs have been damaged by human activity and sedimentation and exhibit low percent coral cover Coral reefs along the western coast of Puerto Rico are also well developed. Both fringing and patch reefs are found; however, several areas have been heavily impacted by human activity.

U.S. Virgin Islands



In the U.S. Virgin Islands, the extent of coral community development is not well documented. However, the eastern and southeastern barrier reef in St. Croix is one of the best developed reef systems in the tropical-Atlantic Caribbean (Adey et al., 1981). This area has also been suggested to be the largest reef structure among the insular territories, with the possible exception of some U.S. Indo-Pacific island reefs.

St John is the site of the Virgin Islands National Park and Biosphere Reserve and coral reefs are well represented The best developed is Johnson's Reef on the east coast and in Haulover Bay (USEPA, 1992). St. John's reefs were damaged by Hurricane Hugo in 1989. In St. Thomas, coral cover on reefs has been estimated as high as 49 percent, but most documentation of reefs is for the south coast of the island.

The Pacific Islands

American Samoa

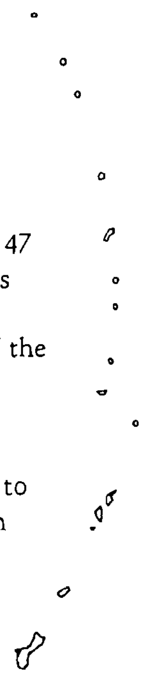
American Samoa is an unincorporated territory of the United States. It comprises six eastern islands of the Samoan Archipelago, as well as Swain's Atoll, which is geographically part of the Tokelau group. Land area covers approximately 76 square miles. All islands except Swain's Atoll are aligned along a crest of a discontinuous submarine ridge, extending over 290 miles, northwest by southeast (UNEP/IUCN, 1988) The largest island, Tutuila, lies atop a composite volcano rising approximately 3 miles from the ocean floor Other islands in the group include Aunu'u (1 mi^2, 200 feet highest elevation), Olosega (2 mi^2, 3,169 feet highest elevation), Ta'u (17 mi^2, 3,169 feet highest elevation), the Rose and Swain's atolls, and Ofu (3 mi^2, 1,621 feet highest elevation). All islands are bordered by well-developed fringing reefs, although many are narrow and lack substantial nearshore dropoffs. Most reefs typically have a shallow moat (<6 feet in depth), a shallow forereef, a reef crest (usually emergent at low tide), a surge zone with spur and groove formations, and a distinct forereef slope, with 16- to 33-foot relief gradually descending into deep water (UNEP/IUCN, 1988)

The coral reefs of American Samoa are among the best documented in the south Pacific region. The most important reefs identified (by IUCN) are Pago Pago Harbor, Utulei, Aua, Faga'alu, Tafananai, Alega Faga'itua, Aoa, Masefau, Afono, Vatia, Fagasa, Massacre, Maloata, Poloa, Amanave, Nua-Se'etaga, Leone, Asili, Pala Lagoon, Matuu, and around Aunu'u Island Tuituila is the most populated island with 90 percent of American Samoa's population (UNEP/IUCN, 1988) One-third of the population lives around Pago Pago Bay, with the remainder residing in small villages along the coast Human activities have increased impacts to the reefs through pollution, and fish poisoning and other extraction techniques. From 1942 to 1945, the U S military services dredged large sections for wartime ship fleets Coral reefs in Pago Pago Bay particularly have suffered damage from human activity.

The Marshall Islands

In 1986 the Republic of the Marshall Islands became freely associated with the United States. Twenty-nine coral atolls and five coral islands with low elevation (1.5 to 25 m, 5 to 83 feet) form two chains The Ratak Islands occur to the east, and the Ralik Islands to the west, including the Enewetak, Bikini, and Ujelang atolls.

The Commonwealth of the Northern Marianas Islands and Guam



The Commonwealth of the Northern Marianas Islands (CNMI) was granted status as a sovereign territory by the United States in 1986. CNMI comprises all the Marianas except Guam. Sixteen islands compose the archipelago, and they range in size from 0.3 mi^2 (Farallon de Medinilla) to 47 mi^2 (Saipan). The relief of the islands ranges from 265 to 3,166 feet. The shorelines of Aguijan, Farallon de Medinilla, and most of the smaller northern islands do not have coral reefs, largely because of the sea cliffs and steep, rocky slopes (UNEP/IUCN, 1988) People live on only the three largest islands to the south—Saipan, Tinian, and Rota—with over 87 percent of the population living on Saipan (roughly 35,000). Saipan and Tinian have offshore barrier reefs with shallow lagoons along portions of their western coasts.

Guam, located southwest of CNMI, is the largest and most populated island in the Marianas chain. Like the other islands in the southern chain, Guam is volcanic with high relief, but it has a long geologic history of carbonate accretion from reefs. Over 45 species of corals occur on the fringing and barrier reefs that surround the southern and western coasts Reef structures are also covered by coralline algae (e.g., *Porolithon* sp.).

Coral reefs in Guam experience degradation from human-related impacts. Land construction activity has caused *sublethal* effects on reefs along the southern coast (Richmond, 1993). Increased freshwater runoff laden with sediment has caused high levels of mortality and rapid response in growth by fleshy algae.

Section 2

Threats and Impacts to Coral Reefs: Natural Processes and Human Activities

The marine environments in which coral reef communities have evolved are noted for their relative stability. The daily and seasonal changes in the coral reef environment tend to occur slowly and over relatively narrow ranges Coral species vary in their ability to tolerate extremes in physical and chemical parameters, such as salinity, temperature, nutrients, and turbidity, although tolerance ranges are generally narrow Healthy corals are better able to adapt to environmental changes than corals under stress.

A variety of direct and indirect environmental impacts pose a threat to the health of coral reef ecosystems. They result from both natural processes and human activities. Direct impacts to reefs can be caused by natural events like storms and hurricanes, or by human activities like boating (e g., groundings, propeller damage, anchor damage), diving, overfishing, and dredging. Indirect impacts result from water quality degradation from waste discharges, runoff, deep well injection, septic tanks, chemical spills, and litter (Grigg and Dollar, 1990) Indirect impacts can be more serious than direct impacts in terms of long-term effects due to the difficulties encountered in finding and reducing or eliminating sources of stress such as excessive nutrients or toxic contaminants.

Table 2 is a summary of known threats to reefs throughout the Atlantic and eastern Pacific. Figure 1 is a conceptual illustration of the land-based activities that affect coral communities. Figure 2 shows some of the impacts to coral communities that result from different stressors.

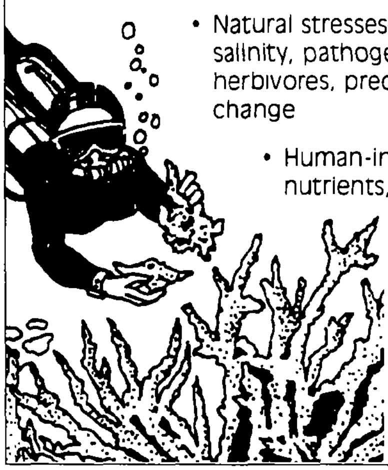
This section discusses natural and human-induced stresses to coral ecosystems. The impacts these stresses have on coral ecosystems are also discussed.

Natural Stressors

Light

Because of their zooxanthellae, corals respond to both the intensity and spectral quality of light. It has been suggested that the unprecedented coral bleaching (loss of zooxanthellae) events that occurred in the Caribbean in 1987 might have been due in part to increases in ultraviolet radiation related to stratospheric ozone depletion (Goenmaga et al., 1989; Williams et al., 1987). However, warmer-than-normal seawater temperatures were also suggested as an additional factor

Typical threats to coral ecosystems include:



- Natural stresses—light, temperature, salinity, pathogens, sediment, herbivores, predators, weather, climate change
- Human-induced stresses—nutrients, sediment, chemical contaminants, direct impacts

Table 2. Known Threats to Reefs

	Land Clearance	Coastal Development	Pollution	Overcollecting	Recreational Use	Others
Anguilla				lobster	anchor damage	fish traps, spearfishing
Antigua/Barbuda				conch, lobster	anchor damage, boat groundings	bleach, explosives
Bahamas				stony and black corals, lobster, conch, fish	anchor damage	explosives, bleach, spearfishing
Barbados	vegetation, mangroves	dredging	fertilizers, sewage, thermal		tourism	explosives
Belize	mangroves on cays	urbanization on cays		lobster, fish, conch	tourism, anchor damage	sportfishing
Brazil	deforestation	tourism, industry		coral		spearfishing, sportfishing, dynamiting
British Virgin Islands	vegetation, mangroves	marinas, jetties, dredging, sand mining	sewage (boats), industrial antifouling paints	fish, lobster, conch, black coral	anchor damage, boat groundings, littering	dynamiting, spearfishing, wreck excavation, fish traps
Cayman Islands	mangroves	hotel building, marl/sand extraction, swamp reclamation	sewage, oil	fish, lobster, conch, coral	anchor damage, littering, tourism	spearfishing
Chile (Easter Islands)	deforestation*	construction*	oil spill (1983)			
Columbia	deforestation, mangroves	holiday homes, runaway construction, sand extraction, land reclamation	sewage, thermal, insecticides, refuse	conch, lobster, fish, aquarium fish	anchor damage, boating, littering	dynamite, lobster traps, wrecks*
Costa Rica	deforestation, other vegetation	housing, hotels, roads	sewage (urban, boats)	coral, fish, lobster, shells	trampling, littering	
Cuba		urban development, sand dredging	industrial, oil spill (1980)	conch		spearfishing
Dominica	deforestation	industrial, urban	refuse	fish, lobster, conch, shellfish		
Dominican Republic	vegetation, mangroves	sand dredging, port and airport construction	sewage, industrial, thermal	fish, lobster, conch, coral, shells	diving, tourism, littering, sportfishing	spearfishing
Ecuador (Galapagos)				black coral	tourism*	
Grenada	vegetation	sand dredging	pesticides, herbicides, refuse	fish	trampling	dynamiting
Guadeloupe	deforestation, mangroves	urban development, sand mining, dredging*	industrial, agriculture, refuse, sewage, pesticides, oil, heavy metals	coral, fish, mollusks	tourism	dynamiting
Haiti	deforestation		urban	coral, shells, conch		
Honduras	vegetation	airports, roads	sewage*		tourism, anchor damage	
Jamaica	vegetation along rivers	hotel development, river channelization	sewage, oil*	stony and black corals, fish, conch	trampling, anchor damage, boat groundings	dynamiting, fish traps, spearfishing

Table 2. Known Threats to Reefs, cont.

	Land Clearance	Coastal Development	Pollution	Overcollecting	Recreational Use	Others
Martinique	deforestation, mangroves	urban, airport, industrial, road construction	sewage	conch, fish, lobster	tourism	
Mexico	deforestation*	urban, tourism, petroleum industry	oil spills, industrial sewage	conch, lobster, coral, fish	tourism,* trampling, boat groundings, littering	spearfishing
Montserrat St Kitts-Nevis		sand mining		conch, lobster	tourism	
Netherlands Antilles	mangroves	sand mining, harbor development, hotels,* landfill	oil, thermal, industrial, refuse, sewage, toxic metals, hypersaline water	shells, fish, lobster, conch, coral	anchor damage, scuba diving	spearfishing, fish traps
Nicaragua	deforestation					
Panama	deforestation, mangroves	sea level canal,* oil pipeline and terminal, landfill, dredging	sewage, herbicides, freshwater input,* oil spill (1983), oil*	fish		
Puerto Rico	deforestation, mangroves	dredging, sand/coral extraction, urban, industrial, jetty construction, holiday homes	industrial, oil, sewage, thermal, chemical	coral, fish	anchor damage	ship traffic, spearfishing, bombing, wrecks
St Lucia		hotel development, sand dredging, mining, construction	thermal*	coral, fish	anchor damage, scuba diving	dynamiting, spearfishing, potfishing
St Martin and St Barthelemy		sand extraction	unspecified	coral	unspecified	
St Vincent			detergent, boat refuse	coral		
Trinidad and Tobago	coastal vegetation, mangroves	shore development		coral, shells	anchor damage, trampling	
Turks and Caicos	vegetation*	hotel development,* marinas, dredging	sewage,* oil	fish, lobster, conch	tourism, littering	ship groundings, bleach, spearfishing, aragonite mining* ballast dumping
U S		dredging, condominiums, marinas, beach renourishment	sewage, oil,* heavy metals, industrial,* desalinization plant	lobster, coral, shells, conch	anchor damage, littering	ship grounding and salvage, artificial reefs, oil drilling,* dumping of fishing gear, ship traffic, wrecks, roller trawl fishing, fish traps, hook and line fishing, spearfishing
U S Virgin Islands	mangrove	industrial, dredging, sand mining, marina/hotel development,* housing	industrial, oil, sewage, urban, thermal, heavy metals, bauxite and aluminum plants	conch, lobster, coral, shells, fish	tourism, littering, anchor damage, trampling, diving/swimming	
Venezuela	deforestation, mangroves	holiday homes	urban, sewage, industrial, ship refuse	fish		shipping

Source Wells, 1988

**Potential threat*

Because of the light dependence of most corals, they are found in areas with good light penetration. Suspended sediments and overabundance of *phytoplankton* (tiny marine plants suspended in the water column) are two factors that can reduce the amount of light reaching corals. Although corals might adapt to existing light regimes (Dustan, 1979), reduction in light due to turbidity lowers their growth rate and complete shading can cause their death (Rogers, 1979).

Temperature

Corals can be affected by both long-term climatic temperature fluctuations and short-term human-induced temperature changes Concern for the effects of global

warming on coral reefs has been voiced (Goenaga, 1991), but evidence of such impacts to coral reefs is still lacking (Miller, 1991; Roberts, 1991).

Seasonal fluctuations resulting in extremely cold and extremely warm temperatures have been cited as the cause of coral bleaching and coral death in Florida (Jaap, 1984) Typically, coastal marine waters of more northern latitudes are characterized by lower winter minimum temperatures and lower summer maximum temperatures than their more tropical counterparts. Evidence of lower thermal tolerances for subtropical corals compared to tropical corals indicates that higher-latitude corals live in waters even closer to their thermal maximum temperatures than their more tropical counterparts.

Seasonal sources of thermal stress include winter cooling of nearshore surface waters and upwelling of deep, cooler water from offshore. Air temperatures can fluctuate dramatically on a seasonal basis, bringing occasional periods of frost during winter and prolonged heat waves in summer Warm-water stress is usually the result of summer warming of shallow water during warm calm periods, although larger-scale ocean warming events like El Niño can also bring unseasonably warm water into the vicinity of coral reefs

Salinity

Both low and high salinity can stress coral communities. Low salinity can occur as the result of an overabundance of freshwater runoff following storms. Brief episodes of low salinity due to storm water runoff have been reported to cause loss of zooxanthellae and coral death (e g., Goreau, 1964). Elevated salinity has been observed to cause coral mortality at levels only slightly above normal (Johannes, 1975).

Sediment

Sedimentation is a natural process in all marine systems, and all corals have the ability to actively remove some sediments from the surface of the reef. The effect due to sedimentation depends on a number of factors, which include the type of sediment (grain size, carbonate content, organic content, toxic pollutant levels), the amount of sediment, and the duration and timing of coral exposure (e.g., night vs. day, reproductive or recruitment period).

Weather

Storms, especially hurricanes, can have very significant effects on coral reef communities both directly through physical impacts (storm surge damage and sediment resuspension) and indirectly through physical processes associated with heavy rainfall runoff that transports sediment, freshwater, and nonpoint source pollutants into coastal waters. Storms are the primary mechanisms that produce nonpoint source pollution. The sediments washed off during these storms can transport toxicants, oxygen-demanding substances, nutri-

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ents, and pathogens into the marine environment. Suspended sediments limit the amount and quality of light reaching coral reefs

Pathogens, Herbivores, and Predators

Coral, mangrove, and sea grass communities are typified by complex physical, chemical, and biological processes. Probably the least understood of these are the interactions among pathogens, predators, herbivores, and other environmental factors The sources of pathogenic outbreaks in these communities are largely unknown, but such outbreaks have had widespread and devastating impacts Research on the effect of predators and herbivores on community composition, biomass, areal coverage, and productivity has also revealed that these ecosystem components can exert a profound influence on the structure and function of coral communities. How humans influence these factors and the role of natural or random variation are still poorly understood.

Pathogens

Bacteria and filamentous blue-green algae have been identified as pathogenic agents in corals (Hodgson, 1990; Mitchell and Chet, 1975, Peters et al., 1983; Antonius, 1981b). Corals stressed by elevated concentrations of crude oil, copper sulfate, potassium phosphate, or dextrose have produced copious amounts of mucous and died (Mitchell and Chet, 1975). With the addition of antibiotics, however, coral death was not observed, implicating the bacteria as the agents of mortality. This interpretation has been extended to sediment stress through demonstration of antibiotics preventing mortality due to sediment deposition (Hodgson, 1990) The loss of corals due to pathogenic effects can result in dramatic changes in coral community structure, including fish populations (Gladfelter, 1982, Goenaga et al., 1989).

Predators and Herbivores

Community interactions are also important in determining community structure. Effects on coral community structure due to algal grazing by the spiny sea urchin, the territorial behavior of the threespot damselfish, plant eating by reef fish (species of parrotfish and surgeonfish), and predation directly on corals by fish (species of parrotfish and surgeonfish), a polycheate worm, and the flamingo tongue snail have been reported (Jaap, 1984).

Human-Induced Stresses and Impacts

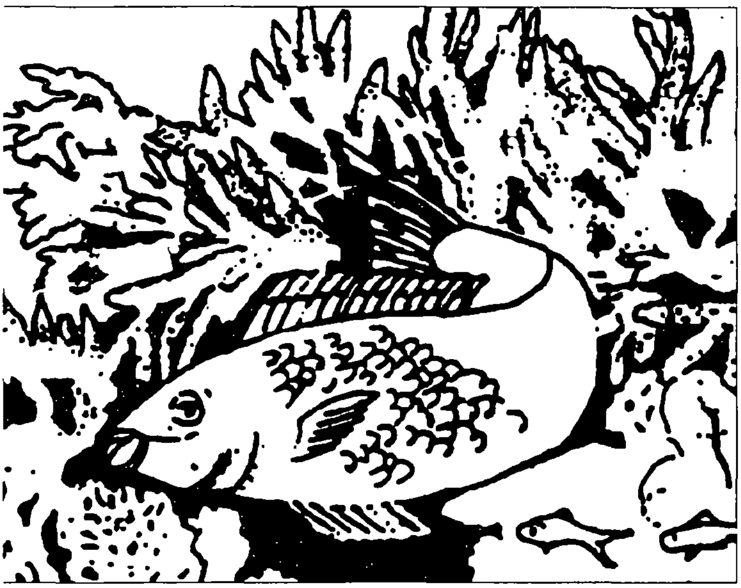
Nutrients

Reef-building corals rely on their relationship with zooxanthellae for calcium carbonate production A by-product of the zooxanthellae's photosynthesis allows the coral to more effectively produce its limestone skeleton. As discussed earlier, corals are limited to warm, oligotrophic (low-nutrient), high-light-intensity marine environments Excess nutrients, primarily nitrogen and phosphorus from sources such as domestic sewage and agricultural runoff, have the potential to adversely affect coral reefs in several ways. Nutrients can enhance the growth of phytoplankton in the water column surrounding the reef, which in turn can increase water turbidity, reducing the amount of sunlight reaching corals The reduction in light intensity can inhibit photosynthesis in the zooxanthellae, reducing coral growth and calcium carbonate production on the reef. Increased phytoplankton also contribute to sediment loading to the reef, an additional source of stress. Algae growth directly on the reef is also enhanced by excess nutrients.

> **Predation on the Reef: The Spiny Sea Urchin Story**
>
> A good example of the effects of the complex interactions in reef communities involves the large-scale mass mortality of the spiny sea urchin. This urchin was abundant on Caribbean reefs before 1983, but the abundance in particular areas might have depended on fishing intensity on the reefs (Hay, 1984). Heavy fishing of some areas on the reefs presumably resulted in the reduction of herbivorous fish and fish predators of the sea urchin (Hay, 1984) Beginning in 1983, however, the spiny sea urchin began to die in large numbers, possibly due to a waterborne pathogenic agent (Lessios, 1988). On reefs where spiny sea urchin density was high, algal biomass was low. Following the reduction of spiny sea urchin density, algal biomass increased (Carpenter, 1990a). Interestingly, algal community productivity decreased (Carpenter, 1990a), and although the numbers of herbivorous fish increased, algal biomass remained high (Carpenter, 1990b). Because the spiny sea urchin preys on settled coral larvae, but also grazes on algae that inhibit coral larval settlements, the density of the spiny sea urchin might have additional implications for coral community structure (Sammarco, 1980).

Nuisance algae can occupy areas where new coral grow, interfering with reef growth. These algae also colonize damaged and diseased coral skeletons, inhibiting recovery and regrowth of coral tissues.

The effect of increased nutrient input to coral reef areas is not well understood, and conflicting evidence has been presented. Nutrients, particularly phosphate, can directly affect coral skeletal growth by inhibiting skeletal formation (Simkiss, 1964) and can indirectly affect the coral community through enhancement of the growth of attached algae. The algae can overgrow living corals or interfere with new coral growth (Birkeland, 1977)



Sediment from Human Activity

Sediment suspended as a result of human activity (e.g., land-based construction or dredging and filling) has significant effects on adjacent coral reefs. Point and nonpoint sources of pollution, which are discussed in detail later in this section, can add significantly to coastal sedimentation rates. Poor forestry and agricultural practices, as well as construction activity where erosion is not controlled, result in sediment-laden runoff. Point sources contribute suspended solids and particulate organic matter from nutrient enrichment.

Excess sedimentation over an extended period can cause corals to expend energy on cleaning that would otherwise have gone into processes such as feeding, growth, and reproduction. Extreme sedimentation rates can cause coral mortality through smothering and burial. High sedimentation rates can interfere with coral recruitment because coral larvae will not settle on soft sediments. Sediment loads in the water column minimize sunlight penetration to the coral reef, causing reduced photosynthesis and the loss of zooxanthellae.

Excessive amounts of sediments and sedimentation result in the death of the reef-forming coral organisms and degradation of the reef framework Loss of the reef framework and its associated structural complexity results in habitat loss and reduction of coral reef fish (Rogers, 1990) Heavy sedimentation has led to fewer coral species, less live coral, lower coral growth rates, decreased reef building, decreased net productivity, decreased reef building rates, and reduced coral growth (Rogers, 1990). Because many toxic substances bind to sediment particles, sediments also transport particulate-associated toxic pollutants, nutrients, oxygen-demanding organic matter, and pathogens.

Chemical Contaminants

Chemicals from industrial processes and petroleum exploration and production can cause both short- and long-term effects on corals and other living components of the reef community Toxicants like chlorine, metals, pesticides, and petroleum products can directly affect the various life stages of corals or the life stages of animals and plants that make up the coral community. Coral colonies themselves might be fairly resistant to toxic pollutants (Marszalek, 1987), but other coral life stages might be more sensitive. Corals exhibit a variety of reproductive strategies, including timing of spawning and spawning synchrony among species (Richmond and Hunter, 1990) Therefore, the timing of pollutant input might play an important role in toxic effects on coral life stages.

Petroleum

Coral mortality and coral community alterations due to oil pollution have been noted in several areas of the Caribbean (e.g., Bak, 1987; Jackson et al, 1989). Oil pollution in direct contact with corals can impair coral growth, reproductive systems, and larvae and can cause death of corals (Loya and Rinkevich, 1987). The shallow-water Caribbean coral *Manicina areolata* has been shown to *bioaccumulate* petroleum hydrocarbons (Peters et al., 1981) This results in the pollutants being passed along the food chain

Pesticides

Pesticides can exhibit both *lethal* and *sublethal toxicity* to marine animals, including corals Concentrations of pesticides too low to cause death in adults might be lethal to more sensitive younger stages. Sublethal effects can include impairment of settlement, feeding, growth, disease resistance, reproduction, and adaptation to environmental change. Herbicides might have similar effects on reef organisms, including zooxanthellae.

Sources of Pollution

The primary sources for water quality-related stress to coral reef ecosystems are point source discharges and nonpoint sources of pollution *Point source* is a term used to describe a discharge at a single, identifiable point, such as a culvert or pipe. Point sources are usually associated with treated or untreated wastewater discharges, but they can consist of stormwater runoff or other diffuse nonpoint sources collected and discharged as a point source. Many of these sources are depicted in Figures 1 and 2.

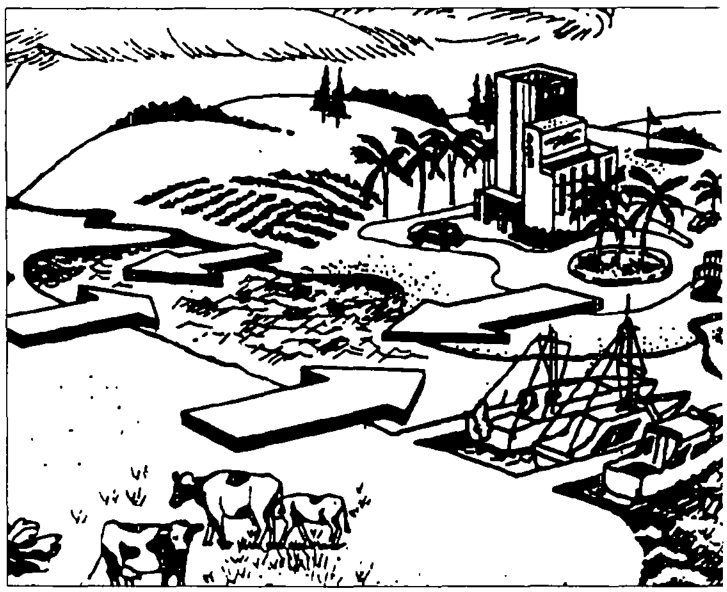
A nonpoint source of pollution does not have a defined point of origin. Nonpoint sources typically are a collection of waters from runoff, rainfall, drainage, or other natural or human-made sources that discharge to surface waters via rivers and streams or indirectly through ground water flows (USEPA, 1993). Nonpoint source discharges include storm water from agricultural and urban areas, discharges from marinas and other nearshore industries, accidental releases of chemicals (e.g , oil spills), septic system failures, and sediments suspended during construction and dredging activities

Water quality degradation from point and nonpoint sources can contribute to a host of adverse impacts to a coral reef community They range from coral mortality to stress resulting from subtle alterations in community structure caused by chronic toxicity and low levels of physical stress.

Nonpoint Source Pollutants

Urban Stormwater Runoff

As an area is developed, the amount of impervious surface increases, thereby increasing the volume and velocity of runoff to receiving waters. In addition, the amount of actively maintained landscape increases as an area is developed. This can lead to an increase in nutrient and pesticide loadings from excess application. Construction activities can contribute a large amount of sediment to coastal waters if proper techniques for controlling erosion and sediment transport are not used. Urban runoff contains a variety of pollutants, including sediment, heavy metals, hydrocarbons, fertilizers, pesti-



cides, and oils and greases, depending on the land uses. Unless urban runoff is treated using best management practices (BMPs) prior to its discharge to coastal waters or their tributaries, these pollutants can end up offshore

Pollutant loadings vary depending on several factors, including volume of rainfall, amount of impervious surface, land use, and effectiveness of BMPs in use Practices such as maintaining open space and buffer areas to filter storm water runoff, minimizing use of pesticides and fertilizers, street sweeping, and public education minimize the contributions of urban areas to nonpoint source pollution.

Agricultural Runoff

Nonpoint source pollutants from agricultural lands include nutrients, sediment, hydrocarbons, and pesticides. Agricultural land uses are very chemical-intensive. Although pesticide and fertilizer application is a necessary component of agriculture, overuse might eliminate desirable organisms in near coastal waters, destroy higher organisms' food sources, result in lethal combinations when more than one compound is used, or result in bioconcentration of compounds through the food chain. Land tilling and erosion account for large amounts of sediment being carried away by runoff. In areas with relatively flat topography, erosion is not as critical a concern as it is in more mountainous areas; however, the geology of an area can allow pollutants to be introduced directly into the water table and ultimately flow to the coast. An example of this would be an area with porous limestone containing an unconfined aquifer.

Nutrients have a number of sources, including fertilizers, manure from animal production facilities, and irrigation water, and can result in overenrichment of nearby waters. In addition, animal wastes contain oxygen-demanding substances, bacteria, and sediments, which can affect surface water quality.

Marinas and Recreational Boating

Impaired water quality and biotic impacts are associated with marinas and recreational boating Specifically, facility design, operation, and maintenance, in combination with increases in surrounding impervious surfaces, can result in low dissolved oxygen, as well as increased concentrations of metals and hydrocarbons in the immediate vicinity. In addition, facility construction and operation, shoaling and shoreline erosion, and boat propellers in shallow areas can increase sediment levels.

Metals and metal-containing compounds have many functions in boat operation, maintenance, and repair Copper and tin are used in compounds used to kill marine fouling organisms that attach themselves to boats and pilings. These metals slowly leach into the water column Lead is used as a fuel additive and can be released through incomplete combustion and boat bilge discharge Zinc anodes are used to deter corrosion of metal hulls and engine parts. Because they do not dissolve in water and are readily bound to sediment, many of the pollutants associated with marina activities do not cause problems in the water column but do accumulate in the bottom sediments. They become a water quality concern when resuspension of sediment occurs.

Forestry

Forestry activities can be a major nonpoint source of pollution in tropical watersheds. Impacts can result from activities like the cutting of timber, the construction of logging roads, and pre- and post-harvest timberland management. The types of nonpoint pollution associated with forestry activities include sediment, nutrients, chemicals, and organic debris.

Hydromodification/Alteration of Natural Hydrologic Features

Modification or alteration of natural hydrologic features (such as stream channels and wetlands) can result in sediment supply changes, reduced or increased freshwater availability, accelerated delivery of pollutants, loss of contact with overbank areas, and changes to overall ecosystems, as well as secondary instream/waterbody effects.

While nearshore habitats (intertidal wetlands and submerged aquatic vegetation) might not be considered a hydrologic feature, alteration or destruction of these areas is a potential source of nonpoint source pollution, which can affect coral reef ecosystems. The removal or fragmentation of these vegetated areas can result in the elimination of the natural line of defense that prevents nonpoint sources of pollution from reaching offshore. In some areas, submerged aquatic vegetation is removed to create a "clean-bottom beach" for tourist use. The removal of such vegetation results in an increase in turbidity caused by increased wave- and current-induced bottom scouring.

Freshwater runoff (and therefore stress caused by low salinity) is the product of rainfall. The quantity of freshwater runoff discharged to coastal waters can be increased by removing vegetation that retains runoff; paving large areas, which prevents infiltration of runoff; and channelizing runoff.

Alterations of coastal barriers or channels of tidal exchange can result in increased or decreased exchange of seawater, resulting in increased or decreased salinity of the affected areas. This happens when inlets are cut through the barrier islands or causeways are constructed without adequate culverts.

Sand Mining/Other Mining

Mining of sand and coral for use as construction materials, beach nourishment projects, and other uses occurs in many areas of the world. The physical damage and high degree of suspended sediment generated by these activities can have severe impacts on the coral reef ecosystem Mining for minerals, metals, soil, and other materials within the watershed can result in increased levels of sediment and metals in the mining runoff.

Atmospheric Deposition

In some areas atmospheric deposition of nutrients, heavy metals, and toxins can be a significant contributor to nonpoint source pollution loadings. However, sources of atmospheric deposition—remote and even local—might be difficult and too expensive to identify and monitor effectively

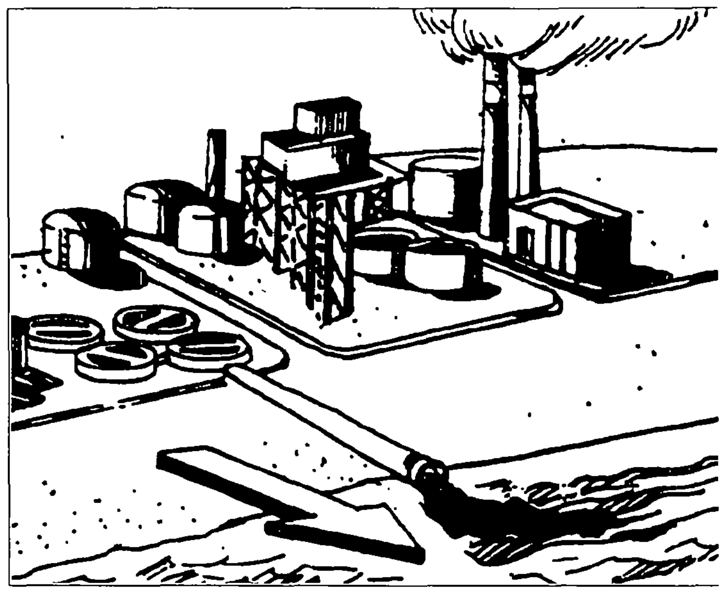
Point Source Pollutants

Compared to nonpoint sources, point sources have significantly lower total flow and therefore do not pose as serious a threat to coral reef environments. Land-based point source discharges tend to be restricted to urban and industrial centers, limiting the geographic scope of impacts to reefs adjacent to these areas. Offshore point source discharges (mining, shipping, oil and gas activities) can be more widely distributed. Where point source discharges do occur, however, they can contribute significantly to localized impacts to coral reefs.

Sewage Effluent

The nutrients, pathogens, and toxicants associated with sewage outfalls pose a serious threat to coral reef ecosystems, which are dependent on low-nutrient, high-clarity water (De Freese, 1991). The impacts of sewage pollution can be placed into three broad categories nutrient enrichment, sedimentation, and toxicity. The following impacts can have an adverse effect on coral reefs (USEPA, 1982).

- Accumulation of discharged solids on the seabed
- Stimulation of phytoplankton and/or macroalgal growth due to nutrient enrichment
- Reduction of phytoplankton and/or macroalgal growth due to turbidity increases
- Reduction of dissolved oxygen due to phytoplankton blooms and subsequent die-offs, causing mass mortalities of fishes and invertebrates
- Bioaccumulation of toxic pollutants due to direct contact or ingestion of sediment, direct uptake from the effluent, or ingestion of contaminated organisms
- Induction of diseases from contact with sediments, ingestion of contaminated organisms, or exposure to the effluent.



Black-band disease has been observed on corals in the vicinity of sewage discharges. This disease, caused by bacteria, has been linked to nutrient enrichment, high sedimentation rates, elevated temperatures, direct toxicity, and physical damage. Excessive nutrients can also stress coral reefs by promoting the growth of fleshy algae, which outcompete corals and other organisms. Increased phytoplankton and related eutrophication problems such as deposition of suspended solids, can reduce light penetration (Tetra Tech, 1983). Because the corals derive a portion of their nutrition from algae (zooxanthellae) living within their tissues, reduced light levels that decrease photosynthesis can also affect the general health of the coral.

Thermal Effluent

Human-induced temperature stress is caused mainly by heated effluent from power plants and water desalinization plants Such effluent can also be associated with additional stress factors such as toxicants used in the elimination of fouling organisms and metals associated with corrosion of the cooling system (Neudecker, 1987). Salinity is an additional stressor if the thermal effluent consists of hypersaline brine from a water desalinization plant. How these effluents affect coral communities depends on the initial temperature of the effluent, the salinity of the effluent, the toxicant concentration, and the mixing characteristics of the discharge. For example, the plume of a warm freshwater discharge to surface waters tends to float on the denser seawater, affecting only shallow coral communities that encounter the surface plume.

Water temperatures 4 to 6 °C above ambient levels are lethal to corals, and corals stop feeding at temperatures only 1.5 to 3 °C above ambient temperatures (Johannes, 1975). The sensitivity of corals to heat stress is inversely proportional to the corals' growth rate (Neudecker, 1981); the fastest-growing corals are most susceptible to stress induced by elevated temperatures.

Other Sources and Impacts

A variety of other *anthropogenic* activities can have an adverse effect on coral communities. These activities and their associated pollutants and impacts are discussed briefly below. The effects of the specific pollutants associated with these activities have already been described.

Seafood Processing

Discharges from land-based or shipboard seafood processing plants provide high organic loading, resulting in phytoplankton blooms and decreases in the oxygen in the water

Industrial Wastes

Industrial activities can discharge a variety of chemical contaminants, depending on the industry. These include but are not limited to toxics, suspended solids, heavy metals, and heated water.

Mining and Petroleum Wastes

Pollutants from land-based and offshore mining and from oil and gas exploration and production include petroleum hydrocarbons, heavy metals, other chemical contaminants, suspended solids, and salt brine.

Desalinization Effluent

Hypersaline water can be discharged from water desalination plants, causing a change in the salinity If the brine is warm, the discharged wastewater tends to sink and mixes poorly, severely affecting benthic communities (Chesher, 1975) In addition, the effluent might have low dissolved oxygen levels or might contain pesticides found in antifoulants or naturally occurring radioactive materials.

Physical Damage and Physical Alteration of the Environment

Two additional types of stress that are not directly related to water quality are direct physical damage and physical alteration of the environment. Direct physical damage can be human-induced (i.e., direct impact during construction, boat anchoring, and/or dredging activities) or due to natural causes like tropical storms and hurricanes.

Severe physical impacts can crush live coral or cause breakage, fractures, or tissue lesions that make coral susceptible to disease (Peters, 1984). Loss of coral cover can result in changes in the fish community, which might change over time as the area is recolonized (Dennis and Bright, 1988) The open space created when corals die can also be quickly colonized by benthic algae.

Physical damage and changes in coral community structure have been noted following hurricanes; ship groundings; dredging and channel construction; coastal construction; recreational activities like snorkeling, skin diving, and scuba diving; and boat anchoring.

Section 3

Watershed-Wide Planning for Coral Reef Protection

Over the years, regulations and controls have been developed to control point sources of pollution. Point sources are easily identified, and the technology has been available to control many of the pollutants typically associated with them. This approach has resulted in improved water quality in coastal waters. However, several challenges to addressing degradation of coastal water quality remain. These challenges concern controlling nonpoint sources of pollution and reducing their impact on coral communities.

Nonpoint source pollution, in contrast to pollution from point sources, cannot be easily regulated One way to control nonpoint source pollution, however, is to address suspected problems or sources (e g., urban runoff, agricultural activities, marinas) on a *watershed* scale. By addressing issues on a watershed scale, using a watershed planning approach, those areas that pose the greatest risk to human and ecological health can be targeted, several pollutants can be addressed at one time, the public can be involved in cleaning the environment and protecting coral habitats, and integrated solutions for environmental protection can be considered.

Many nonpoint sources of pollution and watershed-wide impacts are tied to land use. How an area is developed can be an indication of the types of pollutants that can ultimately end up in receiving waters For example, pollutants commonly associated with residential development include nutrients from lawn fertilizers, pet waste, and decomposing yard waste. Heavy metals like lead and hydrocarbons from automobiles are commonly associated with commercial development because of the large parking areas typical of such development Agricultural land uses can contribute large amounts of sediment, pesticides, and fertilizers to runoff Open space and conservation areas can serve as buffers and filters for more sensitive ecosystems. Because of these associations, an effective way for local governments to control pollutants throughout the watershed is to carefully plan for the land uses in the watershed.

This section begins by outlining the steps of a typical planning process and describing how planning for coral reef management might be done at the local level The section then discusses how the local planning approach can be expanded to consider the entire watershed to achieve more effective protection of coral reef ecosystems.

A watershed is a geographic area in which water, sediments, and dissolved materials drain to a common outlet, such as a river, lake, bay, or ocean.

(USEPA, 1991)

Developing a Local Plan

The development of a plan helps a community understand the value of its resources, the issues affecting those resources, and what is required to protect the resources. Plans are usually developed at the local level with broad community participation and agreements reached by consensus The planning process establishes a conceptual and legal framework for land use decisions based on a community's shared vision of its future.

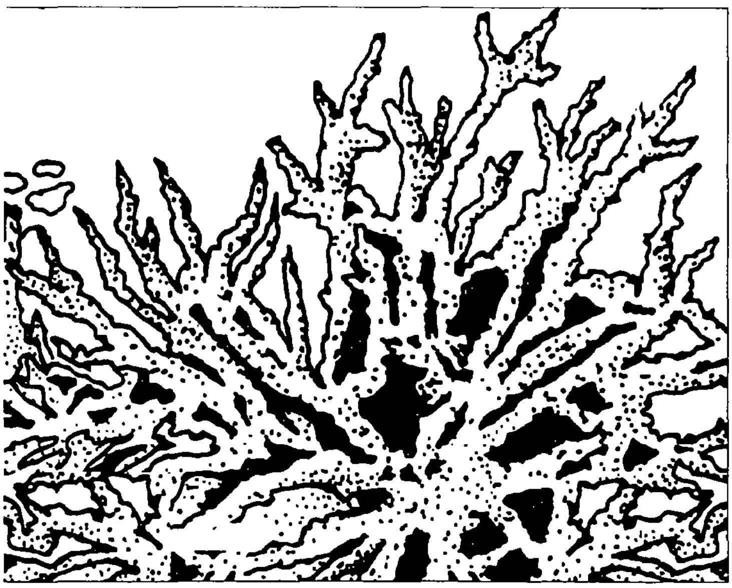
Community-based protection typically has three general characteristics.

1 The scale of involvement is local.

2 Participation is broad, with representation of all areas of the community, the public, and industry.

3 Agreements are arrived at by consensus

Making land use decisions is largely the responsibility of local governments. The local population is best



suited to understand local problems and develop remedial actions. There are strong reasons for making and implementing policies affecting coral reef management at the local level.

- Local citizens and officials are the most familiar with local problems and needs, and they are in the best position to articulate and reconcile competing land use interests

- Much of the power to influence local land use patterns is at the local level.

- Because environmental losses can be permanent and delays for action costly, it is important to act in a timely manner. Local citizens and officials can often act more quickly than the state or federal government.

- Many of the benefits of protecting ecologically sensitive coastal areas, which are associated with coral ecosystems, are realized at the local level. These include tourism, recreation, and commercial fishing

- Local governments are responsible for providing and maintaining public services. They will bear any increased cost for poor or ineffective planning

Communities can address coral reef protection either as part of a comprehensive plan or as a more focused special use plan. Comprehensive or master plans articulate a community's vision for its future by establishing long-range goals for a variety of issues, such as land use, education, infrastructure, capital expenditures, and natural resource protection. They also provide guidance on broad policy questions such as the formulation of regulations, public investment, and the issuance of building permits. Comprehensive plans can include guidelines and policies for the protection of near coastal areas and reefs. Special use plans address particular concerns, which might be necessary to protect coral communities These plans can stand alone or can be incorporated into comprehensive plans.

An excellent resource on the planning concept is *Protecting Coastal and Wetland Resources: A Guide for Local Governments* (EPA 842-R-92-002), published by EPA in October 1992. This guidance is focused on coastal and wetland resources, but it can be applied to near coastal coral reef communities as well.

The *Management Plan for Ugum Watershed—Territory of Guam* (U.S Department of Agriculture/Natural Resources Conservation Service, 1996) describes a series of management plans for the Ugum watershed developed using a planning concept that involves all levels of the community, and it proposes four alternative management scenarios for consideration A synopsis of the Ugum watershed study is provided in Section 4 of this document

The Importance of Planning

A plan facilitates land use decisions by describing existing patterns of the community—housing, economics, natural resources—and recommending policies that will manage future development for the protection of near coastal environments and coral ecosystems. For a plan to be successful, it must outline a framework on which to build future actions. It must have adequate community leadership and funding, as well as technical support to help make decisions.

A local planning commission (elected or appointed) or other governing body usually oversees the planning process and adoption of a legally acceptable plan. A process conducted openly, in the public forum, usually means decisions are made ethically and are not politically driven.

The Planning Process

The planning process typically has five main steps:

1. Define the context of the planning effort.

2. Understand the community, its resources, and the challenges facing it. Gather data to clarify and substantiate the existence of resources and problem areas.

3. Establish goals and objectives.

4. Prepare the plan.

5. Implement, monitor, and enforce the plan.

The following is a description of each step

Step 1:
Define the Context of the Planning Effort

Investigate Existing Programs That Affect the Planning Jurisdiction

Variations in local decision-making power directly affect the planning process. Some localities have more latitude than others in their authority to make decisions. Others must rely on broader regional governmental bodies No matter what the level of authority, every community exists within a larger political framework and it is important for all levels of government to work together For example, municipalities must work with county and state agencies and the state environmental agency must coordinate with the appropriate federal agencies Although in most areas local planning will remain within the purview of local government, the success of the plan depends on cooperation from all levels of government.

Review Existing Local Land Use Policies That Affect Coral Communities

Many communities have enacted regulations to directly or indirectly protect coral ecosystems. However, they might also have policies that inadvertently harm those ecosystems The existing regulatory programs that control land and water uses will play an important role in shaping the community's options for effecting change.

Identify Constituencies Interested in Local Action

Planning is a public process. The early involvement of the general public in planning efforts is very important. Educating participants and raising awareness of the issues will greatly increase public involvement in the planning process Both public and private stakeholders in land use decisions need to be represented. These stakeholders include the agricultural community, business owners, planners, developers, local and state government representatives, environmental groups, and residents.

Organize Available Resources and Assess the Potential Scope of Legal Action

Planning efforts are limited by a community's willingness to devote time, staff, and financial resources to what can be a time-consuming and complicated process. A careful inventory of planning resources will help organizers determine the possible scope of the planning effort It is important to look to both governmental and nongovernmental bodies for technical assistance and financial support.

Step 2:
Understand the Community

Collect Information

Effective management plans for coral ecosystems require collecting a great deal of information on the areas that are considered upstream from these ecosystems

The information gathered during this step will allow planners to realistically assess the issues, problems, and opportunities facing their community This information will also allow planners and local officials to put actions in priority order based on the needs of the community This step is important in developing public support

Build Public Support and Educate the Public
An important step in understanding the community is knowing what is important to the people living there Planners and local officials should hold public meetings or hearings—formal and/or informal—early and often. This approach allows affected parties to enter the process before decisions have been made.

Education is a key component of public support. Planners and resource managers should raise the community's awareness of the value of coral ecosystems. They should show how important reefs are aesthetically or how they protect shorelines from erosion, produce sand for local beaches, and help support the tourism industry. Planners could illustrate how clustering development can lower costs for developers and also benefit natural resources.

The planners and resource managers should be a source of technical assistance and information on the coral ecosystem and coastal habitats, offering citizen education programs, community workshops, and training for all sectors of the community. Alternative methods for dissemination of information, such as electronic media or the Internet, should be considered.

The public should be encouraged to become active stewards of their environment by reporting suspected violations of environmental laws and participating in the enforcement process. Local authorities must respond promptly to such reports to maintain a credible relationship with the community.

Involve Everyone
The following, at a minimum, should be involved in the development of a local plan

- Federal, state, county, and local government officials (elected and appointed)
- Business representatives
- Community organizations
- Landowners
- Recreational interests
- Environmental and conservation groups
- Technical support: scientists, engineers, lawyers

Develop Mechanisms for Effective Communication
Participants in the process should always feel that their input is welcome and that they have a place to go if they have any questions or concerns. The importance of property rights should be recognized in the decision process People are generally reluctant to support policies that reduce the value of their property

Step 3:
Establish Goals and Objectives

The community needs to decide on the relative importance of various land uses and governmental priorities and their relationship to potential impacts on coral reef habitat. These priorities can include economic growth, preservation of open space, or maintenance of infrastructure. The community can then delineate specific goals and objectives for different land areas according to community needs, fiscal capacity, and the physical features of the land. It is critical that all stakeholders be involved in the formation of goals and objectives for the community. Only then can decisions be made that consider both the economic well-being of the community and the protection of natural resources. Considering all perspectives will ensure that future actions adequately protect valued resources and promote the community's shared vision for its future

Identifying Overarching Goals
The community will have overarching goals that will act as a guide in its land use decisions In some small communities, certain concerns that might be embodied as goals include the following:

- Managing and directing growth.
- Providing for economic development.
- Ensuring the availability of sufficient affordable housing.
- Preserving rural character
- Protecting life and property from floods.
- Maintaining the viability of agricultural uses in the face of more profitable development options
- Protecting open space, natural resources, and unique sites.

The plan will usually incorporate a time frame (e g., 10 years, 5 years, or 1 year) for meeting the goals. The goals express local desires regarding land use and development (e g , commercial, industrial, and residential placement, recreation, public facilities and infrastructure; open space; and other natural environment considerations). They reflect:

- The heterogeneity of the community
- The diverse demands on and needs of the community
- Long- and short-term costs and benefits
- Infrastructure impacts
- Risks to human health and the environment

It is crucial to evaluate and reconcile these many competing interests. Once local goals have been identified, the community can determine where planning efforts should focus and what other jurisdictions might need to become involved.

Within these broad goals, planners need to consider protection of critical areas While coral reefs themselves usually constitute a critical area, other examples might include:

- Protection of ground water supplies
- Protection of fish spawning areas and shellfish beds
- Protection of endangered species and wildlife habitats
- Provision for recreational uses

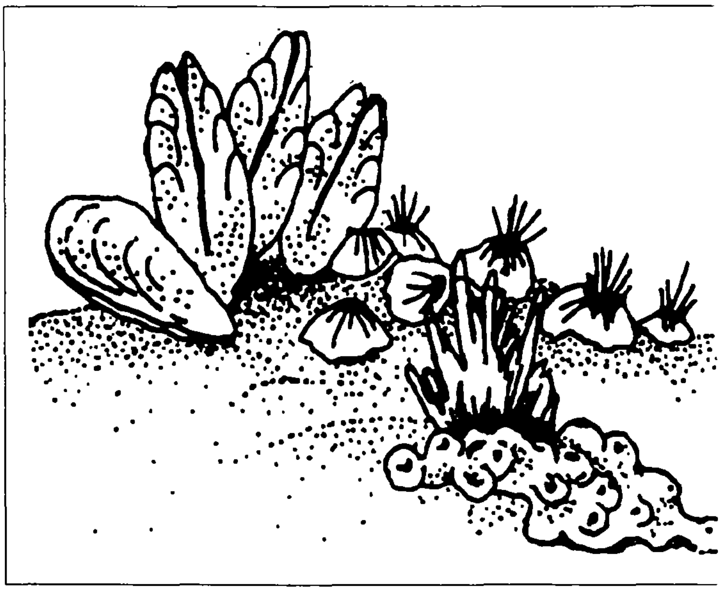
Each goal has a set of objectives that describe the specific actions for achieving the goals. For example, if a community's goal is to improve the water quality on the barrier reef, objectives might include developing a storm water management ordinance to control nonpoint source pollution, banning detergents containing phosphates, and improving inspection programs for septic tanks.

In light of these goals and objectives, a community's land use policies might prohibit development in some areas. In other areas, they might limit land uses to those with minimal environmental impacts In still others, they may impose few or no restrictions, or provide for new development or increased density of development

Building Consensus

Land use decisions and development policies have often been contentious. The increasing concern for and complexity of environmental issues has merely added challenges to the process If a community's actions are to be effective and endure, land use decisions must involve all groups with a stake in the community's growth and development. From this participation must come consensus—if not on the specific details of every project, at least on the overall goals and objectives of the community.

Building and maintaining consensus is important throughout the development and implementation of a plan, but is perhaps most essential when developing



goals and objectives. The goals and objectives represent the community's shared vision of its future. They generally are not associated with specific development or conservation projects, but instead provide the general framework within which specific decisions are made. Preplanning consensus building requires making every effort to include all interested parties in shaping these goals and objectives, ensuring that each group articulates its vision for the future and enabling the groups to work cooperatively to generate a shared view. With this framework in place, the plan for guiding growth, development, and conservation can then be structured.

Step 4:
Prepare the Plan

Preparing a comprehensive plan involves synthesizing the many concerns analyzed during the information-gathering and assessment phases (Steps 1 and 2) to develop a detailed statement of what a community intends to be (Step 3) and to specify the steps it will take to get there (Step 4). The review of existing land-use policies that affect coral communities, from Step 1, will help estimate the amount of land suitable for different uses and the areas where development should be restricted. It will also help determine the amount of land needed to meet population growth and economic demand. The plan should help the local government minimize conflicts between existing land uses and ensure that future uses will be environmentally sensitive

This step in the process involves developing alternatives to the implementation of the goals and objectives summarized in the plan. A community's list of alternatives is developed by applying the information it has garnered to a series of policy and program options that support the goals and objectives of the plan. Development of management options is exemplified in the case studies for both the Florida Keys National Marine Sanctuary and the Ugum Watershed in Section 4.

Step 5:
Implement, Monitor, and Enforce the Plan

A well-structured plan will include an implementation strategy that describes steps for translating the plan into action and monitoring the extent to which the plan's goals and objectives are being achieved The plan should also include provisions for modifying the plan, as needed, to accommodate new goals, achieve better results, or address unforeseen issues.

Considering a Watershed Planning Approach

Since the effectiveness of any coastal protection strategy is tied to oversight of activities in the entire watershed, it might be most effective to consider the watershed planning approach Consideration of the entire watershed is important for several reasons. First, the impacts of development are not always localized and can affect resources throughout the watershed Second, by examining the entire watershed, planners can best discern areas where growth and development would be most suitable, due to either the presence of existing infrastructure or the lack of significant threats to sensitive natural resources. Finally, local planners can evaluate the progress of existing control efforts throughout the watershed and can use this information to target scarce resources and to identify where protection of coastal areas is weakest.

The Integrated Watershed Management Plan

The ideal management plan establishes the goals and objectives of watershed management with respect to coral reef protection and enhancement It also outlines the specific actions for achieving the goals and objectives. The plan documents the processes and schedules for achieving specific remedial actions, defines stakeholders' roles, and identifies the parties responsible for the plan's implementation. Stakeholders are all those in the community that will be affected in some manner by management actions within the watershed. They may include agencies, organizations, and individuals. The plan also specifies how the effectiveness of selected management options is to be assessed Management options are discussed later in this section.

Setting Goals and Objectives

The first step in the development of an integrated watershed management plan is to develop goals and objectives for corrective actions. Each goal should clearly state what needs to be accomplished and when, and the objectives should clearly describe how the goal is to be met. Goals and objectives can be very detailed and specific. Several preparatory activities should accompany the development of the goals and objectives statement:

Watershed Identification and Delineation—A first step is the identification of the watershed(s) contributing to the degradation of the coral reef ecosystem. The watershed becomes the management unit, and therefore its geographic boundaries must be established. Geographic features and land use practices constitute the description of the watershed.

Problem Identification and Definition—An important step is the careful evaluation of the water quality problems within the watershed that are affecting adjacent coral reef communities and preparation of a problem statement. Point and nonpoint sources of pollution are identified and characterized. Here the manager determines the nature and extent of the watershed's impact on the coral reef ecosystem. The evaluation can be conducted through literature searches, surveys, interviews, site visits, and information from previous management efforts, if applicable.

Developing Management Options

An important step in the planning process is to identify and evaluate the range of management options available to meet the stated goals and objectives. In this step the important sources of stress to the coral environment are evaluated with respect to the costs and associated benefits of remediation. The best management options are those which control the sources of stress in the most reasonable, acceptable, and cost-effective manner. Management options for achieving the goals and objectives of the plan need to be identified. They contain four key elements:

- *Scientific Validity*—Management options selected must be demonstrated to be effective in achieving the intended environmental result.

- *Cost-Effectiveness*—Management options selected should achieve the desired environmental result at the lowest practical social and economic cost.

- *Measurability*—Measurable environmental indicators of a plan's success are an essential component of any management option for achieving and communicating environmental results.

- *Sociopolitical Acceptability*—Management options selected should have the support of the major stakeholders in the affected community.

Managers should factor in unique aspects of the individual watershed, resources available for each option, community support, and legal authorities. Several analytical tools, useful in the evaluation process, are available to the resource manager. They measure different aspects of resource management, and their use depends on the information available and what managers need to know. Three of the analytical tools are briefly discussed here. More detailed discussions of these and other methods can be found in (citations).

- *Economic Impact Analysis*—This analysis aids in the determination of how a management action affects the regional economy. Such information can be critical to the resource manager because economic impacts will be a major determining factor in stakeholders' acceptance of the management plan. This analysis technique measures changes in business activity and does not account for effects on social benefits or values; an economic impact analysis considers only those things with market value.

- *Cost-Effectiveness Analysis*—This analytical tool assists in finding the lowest-cost alternative to achieve a desired objective. Cost-effectiveness analysis is useful in situations where the monetary value of any benefit of a management action is not considered. An option is cost-effective if it provides a given amount of benefit at a lower cost than its alternatives.

- *Cost-Benefit Analysis* — This method of analysis compares the costs associated with a management action with the value (economic and social) of the benefits derived as a result of the action. The social benefits of a healthy coral reef ecosystem must be expressed in terms of monetary value for a cost-benefit analysis. Because the coral reef environment is not traded in the marketplace and has no associated price and quantity data, special techniques are needed to assign a monetary value to it. Several methods of environmental valuation (placing a monetary value on environmental change) are available to the resource manager (citations).

Promoting Community Involvement

The success of the watershed management approach to coral reef ecosystem protection depends on the support and participation of the community and stakeholders. The community can be one of the watershed manager's most valuable and important assets in the development, implementation, and continued success of the management plan. Several steps will ensure that stakeholders play a meaningful role in watershed management and coral reef protection

- *Identification*—Stakeholders should be identified early in the development of the watershed management plan. The various stakeholder factions should be the focus of investigation to determine their interest in watershed management and coral reef protection, as well as what impacts management actions might have on them.

- *Outreach and Education*—The purpose of outreach is to explain the environmental protection need (coral reef protection) and approach (watershed management), and to establish a dialogue between managers and the community. Methods for reaching out to stakeholders should be developed and implemented prior to the development of the watershed management plan.

- *Input*—Effective mechanisms for stakeholder input at all stages of the management process should be developed. One method would be to form steering committees that represent all of the important stakeholders

- *Stakeholder Roles*—A process is needed to determine the roles and responsibilities of the various community factions in the development and implementation of the watershed management plan.

Implementing the Plan

The watershed management plan must clearly outline the processes for its implementation. The plan needs to identify responsibilities, schedules, and resources required for the timely and efficient execution of its key elements. Implementation has several important components.

- *Prioritization*—The most critical elements of the plan must be determined to prioritize schedules and resource allocation

- *Planning*—Management actions should be implemented only when all responsible parties understand fully what is expected and when all resources needed are in place.

- *Coordination*—Responsible parties should be in constant communication so that each knows what the other is doing and all fulfill their roles at the appropriate times.

- *Leadership*—A Steering Committee or Management Committee composed of the principal stakeholders is needed to guide implementation of the plan

Assessing the Plan's Effectiveness

The watershed management plan should provide for a periodic assessment and evaluation of progress. The environmental indicators used to determine the effectiveness of management actions must be evaluated so that successes and failures can be reported and addressed. Social and economic impacts to the community should also be part of periodic assessments. The next section provides an overview of monitoring to determine a plan's effectiveness.

Monitoring Tools and Protocols

Monitoring is an important component of any coral reef watershed management plan. Monitoring data provide the information needed to determine whether corrective actions are achieving the desired effect on water quality. Monitoring data can be used to adjust watershed protection activities to achieve the best effect. Protection activities determined to be ineffective or activities whose costs outweigh their benefit to the environment can be eliminated or exchanged for more beneficial activities.

Types of Monitoring

Monitoring the results of coral reef watershed protection activities can be separated into two broad categories: (1) water quality monitoring and (2) ecological monitoring. The two types of monitoring provide different kinds of information and require different levels of ability, resources, and labor.

Water Quality Monitoring

Water quality monitoring is the periodic measurement of key chemical and physical parameters in the water column Water quality can be monitored anywhere in the watershed, including on the coral reef. Because watershed management activities are designed to improve the quality of water ultimately reaching the reef, water quality monitoring directly measures whether corrective actions in the watershed are having the desired effect.

Ecological Monitoring

Ecological monitoring attempts to measure the impacts of water quality on the coral reef community. Examples include monitoring of community structure or ecological functions, such as coral mortality, recruitment, bleaching, disease, and other signs of stress Ecological monitoring indirectly measures the effectiveness of corrective actions in the watershed because the current conditions and changes in coral reef communities might be only partly caused by activities in the watershed.

The Monitoring Plan

Like the watershed management plan, the monitoring plan should describe goals and objectives, schedules, responsible parties, and resources required for implementation. To be effective, monitoring plans should be developed and implemented along with other plans in the watershed. Monitoring often precedes the protective actions to acquire baseline data for later comparisons. The first step in the development of an effective monitoring plan should be careful consideration of a number of important factors to determine the appropriate types and levels of monitoring for a given situation.

- *Information Needed*—The overall goal of coral watershed management is to minimize the watershed's impact on the coral reef environment via improvements in water quality. The goal of monitoring is to determine whether watershed management is successful in achieving that goal. Managers should determine the level of information they need to assess the program's success and design monitoring plans to obtain only that level of information.

- *Resources Available*—Monitoring activities can be a significant drain on limited money and staff resources Resources applied to monitoring cannot be used for corrective actions or other activities in the watershed. A careful consideration of priorities is essential to determine what resources are needed for important protection activities and what resources will remain for monitoring. When resources are limited, care should be used in determining monitoring parameters. A solid database for a few important parameters will prove more valuable than limited data for a large number of variables Resource availability from year to year is often uncertain. Monitoring should be designed to provide meaningful data within the time periods for resource allotments

- *Scientific and Technological Skill Needed*—Water quality and ecological monitoring activities vary widely in terms of the scientific knowledge and technical skills required. It is critical in monitoring that the scope of work be well within the level of skills available.

Water Quality Monitoring vs. Ecological Monitoring

Water quality monitoring will provide the simplest, quickest, and most direct measure of the effectiveness of any corrective action in the watershed and, therefore, should be part of any monitoring plan. An important consideration is whether monitoring should focus only on water quality or extend to ecological measurements of the coral reef community. Careful consideration of some important factors regarding attributes of the coral reef and its relationship to water quality is needed.

- *Coral Reef Ecology*—The coral reef ecosystem is an extremely complex system from an ecological perspective. Though much has been written about coral reef ecosystems, their intricacies are not yet well understood. Inferences of cause-and-effect relationships based on interpretations of coral reef monitoring data are problematic and might lead to erroneous conclusions regarding the effectiveness of corrective actions.

- *Factors Affecting Reef Communities*—The ecological condition of a coral reef is affected by many biotic and abiotic factors, of which only a few might be a direct result of human activities The watershed might have a great deal or very little to do with the health of the coral reef ecosystem. Ecological monitoring measures the cumulative impacts to the reef and usually cannot distinguish between watershed impacts and other impacts. Such information may over- or underestimate the effectiveness of watershed activities.

- *Pollutant Effects*—Various pollutants can affect coral reef communities in a variety of different ways (see Section 2). A single pollutant can exhibit different effects under different sets of conditions, including synergistic effects in the presence of other pollutants and stresses. In addition, the effects of most pollutants on coral physiology and resultant impacts on community structure are poorly understood or completely unknown.

- *Recovery Times*—The degradation of an impacted coral reef might occur slowly or very rapidly Recovery of a severely impacted coral reef, on the other hand, is likely to take years. Resource managers should consider how long they can wait for an indication of success.

- *Monitoring Methods*—Scientists continually debate issues regarding the appropriate types and levels of effort needed to adequately monitor conditions and changes in coral reefs. Currently, there is no clear consensus regarding study parameters and monitoring methods.

Determining Success of the Planning Process

Examination of local efforts to protect coastal and coral resources nationwide points to a number of criteria for successfully using watershed management as one way of protecting these resources. Among these criteria for success are the following:

1. *Clearly defined goals and objectives.* Communities that have been most successful in protecting their coastal resources have implemented programs and policies that reflect clearly defined and realistic goals and objectives. These goals and objectives are generally the product of an acutely felt need to do something to protect certain resources, a well-informed and scientifically based understanding of the characteristics of that resource and the threats to it, and, perhaps most important, a significant planning effort.

2. *Strong information base and readily available technical backup.* The community has surveyed and defined its resources and analyzed its land. It has carefully analyzed policy options with respect to their economic, social, political, and environmental impacts.

3. *Regulatory and legal authority.* The community has established its regulatory and legal authority to protect sensitive areas through an adopted comprehensive plan, clear enabling statutes at the state and/or local level, and minimum state standards.

4. *An explicitly integrated approach.* The community has developed an explicit approach to ensure that land use policy is consistent with and bolstered by other environmental protection efforts, such as pollution prevention efforts at nearby industrial sites. Land use planning and regulation take place in conjunction with prohibition of certain activities, rational siting, nonpoint pollution programs, and other activities. A community is more likely to succeed when it recognizes the interdependent nature of land use management decisions and coordinates its actions to pursue its goals in an integrated fashion.

5. *Public participation.* Successful efforts to protect coastal resources are based on public participation in the decision-making process Public support is important to all aspects of protecting coastal and coral resources., including planning, program development, implementation, and enforcement Public understanding and support are fostered through an open, organized, and credible process that includes all affected parties. The first step is to develop publicly accepted common goals and

to build a coalition that addresses the many dimensions of the growth management and sensitive area protection issue An alliance of development and environmental interests and landowners will clearly be an asset, whereas a lack of public participation could become an impediment to protection efforts

6. *Political leadership.* Political leadership is a major factor in building strong public support. In many respects, protecting coral ecosystems and near coastal waters is more a political problem than a technical one. Inadequate leadership can hinder implementation of protection plans.

7 *Public education.* An educated public is paramount to the community's having a full understanding of the issues involved in the establishment of the plan's management options and sustainable use practices.

8 *Adequate financial support.* Adequate funding is necessary not only for establishing the program but also for implementing and enforcing it.

9. *Monitoring and assessment.* This final component is often overlooked. Periodic monitoring not only provides status and trends data for evaluating the coral system, but also provides the information needed to address changes that will be needed from time to time. It will also indicate the effectiveness of management This will broaden community involvement and provide an economical way to strengthen the monitoring database. EPA has published a guide for citizens who do volunteer estuary monitoring, which might be helpful in monitoring bays or estuaries in association with coral communities (*Volunteer Estuary Monitoring: A Methods Manual*, USEPA, 1993).

Section 4

Case Studies

Florida Keys National Marine Sanctuary: A Managed Reef System

Overview

The Florida Keys form a limestone archipelago that extends southwest from the southeast tip of Florida for 320 km (198 mi). The Keys comprise more than 1,700 islands with a total land area of approximately 266 km^2 (103 mi^2) and generally less than 1 m (3 ft) of relief. The tropical climate of the region has a wet summer from May to October followed by a dry winter. An average of 124.5 cm (49 in) of rain falls annually, mostly as locally intensive storms. Tropical depressions and hurricanes also occur in the region.

The large region of which the Keys are a part contains five distinct physiographic regions: Florida Bay, the southwest continental shelf, the reef tract, the islands or keys, and the straits of Florida (Figure 3). Three land uses—vacant land, conservation land, and residential land—predominate on the Keys themselves. Vacant and conservation lands are predominant in the lower keys; vacant and residential lands have approximately equal predominance in the middle keys; and conservation land is predominant in the upper keys.

Use of the region by people is varied and seasonally intensive. The popularity of the region as a vacation spot places stress on the ecosystems and infrastructure of the region and has resulted in intensive development in some areas. The 1990 peak population in the Keys was estimated at 134,600, only 78,000 of whom were permanent residents. Visitors to the Keys enjoy recreational boating, recreational fishing, scuba diving and snorkeling, swimming, and beach-going. The waters near the Keys are also important for commercial shipping.

Management Approach Development

An effort to protect the Keys grew out of years of public and scientific discussion about their health and future. Declines in coral recruitment, increases in fish kills, and sea grass die-offs were attributed to declining water quality from point and nonpoint sources of pollution.

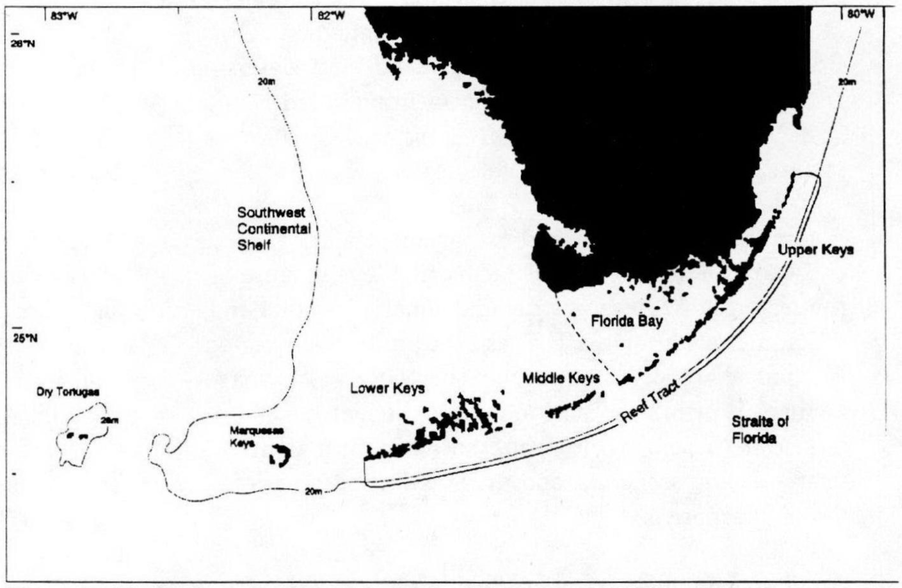


Figure 3. Florida keys Region (U.S. Dept. of Commerce, 1995)

Point sources of pollution in the Keys include 10 domestic wastewater treatment plants and 9 other dischargers (water supply treatment plants, power plants, and 2 industrial facilities). The most significant nonpoint source of pollution in the Keys is domestic wastewater. There are approximately 30,000 onsite disposal systems (septic tanks) and 670 injection wells from hospitals, restaurants, schools, campgrounds, and other facilities. Active and abandoned landfills, marinas, liveaboards, and storm water runoff also contribute to the nonpoint sources of pollution in the Keys. All of these sources collectively contribute hydrocarbons, pesticides, herbicides, heavy metals, and nutrients to the waters of the region.

Sources of pollution from "higher up" in south Florida's watershed can also affect water quality in the Keys. Water quality in Florida Bay, which lies between the upper keys and the southern edge of Florida (see Figure 3), is periodically degraded due to past alterations of the freshwater flow to the bay from the Everglades and pollutants, especially nutrients and fertilizers from agriculture, transported from the north. The loop circulation, which is the clockwise circulation in the Gulf of Mexico, and the Florida current, which runs north along the eastern edge of the Keys, transport pollutants from Florida's west coast and the Mississippi River to the Keys as well.

As part of the effort to protect the region's unique ecology, the National Oceanic and Atmospheric Administration designated the area as the Florida Keys National Marine Sanctuary (FKNMS) in 1990. Approximately 9,500 km^2 (3,667 mi^2) of submerged lands and waters—the largest reef system in the continental United States—is included in the FKNMS and protected for its scientific, recreational, and ecological value

A comprehensive watershed management approach was chosen to address the issues facing the Keys because of the region's diverse terrestrial and aquatic habitats and the numerous human activities that occur in the region. The process followed to develop the watershed management plan included coalition building, scientific characterization, development of alternative management strategies and scenarios, and finally selection of a preferred alternative

Public scoping meetings were held initially to identify the range of issues to be addressed in the Sanctuary Management Plan (SMP) A FKNMS Advisory Council was assembled to provide a forum for public input to the process. A core group of concerned and involved citizens was then formed to oversee the development and implementation of the SMP. The Core Group included representatives of the following·

Federal government
- National Oceanic and Atmospheric Administration
- U.S Environmental Protection Agency
- National Park Service
- U.S. Fish and Wildlife Service

State government
- Executive Office of the Governor
- Department of Community Affairs
- Department of Environmental Protection
- South Florida Water Management District

County government
- Growth Management Division of Monroe County

Five major issue groups that affect the Keys were identified:

- Boating
- Commercial and recreational fishing
- Recreation and cultural/historical resources
- Land use
- Water quality

Each issue group was then comprehensively analyzed in the context of its potential impact to four entities in the Florida Keys region: habitats, species, uses and users, and water quality.

In keeping with the watershed approach, the comprehensive analyses of the issue groups took into account all potential influences within the Keys region. Impacts to sea grass, coral, hardbottom, dead coral rubble, wetland, and mangrove community habitats were examined Impacts to species included those to manatees, birds and bird colonies, marine turtles, American crocodiles, shallow-water fishes, and crustaceans (lobsters, crabs, etc.). Conflicts between uses and users and impacts to individual uses and users that were examined included recreational and commercial fishing, treasure hunters, recreational divers, swimmers and beach goers, and tourism in general The water quality impacts of uses and activities that occur both in the Keys and within the region of influence surrounding the Keys were examined.

A variety of potential management strategies were identified from these analyses. Each management strategy identified how the management issue(s) to which it applied were to be addressed. Example management strategies were management of boat access, pollution discharges, visitor registration, limited-entry fishing, exotic species, spear fishing, marina operations, dredging, public access, and recreational carrying capacity;

wastewater management; spill reporting, water quality monitoring, zoning, and education. Each strategy had to be completely developed in the sense of accounting for costs, implementation schedules, responsible institutions, prerequisites, financing, regulatory requirements, staffing, other resource requirements, and identification of the geographic area affected by the management actions.

From these management strategies, five management alternatives were identified. They differed primarily in level of regulatory control and use restrictions, ranging from most restrictive to no action.

Management Alternatives

Alternative 1 is the most restrictive alternative. It stresses resource conservation and prohibits most consumptive uses of sanctuary waters and resources. Only research activities would be allowed. Strict water quality standards would be imposed under this alternative. This alternative does not provide a balance between resource protection and sanctuary use and would have significant impacts on users and the Florida Keys' economy.

Alternative 2 stresses resource conservation but facilitates access and use of sanctuary waters. Ecosystem protection is provided through regulations that prohibit or limit many consumptive uses. Alternative 2 would not have a significant impact on current or future users, and in most cases consumptive uses would continue although they would be separated in time and space as necessary. Land uses with negative impacts would be minimized under Alternative 2.

Alternative 3 maintains a traditional approach to management and use in the Keys and provides for increased resource protection through prohibitions and limitations on some uses. Most current uses would be maintained, although they would be separated temporally and spatially as necessary.

Alternative 4 provides some additional ecosystem protection above the current level. It would not have significant positive impacts on habitats, species, or water quality and would not negatively impact users as much as Alternative 1, 2, or 3. All traditional uses would continue, although some spatial and temporal separation would be established.

Alternative 5 is the "no action" alternative. It would not result in an increase in resource or ecosystem protection and would not improve habitats or species or decrease user conflicts. Existing threats to sanctuary resources would continue.

Selection of Preferred Alternative

The Core Group and the FKNMS Advisory Council considered Alternatives 1 and 5 to be undesirable and impractical. The three remaining alternatives were then analyzed and compared. The environmental impacts of implementing the three alternatives—categorized as impacts to habitats, species, and water quality—were compared collectively by federal, state, local, and private resource managers and scientists. Key issues related to environmental impacts in each of the impact categories (habitats, species, and water quality) were analyzed most intensively. The key issues are listed in Table 3. Education and enforcement were identified as activities that affect all categories.

Table 3. Key issues related to environmental impacts

Water Quality	*Habitats*	*Species*
- growth management	- growth management	- growth management
- marinas/boat discharge	- zoning	- zoning
- water use and reuse	- carrying capacity	- carrying capacity
- dredge and fill	- restoration	- consistent regulations
- research and monitoring	- vessel groundings	- limited entry
- domestic wastewater	- access	- gear/methods
- storm water	- marinas/boat discharge	- exotic species
- canals	- fishing	- marina operations
- zoning	- submerged cultural resources	- access
		- restoration

The socioeconomic impacts of the management alternatives were also analyzed and compared Socioeconomic impacts to boating, fishing, land use, recreation, water quality, zoning, and education were included in the analysis

The FKNMS Advisory Council found Alternative 3 to be the most reasonable and recommended it to the Core Group, with modification, as the preferred alternative. Although Alternative 4 was anticipated to result in fewer negative socioeconomic impacts on sanctuary users, it did not adequately address the long-term environmental impacts on the sanctuary. Alternative 2 was judged to provide adequate environmental protection for the long-term health of the ecosystem but to place too great an economic burden on sanctuary users. The Core Group accepted the recommendation of Alternative 3 as the preferred alternative and also accepted most of the modifications recommended by the Advisory Council Table 4 summarizes the key management strategies in Alternative 3

Contact

Copies of the Florida Keys National Marine Sanctuary Management Plan are available from:

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National Ocean Service/NOAA
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Table 4. Summary of key management strategies in Alternative 3

STRATEGIES	PURPOSE	ACTIONS
Boating Strategies		
Boat Access	Reduce resource impacts from boating activities	Direct public access to low-impact areas Modify access ramps in sensitive areas
Habitat Restoration	Promote research and development of new technologies to restore and enhance coral, sea grass, and mangrove habitats	Develop and implement a restoration plan for severely impacted areas
Derelict Vessels	Reduce direct and indirect impacts to natural resources from derelict and abandoned vessels	Provide a plan for removing derelict vessels based on prioritization of problem areas
Channel Marking	Reduce damage to natural resources caused by boating activities	Implement a detailed and comprehensive plan for high-use and sensitive areas Identify problem areas and set priorities Mark frequently used channels, shallow-water reefs, shoals, and other significant features Reduce erosion from various causes
Additional Enforcement	Increase the presence of law enforcement officers on the water	Add 30 law enforcement officers to patrol sanctuary waters
User Fees	Generate funds for sanctuary management and related research	Provide a fair and equitable method of charging user fees
Salvaging/Towing	Reduce damage to natural resources from improper vessel salvage procedures	Establish regulations and procedural guidelines for commercial salvaging and vessel towing operations Require permits for commercial salvaging and towing operations Establish a salvage operator training program
Mooring Buoys	Decrease user conflicts, prolong mooring buoy life, and reduce the risk of vessel groundings	Develop and implement a comprehensive mooring buoy plan Prioritize areas of concern
Personal Watercraft (PWC) Management	Reduce damage to natural resources due to improper operation of motorized boats and personal watercraft, and address user conflicts	Offer the most enforceable options regarding the distance PWCs and other motorized vessels must maintain from other users, edges of flats, and other sensitive areas

Table 4. (cont)

STRATEGIES	PURPOSE	ACTIONS
Fishing Strategies		
Stocking	Build on stock research conducted elsewhere to determine the effect of fish stocking on the genetic integrity of native species	Implement a moratorium on stocking activities until adequate research has been conducted to prevent damage from stocking
Aquaculture Alternatives	Reduce fishing pressures on commercially harvested marine species Help satisfy the commercial demand for these species	Research and promote appropriate aquaculture operations Establish regulations
Limited Entry	Through existing fishery regulatory programs, limit the number of persons, vessels, or fishing gear units using specific sanctuary fisheries	Implement appropriate limited-entry mechanisms for selected fisheries to adjust fishing efforts and harvests
Fisheries Sampling	Evaluate and modify existing commercial landing and recreational creel census programs	Improve fisheries sampling, effort levels, and catch to provide more accurate data on resource status and use
Gear/Method Impacts	Reduce impacts to corals, hardbottoms, sea grasses, and other habitats	Develop alternative gear designs and types Establish regulations that require low-impact gear and methods in priority areas
Spear fishing	Determine the impacts of spear fishing on species composition and abundance Reduce incidental habitat damage Reduce user conflicts	Develop and impose spear fishing regulations in high-priority areas
Sponge Harvesting	Determine harvesting methods with low adverse impacts on both species and habitats Identify areas with low abundance, low recovery rates, and habitat damage	Implement appropriate research-based regulations
Recreation Strategies		
Submerged Cultural Resource (SCR) Management	Protect SCRs from disturbances Maintain SCRs for research, education, science, and recreation	Implement an SCR Management Plan/Program, Abandoned Shipwreck Act guidelines, NOAA policy statements and permit decisions

Table 4. (cont)

STRATEGIES	PURPOSE	ACTIONS
***Recreation Strategies* (cont)**		
Recreation Survey	Provide data on types, levels, users, and locations of recreational activities Improve planning	Conduct routine surveys Identify specific access and carrying capacity problems and high-use areas where user conflicts occur Implement a permitting system to regulate use for charter and rental vessels
Carrying Capacity	Provide information used to reduce impacts from recreational activities	Determine the carrying capacity of different habitats
Zoning Strategies		
Wildlife Management Areas	Reduce the disturbance to wildlife populations and their habitats	Complement management efforts of FWS through a cooperative enforcement agreement with FWS
Replenishment Reserves	Establish replenishment reserves to protect commercial fish habitats and species, protect fisheries from collapse, provide control areas in exploited areas, and improve resource monitoring	Limit consumptive activities, but allow recreational activities compatible with resource protection
Sanctuary Preservation Areas (SPAs)	Enhance the reproductive capabilities of renewable resources Protect areas critical for sustaining and protecting important marine species Reduce conflicts in high-use areas	Establish nonconsumptive SPAs
Special-use Areas	Reduce user conflicts and negative environmental effects of high-impact activities	Establish special-use areas
Land Use Strategies		
Boat Maintenance	Evaluate refueling operations and reduce pollution	Inventory fueling facilities Assess typical fuel-handling techniques Establish containment areas for boat maintenance Establish secondary containment areas for hazardous and toxic material storage

Table 4. (cont)

STRATEGIES	*PURPOSE*	*ACTIONS*
***Land Use Strategies** (cont.)*		
Containment Options	Determine what regulations are necessary to meet state recycling goals, implement retail packaging standards, and require source separation	Study containment and relocation options for solid waste facilities Implement appropriate recommendations within 5 years
Dredging Prohibitions and Regulations / Wetland Dredge and Fill	Reduce or eliminate degradation of wetland and submerged resources Improve water quality Eliminate suspension of sediments and sediment-associated toxicants Maintain species and habitat character	Prohibit new dredging permits unless they are in the public interest or no environmental degradation will occur
Public Access	Provide information on problems associated with existing public access areas, including habitat damage and user conflicts	Assess existing public access Develop standards for improving and constructing public access areas
Water Quality Strategies		
Wastewater Management Systems	Reduce the amount of pollutants entering ground water	Enforce existing standards Conduct research to estimate the level of wastewater nutrient loading reduction needed to restore/maintain water quality
Surface Discharges	Control point source discharges	Require all NPDES-permitted facilities with surface discharges to develop resource monitoring programs
Canal Water Quality	Improve water quality in dead-end canals through improved circulation	Monitor water quality in dead-end canals and other near shore confined areas Implement improvements
Storm Water Retrofitting	Reduce sediment, toxic material, and nutrient loadings	Implement various engineering methods
Education Strategies		
Education Program	Develop a comprehensive education program	Develop printed and audiovisual materials, a sanctuary library, displays and signs, a training program, public service announcements, an education advisory council, visitor booths, and presentations Hold periodic public meetings

Reef Relief, Key West, Florida: Community-Based Education and Advocacy for Coral Ecosystem Protection

Overview

Undertaking a watershed-scale effort to protect coral ecosystems implies that people with a wide variety of interests will become involved in the protection effort. Gaining their involvement can be difficult because many people can offer only limited time and effort, but that involvement is necessary if a broad-based coral reef protection effort is to succeed. A community-based outreach, education, and advocacy approach, which requires minimal staff and funding and relies largely on voluntary contributions of time and expertise from people, organizations, and businesses in the watershed that have an interest in coral ecosystem protection, can be an effective means to gain citizen and community involvement in a watershed-wide protection effort. A community-based approach allows participants to define their level of involvement and donate their skills and knowledge as they are needed. It also creates a sense of stewardship for the watershed that more formal approaches often lack.

This case study reviews the approach and contributions of one successful community-based advocacy and education organization, Reef Relief in Key West, Florida, in its efforts to protect the Florida Keys coral reef tract It demonstrates how community-based action can be applied successfully to watershed protection efforts.

A Community-based Outreach Approach

Reef Relief is a small organization dedicated to the preservation and proper use of the Florida Keys ecosystem. It began in 1986 as an effort to protect the coral reefs in the Keys from boat anchoring damage by installing permanent mooring buoys at popular dive spots Reef Relief relied on public announcements about the damage caused to the reefs by boat anchors and education aimed at dive shops and the diving community to gain support for buoy deployment. This strategy helped the organization gain recognition and credibility in the community and began its focus on education about issues facing the Florida Keys.

The organization and its initial efforts were well received, and soon Reef Relief began to take a more active role in the effort to protect the Keys. The effort to designate the Keys as a National Marine Sanctuary was gaining speed at approximately the same time Reef Relief was founded, and Reef Relief expanded its advocacy role for Keys management as more issues facing the region were brought to the public's attention and more people and organizations became interested and involved in the issues Marine debris, water quality, and offshore oil drilling were some of the issues Reef Relief addressed in its public education and advocacy campaigns.

Reef Relief, which has very few paid personnel, has relied primarily on the local community and the larger community of people and organizations dedicated to the preservation and protection of coral reefs to accomplish its goals It has developed an approach to advocacy that relies heavily on community efforts. When an issue that affects the Keys ecosystem attracts its attention, Reef Relief first identifies the matter and the subissues related to it as clearly as possible. It then gathers as much information about the issue as possible and maintains a constant dialog with policy makers, coral reef users, scientists, and citizens to keep abreast of new developments and information relevant to the issue. Reef Relief uses this information base to communicate with policy makers at the local, state, and national levels to make its opinions known and to influence any decisions taken with respect to the issue.

When Reef Relief became involved in the effort to designate the Keys as a national marine sanctuary, it realized that its reach had to extend beyond the Florida Keys community somehow to reach national policy makers While continuing with its community-based action strategy, it helped form the Coral Reef Coalition to lobby for wise management in the Keys under the federal National Marine Sanctuary Program The coalition includes organizations such as the Wilderness Society, The Nature Conservancy, the Sierra Club, and Florida Audubon

Education Programs

Education is a very important element of Reef Relief's outreach strategy. Flyers that contain information about relevant topics, called "Action Alerts," are distributed to people on Reef Relief's extensive mailing list. These flyers encourage action in the form of letter writing and phone calls on the part of recipients and are a primary means for Reef Relief to build wide support for protection in the Keys General information packets about Keys issues are also sent to citizens and community groups, businesses, and other nongovernmental organizations, which are encouraged to contact their members about the issues and urge them to take action

Reef Relief also develops and implements numerous education programs as part of its community outreach effort The Environmental Education Center was established in 1990 as a base for Reef Relief's education programs. The center houses a small museum with displays showing reef ecology and human impacts on it. It makes presentations to schools and produces television and radio spots, posters, handbooks, videos, flyers, and teaching kits. The center also produces and mails a quarterly newsletter to dive shops, marinas, and Reef Relief members.

Accomplishments

Its active, community-based involvement in Keys issues has helped Reef Relief log many accomplishments over the past 10 years, including:

- Deployment of 119 mooring buoys for use by dive boats and others.
- Participation in a national campaign to place a 10-year ban on oil drilling in the Florida Keys.
- A ban on U.S Navy weapon testing in the Florida Keys.
- Participation in the designation of the Florida Keys National Marine Sanctuary.
- Imposition of a limit on the phosphate level allowed in cleaning products sold in the Florida Keys.
- Passage of regulations limiting the harvest of reef organisms by users.
- Participation in numerous successful beach cleanups.
- Regular monitoring of the condition of the Keys by members and volunteers, which enables Reef Relief to take action quickly when there is a threat to the Keys ecosystem.

Because Reef Relief is funded through grants and contributions of money and in-kind services, it relies primarily on the dedicated efforts of volunteers to accomplish its goals. However, its education programs and cooperation with the community and other organizations dedicated to conservation in the Key allow it to accomplish far more than its small size indicates might be possible. Reef Relief is an example of how a small organization can enlist the assistance of the community to develop an effective program for coral reef protection.

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The Tar-Pamlico River Basin: A Watershed Approach to Protecting North Carolina's Coastal Waters

Introduction

North Carolina is one of the first states to adopt a holistic and comprehensive approach to protecting and maintaining the integrity of its water resources. The North Carolina Division of Environmental Management (NCDEM) is implementing a watershed management initiative targeted at protecting the state's surface drinking water sources and near coastal waters. This initiative moves beyond traditional point source management strategies by integrating both point and nonpoint source pollution control efforts on a watershed scale It serves as a means of better identifying water quality problems, developing appropriate management strategies, maintaining and protecting water quality and aquatic habitat, and ensuring equitable distribution of waste assimilative capacity for dischargers.

This case study focuses on watershed planning and management efforts in one of the state's major river basins, the Tar-Pamlico River basin. Watershed management in the basin is unique in that a nutrient reduction strategy that involves pollution credit trading is being implemented in conjunction with the basinwide water quality management plan. Although this case study outlines the overall Tar-Pamlico basinwide management strategy, special emphasis is placed on tracing the development and implementation of the pollution credit trading approach to protecting the nutrient-sensitive estuarine waters of the Tar-Pamlico Lessons learned from North Carolina's efforts are identified in an effort to facilitate and guide the effective application of this watershed management approach to the protection of coral reef ecosystems.

Background

The Tar-Pamlico basin encompasses portions of 17 counties and covers approximately 2.9 million acres The Tar River, the major river in the basin, flows approximately 140 miles through the North Carolina piedmont and across the coastal plain, and widens just east of Washington, North Carolina, where it forms the Pamlico River. The Pamlico flows into the Pamlico Estuary and empties into the Pamlico Sound off the North Carolina coast. The sound is protected by an extensive barrier island system with only a few small inlets connecting to the Atlantic Ocean (NCDEM, 1989)

The waters of the Tar-Pamlico basin are a highly economically and ecologically valuable natural resource that supports commercial and recreational fisheries, recreational boating, and swimming. The basin also serves as a primary drinking water source for eight cities and towns in central and eastern North Carolina. (NCDEM, 1987).

Agriculture and forestry are the dominant land uses in the Tar-Pamlico basin. Forestry operations are mostly concentrated in the lower coastal plain, forest cover in the upper portion of the basin has been relatively undisturbed. Agricultural activities, including row crop cultivation and intensive livestock operations, dominate land use in approximately 37 percent of the basin. (Harding, 1990).

Both agricultural and forestry operations, in conjunction with increases in human population and development, have contributed to declining water quality in the Tar-Pamlico basin. Specifically, point and nonpoint source pollution from these activities have led to increased levels of fish contamination, sporadic fish kills, elevated sediment and nutrient loads, phytoplankton blooms, and decreases in dissolved oxygen (DO) levels. As of 1992, only 59 percent of the stream miles in the Tar-Pamlico basin were supporting their state designated uses, 25 percent were partially supporting, and 7 percent were not supporting these uses (NCDEM, 1992)

The Pamlico River Estuary is one of the waterbodies that have been particularly affected by elevated nutrient inputs from point and nonpoint sources in the basin. Nitrogen and phosphorus loading to the Tar and Pamlico rivers has been identified as the primary cause of degraded water quality in the estuary (NCDEM, 1989). High nutrient loads have been associated with the phytoplankton blooms that have depleted oxygen in bottom waters. In addition, the economically valuable commercial fisheries in the estuary have been impaired by losses in submerged aquatic vegetation (NCDEM, 1987)

Watershed Management in the Tar-Pamlico: Addressing the Problem

In confronting the problems of nutrient loading and water quality degradation in the Tar-Pamlico basin, the North Carolina Department of Environmental Management (NCDEM) has adopted a watershed-wide approach to water quality management. This approach has evolved from the development of two separate water quality management initiatives—the 1989 NCDEM effort to manage the basin as a Nutrient-Sensitive Water (NSW) and the 1991 NCDEM basinwide water quality management program While developed separately, these two initiatives have recently been integrated through the incorporation of the nutrient control strategy into the Basinwide Water Quality Management Plan. Both initiatives have been successful and have been based on the principles of a watershed-based management approach.

The Tar-Pamlico Nutrient Control Strategy

Initial Nutrient Control Measures

Efforts to address nutrient loading on a watershed scale in the Tar-Pamlico basin were initiated in April 1989 with NCDEM's decision to designate the basin as a Nutrient-Sensitive Water (NSW). Pursuant to North Carolina state law, the NSW designation required the development and implementation of a basinwide management strategy for both point and nonpoint nutrient sources In developing a comprehensive strategy for the basin, NCDEM began by reviewing a nutrient source budget that was prepared for the Tar-Pamlico basin in 1986. This nutrient budget, however, was outdated. NCDEM realized that more information was needed before a basinwide management strategy could be designed. Consequently, the state proposed an interim strategy that required mandatory limits on nitrogen and phosphorus for new and expanding dischargers in the basin. The goal of the interim measure was to significantly reduce point source discharges until a scientifically defensible nutrient reduction plan could be developed and implemented.

The Nutrient Trading Approach

In response to NCDEM's interim proposal, point source dischargers in the Tar-Pamlico basin expressed concern regarding the high costs of the new wastewater treatment facility construction that would be necessary to achieve the nutrient control goals. Point source dischargers, in recognition of their mutual interests, formed a coalition and began negotiations with the state, the Environmental Defense Fund (EDF), and the Pamlico-Tar River Foundation The point source discharger coalition, know as the Tar-Pamlico Basin Association, emerged from the negotiations with a new proposal that allowed for "nutrient trading" between point source dischargers and agricultural operations while achieving the overall nutrient reduction goals. The North Carolina Environmental Management Commission reviewed and approved the proposal in December 1989.

The basic premise of the nutrient trading approach is that nutrient reductions achieved through the implementation of best management practices (BMPs) can be more cost-effective than capital outlays for new wastewater treatment facilities. The program calls for the establishment of an overall reduction goal and then allows nutrient sources to find the most cost-effective way to allocate allowable loads. The state does retain the right to control localized impacts through individualized permitting and enforcement. Polluters, however, are given the flexibility to trade reduction credits among themselves or to pay to control pollution at other sources as long as the total nutrient limit for the basin is not exceeded (EDF, 1993). As a result, the strategy calls for the Tar-Pamlico Basin Association to contribute funding for agricultural BMPs to achieve all or part of the total nutrient reduction goals established for the member facilities.

Funds provided by the Association for BMP implementation and maintenance are given to the North Carolina Division of Soil and Water Conservation. The division distributes the monies to the local soil and water conservation districts, which then distribute funds to BMP projects through the North Carolina Agricultural BMP Cost Share Program Individual BMP projects are selected by the districts through a ranking process that considers the severity of the area's nutrient control problems.

Implementing Nutrient Trading

Implementation of the nutrient trading strategy is being divided into two phases. Phase I of the program was initiated in 1989 and completed in 1994 The purpose of Phase I was to develop and evaluate the nutrient trading approach. NCDEM established the initial load reduction goal of 200,000 kg/yr (220 tons/year) (180,000 kg/yr for nitrogen and 20,000 kg/yr for phosphorus) and estimated nutrient reduction control costs at $11.8 million—$10 million for construction, infrastructure, etc , and $1 8 million for administration In addition, Phase I required that the Association fulfill several conditions or requirements These included (1) the development of an estuarine model to aid in estimating the relative contribution of nutrient loads from various sources in the watersheds throughout the basin, (2) an analysis of several municipal treatment plants to determine the changes needed to ensure optimal operating efficiency, and (3) annual payments to the trading fund in addition to the $150,000 used for program administration and BMP implementation

Phase II of the nutrient trading program was initiated in early 1995 and is scheduled to run through 2004 The purpose of the second phase is to refine and improve the implementation of the nutrient trading approach. Program efforts will be focused on tracking compliance, determining accountability, and ensuring that load reductions are actually achieved. In addition, NCDEM will use the watershed modeling capabilities developed during Phase I to improve the determination of basinwide nutrient reduction goals and loading calculations. Phase II will also encourage new efforts to reduce nonpoint source pollution throughout the basin. EDF has proposed that wetland restoration will be a key element in the second phase of the program

Program Results

Implementation of the nutrient trading program has largely been the subject of praise from the state, dischargers, and environmental groups By addressing both nonpoint and point source discharges from a watershed perspective, NCDEM and other program participants have achieved a reduction program that is more comprehensive than the original NSW strategy Dischargers have already benefitted from the increased flexibility and cost-effectiveness of the trading approach. In addition, monitoring data show that nutrient reduction levels have been achieved (Table 5)

Although the program appears to be working, it is important to point out that there are problems with the program In particular, the economic values used to guide nutrient trading have been debated (Woods, 1991). In addition, the applicability of this approach to other areas has been questioned. To be successful, a point and nonpoint source trading system is dependent on similar quantities of a common pollutant being present at both sources (Hall, 1994)

Basinwide Water Quality Management

An Integrated Approach

The second major initiative that has helped shape watershed management in the Tar-Pamlico basin is NCDEM's basinwide water quality management program NCDEM began formulating the idea of basinwide management in the late 1980s In 1990, the Division established a permitting schedule and began basinwide monitoring activities. A formal basinwide management program description was published in August 1991 The basinwide management approach adopts watershed-based management principles and seeks to integrate existing point and nonpoint source control programs

Table 5: Nutrient Loading in the Tar-Pamlico Basin, 1991-1994

Year	*Total Allowable Loading (kg/yr)*	*Measured Total Nitrogen (kg)*	*Measured Total Phosphorus (kg)*	*Measured Total Nutrients (kg)*	*Percent Reduction*
1991	525,000	396,916	64,478	461,394	12%
1992	500,000	386,014	50,113	436,128	13%
1993	457,000	371,336	45,881	417,217	12%
1994	425,000	319,578	51,623	371,201	12%

Note 1 ton equals 900 kg.

Central to North Carolina's management efforts is the delineation of river basins and sub-basin watersheds throughout the state. NCDEM has divided the state into a total of 17 major river basins and 135 sub-basin watersheds For each basin, a 5-year basin planning/management approach is being implemented. The management approach involves the integration of several key activities including data collection, data analysis and modeling, basinwide management plan development, plan review and approval, and NPDES permitting

Implementation

The implementation of basinwide management in the Tar-Pamlico basin was initiated in 1991. The key element of implementing the basinwide approach was the development of a water quality management plan. The preparation of the basinwide management plan was a 5-year process involving several key steps or stages. These steps include (1) water quality data collection/identification of goals and issues, (2) data assessment and model preparation, (3) preparation of a draft basinwide management plan, and (4) public review and approval of the plan (NCDEM, 1994).

The next step for the Tar-Pamlico basin is the implementation of the basinwide management plan. A key element will be the implementation of permitting activities and associated routine support activities, such as field sampling, modeling, and wasteload allocations. NPDES permitting will drive the schedule for developing and updating the basinwide management plan at 5-year intervals. Most importantly, however, the insights and developments from the Tar-Pamlico basin's nutrient reduction strategy will be incorporated into and integrated with plan implementation. Specifically, the nutrient load reductions and allocation strategy will serve as a formal TMDL strategy for the basin.

Expected Benefits of Plan Implementation and Basinwide Management

Implementation of the basinwide management approach in the Tar-Pamlico basin, as well as in other major basins throughout the state, is expected to yield a number of benefits The approach already appears to be an effective way of integrating point and nonpoint source pollution assessment and controls. It is anticipated that basinwide planning will improve water quality management throughout the state NCDEM has outlined several benefits that are expected to be realized through the implementation of this approach. They include improved program efficiency, increased effectiveness of water quality management efforts, improved consistency and equitablility, and increased public awareness (NCDEM, 1994).

Lessons Learned and Insights for Improving Coral Reef Management

The implementation of NCDEM's basinwide management approach and the development of the watershed-scale nutrient control strategy in the Tar-Pamlico basins provide some important lessons for the application of a watershed management approach to protecting coral reefs The Tar-Pamlico experience clearly supports the conclusion that a watershed management approach is an effective way to protect and manage water quality in coastal areas. Some of the important conclusions or lessons learned include the following.

Importance of Stakeholder Involvement. In both the development of the Tar-Pamlico water quality management plan and the implementation of the nutrient reduction strategy, NCDEM incorporated the input of different government and nongovernment organizations, as well as the public. In fact, the involvement of and collaboration among dischargers, NCDEM, and environmental groups was instrumental in the development of the nutrient trading program. By involving and incorporating the opinions of diverse interest groups, the legitimacy and effectiveness of subsequent management efforts can be enhanced.

Importance of Data Quality. Obtaining high-quality data on the condition and status of the resource being managed, the sources that are contributing to impairment, and the impacts associated with increased pollutant loadings is critical in devising effective and responsible control strategies. The development of the nutrient control strategy and the Tar-Pamlico management plan both involved effective data collection and modeling efforts. The importance of data quality is particularly relevant when considering the management of coral reef systems. The sensitive nature of coral reefs makes them highly susceptible to changes and increases in nonpoint source pollutants, such as nutrients and sediment loads. As a result, a sound understanding of how the system responds to different contaminant levels can aid management strategies

Importance of Cost-Effectiveness. Critical to any watershed management approach is the achievement of tangible environmental improvements at a reasonable financial cost. In the case of the Tar-Pamlico, both initiatives were effective in addressing and accomplishing this objective. The basinwide management plan targeted reductions in administrative and implementation costs by seeking to integrate water quality management efforts throughout the basin. The nutrient reduction strategy pursued the idea of "nutrient trading" as a cost-effective alternative to stringent point source controls

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The Ugum Watershed Project: Managing a Tropical Watershed

Overview

Guam is the largest island of the western Pacific's Marianas Island chain. It is a territory of the United States and is under the jurisdiction of some U S laws. The island is approximately 549 km^2 (212 mi^2) in area. The reefs are predominately of the fringing type, although two barrier reef lagoons occur on the western side of the island (Figure 4).

Conservation plans, management plans, and environmental regulations are administered by a variety of federal and territory governmental agencies. Guam also administers environmental controls under the federal Endangered Species Act, the Coastal Zone Management Act, and the Clean Water Act. The entire island is defined as a coastal zone

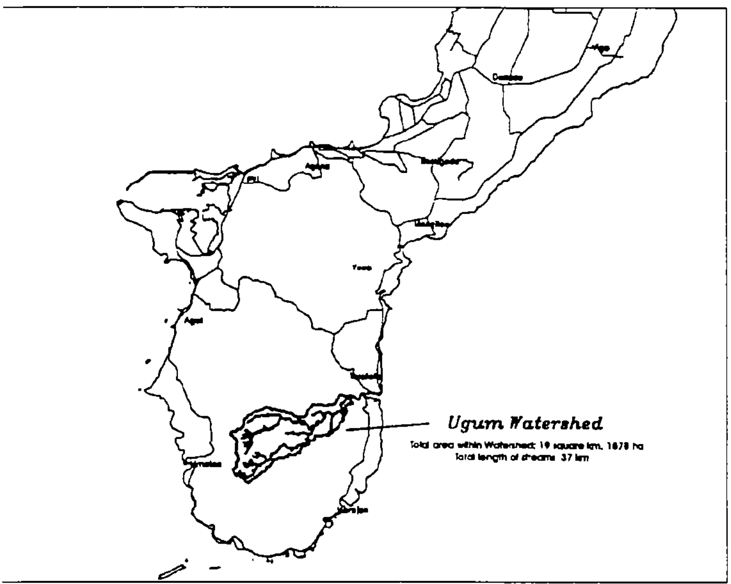

Figure 4. Location of Ugum Watershed on Guam

The Ugum River is a major source of potable water for southern Guam In an effort to maintain and protect the surface and ground water quality of the watershed, the Ugum Watershed Project was established. This project is a cooperative effort by Guam government agencies, with technical assistance provided by the Natural Resources Conservation Service of the U.S. Department of Agriculture. The project is divided into three phases (1) assessment of resources, (2) development of a management plan and (3) implementation of demonstration projects.

The management plan provides the guidance necessary to protect the integrity of the Ugum watershed It also provides the basis for actions relating to the water quality and quantity of this basin. The plan presents alternatives for controlling nonpoint source pollution and managing the natural resources of the watershed The scope of the Ugum Watershed Project is long range and comprehensive The management plan projects present conditions forward 20 years and proposes alternative management scenarios and recommendations.

Watershed Characterization

The Ugum watershed encompasses 18.9 km^2 (7 3 mi^2) of rolling hills and areas of extremely steep slopes. The volcanic uplands rise 378.5 m (1,250 ft.) and are transected by steep slopes. The gently sloping foothills are cut by major streams The watershed drains the Ugum and Bubulao rivers into the Talofofo River which flows to Talofofo Bay. Heavy rainfall from typhoons and intense local storms are common. The heavy rainfall and strong winds cause severe erosion which is accompanied by sedimentation of streams and coastal areas.

Approximately 37 km (23 mi) of rivers and streams drain the watershed. The surface waters are a source of drinking water for southern Guam and supplement northern ground water sources Seventy percent (13.2 km^2 or 5.1 mi^2) of the drainage basin is privately owned and the other 30 percent (5 7 km^2 or 2 2 mi^2) is in public ownership. The public lands are in the highlands, which limits development. This will help maintain the integrity of the headwaters and protect downstream water quality

All of the private land is zoned as "Agriculture" with the exception of 75 hectares (185 acres) that are developed as a resort Currently, there is very little active farming in the watershed. Most activities are related to recreational uses, such as hunting Off-road vehicle usage in the watershed has increased. Fires are common in the watershed and are related to hunting activities. Both off-road vehicles and fires increase erosion rates and the sediment loads carried to nearshore environments

Watershed Assessment

A technical assistance team, referred to as the Ecosystem Based Assistance Team, or EBAT, was formed to identify and rank areas of concern that needed to be addressed in the management plan

Public meetings and agency meetings allowed for broad involvement in the identification of significant issues related to the Ugum Watershed. Twenty-six environmental, economic, social, and cultural concerns were identified at these meetings. These concerns were prioritized, as shown in Table 6. Sedimentation of streams, coastal waters, and reefs was one area given a high degree of concern.

A possible set of action scenarios to be carried out from 1995 to 2015 was developed based on the potential effects they would have on the top four major areas of concern defined by the EBAT These areas are soil erosion, fires, water quality, and fish and wildlife habitat protection. It was felt that most of the 26 concerns prioritized would be addressed to some degree by dealing with these top four concerns since many are overlapping or closely related issues

Watershed Management Scenarios

The EBAT proposed four management scenarios for the Ugum Watershed Each of the scenarios takes into consideration the land use trends that might develop within the watershed over the 20-year planning period Each scenario was presented for consideration along with a summary and comparison of alternatives and the EBAT's recommendation of the most appropriate scenario for the management plan to implement.

No Action Scenario

The *No Action Scenario* describes the predicted future watershed condition without the implementation of an organized management plan in the Ugum Watershed. It assumes that the existing island-wide trends for development, resource use, management, and land use practices will continues unabated into the future No additional environmental protection measures would be implemented. No mitigation recommendations were offered

Under this scenario, no additional restrictions would be placed on landowners in the watershed. Landowners would be free to use their property in any way. This approach would also minimize the cost of government intervention in island land use policy It is assumed that public education would adequately inform individuals of sound environmental decision making.

Maintenance Scenario

Under the *Maintenance Scenario*, the plan would maintain the current levels of functionality of the watershed. The goal is to preserve the functions and benefits of the ravine forest, riparian areas, and wetland ecosystems at the existing levels, with no future loss in area or benefits.

This scenario is based on the assumption that any development includes the necessary conservation and environmental protection measures necessary for maintaining watershed integrity and water quality at current levels. It also recommends that developers be encouraged to monitor their own ground and surface water so identified problems can be addressed quickly.

Improvement Scenario

The goal of the *Improvement Scenario* is to improve the ecosystem functions and minimize the present problems in the watershed. The primary difference between the maintenance scenario and the improvement scenario is that the improvement scenario focuses on minimizing and controlling soil erosion, controlling fires, protecting wetlands, and improving wildlife habitat in the watershed. This scenario also allows for the implementation of a number of mandatory conservation practices and best management practices, and it imposes restrictions for land uses.

Watershed Reserve

The *Watershed Reserve Scenario* calls for the purchase of all the private lands in the watershed by the Government of Guam so that the watershed can be controlled for the production of water. No development or land disturbance would be allowed The Ugum watershed would be managed as a park.

This type of management has many benefits. They include improved water quality and quantity and increased rate of flow. Other benefits include an increase

Table 6. Ranking of Concerns for the Ugum Watershed

Environmental, Economic, Social, and Cultural Concerns	*Degree of Concern and Significance to Decision Making**
Soil erosion	High
Fires	High
Water quality and quantity	High
Fish and wildlife habitat protection	High
Off-road vehicle impacts	High
Sedimentation of streams	High
Sedimentation of coastal waters and reef	High
Pesticides and fertilizer usage	High
Development of agricultural uses	High
Impact of development	High
Land use conflicts	High
Infrastructure needs	High
Road building and grading	High
Wetland protection	Medium
Threatened and endangered species	Medium
Cultural resources	Medium
Water rights	Medium
Water pressure	Medium
Security of PUAG intake facility	Medium
Access to public lands	Medium
Interagency coordination	Medium
Suitable commercial activities	Medium
Capturing excess water	Medium
Beautification of watershed	Low
Regulation for protecting the resources	Low
Access to private land	Low
Health effects of cattle grazing	Low
Water availability for agriculture	Low
Flooding	Low
Illegal fishing and hunting	Low
Effect of recreation on water quality	Low
Monitoring development in the Dan Dan area	Low

in wildlife habitat and wetland functions and a decrease in erosion and the accompanying sediment loads to waterbodies

Table 7 offers a summary and comparison of the proposed alternatives.

Recommended Action

The EBAT chose to provide general rather than specific recommendations It considered the Maintenance Scenario and the Improvement Scenario to be best suited for the goals of the sponsors and the landowners The Watershed Reserve Scenario was not recommended since it would remove control of land from the present owners at considerable cost to the Government of Guam.

Conclusions

Development of this management plan highlights some important steps that should be considered in the development of any conservation or management plan. Specifically, it included.

- Organization of a broad-based technical assistance team.
- Involvement of interested parties through public and governmental meetings, which identified a broad array of environmental and economic issues.
- Identification by a technical team of major areas of environmental concern that the management plan would need to address to maintain the ecological integrity of the watershed
- Development of a proposed set of action scenarios as alternatives for consideration in developing the management plan.
- Presentation of advantages and disadvantages of possible actions. The technical team provided a recommended plan with justification.

Contact

Copies of the Ugum Watershed Management Plan are available from:

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Natural Resources Conservation Service
Pacific Basin Area
Suite 301 FHB
400 Route 8
Maite, Guam 96927
011-671-472-7490 (phone)
011-671-472-7288 (fax)

Table 7. Summary and Comparison of Alternative Scenarios of the Ugum Watershed Management Plan

Effects	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*
Cost	None	Voluntary	Voluntary, local and federal programs, and incentive programs	Gov Guam - $6 million to $80 million
Ravine Forest Ecosystem	707 hectares and less diversity	807 hectares and maintain diversity	918 hectares and improve diversity	918 hectares and maintain diversity
Savanna Grassland Ecosystem	627 hectares	527 hectares	416 hectares	696 hectares
Riparian Buffer Ecosystem	Impacted by agriculture and development	159 hectares maintained	159 hectares improved	159 hectares maintained
Wetland/Stream Ecosystem	Impacted by fire and erosion	Maintained at present levels	Improved with protection	Improved with less disturbance
Soil Erosion	196,508 tonnes/year	142,074 tonnes/year	111,785 tonnes/year	120,342 tonnes/year
Sedimentation	91,376 tonnes/year	66,064 tonnes/year	51,980 tonnes/year	55,959 tonnes/year
Fires	200 hectares	161 hectares	121 hectares	80 hectares
Water Quality	Adverse effect	No effect	Improved	No effect or improved
Wildlife Habitat and Wetlands	Negatively Impacted	Maintained	Improved	Reserved, improved
Roads	140 km with no design or controls	140 km with minimal design	140 km with improved design	63 km, no new roads
Public Education	None	Program for fire retention	Program for fire control and habitat protection, etc	Program for fire control and habitat protection
Measures	None	Minimum land treatment Water quality monitoring Minimum wetland and wildlife habitat protection Erosion and sediment control systems	Land treatment Pest and nutrient management Waste management systems Road surface and ditch stabilization Erosion and sediment control systems Riparian buffer management Fire management Water quality monitoring Wetland and wildlife habitat protection	Land treatment Revegetation of unused roads Maintenance of trails
Agriculture and Development	280 hectares, uncontrolled location, major impacts on all natural resources	280 hectares, limited to areas best suited for dwellings Minimum impacts	280 hectares, limited to areas best suited for dwellings Resource management systems Conservation plans Farmstead assessment systems	None allowed, no effect

Conclusion

While there are several traditional ways to manage direct impacts to coral ecosystems, degradation of coral communities will not be totally curtailed until the indirect land-based impacts are addressed. Runoff from urban and agricultural activities, pollutants discharged from marinas, nutrients and pathogens from failing or improperly installed septic systems, and increased turbidity from mining and dredging all have a major, long-term impact on coral ecosystems.

Watershed planning is a key to controlling land-based impacts By evaluating and assessing the activities in the coastal watershed and correlating them to potential and actual impacts to the offshore coral ecosystems, planners and resource managers can mitigate or eliminate the indirect stresses to coral ecosystems. The essential elements of watershed planning include the following:

- Allow the planners and managers to be flexible and build a plan that is best for their community given the unique features of an area, such as socioeconomics, natural resources, and political atmosphere.
- Involve the public in all phases of development. Public buy-in is an essential component of watershed planning since it is the residents, business owners, and special interest groups within the watershed that will be implementing the plan.
- Include monitoring of the plan's effectiveness. If some components of the plan are not practical or are not helping to solve the problems related to coral reef degradation, they can be modified.
- Take into account all components of the watershed such as land use, point and nonpoint sources of pollution, hydrology, existing plans and regulations, and financial resources available to implement the plan.

A variety of techniques to control watershed-wide impacts are available. When they are used in conjunction with traditional resource management tools, the decline of coral communities can be slowed, if not stopped.

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Glossary

Accretion Increase in size Coral accretion is adding more coral coverage to a reef or other structure

Algae. Simple rootless plants that grow in sunlit waters in relative proportion to the amount of nutrients available They can affect water quality adversely by lowering the dissolved oxygen in the water.

Algal blooms. Sudden spurts of algal growth, which can indicate adverse changes in water quality

Ambient. Surrounding conditions.

Atolls. Coral islands that form circular reef structures, often with islets and often with calm-water lagoons in the center.

Bank reef. Deeper reef that forms separate from other reef sections.

Barrier reef. A coral reef that forms offshore in ramparts and is separated from land by a shallow, sand-floored lagoon.

Best Management Practice. Controls for stormwater and other forms of nonpoint source pollution that are best able to prevent or minimize adverse impact within given environmental, social, and economic parameters.

Biomass. All the living material in an area

Calcium carbonate. A colorless grey powder found naturally in limestone Calcium carbonate dissolves in seawater and is extracted by coral to form reefs.

Coral bleaching Loss of zooxanthellae, the algae that live in coral polyps.

Coral coverage. The amount of living coral on a reef structure.

Coral mortality Death of coral organisms

Coral recruitment New coral growing on a hard substrate, like a reef structure

Crustacean Class of animals, primarily aquatic, having a body covered by a hard shell or crust. Examples include lobster, crabs, and shrimp.

Desalinization. The process by which salts are removed from seawater to make potable water.

Dredging. To clear or deepen the bottom of a waterbody.

Ecosystem. The interacting system of a biological community and its nonliving surroundings.

Effluent. Wastewater (treated or untreated) that flows out of a treatment plant, sewer, or industrial outfall.

Erosion. The wearing away of land surface by wind or water.

Eutrophication. A process that occurs when too many nutrients are added to a waterbody, thereby encouraging accelerated growth of undesirable plants, such as algae.

Fouling organisms. Organisms, such as barnacles and some worms, that grow on submerged surfaces like boat hulls, pilings, and water intake pipes

Fringing reef. A coral reef that forms close to shore and in shallow water.

Habitat. The place where a population lives and its surroundings, both living and nonliving

Hard coral. Coral that secretes calcium carbonate around its living tissue, forming an exterior skeleton.

Herbivore. An animal that feeds on plants

Hydrocarbon A chemical compound that consists entirely of carbon and hydrogen, examples include gasoline and oil.

Hydromodification Alteration of the hydrologic characteristics of coastal and noncoastal waters, which in turn could cause degradation of water resources.

Hypersaline. A condition that occurs when there is an abnormally high concentration of salts in the water.

Impervious surface. Surfaces that do not allow water to seep into the ground

Insular. Of or pertaining to an island.

Larva The early form of many organisms, such as coral, that occurs after an egg "hatches." Coral larvae are free-floating and eventually settle on a hard substrate and form coral polyps.

Lethal. Deadly; fatal.

Mangrove A species of tree found in tropical coastal areas. Mangroves form thick stands at the edge of the water and are important habitat for many aquatic organisms.

Mollusk. An animal having a soft segmented body covered by a hard shell. Examples include snails, clams, conch, and oysters

Nonpoint sources. Pollution sources that are diffuse and do not have a single point of origin or are not introduced into a receiving stream from a specific outlet.

Nutrient. Any substance used by living things to promote growth.

Nutrient enrichment. The addition of nutrients, such as nitrogen and phosphorus, which can result in eutrophication.

Oligotrophic Low in nutrients.

Overnourishment. The addition of too many nutrients to the water.

Pathogens Microorganisms that cause disease in other organisms, examples include bacteria, viruses, and parasites

Photosynthesis. The process by which plants make carbohydrates and oxygen from carbon dioxide and water in the presence of chlorophyll, using light as the energy source.

Phytoplankton Tiny plants that live in the water column, many invisible to the naked eye.

Platform/patch reef. A small circular or irregular reef that forms where the hard seabed rises close to the surface and is distinct from other reef sections.

Point source. A stationary location or fixed facility from which pollutants are discharged.

Polyp A sedentary animal having a hollow cylindrical body with a fixed base at one end and a mouth surrounded by tentacles at the other

Predator Something that preys on other animals.

Salinity The amount of salt in the water, usually measured in parts per thousand, or ppt.

Seaward. Directed toward the sea.

Sedimentation. The process of solids settling out of the water column.

Septic tank. An underground storage tank for wastes for homes with no connection to a sewage treatment plant. The waste goes directly from the home to the tank, where organic waste is decomposed by bacteria and settles to the bottom. The sludge is pumped out of the tank periodically. The effluent flows out of the tank to a drainfield.

Soft coral Coral that deposits calcium carbonate in its tissue, making it "fleshy" and fan-like.

Spawning Reproducing.

Species diversity. The number of different species in an area. High species diversity means there are many different species in an area

Species richness The number of one specific species in an area High species richness means there are many of a particular species in an area.

Sublethal. Below the lethal dose of a toxicant; a dose that will not cause death, but may cause harm.

Symbiotic. A situation in which two dissimilar organisms are living in close proximity to each other and each benefits from the association.

Toxic. Harmful to living organisms

Toxicants. Poisonous agents that harm or kill animal or plant life.

Toxicity. The degree of danger posed by a substance to animal or plant life.

Turbidity. Cloudy condition in water caused by suspended sediment or organic matter.

Watershed. The land area that drains into a stream, river, lake, or estuary.

Wetland An area that is regularly saturated by surface or ground water and subsequently is characterized by a prevalence of vegetation that is adapted for life in saturated soil conditions.

Windward. Being on the side toward which the wind blows

Zooxanthellae. Algae found in coral polyps that give the coral its color. The algae also provide the coral with oxygen and carbon dioxide (through photosysthesis) and assist reef-building corals in extracting calcium carbonate from seawater.

Appendix A

Rules and Regulations

Much of the following information was reproduced from *Covering the Coasts: A Reporter's Guide to Coastal and Marine Resources*, with permission from the Environmental Health Center of the National Safety Council.

National Statutes and Programs that Pertain to Coral Reef Protection and Management

Umbrella Laws

National Environmental Policy Act (1969)
Responsible Agencies: President's Council on Environmental Quality (CEQ) and the Environmental Protection Agency (EPA)

The National Environmental Policy Act (NEPA) requires that the applicable federal agency prepare a detailed environmental impact statement (EIS) for major federal actions that might significantly affect the quality of the human environment. Not only does NEPA require full disclosure of a proposed project's environmental impacts, but the authorizing agency must also evaluate a complete set of alternatives to the project including the "no build" alternative. The intended outcome of the EIS process is that any identified adverse environmental effects have been evaluated and, where appropriate, avoided, minimized and/or mitigated

Federal Water Pollution Control Act Amendments of 1972
Responsible Agencies. EPA, U S. Army Corps of Engineers, U S. Coast Guard

The 1972 Amendments to the Federal Water Pollution Control Act greatly increased federal financial assistance to municipal wastewater treatment facilities. The Amendments established uniform technology-based effluent limitations for industrial dischargers as well as established a national permit system for all point source discharges, called the National Pollutant Discharge Elimination System (NPDES). The law encourages nonpoint source pollution assessment and control programs. Finally, the amendments granted the U.S. Army Corps of Engineers the authority to issue permits for the discharge of dredged or fill material into waters of the U.S

Clean Water Act Amendments of 1987 (Water Quality Act of 1987)
Responsible Agency: EPA

The Federal Water Pollution Control Act was reauthorized and amended in what became known as the Water Quality Act of 1987. The Act authorizes EPA to delegate issuance andenforcement of NPDES permits to states with appropriate regulatory programs and procedures. Finally, the Act added priority toxic pollutant control to the federal program.

Coastal Zone Management Act (1972)
Responsible Agencies: EPA and NOAA

The Coastal Zone Management Act (CZMA) of 1972 provides for management of the nation's coastline, including the Great Lakes, by balancing economic development with environmental preservation Its goals are "preserve, protect, develop, enhance, and restore where possible, the coastal resources." CZMA encourages states to exercise full authority over their coastal lands and waters

Coastal Zone Management Program

The Coastal Zone Management Act (CZMA) encourages states to produce and enforce their own Coastal Zone Management Programs consistent with the federal law and its goals. CZMA provides federal financial assistance to states that produce CZM programs approved by the Secretary of Commerce (NOAA).

Thirty-six states and territories are eligible to participate in the CZM program. By early 1992, 29 states had created approved programs covering more than 95 percent of the country's coastline (National Safety Council). Georgia, Indiana, Minnesota, Ohio, and Texas are developing CZM programs Illinois was not pursuing development as of late 1992 (National Safety Council, date)

Coastal Nonpoint Pollution Control Program

In 1990, Congress passed the Coastal Zone Act Reauthorization Amendments, adding a section designed to reduce nonpoint source pollution of coastal waters Section 6217 requires states that have Coastal Zone Management Programs to develop and implement Coastal Nonpoint Pollution Control Programs

Endangered Species Act (1973)

Responsible Agencies: U S Fish and Wildlife Service and NOAA's National Marine Fisheries Service (NMFS)

This law is intended to protect endangered or threatened species by requiring all federal agencies and their permittees and licensees to ensure that their actions do not jeopardize these species or damage their critical habitats. The act also prohibits imports and exports of endangered species and the taking of any endangered species within the territorial sea or on the high seas. The law authorizes civil and criminal penalties and gives federal and state agencies enforcement authority

Conservation

Marine Protection, Research and Sanctuaries Act Title III National Marine Sanctuary Program (1972)

Responsible Agency: NOAA

Under the act, NOAA is charged with preserving and protecting marine areas that have special significance based on their "conservation, recreational, ecological, historic, research, educational, or aesthetic qualities." The National Marine Sanctuary Program allows areas to be designated as sanctuaries

Fagatele Bay in American Samoa; Key Largo and Looe Key of the Florida Keys, the Flower Garden Banks in the Gulf of Mexico, and the Hawaiian Islands Humpback Whale, Hawaii are approved sanctuaries that include coral reef habitat. As of 1992, there were 12 sanctuaries covering a total of 10,000 nautical miles.

Marine Mammal Protection Act (1972)

Responsible Agencies. U.S. Fish and Wildlife Service and NOAA's NMFS

This act places a moratorium on the taking and importing of marine mammals and their products for any purpose other than scientific research or public display. The term "take" means to harass, hunt, capture, or kill any marine mammal. The act also prohibits imports of fish caught with gear that causes incidental death or injury to marine mammals.

Fisheries Conservation and Management Act of 1976 (Magnuson Act)

Responsible Agencies: U.S. Department of State, NOAA, NMFS, U.S Coast Guard, and Regional Fishery Management Councils

This law provides for the conservation and management of all fishery resources within the U.S Exclusive Economic Zone (EEZ) and some resources beyond the EEZ. The act also establishes eight Regional Fishery Management Councils charged with preparing Fishery Management Plans (FMPs) for their regions. More than 30 fishery management plans are in place, including a fishery management plan for coral and coral reefs in the Gulf of Mexico and the South Atlantic.

Land and Water Conservation Fund Act (1965)
Responsible Agencies: Fish and Wildlife Service and U.S Army Corps of Engineers

This act promotes land and water conservation by establishing funds to acquire land or water, or interests in land or water to promote outdoor recreational opportunities. The act authorizes the Land and Water Conservation Fund to be collected from surplus property sales, motorboat fuel taxes, certain revenues authorized from the Outer Continental Shelf Lands Act, and user fees at designated National Park system "units." It authorizes the Department of the Interior to acquire lands or allocate funds to states to carry out the Act

Estuary Protection Act of 1968
Responsible Agency· Fish and Wildlife Service

This act was established for the conservation of estuarine areas.

Fish and Wildlife Coordination Act (1958)
Responsible Agencies: Fish and Wildlife Service and the U S. Army Corps of Engineers

The Fish and Wildlife Coordination Act provides that the Fish and Wildlife Service review all proposed federal actions that might affect any stream, wetland, or other body of water and to make recommendations for the conservation of fish and wildlife. The Service reviews both development and regulatory actions

North American Wetlands Conservation Act
Responsible Agency: Fish and Wildlife Service

Provides funding for purchase of critical wetlands in the United States, Canada, and Mexico and provides for matching funds for wetlands conservation projects in North America

Coastal Wetlands Planning, Protection and Restoration Act of 1990
Responsible Agencies Fish and Wildlife Service, U.S. Army Corps of Engineers, and EPA

Encourages wetland conservation and planning in U S. coastal areas and provides for state grants for wetlands conservation Also, grants the U S Army Corps of Engineers authority to create wetlands across the United States and specifically in Louisiana.

Water Resources Development Act of 1976 and of 1986 (as amended in 1990 and 1992)
Responsible Agency: U.S Army Corps of Engineers

Authorizes the U.S. Army Corps of Engineers to use dredged material for wetlands creation, to modify existing projects or operations for environmental improvement, and to mitigate fish and wildlife losses associated with authorized water resources projects, including the acquisition of lands or interests in lands.

Rivers and Harbors Act of 1899
Responsible Agency. U S. Army Corps of Engineers

This act prohibits construction in any navigable waters without Corps approval. In addition, it prohibits the discharge of refuse into navigable waters or their tributaries without a permit from the U.S. Army Corps of Engineers. Until passage of the 1972 Federal Water Pollution Control Act Amendments, the 1899 Rivers and Harbors Act had provided the primary federal basis for managing and regulating dredged and fill activities in wetlands

Fish and Wildlife Conservation Act
Responsible Agency· Fish and Wildlife Service

This act was established for the conservation and promotion of nongame fish and wildlife and their habitats, including grants to states

Fish Restoration and Management Projects Act
Responsible Agency: Fish and Wildlife Service

This act was established to fund state programs for the restoration and management of fishery resources, including coral habitats.

National Wildlife Refuge System Administration Act
Responsible Agency. Fish and Wildlife Service

This act establishes resources management programs for fish and wildlife habitat and acquires lands and waters for the purpose of fish and wildlife conservation.

Federal Water Project Recreation Act
Responsible Agency: Fish and Wildlife Service

This act provides federal funds for fish and wildlife enhancement and land acquisition for these same purposes in conjunction with federal water development projects

Fish and Wildlife Act of 1956
Responsible Agency. Fish and Wildlife Service

This act establishes a comprehensive national fish, shellfish, and wildlife resource policy emphasizing the commercial fish industry.

Interjurisdictional Fisheries Act
Responsible Agency: NOAA

This act promotes and encourages management of interjurisdictional fishery resources throughout their range.

North Pacific Fisheries Act of 1954
Responsible Agency: NOAA

This Act enforces the agreements of the International Convention for the High Seas Fisheries of the North Pacific Ocean.

Reefs for Marine Life Conservation and the National Fishing Enhancement Act of 1964
Responsible Agency: U.S Department of Transportation

Conserves marine life through the use of obsolete ships as artificial reefs for the conservation of marine life.

Marine Pollution

Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other matter (London Dumping Convention) (1972)
Responsible Party: United Nations

The London Dumping Convention (LDC) grew out of proposals made by the 1972 United Nations Conference on the Human Environment in Stockholm. The LDC regulates ocean dumping to prevent pollution of the marine environment, harm to living marine resources, hazards to human health, and damage to amenities. Dumping involves any deliberate disposal at sea from vessels, aircraft, platforms, or other man-made structures, but excludes waste disposal from normal operation of vessels. The United States implements the Convention through Title I of the Marine Protection, Research and Sanctuaries Act (see below).

Marine Protection, Research and Sanctuaries Act Title I or Ocean Dumping Act (1972)
Responsible Agencies. EPA, U.S. Army Corps of Engineers, U.S. Coast Guard

Title I of the Marine Protection, Research and Sanctuaries Act (MPRSA), commonly known as the Ocean Dumping Act, regulates the transportation of material for the purpose of dumping into ocean waters. In general, the act prohibits the transportation of material from the United States or by U.S.-registered vessels for the purpose of ocean dumping unless authorized by a permit issued under the act. In addition, the MPRSA was amended in 1988 to make ocean dumping of industrial waste and sewage sludge unlawful.

Ocean Dumping Ban Act (1988)
Responsible Agency: U.S. Coast Guard

The Ocean Dumping Ban Act of 1988 amended the Marine Protection, Research and Sanctuaries Act. Its primary purpose is to prohibit ocean dumping of sewage sludge and industrial wastes after December 31, 1991.

International Convention for the Prevention of Pollution From Ships (1973 and 1978)

Responsible Parties: United Nations and U S Coast Guard in U.S. waters

The 1973 International Convention for the Prevention of Pollution From Ships, known as MARPOL, did not go into effect until 1983 after several modifications. Its intent is to end "the deliberate, negligent or accidental release of . harmful substances from ships" and to "achieve the complete elimination of international pollution of the marine environment . by harmful substances " MARPOL is concerned primarily with wastes generated during the normaloperations of vessels

Oil Pollution Control Act (1990)

Responsible Agencies: EPA and U S. Coast Guard

The law combines various oil spill response mechanisms from the Clean Water Act, the Deepwater Port Act of 1974, the Trans-Alaska Pipeline Act, and the Outer Continental Shelf Lands Act and seeks to harmonize them with state laws, international conventions, and the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA or Superfund). The act provides for emergency response planning through establishing contingency plans for specific areas to deal with worst-case scenario oil spills. A National Contingency Plan (NCO) was also established that provides a method of ranking waste sites for inventory and cleanup.

Ocean Thermal Energy Conversion Act

Responsible Agency: NOAA

This act licenses the construction and operation of ocean thermal energy conversion plants. The licensing process takes into account impacts on ecosystems, including coral habitat

The National Ocean Pollution Planning Act (1988)

Responsible Agency: NOAA

This act establishes a comprehensive 5-year plan for federal ocean pollution research and development and monitoring programs. In addition, it provides for the development of the necessary information base to support and provide for equitable utilization, conservation, and development of ocean and coastal resources.

Toxics and Wastes

Article 39 of the Lome IV Treaty (1989)

Responsible Party. United Nations

This treaty represents the world's most comprehensive hazardous waste trade ban prohibiting the European Union from shipping any hazardous (including nuclear) wastes to the 69 African, Caribbean, and Pacific (ACP) countries. Under this agreement, the ACP countries also agreed to prohibit hazardous (including radioactive) waste imports from any country. Caribbean nations protected under the treaty are Antigua and Barbuda, the Bahamas, Barbados, Belize, Dominica, Dominion Republic, Grenada, Guyana, Haiti, Jamaica, St. Kitts and Nevis, St Lubic, St Vincent and the Grenadines, Surimane, and Trinidad and Tobago

Shore Protection Act of 1988

Responsible Agency: EPA

Protects coastal water from litter and pollution by regulating waste-handling practices by wastesources, vessels, and receiving facilities to minimize deposition of waste into coastal water.

Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) of 1980, as Amended (Superfund)

Responsible Agencies: EPA, U S. Coast Guard

The basic purpose of CERCLA is to respond to past releases of hazardous substances into the air, water, or land If a responsible party (RP) does not take the appropriate removal and remedial actions, EPA can order it to do so. If the RP still does not respond, EPA can use federal funds to do the necessary work and then recover expenses from responsible parties at a particular site. If there is no "potentially responsible party" (PRP), the clean-up costs come from Superfund. While EPA is the responsible agency on land, EPA and the Coast Guard share responsibilities for responding to emergencies such as oil or hazardous chemical spills in coastal waters.

Resource Conservation and Recovery Act of 1976

Responsible Agency: EPA

Just as Superfund is designed to clean up existing and abandoned hazardous waste sites, the Resource Conservation and Recovery Act (RCRA) is intended to prevent creation of new threats to human health by improper hazardous waste disposal. The law establishes a "cradle-to-grave" system to track hazardous wastes from generation to final disposal

Toxic Substances Control Act (TSCA) of 1976
Responsible Agency: EPA

TSCA regulates the introduction into commerce of new hazardous chemical substances and mixtures for the purpose of avoiding unreasonable risk or injury to human health or to the environment.

Federal Insecticide, Fungicide and Rodenticide Act (FIFRA), as amended (1988)
Responsible Agency EPA

FIFRA regulates the production and use of pesticide chemicals. It gives EPA the authority to deny or cancel registrations of pesticides whose use would or does cause fish contamination It also establishes "action levels" or "tolerances" for unavoidable pesticide contaminants in fish and shellfish.

Submerged Lands and Mineral Resources

Outer Continental Shelf Lands Act, as amended in 1978
Responsible Agencies. Department of the Interior's Minerals Management Service and U S. Coast Guard

The Outer Continental Shelf Lands Act requires the Interior Department to develop and maintainestimates of oil and gas reserves and undiscovered resources in the OCS. It must assess the likely effects of gas and oil activities on marine, coastal, and human environments. It administers competitive lease sales of offshore tracts and regulates OCS activities to ensure safety and environmental protection.

Submerged Lands Act (1953)
Responsible Parties· States

This act establishes ownership of lands beneath navigable waters within the boundaries of the states and the right to develop these lands. The lands beneath navigable waters are defined as lands within state boundaries that were navigable when the state became a member of the Union; lands periodically or permanently covered by tidal waters, or lands that were filled in or reclaimed lands that were formerly beneath navigable waters. The seaward boundary of each state was confirmed as a line three geographical miles from its coastline or, in the case of the Great Lakes, to the international boundary.

The federal government retained certain rights to use the submerged lands for commerce, navigation, defense, and international affairs, but not the rights of ownership or management, which were specifically granted in the act.

Deep Seabed Hard Minerals Resources Act (1980)
Responsible Agency· NOAA

This act provides authority to the Department of Commerce (NOAA) to license consortia for the mining of hard minerals beyond the continental shelf.

State and U.S Territory Regulatory Statutes that Pertain to Coral Reef Protection

American Samoa

Fagatele Bay National Marine Sanctuary Regulations

The Fagatele Bay National Marine Sanctuary Regulations (15 CFR 941 8) state that no person shall gather, take, break, cut, damage, destroy, or possess any invertebrate, coral, bottom formation, or marine plant. Section 307 of the Act, 16 U S.C. 1437, authorizes the assessment of a civil penalty of not more than $50,000.00 for each violation of any regulation issued pursuant to the Act.

Department of Marine and Wildlife Resources: Rules and Regulations

Several sections of the Department of Marine and Wildlife Resources' rules and regulations address activities in coastal areas. Chapter 3 regulates fishing areas and prohibits the taking or damage of natural resources, including coral, from Fagatele Bay National Marine Sanctuary and Rose Atoll National Wildlife Refuge Chapter 5 states that it is unlawful to collect any livingcoral above the 60-foot contour surrounding all islands of American Samoa and offshore banks in the waters of American Samoa. The commercial harvest of any coral below the 60-foot contour requires a valid Coral Collection Permit from the Department.

The American Samoa Coastal Management Program (ASCMP)

ASCMP administrative rules are adopted pursuant to authority granted by the Development Planning Office under Public Law 21-35, the American Samoa Coastal Management Act of 1990. The ASCMP specifically applies to land use practices and prohibits the impairment of any ecosystem

Commonwealth of the Northern Marianas Islands

Commonwealth of the Northern Marianas Islands Coastal Resource Management Program Lagoon Master Plan

[Information Pending]

Florida

Draft Management Plan/Environmental Impact Statement for the Florida Keys National Marine Sanctuary

The Florida Keys National Marine Sanctuary and Protection Act of 1990 and the Amendments Act of 1992 directed the Secretary of Commerce to develop a comprehensive management plan and implement regulations to protect sanctuary resources. All requirements have been addressed in this plan. NOAA regulatory actions (section 929) address boating, fishing, land use, recreation, and zoning (Dept of Commerce, 1995)

Chapter 370 of the Florida Statute

Florida Statute section 370 states that it is unlawful for any person to take, otherwise destroy, sell or attempt to sell (1) any sea fan of the species *Gorgonia flabellum* or the species *G. ventalina* (2) any hard or stony coral (Scleractinia), or (3) any fire coral (Millepora). Indirect authorities with relevance to coral protection include fishery gear regulations (section 370 15, F.S.), a permit system for the use of chemicals to collect marine specimens (section 370 08, F.S), ocean water contamination regulations (section 370.09, F.S.), and dredge and fill regulations (section 370.03, F.S.)

Marine Life Rule

Florida Administrative Code, Chapter 46-42.001, protects and conserves Florida's tropical marine life resources and ensures the continuing health and abundance of these species. Thischapter ensures that harvesters in the fishery use nonlethal methods of harvest and that the fish, invertebrates, and plants harvested are maintained alive for the maximum possible conservation and economic benefits.

Fishery Management Plan for Coral and Coral Reefs of the Gulf of Mexico and South Atlantic as Amended

This plan was produced by the Gulf of Mexico Fishery Management Council and the South Atlantic Fishery Management Council under the authority provided in the Fisheries Conservation and Management Act of 1976 (Magnuson Act) The plan specifically addresses the Florida reef tract. Federal regulations for the plan are under 50 CFR Part 638 (SAFMC, 1982).

Flower Garden Banks, Texas

Fishery Management Plan for Coral and Coral Reefs of the Gulf of Mexico and South Atlantic as Amended

This plan was produced by the Gulf of Mexico Fishery Management Council and the South Atlantic Fishery Management Council under the authority provided in the Fisheries Conservation and Management Act of 1976 (Magnuson Act). The plan specifically addresses the Flower Garden Banks National Marine Sanctuary Federal regulations for the plan are under 50 CFR Part 638. Federal regulations for the Flower Garden Banks National Marine Sanctuary are under 15 CFR Part 943 (SAFMC, 1982).

Note: Texas has no direct coral protection laws relevant to coral resources. However, the state does have regulations on fishing (Texas P&W Code section 77), ocean pollution (Texas Water Code section 26), use of electroshock (Texas P&W Code section 66), and dredge and fill activities (Texas Natural Resources section 33).

Appendix B

Compendium of Organizations and Services

A Resource of Science and Policy on Coral Reefs

Nongovernmental Organizations

Aquarium for Wildlife Conservation
Osborn Laboratories for Marine Science
West 8th Street & Surf Avenue
Brooklyn, NY 11224
phone: (718) 265-3435
fax. (718) 265-0419
Contact: Paul Boyle, Director

American Fisheries Society
5410 Grosvernor Lane, #10
Bethesda, MD 20814
phone. (301) 897-8616
fax: (30) 897-8096
Contact: Paul Brouha

American Oceans Campaign
235 Pennsylvania Avenue, SW
Washington, DC 20003
phone. (202) 544-3526
fax: (202) 544-5625
Contact: Robert Sulnick, Executive Director

Asia-Pacific Region Conservation International
1015 18th Street, NW
Suite 1000
Washington, DC 20036
phone: (202) 973-2240
fax (202) 887-5188
Contact: Cynthia Mackie, Vice President

Association of Southeast Asian Nations Cooperative Project
195 Pemberton Avenue
Vancouver, British Columbia V7P2R4
phone: (604) 986-4331
Contact: Beth Power

Australian Cooperative Project
195 Pemberton Avenue
Vancouver, British Columbia V7P2R4
phone: (604) 986-4331
Contact: Beth Power

Biodiversity Conservation Network
c/o World Wildlife Fund
1250 24th Street, Suite 500
Washington, DC 20037
phone: (202) 293-4800
fax: (202) 861-8324
Contact: Hank Cauley

Caribbean Association of Environmental Health Officers
NUPW Building, Second Floor
Dalkeith Road
St. Michael, Barbados
0West Indies
phone: (809) 436-7347
Contact: Lenore Harvey, Project Manager

Caribbean Environment Program
United Nations Environment Program
14-20 Port Royal Street
Kingston, Jamaica
phone: 1 (809) 922-9267 to 9

Caribbean Fishery Management Council
Banco de Ponce
Suite 1108
Hato Rey, PR 00918
Contact: Hector Vega-Morrera, Chairman

Conservation Education Diving

Archeology and Museums International
Fox Road
Croton-on-Hudson, NY 10520
phone (914) 271-5365
fax: (914) 271-4723
Contact: Rick Sammon

The Conservation Trust of Puerto Rico
P.O. Box 4747
San Juan, PR 00902-4747
phone: (809) 722-5834
fax: (809) 722-5872
Contact: Francisco Blanco, Executive Director

Coral Forest
400 Montgomery Street
Suite 1040
San Francisco, CA 94104
phone: (415) 788-7333
fax: (415) 398-0385
Contact. Jessica Abbe, Co-director
Contact: Wendy Weir, Co-director

CORAL—The Coral Reef Alliance
809 Delware Street
Berkeley, CA 94710
phone: (510) 528-2492
fax: (510) 528-9317
Contact: Stephen Colwell, Executive Director

Coral Reef Coalition
Center for Marine Conservation
1725 DeSales Street, NW
Suite 500
Washington, DC 20036
phone: (202) 429-5609
fax: (202) 872-0619
Contact: Jack Sobel

Cousteau Society
870 Greenbrier Circle
Suite 402
Chesapeake, VA 23320
phone: (804) 523-9335
fax: (804) 523-2747
Contact: Richard Murphy

777 United Nations Plaza
New York, NY 10017
phone: (212) 949-6290
fax: (212) 949-6296
Contact Paula DiPerna

Defenders of Wildlife
1244 19th Street, NW
Washington, DC 20036
phone. (202) 659-9510
fax. (202) 833-3349
Contact: Maureen Hearn

Earthwatch
680 Mt Auburn Street
Box 403
Watertown, MA 02272
phone: (617) 926-8200
fax: (617) 926-8532
Contact: Andrew Hudson, Program Director

Environmental Defense Fund
5655 College Avenue
Oakland, CA 94618
phone: (510) 658-8008
fax: (510) 658-0630
Contact: Rodney Fujita

257 Park Avenue, South
New York, NY 10010
Contact. Fred Krupp, Director

Environmental Solutions International
13826 Castle Cliff Way
Silverspring, MD 20904
phone: (301) 989-1731
fax: (301) 384-4369

Friends of the Puako Reef
26 Puako Beach Drive
Kamuela, HI 96743
phone: (808) 882-7625
fax: (808) 882-7556
Contact. Gary Wagner
Contact Shirley Wagner

Global Coral Reef Alliance
324 North Bedford Road
Chappaqua, NY 10514
phone: (914) 238-8788
fax: (914) 238-8768
Contact: Tom Goreau

Great Barrier Reef Marine Park Authority
P.O. Box 1379
Townsville QLD 4810
phone: 077-81-8811
fax: 077-72-6093
Contact: Richard Kenchington

Greenpeace International
Waste Trade in the Caribbean Campaign
Keizersgracht 176
1016 DW Amsterdam
Netherlands

1436 U Street, NW
Washington, DC 20009
phone: (202) 462-1177
fax: (202) 462-4507
Contact: Cliff Curtis

Greenpeace Latin America Project
Toxics Coordination Unit
9a. calle A 3-56, Zona 1
Ciudad de Guatemala
Guatemala
phone: 502-2-29432-81997
fax: 502-2-532771

Hawaii Audubon Society
1088 Bishop Street
Suite 808
Honolulu, HI 96822
phone (808) 528-1432
Contact: Linda Paul, President

Hawaii Green Party
1684 Halekoa Drive
Honolulu, HI 96821
phone: (808) 732-5497
fax: (808) 956-6877
Contact: Ira Rohter

International Coral Reef NGO Network
Center for Clean Development
1227 West 10th Avenue
Eugene, OR 97402
phone (503) 687-1043
fax: (503) 346-2040
Contact: Jeanne Kirby, Coordinator

International Marinelife Alliance
201 W Stassney
Suite 408
Austin, TX 78745-3156
phone: (512) 326-5265
fax: (512) 326-4017
Contact: Peter Rubec, President

International Union for the Conservation of Nature
1400 16th Street, Suite 502
Washington, DC 20036-2266
phone: (202) 797-5454
fax: (202) 797-5461
Contact: Achim Steiner

International Society for Reef Studies
State of Florida Institute of Oceanography
830 First Street
St. Petersburg, FL 33712
phone: (813) 893-9100
fax: (813) 893-9109
Contact John Ogden

Island Resources Foundation
1718 P Street, NW
Suite T-4
Washington, DC 20036
phone: (202) 265-9712
fax: (202) 232-0748
Contact: Edward Towle, President

Le Vaomatua
P.O. Box B
Pago Pago, 96799
American Samoa
phone: (684) 633-7458
fax: (684) 633-7458
Contact: John Enright

Life of the Land
1111 Bishop Street
Suite 511
Honolulu, HI 96813
phone (808) 533-3454
fax: (808) 537-9019
Contact. Henry Curtis

Man and the Biosphere Biodiversity Program
Smithsonian Institution
1100 Jefferson Drive, SW
Suite 3123
Washington, DC 20560
phone: (202) 357-4792
fax: (202) 786-2557

National Audubon Society
801 Pennsylvania Avenue, SE
Suite 200
Washington, DC 20003
phone: (202) 547-9009
fax. (202) 547-9022
Contact: Stephen Parcells

Natural Resources and Rights Program
Rainforest Alliance
65 Bleecker Street
New York, NY 10012
phone: (212) 677-1900
fax. (212) 677-2187
Contact: Charles Zerner

Nature Conservancy
P.O. Box 1738
Koror, Palau 96940
phone: (680) 488-2017
fax: (680) 488-1725
Contact: Chuck Cook

Ocean Watch Foundation
P.O Box 462
Fort Lauderdale, FL 33302
phone. (305) 467-1366
Contact

Pacific Science Association
P.O. Box 17801
Honolulu, HI 96817
phone: (808) 848-4139
fax. (808) 841-8968
Contact L.G. Eldredge, Executive Secretary

Pacific Whale Foundation
101 N. Kihei Road
Suite 21
Kihei, HI 96753
phone: (808) 879-8860
fax: (808) 879-2615
Contact: Eric Brown

Professional Association of Diving Instructors
Aquatic World Awareness, Responsibility and Education Program
1251 East Dyer Road
#100
Santa Ana, CA 92705-5605
phone. (714) 540-7234
fax: (714) 540-2609
Contact: Tiera Olson

Island Resources Foundation
6296 Estate Nazareth No 11
St. Thomas, USVI 00802
phone: (809) 775-6225
fax: (809) 779-2022
Contact Edward Towle, President

Project ReefKeeper
Operations Center
Suite 162
2809 Bird Avenue
Miami, FL 33133
phone: (305) 358-4600
fax: (305) 358-3030

Pacific Region
Suite 106-542 350 Ward Avenue
Honolulu, HI 96814

Latin American Region
Calle 60 No. 387-C, Marida
Yucatan, Mexico 97000

Caribbean Region
Suite 1271
Castillo Del Mar
Isla Verde, PR 00913
Contact Alexander Stone, Director

Reef Education Project
391 Braeburn Drive
Eugene, OR 97405
phone. (503) 687-9115
fax: (503) 687-9115
Contact. Aubrey Hord

Reef Environmental Education Foundation
P.O. Box 246
Key Largo, FL 33037
phone (305) 451-0312
fax. (305) 451-0312
Contact. Laddie Akins, Executive Director

Reef Relief
P.O. Box 430
Key West, FL 33041
phone: (305) 294-3100
fax: (305) 293-9515
Contact DeeVon Quirolo

REEF USA
6 Keyes Street
Florham Park, NJ 07932
phone: (201) 377-1183
fax: (201) 377-1183
Contact: Agnes Kammerer-Kovacs, Director

Rescue the Reef Program
The Nature Conservancy
1815 North Lynn Street
Arlington, VA 22209
phone: 703.841.5366
fax (703) 841-4880
Contact· John Tschirky

Sierra Club
1414 Hilltop Drive
Tallahassee, FL 32303
phone: (904) 385-7865
fax. (904) 385-7862
Contact: Shirley Taylor

1621 Mikahala Way
Honolulu, HI 96816-3321
phone (808) 734-4986
fax· (808) 856-4933
Contact. Dave Raney

Sierra Club Legal Defense Fund
Ahupua'a Action Alliance
223 South King Street
#400
Honolulu, HI 96813
phone (808) 599-2436
fax: (808) 521-6841
Contact· Denise Antolini

Wildlife Conservation Society
185th Street and Southern Boulevard
Bronx, NY 10460-1099
phone: (718) 220-5155
fax: (718) 364-4275
Contact. John Robinson, Vice President

World Resources Institute
1709 New York Avenue
Suite 700
Washington, DC 20006
phone· (202) 662-2529
fax: (202) 638-0036
Contact· Nels Johnson

Worldwatch Institute
1776 Massachusetts Avenue, NW
Washington, DC 202 452-1999
fax: (202) 296-7365
Contact: Lester Brown

World Wildlife Fund
1250 24th Street, NW
Washington, DC 20037
phone· (202) 861-8301
fax: (202) 293-9211
Contact: Tundi Agardy

Federal Government

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Peter Thomas
Coordinator, International & U S. Coral Reef Initiative
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OES/ETC, Room 4325
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U.S. Man and the Biosphere Program
Islands Directorate
State Department -- OES/ENR/MAB
Washington, DC 20520

U.S. Department of Commerce

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P.O. Box 4318
Pago Pago, AS 96799
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fax. 011-684-633-7355
Nancy Daschbach, Santuary Coordinator

Florida Keys National Marine Sanctuary
P.O. Box 500368
Marathon, FL 33050
phone. (305) 743-2437
fax: (305) 743-2357
Billy Causey, Superintendent

Florida Keys (Lower Region) National Marine Sanctuary
216 Ann Street
Key West, FL 33040
phone. (305) 292-0311
fax: (305) 292-5065
George Schmahl, Sanctuary Manager

Florida Keys (Upper Region) National Marine Sanctuary
P.O Box 1083
Key Largo, FL 33037
phone: (305) 451-1644
fax. (305) 451-3193
LCDR Paul Moen, Sanctuary Manager

Flower Garden Banks National Marine Sanctuary
1716 Briarcrest Drive
Suite 702
Bryan, TX 77802
phone. (409) 847-9296
fax: (409) 845-7525
Dr. Steve Gittings, Sanctuary Manager

Ocean Assessments Division
National Oceanic & Atmospheric Administration
N/OMA 3, Room 323, WSC-1-6001 Executive Building
Rockville, MD 20852
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Andrew Robertson, Chief

National Oceanic and Atmospheric Administration
Office of Ocean and Coastal Resource Management
1305 East-West Highway
Silver Spring, MD 20910
phone: (301) 713-3086 x 206
Stephen Jameson

National Oceanic & Atmospheric Administration
Sanctuaries and Reserves Division
1305 East-West Highway
Silver Spring, MD 20910
phone· (301) 713-3145
Dr. Charles Wahle

NOAA/OCRM
Ocean and Coastal Resource Management
NOAA, SSMC-4, Room 11536
Silver Spring, MD 20910
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Michael Crosby
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Office of Global Programs, NOAA
1000 Wayne Avenue, Suite 1225
Silver Spring, MD 20910-5603
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C. Mark Eakin
Co-Chair, Research Assessment and Monitoring Task Group

NOAA, International Affairs
14th & Constitution Avenue
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Washington, DC 20230
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Arthur Paterson

NOAA, Satellite Oceanography
NOAA/OGP
1305 East-West Highway
Building 4, Room 8402
Silver Spring, MD 20910
phone: (301) 713-1193
Bill Patzert

NOAA, Sanctuaries & Reserves
Technical Projects Branch
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Janice Sessing, Damage Assessment Coordinator

U.S. Department of the Interior
Territorial and International Affairs
1849 C Street, MS 4328
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