Chapter 3. THREATS TO CORAL REEFS

Rising population densities and associated coastal development as well as increased fishing, agricultural, and industrial activities are the major causes of pressures on Caribbean coral reefs. These sources have changed little in recent decades, but they have intensified dramatically.[8] Over millennia, reef communities have adapted to many natural pressures, such as hurricanes, where damage was followed by recovery, but now, a great range of direct and indirect human pressures have been added. Acting alone or in combination, these pressures can lead to acute or chronic ecosystem stress, which results in the breakdown and loss of coral communities, or to more subtle changes in ecosystem structure, such as the flourishing growth of algae on reefs. Changes to reefs can be gradual or rapid, but ultimately these changes diminish the value of goods and services derived from reefs by, for example, reducing coral reef habitat available for fisheries or reducing the shoreline protection afforded by reefs.

Coral reefs vary considerably in their ability to withstand pressures and to recover from damage or disturbances. This may be partly driven by ecological factors, including the species composition of the reef itself and its connectivity to other reefs. In addition, the physical setting of a reef (distance from land, reef depth, and the rate of water flow in the area) influences its vulnerability. Characterizing the pressures acting on any reef is complex, as there are multiple sources of stress operating over several spatial and temporal scales.[9]

This chapter examines the four region-wide threats included in the Reefs at Risk Caribbean model: coastal development, sedimentation and pollution from inland sources, marine-based threats, and overfishing. In addition, the issues of climate change (including coral bleaching) and coral diseases are discussed. Remedies applicable across the Caribbean region are suggested to address each of these threats. The chapter concludes with the integration of these four threats into the Reefs at Risk Threat Index, which attempts to represent the cumulative threat to coral reefs from these four key categories. In the following chapter, Chapter 4, these region-wide projections of threat are linked with observed changes in coral reefs and management responses in nine Caribbean sub-regions.

COASTAL DEVELOPMENT

The estimated number of people living within 10 km of the Caribbean coast grew from 36 million in 1990 to 41 million in 2000.[10] Some 36 percent of Caribbean coral reefs are located within 2 km of inhabited land and are thus highly susceptible to pressures arising from coastal populations.[11] Extensive construction and development for housing, roads, ports, and other development has been required to support both the residential and tourist populations.

Poorly managed coastal development puts stress on coral reefs through direct damage from dredging, land reclamation, and sand and limestone mining for construction as well as through less direct pressures such as runoff from construction sites and removal of coastal habitat. The loss of mangroves and seagrass, which filter sediment and nutrients coming from the land, has been widespread in the Caribbean[12] and adds to the pressure. Increased sediment in coastal waters reduces the amount of light reaching the corals and hinders the ability of their symbiotic algae *(zooxanthellae)* to photosynthesize.[13]

In addition, the widespread discharge of untreated sewage is a major source of nutrients entering coastal waters. Coral reefs flourish in waters nearly devoid of nutrients, and increased nutrient concentrations promote algal growth at the expense of corals.[14] Although information is incomplete, data suggest that less than 20 percent of sewage generated within the Caribbean region is properly treated.[15]

MAP 2. REEFS THREATENED BY COASTAL DEVELOPMENT

Threats to reefs from coastal development were estimated based on distance from cities, ports, airports, and dive tourism centers, as well as population density, population growth, and tourism growth in the area. For reefs inside marine protected areas (MPAs), management effectiveness was included as a factor mitigating threat. (*See Box 3 in Chapter 4 and Table A5 in Appendix A.*)

Source: WRI, *Reefs at Risk in the Caribbean*, 2004 (*see Appendix B*).

Sewage discharge is a common problem in developing countries, but it is also a problem in the Florida Keys, where seepage from cesspools and discharge of secondary-treated sewage at ocean outfalls add to nutrient build-up.[16]

Another source of diminished water quality is runoff of motor oil and other waste from roads. Industrial pollution from oil refineries, sugar processing, distilleries, breweries, food processing, and the paper and chemical industries are also a concern.[17]

In recent years, the Caribbean region has undergone massive growth in tourism, a sector of major importance to the regional economy. Well-planned tourism development can have minimal impact, or even a net positive impact, on coral reefs, but rarely is this the case. Unplanned or poorly regulated tourism can kill reefs. Tourism activities can produce both direct physical impacts (such as diver and anchor damage) and indirect impacts from resort development and operation (pollution from untreated sewage). The development of tourism infrastructure (construction of ports, airports, and hotels) also takes its toll on coral reefs. Many of these disturbances are similar to those caused by coastal development more generally, but tourism is a particular problem because it frequently moves into new, undeveloped areas, away from existing urban developments.

Modeling results. The model's indicator of coastal development threat—incorporating estimated pressure from sewage discharge, urban runoff, construction, and tourism development—identified about one-third of the region's reefs as threatened (slightly over 15 percent each at medium and at high threat). Coastal development pressure was identified as significant along the coastlines of most of the Greater Antilles, Eastern Caribbean, the Bay Islands in Honduras, and along parts of the Florida Keys, the Yucatan, and the Southern Caribbean. Areas identified at lowest threat from coastal development were the Bahamas, the Turks and Caicos Islands, and Cuba *(see Map 2)*.

Remedies. Impacts of coastal development on coral reefs can be minimized in many ways. Better planning can ensure protection for important habitats and prevent dredging or building near sensitive and valuable habitats (such as wetlands, mangroves, and seagrass). Guidelines for construction and engineering activities can also help reduce

PHOTO: JON MAIDENS

Where coastal development is implemented and how it is managed profoundly influence the degree of impact to coral reefs.

threats. Investment in building and maintaining sewage treatment systems in towns and tourist areas can reduce sewage discharge to the sea. Innovative legal measures that ensure accountability and payment for waste disposal and treatment, or demand "no net loss" of sensitive ecosystems, can help modify building design and promote environmentally sustainable infrastructure development.

Tourism takes many forms (mass tourism, small hotels, eco-resorts) and can bring a variety of benefits to the local population.[18] Ownership of a resort, sources of food and beverage (local or imported), and taxation rules all affect how much a local community benefits from tourism. In addition, the design and development of the resort, energy sources and use, and degree of sewage treatment affect the resort's environmental impact. Determining the carrying capacity of the area and the reef itself as part of the development planning process can help ensure that tourism development brings maximum benefit to local communities while minimizing damaging environmental impacts. Certification schemes, accreditation, and awards based on actual achievement (not just statement of intent) of good environmental practices by hotels and dive and tour operators provide incentives for environmentally sensible development. Education of tourists, especially teaching divers and snorkelers not to damage reefs, is essential to reducing impacts. Tourists can contribute financially to recovery and management efforts through park entrance fees or donations.

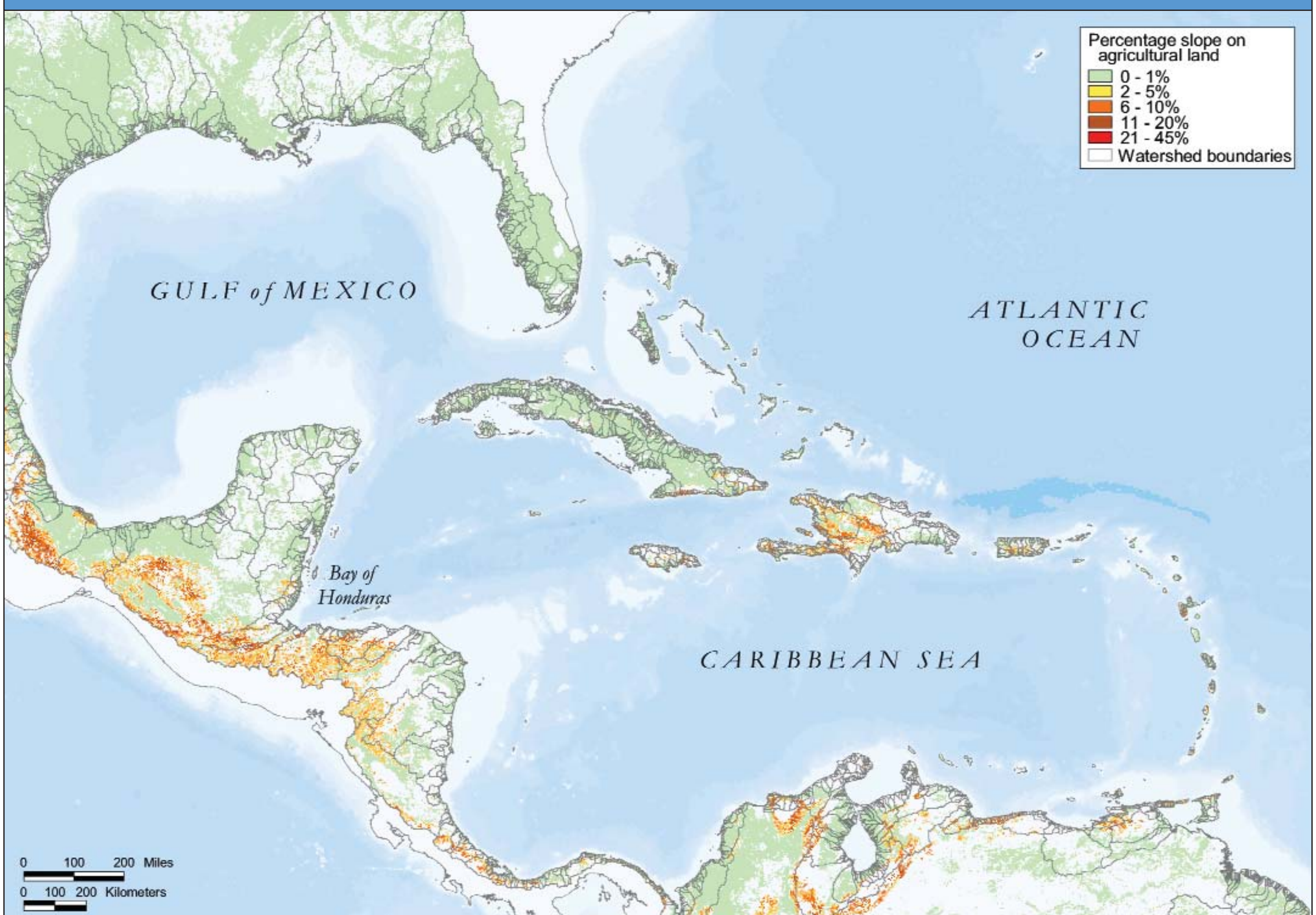
SEDIMENTATION AND POLLUTION FROM INLAND SOURCES

Agriculture, though important to economic development and food security, is a source of increased sediment, nutrient, and pesticide runoff. Conversion of land to agriculture increases soil erosion and sediment delivery to coastal waters. In areas where agriculture coincides with steep slopes and heavy precipitation, soil erosion can be extreme. This analysis classified nearly a quarter of the land area draining into the Caribbean as agricultural land cover.[19] Map 3 shows agricultural lands by slope category. Several watersheds were identified as areas of particularly high erosion risk: in Mexico (discharging to the Gulf of Mexico); in Guatemala and Honduras (discharging to the Bay of Honduras); and Colombia, Eastern Jamaica, Haiti, and Puerto Rico (discharging into the Caribbean Sea).

Increased sediment delivery to coastal waters is a key stress on coastal ecosystems. It screens out light needed for photosynthesis, jeopardizes survival of juvenile coral due to loss of suitable substrate, and, in extreme cases, can lead to complete smothering of corals. Coral reef damage from siltation has been documented on the coasts of Panama, Costa Rica, and Nicaragua, among other locations.[20]

Runoff of fertilizer and livestock manure from agricultural lands is a significant source of nutrients (especially nitrogen and phosphorus) entering coastal waters. Some of the major crops in the region—sugarcane, citrus, bananas,

MAP 3. AGRICULTURAL LANDS BY SLOPE CATEGORY



Sources: Watershed boundaries derived at WRI. Percentage slope on agricultural land derived at WRI from Global Land Cover Characteristics Database (U.S. Geological Survey (USGS), 2000) at 1-km resolution and HYDRO1K Digital Elevation Model (USGS, 2000) at 1-km resolution.

grains, and coffee—require large inputs of fertilizer and pesticides.[21] For example, the average fertilizer application rate for cultivation of bananas is 479 kilograms per hectare per growing season.[22] The discharge of nutrients into coastal waters is a major cause of eutrophication, especially in low-flow areas, and can cause algal blooms, changes in the aquatic community structure, and decreased biological diversity. The presence of algae on substrate can inhibit colonization by larval recruits, thereby initiating a decrease in live coral cover and an increase in algal or other vegetative cover. In extreme cases, high levels of nutrients produce "dead zones" because of massive oxygen depletion in the nutrient-rich waters. Such zones occur regularly off the Mississippi Delta, and smaller events have been recorded along much of the Florida coastline.[23] Where such events meet coral reefs, the results can be devastating. An isolated event in Venezuela in 1996 led to the death of almost all reef organisms over several square kilometers.[24]

Accumulation of toxic pesticides in coastal organisms is another aspect of threat from agricultural runoff. Negative impacts include damage to seagrass beds from herbicides and changes in reef community structure, such as loss of live coral cover and increases in algae and sponges.[25] The environmental effects of pesticide runoff depend on the chemicals used, amounts applied, farm layout (including vegetation cover, slope, and drainage), and the presence of riparian buffer zones along rivers and streams.

Modeling results. Analysis of more than 3,000 watersheds across the region[26] identified coastal waters likely to experience increased sediment and pollutant delivery related to land-use activities. Approximately 9,000 sq km of coral reefs (about one-third of the regional total) were identified as threatened (about 15 percent at medium threat and 20 percent at high threat). Areas with a large proportion of threatened reefs were identified off Jamaica, Hispaniola, Puerto Rico, Panama, Costa Rica, and Colombia. Some reefs in eastern Cuba were identified as threatened, as were the near-shore reefs in Belize, Venezuela, and reefs near the high islands of the Eastern Caribbean *(see Map 4)*.

Remedies. Sustainable agricultural planning and management encourages soil and water conservation practices that protect coral reefs by controlling cropland erosion and surface water runoff. Terracing helps avoid excessive runoff from farming on steep slopes. Optimal practices in tillage, fertilizer application, and harvesting will further reduce loss of both soil and nutrients, while reforestation near streams helps to reduce erosion. Fertilizers and pesticides can be used in ways that minimize leaching and transport to coastal areas.

PHOTO: LAURETTA BURKE

Construction of roads and housing in steep areas can result in enormous erosion during severe rainfall events.

In sensitive areas where there are particularly important coastal resources, stronger regulation of agricultural practices may help to protect coral reefs and the livelihoods of coastal populations. Elsewhere, adding pollution taxes to the cost of agrichemicals at the point of sale can reduce wasteful or extravagant use. Assuring retention of coastal wetlands, mangroves, and seagrasses near river mouths would mitigate harmful impacts by filtering sediment and nutrients from the water before they reach coral reefs.

MAP 4. REEFS THREATENED BY SEDIMENTATION AND POLLUTION FROM INLAND SOURCES

Threats to reefs from sedimentation and pollution from inland sources were modeled for over 3,000 watersheds discharging into the Caribbean. The model incorporates estimates of relative erosion rates across the landscape (based on slope, land cover type, precipitation during the month of maximum rainfall, and soil type) summarized by watershed to estimate resulting sediment delivery at river mouths. Sediment plume dispersion was estimated as a function of distance from the river mouth and calibrated against observed impacts of sediment on coral reefs.

Source: WRI, *Reefs at Risk in the Caribbean*, 2004 (*see Appendix B*).

MARINE-BASED SOURCES OF THREAT

Within the Caribbean region, marine-based sources of pollution cause great concern. Activities giving rise to this pollution include oil discharge and spills, sewage, ballast and bilge discharge, and dumping of garbage and other human waste from ships. Direct physical damage is caused by groundings and anchors, particularly in high-visitation areas. Anchors can devastate coral reefs. The chain and anchor of a large cruise ship can weigh 4.5 metric tons (mt). Even in calm seas, reckless anchoring can damage up to 200 square meters of ocean bottom.[27]

Most small vessels, including fishing vessels, dive boats, and private recreational boats, remain in coastal waters, but many others, including commercial transport, oil transport, and cruise vessels, crisscross the Caribbean in an intricate network. The Caribbean is also an important oil-producing area, with most of this oil shipped within the region. The areas most vulnerable to spills or accidents are in the vicinity of ports or channels reserved for tanker traffic. Accidental

MAP 5. REEFS THREATENED BY MARINE-BASED SOURCES

Threats to coral reefs from marine-based sources were evaluated based on distance to ports (stratified by size), intensity of cruise ship visitation, and distance to oil and gas infrastructure, processing, and pipelines.

Source: WRI, *Reefs at Risk in the Caribbean,* 2004 (*see Appendix B*).

releases of oil are a relatively minor source of pollution, however, compared to the amount of oil that enters the environment from disposal of tanker bilge water, washing of tanks, and routine maintenance of oil drilling rigs and pipelines.[28] Oil damages coral reproductive tissues, harms zooxanthellae, inhibits juvenile recruitment, and reduces resilience of reefs to other stresses.[29] Discharge of bilge and ballast water from ships releases a toxic mix of oil, nutrients, exotic marine species, and other pollutants. Tides and currents dissipate much of this pollution over time and space, but pollution often lingers in enclosed areas and quiet waters with less circulation and exchange.

Cruise ships are also a significant source of pollution in the Caribbean. A typical cruise ship generates an average of 8 mt (2,228 gallons) of oily bilge water[30] and 1 mt of garbage[31] each day. The volume of cruise-ship tourism has roughly quadrupled in the last 20 years[32] and the Caribbean cruise industry accounts for about 58 percent of the world's cruise ship passengers.[33] According to recent estimates by the Ocean Conservancy, 25 million passenger bed-days on cruise ships in the Caribbean generated an estimated 90,000 mt of waste in 2000.[34]

Ship-generated wastes are a major source of solid waste in coastal areas.[35] During the Ocean Conservancy's Coastal Cleanup for 2003, more than 55,000 people participated in the Caribbean. This effort documented and removed more than 1,200 mt of waste along 2,100 km of coastline.[36]

Sewage discharge from both cruise ships and increasingly numerous yachts causes concern in heavily visited areas. Large ships have sewage-holding tanks and are prohibited from discharging untreated sewage within 7 km of the nearest land, according to Annex IV of MARPOL.[37] Coastal cargo vessels and recreational boats are less likely to have holding tanks. Due to the lack of port reception facilities for sewage wastes in most Caribbean countries, these smaller vessels are more likely than large ships to discharge their wastewaters in marinas and near-shore waters.[38] In the case of recreational vessels, these discharges may take place very close to coral reefs.

Modeling results. Many of the region's small islands were identified as under high threat from shipping and marine-based sources of pollution. Threat was estimated as high in St. Lucia, Montserrat, St. Kitts and Nevis, the Netherlands Antilles (including Aruba), the Virgin Islands, and Bermuda. In addition, Puerto Rico, the Dominican Republic, Jamaica, and Panama were identified as having many threatened reefs *(see Map 5)*. Overall, the analysis identified about 15 percent of the region's reefs as threatened by marine-based sources (about 10 percent at medium and about 5 percent at high threat).

Remedies. The development of a regulatory framework can prompt establishment of facilities to receive and manage ship-generated wastes in ports. This is essential for cruise ships, which contribute an estimated 77 percent of all ship-type waste, compared with 20 percent from cargo ships.[39] Development of legislation to incorporate the international conventions on the prevention of pollution from ships (MARPOL, London Dumping, OPRC, CLC, and FUND)[40] will greatly help reduce the threat. Pollution from small vessels such as yachts can also be addressed through regulations and guidelines, while education of vessel owners helps enforce compliance. In addition, a phase-out of the use of anchors in all coral reef and seagrass areas is crucial, with a clear priority on areas where current boat traffic is high. The use of mooring buoys or anchorage zones can be promoted as an alternative.

OVERFISHING

In the Caribbean region, fisheries have long been the mainstay of coastal communities, particularly in the island nations. Coral reef fisheries—predominantly artisanal, small-scale, subsistence fisheries—are an inexpensive source of protein and provide employment where few alternatives exist. In tourist areas, many fish are sold directly to local restaurants. For countries such as Belize and the Bahamas, the export market in snapper, grouper, and reef-associated lobster and conch generates millions of dollars for the national economy, supplying demand far away from these tropical sources.[41]

The open access of reef fisheries, typically with few regulations, makes reef fish particularly susceptible to overexploitation. Because most reefs are close inshore and geographically contained, fish distribution is highly predictable in space and time.[42] Portable fish traps, the most widely used fishing gear in the Caribbean, are cheap and effective.[43] Unfortunately, such traps can also be destructive and wasteful—destructive when fishers drop them directly onto the reef, breaking up the corals, and wasteful when they are lost underwater because the traps continue to catch fish for many months or years, a process known as ghost fishing. The life cycle of reef fish also makes them vulnerable to fishing pressure. Fishers selectively remove larger organisms because of their greater value, and one typical sign of overfishing is a decline in average size of target species. Because the largest individuals have the greatest reproductive output, removing them from the population reduces replenishment of the stock.[44]

Another particularly damaging form of overfishing in the Caribbean has been the targeting of spawning aggregations. Several of the larger grouper and snapper species, from areas spanning several hundred square kilometers, congregate at known localities once or twice a year to spawn in vast numbers. Where fishers know the location of such spawning aggregations, they can remove the entire population of a species over the course of just a few nights.

In heavily fished reef systems, the large, valuable fish—such as groupers and snappers—become so scarce that people fish for lower-valued species[45] (termed "fishing down the food web"). For example, in Bermuda herbivorous reef fish (e.g., parrotfish, surgeonfish, and triggerfish) increased from less than 1 percent of the catch in the 1960s to 31 percent in the 1990s. The shift led to a ban on fish traps in 1990 that is still enforced.[46]

Overfishing not only affects the size of harvestable stocks but can lead to major shifts, direct and indirect, in community structure, both of fish species and reef communities as a whole.[47] In the competition for space between corals and algae, herbivorous fish help to control algae, thus favoring the growth and recruitment of corals.[48] When the herbivores are removed, algae can flourish and coral cover is reduced. This effect is evident in the sequence of events that led to the dramatic decline of Jamaica's reefs *(see Box 2)*. Overfishing can lead to short-term losses in biodiversity, the loss of species with critical roles in the ecosystem, and may also lower the resilience of the reef to other threats.

Modeling results. The Reefs at Risk indicator for the overfishing threat identified highly populated areas and areas where coastal shelves are narrow (such as in the Eastern Caribbean) as being under high threat, based on the large numbers of fishers and relatively small fishing area *(see Map 6)*. The analysis estimated that fishing pressure is lower in the Bahamas, where the human population is small. In the western Caribbean and Cuba, where many reefs are far from the mainland, the analysis also rated the threat as low.

It should be noted that this indicator does not capture fishing pressure from more remote locations or illegal fishing *(see Chapter 2 - "Limitations of the Analysis" and Table 1)*. In the region as a whole, the study identified about 60 percent of reefs as threatened by overfishing (with about 30 percent each under medium and high threat). Destructive fishing practices (e.g., use of dynamite or cyanide) were not evaluated for the Caribbean, as they are rarely practiced in the region. The destructive impact of trap fishing and of lost fishing nets entangling reefs should be noted. To a broad approximation, these are likely to follow the patterns of fishing pressure as a whole.

Remedies. Effective management of coastal resources is crucial, especially along densely populated coastlines. Less intensive fishing will allow the fisheries resource to build up to the point where the harvest is balanced with the natural replenishment of the population.[49] Financial and other incentives can encourage sustainable fishing practices, while fines and penalties discourage illegal fishing and other breaches of sustainable practices. Licensing new fishers helps limit access to fisheries currently vulnerable to overfishing. Legal systems can also be put in place to restrict the catch of species subject to severe overfishing, such as the bans on all takings of selected conch species instituted in several

BOX 2. JAMAICA'S REEFS – BACK FROM THE BRINK?

Overfishing in Jamaican waters can be traced back over 100 years, with the capture of not only the large predators but also of most of the herbivorous, algal-grazing fish. This reduced the resilience of the reef ecosystem, and it became highly dependent on a single species, the long-spined sea urchin, to keep algal levels down. The reefs were smashed by Hurricane Allen in 1980, but began slowly to recover, with the grazing urchins playing a critical role in keeping down the algae so new corals could settle. Then in 1983 the urchins were all killed by a disease. With overfishing still rampant, there were no major grazers left. The already-established corals could survive, but algal levels began to rise. In 1988 Hurricane Gilbert struck the island, once again devastating the corals. At this point, the algae flourished, perhaps helped by the high levels of nutrient pollution in the water, and clearly benefiting from the lack of any grazers. A "phase shift" occurred in which the coral reefs were largely replaced by algal ecosystems. Between 1977 and 1993, live coral cover declined from 52 percent to 3 percent, and fleshy algae cover increased from 4 percent to 92 percent. The reasons for the change are complex and multiple: overfishing, disease, and two hurricanes, perhaps exacerbated by nutrient pollution.[a] But, recent monitoring provides some signs of hope – return of sea urchins, decreased algal cover and increasing coral cover in a few locations.[b] Increased coastal management efforts and resilience in the system are likely contributing to this modest recovery.

Notes:

a. T.P. Hughes et al. (2003).

b. J. Mendes, J.D. Woodley, and C. Henry, "Changes in Reef Community Structure on Lime Cay, Jamaica, 1989–1999: The Story Before Protection." Paper presented at the International Conference on Scientific Aspects of Coral Reef Assessment, Monitoring, and Restoration, Fort Lauderdale, Florida, 14–16 April 1999; L. Cho and J. Woodley, "Recovery of Reefs at Discovery Bay, Jamaica and the Role of *Diadema antillarum*." Paper presented at the 9th International Coral Reef Symposium, Bali, Indonesia, 23–27 October 2000.

MAP 6. REEFS THREATENED BY OVERFISHING

Threats to coral reefs from overfishing were evaluated based on coastal population density adjusted by the shelf area (up to 30 m depth) within 30 km of the reef. The management effectiveness of marine protected areas (MPAs) was included as a factor mitigating threat to reefs inside their boundaries. The analysis was calibrated using survey observations of coral reef fish abundance. (*See Box 3 in Chapter 4 and Table A5 in Appendix A.*)

Source: WRI, *Reefs at Risk in the Caribbean*, 2004 (*see Appendix B*).

Caribbean countries. Other controls limit the numbers caught, the size of individuals that may be taken (to ensure that individuals can reach breeding age), or the fishing gear used (for example, several countries now require the use of biodegradable panels in fish traps to avoid "ghost fishing" by lost traps). Seasonal restrictions can be used to protect species as they spawn. One of the most important tools, increasingly recognized and put into practice across the Caribbean, is the total closure of areas to fishing. Such "no-take zones" provide fish with a refuge, allowing spawning stocks to build up and adults to spill over into the surrounding waters. These zones have been shown to greatly increase overall catch levels from wider reef ecosystems.[50]

CLIMATE CHANGE

The rapid buildup of greenhouse gases (GHGs) in the atmosphere during the past century has already altered the global climate. GHG concentrations have grown by more than a third since pre-industrial times and, without significant policy intervention, are expected to reach double pre-industrial levels by the end of the twenty-first century.[51] The average temperature of the Earth has risen by 0.6°C to

0.8ºC in the last 100 years, and the global average sea level has risen some 18 centimeters (cm).[52] The impacts of these basic changes have not been fully determined, but could alter patterns of surface currents and upwellings, the location and intensity of extreme climatic events, and chemical processes in the oceans (associated with elevated levels of dissolved carbon dioxide).[53] The following sections describe some of the ongoing and projected impacts of climate change on coral reefs in the Caribbean.

Coral bleaching

The most direct evidence of the impact of climate warming on Caribbean marine biodiversity has been widespread "bleaching" of its reef-building corals. Currently, scientific uncertainties preclude incorporation of climate change or coral bleaching into the Reefs at Risk model. These phenomena must, however, be recognized as important threats to coral reefs in the Caribbean.

Bleaching refers to the loss of a coral's natural color (often hues of green and brown) caused by the expulsion of symbiotic algae *(zooxanthellae)*, leaving the coral very pale to brilliant white in appearance. Bleaching can be a response to many different stresses, including salinity changes, excessive light, toxins, and microbial infection, but increases in sea surface temperature (SST) are the most common cause of bleaching over wide areas.[54] Coral bleaching in the Caribbean is usually triggered by an increase of at least 1.0ºC in SST above the normal summertime maximums with a duration of at least 2 to 3 days.[55]

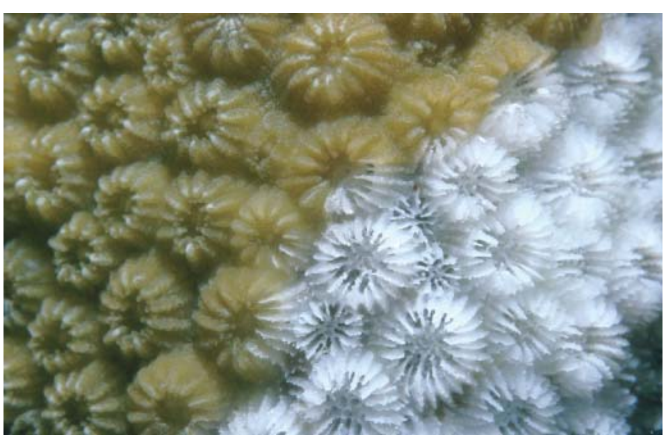
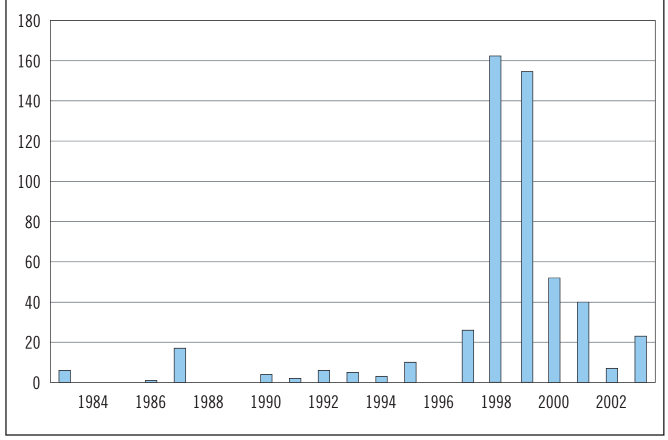


PHOTO: ED GREEN

In response to stress, corals expel their symbiotic algae (*zooxanthellae*) leaving them bleached in appearance. Bleached corals can recover and regain their color, but in more severe cases many die.

FIGURE 1. NUMBER OF REPORTED BLEACHING OBSERVATIONS BY YEAR



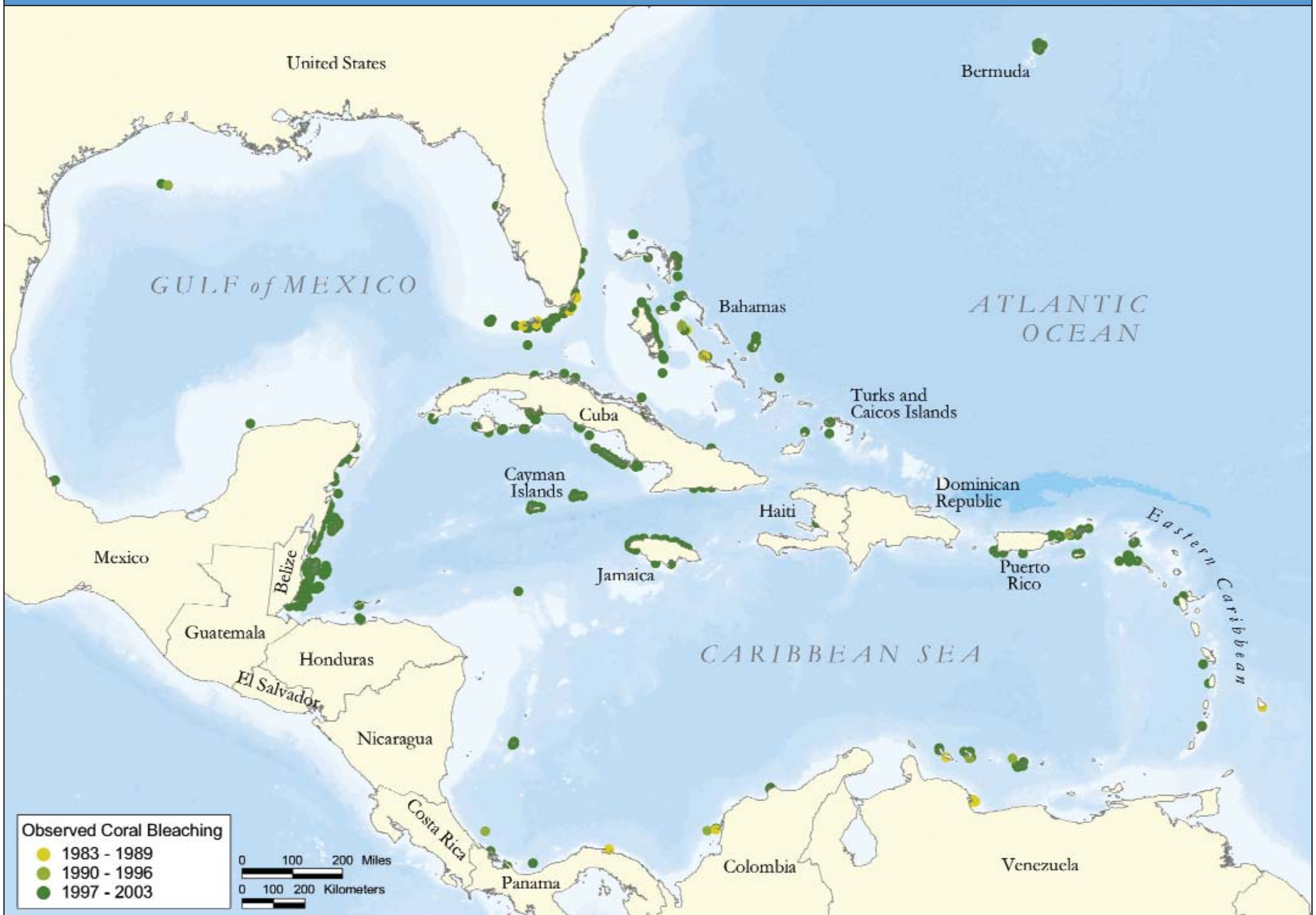
In mild events, bleaching is transient, and corals regain their color (algae) within months with little apparent mortality. In more severe cases, many of the corals die. Post-bleaching surveys have shown that some coral species have higher rates of mortality than others.[56] Repeated bleaching events in the Caribbean over the past decades have caused widespread damage to reef-building corals and contributed to the overall decline in reef condition.[57]

No incidents of mass coral bleaching were formally reported in the Caribbean before 1983.[58] Since the early 1980s, however, more than 500 observations have been reported *(see Map 7 and Figure 1)*.[59] One of the earliest incidences was during the 1982–83 El Niño Southern Oscillation (ENSO), while another major bleaching event occurred in 1987, during an ENSO.[60] Further bleaching incidents were recorded at various locations through the 1990s. In 1998, the highest average maximum SSTs on record in the Caribbean/Atlantic coincided with a large ENSO[61] and extensive areas of the Caribbean experienced bleaching at this time, with particularly severe occurrences in the Bahamas and Western Caribbean.[62]

Predicting Future Bleaching Threat

The conditions under which coral reefs have thrived in the Caribbean for millennia are rapidly changing. Global climate models predict that, by 2070, atmospheric temperatures in the Caribbean region will rise between 2°C and 4ºC, with large changes in the northern Caribbean and

MAP 7. CORAL BLEACHING OBSERVATIONS



Observations of coral bleaching in the Caribbean are widespread. Of the over 500 observations in recent decades, 24 were during the 1980s, over 350 during the 1990s, and over 100 since 2000. The increase in recorded incidents reflects both rising sea surface temperatures and greater awareness and communication of coral bleaching events.

Source: Reefbase, "Coral Beaching Dataset," download from http://www.reefbase.org on 10 August 2004.

around the continental margins.[63] Because current SST levels are near the upper temperature thresholds for survival of corals, bleaching is predicted to become an annual event in the Caribbean by 2020.[64] The long-term survival of shallow-water corals may depend on their ability to adapt to changing temperatures, and research suggests that some corals take on more heat-tolerant algae after bleaching, allowing them to be more resistant to future thermal stress.[65] Also, ocean circulation might allow coral species with higher temperature tolerances to migrate into warming areas.[66]

During the major bleaching events to date, localized areas with less incidence of bleaching have been observed, notably areas of deeper water as well as areas of greater water circulation. Scientists cannot currently predict specific patterns of ecosystem tolerance or cross-regional variation in temperature changes. Widespread monitoring and sharing of information on both patterns of bleaching and recovery are essential to improving our understanding of this very important, overarching threat to Caribbean coral reefs.

Hurricanes and Tropical Storms

Most of the Caribbean lies within the hurricane belt. High-intensity tropical storms develop over areas of warm sea water during the summer months and can sweep across the region, with devastating consequences on land and sea. The largest such storms can drive up waves over 16 meters in height, pounding coastal waters and smashing many shallow reefs to rubble. The high rainfall associated with storms often results in increased sedimentation around reefs close to shore or near river mouths. These are natural events from which coral reefs can recover, though recovery of the most severely damaged reefs may take a decade or two after the fiercest storms.

From 1995 to 2000, the Caribbean region experienced the highest level of hurricane activity in the reliable record. However, this followed a period of lower-than-average storm activity.[67] Climate models cannot yet accurately project how the frequency and intensity of hurricanes will change.[68] If, as models are refined, they point to the likelihood of increasing storm intensity, this should be cause for concern, particularly when added to the mounting pressures on coral reefs from marine and terrestrial pollution and coral disease.

Sea-Level Rise

Over the next century, mean global sea level is predicted to rise about 3 to 10 cm per decade.[69] The Intergovernmental Panel on Climate Change (IPCC) has concluded that such rates of sea-level rise would not pose a major threat to coral reefs.[70] Healthy reef ecosystems have the potential to respond to a rising sea through reef accretion, that is, the upward growth of the reef as corals lay down their calcium skeletons.[71] However, the situation is less clear for reefs already degraded by or under stress from other threats, as well as for associated seagrass and mangroves growing in low-lying coastal zones.[72]

Reduced Calcification Potential

Rising levels of atmospheric carbon dioxide (CO_2) are beginning to alter the chemistry of the shallow ocean.[73] Higher concentrations of dissolved CO_2 increase the acidity of this surface water, in turn affecting the solubility of other compounds. One such compound, known as aragonite, is used by the corals in reef building. Aragonite levels are currently falling, and reductions in the ability of corals to build reefs by laying down their limestone skeletons are becoming evident. This points to a slowdown or reversal of reef building and loss of reef in the future.[74]

Outlook for Reefs under a Changing Climate

Most scientists agree that corals' ability to adapt to shifting environmental conditions resulting from climate change depends on the severity of other human stresses, such as overfishing, coastal development, and land-based sources of pollution. Reef areas not subject to these other threats are likely to be more resilient than those that are heavily stressed. Management efforts can be directed toward reducing localized stress. A key management tool will be the siting of marine protected areas (MPAs). Ideal areas for prospective MPAs include those that might be resistant to coral bleaching (because of depth, greater water circulation, or shading) or areas with good potential for recovery (downstream from a coral larvae source). International efforts under agreements such as the Convention on Biological Diversity and the Framework Convention on Climate Change can leverage political and financial responses to the problems.[75] At the same time, curbing excessive CO_2 emissions is essential to reducing the long-term threat.

DISEASE

Perhaps the most profound and widespread changes in Caribbean coral reefs in the past 30 years have been caused by diseases of corals and other organisms. In recent decades, an unprecedented array of new diseases has emerged, severely affecting coral reefs. Most observations of coral reef disease reported across the globe have come from the Caribbean region.[76] Prominent among these reports have been the Caribbean-wide die-off of the long-spined black sea urchin *Diadema antillarum*;[77] widespread losses of major reef-building corals (staghorn and elkhorn) due to white band disease;[78] the current widespread occurrence of aspergillosis, a fungal disease that attacks some species of gorgonians (sea fans);[79] and numerous outbreaks of white plague.[80]

The Global Coral Disease Database[81] includes 23 differently named diseases and syndromes affecting corals alone in the Caribbean. Three of these diseases—black band disease, white band disease, and white plague—account for two-thirds of the reports in the database and affect at least 38 species of corals across the Caribbean (*see Map 8*). The impact of coral disease varies according to a variety of factors; a disease can cause different levels of mortality in different years at the same location.

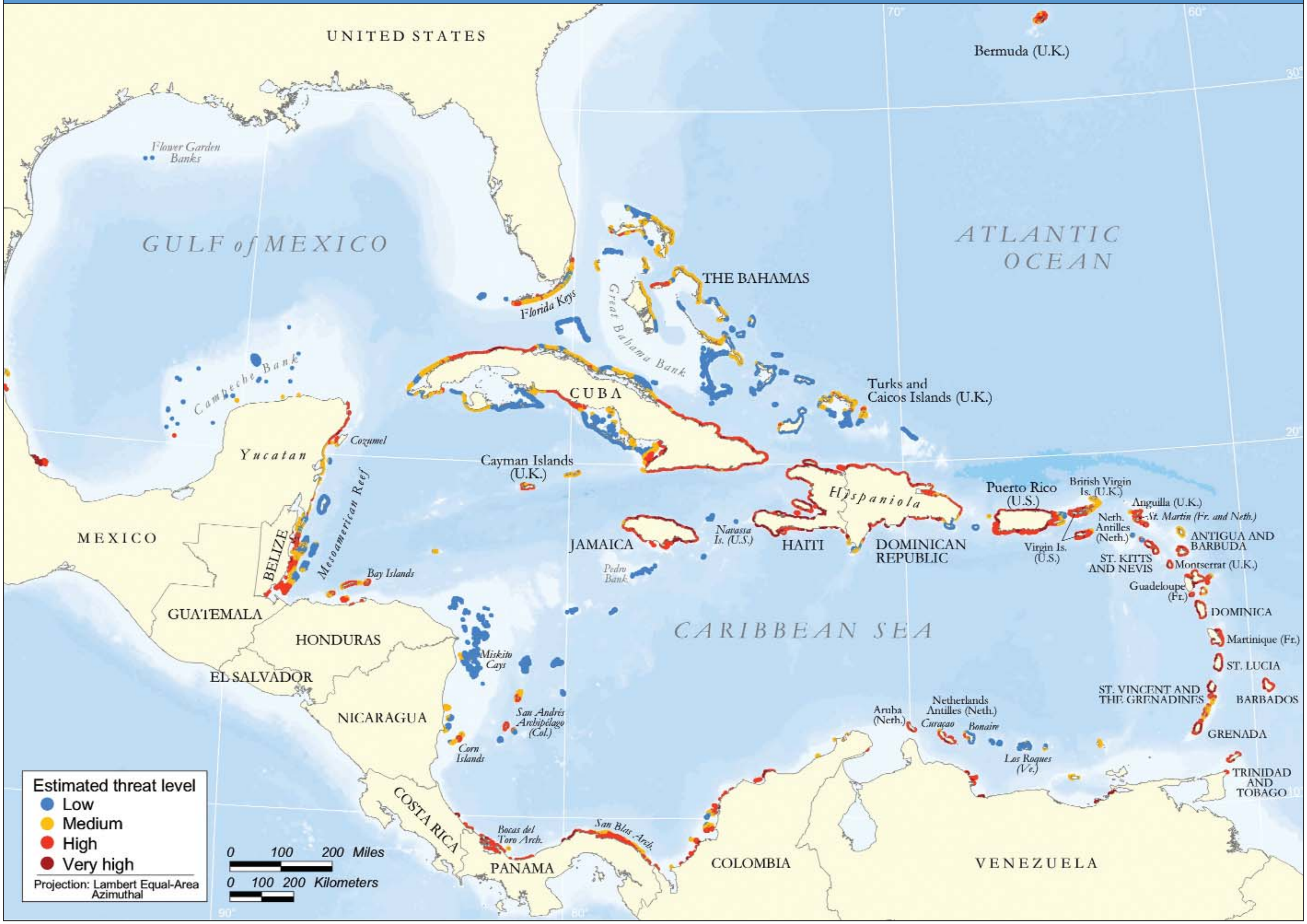
The reasons for this sudden emergence and rapid spread of reef diseases throughout the Caribbean are not well understood. Diseases have been observed all across the Caribbean, even on the most remote coral reefs, far from human stresses.[82] Almost nothing is known about the causal agents; indeed, pathogens have been identified for only three of the 23 diseases observed in the region.[83] Linkages to other sources of stress to reefs (e.g., sedimentation or pollution) are poorly understood and the role of human activities in bringing these diseases into the region is also unclear. At least one pathogen seems related to desertification in Africa, blown with dust across the Atlantic,[84] while the pathogen responsible for the die-off of the long-spined sea urchin may have been transported into the region via the Panama Canal in ballast water from ships.[85] More research and integrated environmental monitoring are needed to better understand and help predict this major, widespread threat to coral reefs.

MAP 8. CORAL DISEASE OBSERVATIONS

Most reported observations of coral disease worldwide have been in the Caribbean. Three diseases occurring widely in Caribbean coral are black band, white band, and white plague. Reporting of disease occurrences is limited by the distribution of monitoring activities in the region.

Source: Global Coral Disease Database, United Nations Environment Programme - World Conservation Monitoring Centre, 2001.

MAP 9. INTEGRATED THREAT — THE REEFS AT RISK THREAT INDEX



Source: WRI, *Reefs at Risk in the Caribbean*, 2004 (*see Appendix B*).

TABLE 2. REEFS THREATENED BY HUMAN ACTIVITIES

							Individual Threats[b]											
			Reefs at Risk Threat Index[a] (%)				Coastal Development (%)			Sediment and Pollution from Inland Sources (%)			Marine–Based Sources of Pollution (%)			Fishing Pressure (%)		
Country/Territory	Reef Area (km^2)	Reef Area as % of Total in Region	Low	Medium	High	Very High	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
Anguilla	70	< 1	0	11	89	0	33	33	34	99	1	0	100	0	0	0	11	89
Antigua and Barbuda	180	< 1	0	39	51	11	29	55	16	71	29	0	71	18	11	0	39	61
Aruba	25	< 1	0	0	85	15	0	28	72	100	0	0	26	48	26	0	0	100
Bahamas	3,580	14	75	24	2	0	95	5	0	100	0	0	99	1	0	78	21	1
Barbados	90	< 1	0	0	86	14	0	20	80	40	60	0	85	15	0	0	6	94
Belize	1,420	5	37	29	32	2	89	11	0	51	20	29	92	8	0	63	30	7
Bermuda	210	< 1	0	20	61	19	51	20	29	100	0	0	38	34	28	0	25	75
British Virgin Islands	380	1	3	62	25	10	54	29	18	83	17	0	76	16	7	4	77	19
Cayman Islands	130	< 1	17	57	26	0	35	43	22	100	0	0	99	0	0	17	63	20
Colombia	2,060	8	56	24	19	1	86	7	7	76	16	8	97	3	0	61	25	14
Costa Rica	30	< 1	0	0	77	23	14	62	24	0	0	100	77	0	23	0	77	23
Cuba	3,290	13	32	32	33	3	78	14	7	71	20	8	92	7	1	32	35	33
Dominica	70	< 1	0	0	63	37	4	49	47	0	25	75	86	10	4	0	0	100
Dominican Republic	1,350	5	18	8	63	10	41	22	37	55	24	21	90	6	4	21	11	68
Grenada	160	< 1	0	20	41	40	15	22	63	43	27	30	76	14	9	0	37	63
Guadeloupe[c]	400	2	0	15	66	18	15	33	52	55	31	13	73	23	4	1	28	71
Guatemala	0	0	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Haiti	1,260	5	0	0	45	55	8	33	59	1	8	91	92	7	0	0	0	100
Honduras	1,120	4	66	13	21	0	75	11	14	90	7	3	94	5	1	70	24	5
Jamaica	1,010	4	32	2	34	32	45	24	32	39	19	42	69	24	7	32	2	67
Martinique	260	1	0	0	65	35	9	43	48	2	79	19	62	31	8	0	0	100
Mexico	1,220	5	50	20	20	10	70	15	15	86	2	12	83	10	7	51	29	20
Montserrat	25	< 1	0	0	71	29	8	81	11	0	30	70	24	47	29	0	100	0
Netherlands Antilles North[d]	40	< 1	48	21	31	0	59	41	0	76	24	0	65	9	26	72	27	1
Netherlands Antilles South[e]	210	< 1	37	15	39	9	57	27	15	100	0	0	55	19	26	64	4	32
Nicaragua	870	3	86	11	2	0	96	2	2	99	1	0	99	1	0	86	14	0
Panama	1,600	6	0	16	75	10	80	12	8	0	18	82	64	28	8	0	98	2
Puerto Rico	1,610	6	7	8	59	25	46	30	24	37	32	31	72	20	8	9	8	84
St. Kitts and Nevis	160	< 1	0	0	77	23	5	67	28	0	81	19	74	15	11	0	3	97
St. Lucia	90	< 1	0	0	39	61	1	32	67	0	51	49	60	29	11	0	2	98
St. Vincent and the Grenadines	140	< 1	0	38	48	14	36	29	35	84	0	16	71	19	10	0	59	41
Trinidad and Tobago	40	< 1	0	0	99	1	1	46	52	13	87	0	99	1	0	0	31	69
Turks and Caicos Islands	1,190	5	50	46	4	0	87	9	4	100	0	0	98	2	0	51	49	0
United States	840	3	38	48	14	0	57	31	11	100	0	0	97	3	0	42	56	3
Venezuela	230	< 1	57	16	11	16	68	16	16	73	0	27	86	8	6	64	14	22
Virgin Islands (U.S.)	590	2	0	9	73	18	42	39	18	66	34	0	57	22	22	0	13	87
Regional Total	**25,960**	**100**	**36**	**21**	**33**	**10**	**67**	**17**	**16**	**66**	**15**	**20**	**87**	**10**	**4**	**39**	**29**	**32**

SOURCE:
WRI, *Reefs at Risk in the Caribbean*, 2004.

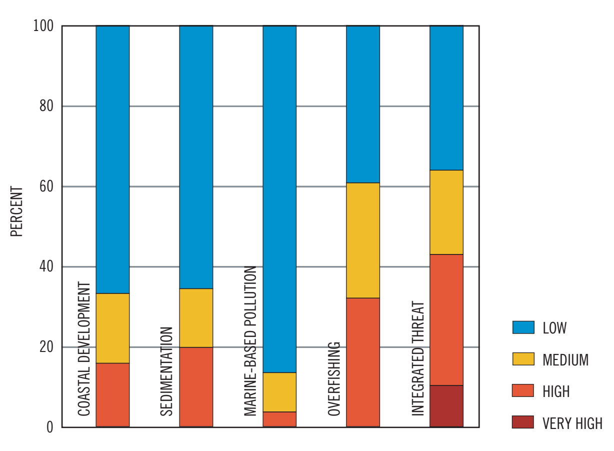
NOTES:
a. The Reefs at Risk Threat Index reflects cumulative threat from four individual threats at a single location. In areas where three or four of the threats were rated as high, the index is set to very high.
b. In the analysis, individual threats are classified high, medium, or low. Threats sum to 100%.
c. Guadeloupe includes the French islands of St. Martin and St. Barthelemy.
d. Netherlands Antilles North includes the islands of St. Maarten, St. Eustatius, and Saba.
e. Netherlands Antilles South includes the islands of Bonaire and Curaçao.

INTEGRATING THREATS: THE REEFS AT RISK THREAT INDEX

Around the world, but perhaps especially in the Caribbean, coral reefs are threatened from a multitude of sources. Quite often, a reef is sufficiently robust to survive a low level of threat from a single source. In many cases, however, reefs are subject to multiple stresses, and the combined, low-level impacts from multiple sources can drive reefs into steep decline. One of the best examples of such combined impacts can be seen in Jamaica's reefs. *(See Box 2.)*

Of the four threats modeled in this study, the most pervasive direct human threat to coral reefs is overfishing, threatening over 60 percent of the region's reefs. Pressures associated with coastal development and sedimentation and pollution from inland sources each threaten about one-third of the region's coral reefs. About 15 percent of the region's reefs are threatened by marine-based sources of pollution. *(See Figure 2 for a summary of these threats.)*

FIGURE 2. REEFS AT RISK BY CATEGORY OF THREAT



When these four threats are integrated into the Reefs at Risk Threat Index, nearly two-thirds of the region's coral reefs are threatened by human activities (about 20 percent at medium threat, one-third at high threat, and 10 percent at very high threat).[86] *(See Map 9.)* Areas with high threat levels include the Eastern Caribbean, most of the Southern Caribbean, Greater Antilles, Florida Keys, Yucatan, and the nearshore portions of the Mesoamerican Barrier Reef and the Southwest Caribbean. In areas identified as threatened, degradation of coral—including reduced live coral cover, increased algal cover, or reduced species diversity—may have already occurred. If not, it is considered likely to occur within the next 5 to 10 years.

In addition to these chronic threats, for which we were able to develop indicators, coral reefs are also affected by the currently less predictable threats of coral disease and coral bleaching. As ocean temperatures warm, increased incidence of coral bleaching can be expected, with some associated mortality. Also, trends over the last decade indicate that coral diseases may persist, or even proliferate—often after coral bleaching events, in response to new pathogens, or possibly in high-pollution or sediment-stressed areas. Taken together, coral diseases and bleaching are significant, region-wide threats that should be taken into account when considering the Reefs at Risk results. All told, the highly valued coastal resources of the region are severely endangered.

No coral reef is guaranteed immunity from the threats of bleaching, disease, or plunder from excessive fishing, but some reefs are at lower risk from land-based threats and from coastal fishing pressures. In several parts of the Caribbean, the analysis identified extensive tracts of reefs as being under low threat from the human activities evaluated. These include areas in the Bahamas, Turks and Caicos Islands, archipelagos off Colombia and Nicaragua, and some reefs off Cuba, Belize, and Mexico. Such areas may still have suffered from coral disease and bleaching, and some have also been targeted for the capture of high-value fish stocks, but overall they are likely to be in a relatively healthy state and may be important refuges for the wider region. Table 2 presents summary statistics by country for each threat examined.

The cumulative threat to reefs from these four categories demonstrates that, to manage development in the coastal zone and all the complex issues associated with it, a holistic, cross-sectoral approach is ideal. In Chapter 6, we discuss some of these management needs and the principle of Integrated Coastal Zone Management. In Chapter 4, threats around nine Caribbean sub-regions are examined in more detail.