USGS
science for a changing world

Science-Based Strategies for Sustaining Coral Ecosystems

Coral ecosystems and their natural capital are at risk. Greenhouse gas emissions, overfishing, and harmful land-use practices are damaging our coral reefs. Overwhelming scientific evidence indicates that the threats are serious, and if they are left unchecked, the ecological and social consequences will be significant and widespread. Although the primary stressors to coral ecosystems are known, science-based strategies are needed to more accurately explain natural processes and forecast human-induced change. Collaborations among managers and scientists and enhanced mapping, monitoring, research, and modeling can lead to effective mitigation plans. U.S. Geological Survey scientists and their partners assess coral ecosystem history, ecology, vulnerability, and resiliency and provide study results to decisionmakers who may devise policies to sustain coral resources and the essential goods and services they provide.

Introduction

Nearly 25 percent of all marine life is linked directly to coral ecosystems, often in complex biogeochemical pathways and food webs (fig. 1). Moreover, millions of people rely on coral ecosystems for the food, shoreline protection, income, recreation, and cultural values that these diverse, productive marine communities can supply. The provision of such natural goods and services is often taken for granted, but if trends observed over the past 30 years persist, the natural capital inherent in our coral ecosystems–worth hundreds of billions of dollars–will be lost over the coming decades. An estimated 20 percent of the world's coral reefs are already damaged, perhaps beyond restoration, and recent assessments of reef health show continued downward spirals (Carpenter and others, 2008).

Coral ecosystems include shallow, sunlit coral reefs in tropical regions (which are the focus of this Fact Sheet) and deepwater or cold reefs. Shallow coral ecosystems, which include coral reefs and associated mangrove and seagrass habitats, are vulnerable to a variety of stressors. At the local to regional level, corals and their associated plant and animal communities show the effects of disease and degradation from overfishing, coastal developments, and changing land-use practices within watersheds that introduce sediment runoff and other pollutant discharges. On a global level, atmospheric emissions of greenhouse gases are causing ocean temperatures to increase, pH levels to decrease (resulting in ocean acidification), and sea levels to rise, according to the U.S. Global Change Research Program (Karl and others, 2009). Most corals are intolerant of increased temperature and lower pH. Depending on the rate of sea-level rise, the growth of coral reefs may not keep pace with rising sea levels. Business-as-usual scenarios that project increasing carbon dioxide concentrations in the atmosphere and oceans from burning fossil fuels and deforestation portend unprecedented changes in the distribution, abundance, and survival of coral communities and life in the global oceans (Intergovernmental Panel on Climate Change, 2007).

Figure 1. A healthy reef requires moderate water temperatures, clear and clean water, and a complex suite of interacting microbes, plants, and animals, including herbivorous and predatory species. Healthy coral reef ecosystems provide essential goods and services. Photograph by Gary Brewer, USGS.

Working with Partners to Identify Research Priorities

U.S. Geological Survey (USGS) scientists work with other Department of the Interior bureaus, other Federal agencies, the U.S. Coral Reef Task Force, academic institutions, and nongovernmental organizations to guide research directions and prioritize studies. The USGS coral ecosystem research priorities are described in a Strategic Coral Plan (USGS, 2007). USGS scientists organize workshops with partners to set research priorities, and they help plan and conduct field and laboratory analyses (fig. 2). The results of such carefully designed research are shared with partners and resource managers so they can manage and plan for environmental change.

The USGS applies these data through models and forecasting tools that enable managers to test hypotheses and create simulations for areas beyond studied coral reefs. Modeling enables researchers to extrapolate results and draw reasonable inferences about the causes and consequences of environmental change. When these models are combined with hydrodynamic, climatic, and socioeconomic models, robust forecasts can be made of how various management scenarios might affect biological and human communities. Models, in combination with ongoing research and monitoring, provide scientists

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and managers with the means to "experiment" with different management options, make refinements, and respond adaptively as environmental conditions change. Such research requires diverse mapping, monitoring, and field and laboratory research to adequately explore the structure, function, and natural history of coral ecosystems, the ability of such ecosystems to tolerate stressors and climatic change, and the complex ecological relations of indicator species living on the reefs.

Linking Science with Management Needs: A Multiscale Approach

Concerns exist that local coral reef conservation efforts (reducing overfishing, pollutants, contaminants, and habitat losses) may be overwhelmed by global factors beyond local control (ocean temperature increases, sea-level rise, and ocean acidification). These concerns underscore the need for scientists to provide data at various scales for managers to use in designing holistic solutions. While mitigation of global factors requires larger scale societal changes at longer time scales, local management changes can be designed to promote resiliency by managing for a healthy ecosystem, potentially allowing some species to adapt to climate change. Science can help local communities and resource managers address and reduce overfishing, harmful land-use practices, and watershed impacts that reduce biodiversity, damage coral habitat, and disrupt fundamental biogeochemical pathways such as those that affect the food web. If the resiliency threshold has not been crossed, some restoration may be possible, although recovery may take much longer than degradation took.

The USGS aims to provide scientific understanding of the natural processes and human activities that influence the development and sustainability of U.S. coral reefs. The USGS promotes partnerships and collaborations among marine scientists, social scientists, environmental economists, and resource managers, thereby informing and enabling decisionmakers with knowledge, forecasts, and decision-support tools.

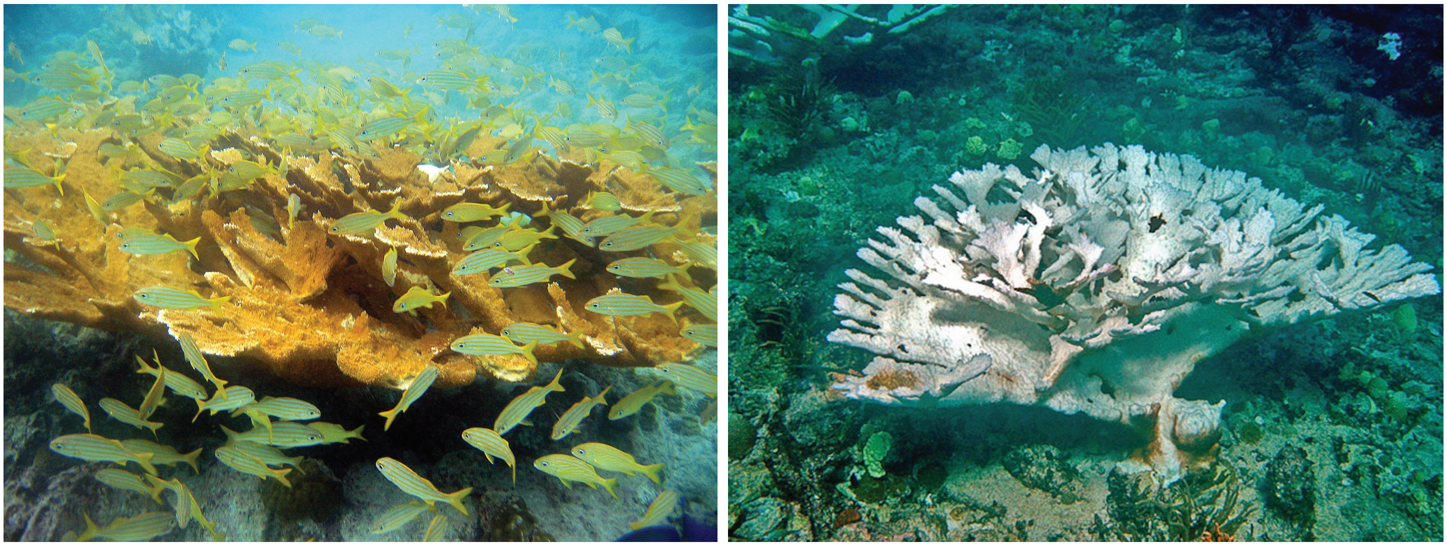
Figure 2. USGS scientists monitor changes in reef communities. Photograph by Caroline Rogers, USGS.

USGS Researchers Address Broad Topics

As societies at local, regional, and global levels address questions about climate change and resource sustainability, coral-reef ecosystems are particularly well suited for study as indicators for understanding links between human activities and resource management. Coral reef structures record historical environmental conditions and provide clues about how human activities influence the ocean's physical and chemical properties, including relative sea level and trends in ocean temperature, pH, currents, nutrients, and anthropogenic contaminants. These properties, together with the variable use, extraction, and protection of reef resources, will largely determine the future of coral ecosystems. USGS researchers seek to understand such complex interactions and the interrelated global- to local-scale management issues and information needs described below.

Carbon sequestration.—The global problem of increasing greenhouse gas emissions has inspired USGS scientists to assess the feasibility of capturing and sequestering carbon dioxide. These efforts include evaluating (1) biological techniques to remove carbon from the atmosphere by increasing photosynthesis with the growth of more plants and trees and (2) physical techniques that capture carbon dioxide (such as that from coal- and gas-fired powerplants) and inject it permanently into natural subterranean reservoirs. Marine systems, and particularly coral reefs, will be increasingly susceptible to unchecked greenhouse gas emissions that raise ocean temperatures and sea level while lowering ocean pH levels. Corals represent an early-warning system for gaging incipient and long-term climate change impacts.

Ocean temperature.—USGS scientists are exploring the relations among high water temperatures, coral bleaching, and coral disease. USGS and National Park Service biologists documented a severe coral bleaching event in the fall of 2005, coincident with the warmest ocean waters ever recorded in the Caribbean. Coral bleaching results in the breakdown of a symbiotic dependency between corals and colorful microscopic-sized algae. The algae live within the coral tissue, providing corals with nutrition they derive from photosynthesis. The bleaching occurs when the corals expel the algae, leaving white coral tissues visible (fig. 3). Over 60 percent of the living coral cover was lost within the Virgin Islands National Park to an outbreak of diseases that followed the 2005 bleaching event (Miller and others, in press). Scientists continue to monitor the long-term response of bleached and diseased elkhorn coral (listed as threatened under the Endangered Species Act) and other species in the U.S. Virgin Islands. Ongoing research in the Virgin Islands and American Samoa will help explain why some corals bleach and others do not; in general, bleaching is variable, even within the same species at the same location. USGS scientists are exploring the mechanisms (such as genetic adaptation, physiological acclimatization, microbial interactions) by which some corals and their algal symbionts tolerate high temperatures and high levels of sunlight. Such knowledge is fundamental to protecting the most tolerant coral colonies and sustaining coral reefs in the future. Natural resource agencies



A *B*

Figure 3. Elkhorn coral colonies in the U.S. Virgin Islands showing (*A*) normal coral and (*B*) bleached coral. Photographs by Gary Brewer, USGS.

need reliable models that forecast shifts in the abundance and distribution of plants, animals, invasive species, and pathogens in response to changing water temperatures.

Ocean acidification.—Coral polyps use calcium from seawater to create their hard skeletons in a process called calcification. Experimental and modeling studies indicate that increases in atmospheric carbon dioxide will significantly affect coral reef growth during this century because of increasing ocean acidification (lower pH) and the resulting decrease in calcification rates by reef organisms. By using incubation chambers and other analytical equipment in reef study areas, the USGS and partnering agencies are measuring baseline rates of calcification, metabolism, growth, and accretion/dissolution of selected corals and coral communities. The goal is to estimate future reef conditions under elevated levels of carbon dioxide, lower pH, and higher temperatures that were forecast by the Intergovernmental Panel on Climate Change (2007).

Sea-level rise.—Warming oceans and melting land ice contribute to rising sea levels. Understanding rates of sea-level rise and rates of coral reef growth will allow scientists to estimate whether corals will keep pace with rising seas. With sea level rising, coral reefs that protect shorelines and human infrastructure from storm waves and erosion may no longer be effective. Communities that inhabit low-lying islands and coastlines may have few options other than relocation. As noted above, USGS scientists are studying how the growth of coral reefs responds to changing temperatures and pH. In addition, our scientists use high-resolution bathymetric and topographic maps and knowledge of subsidence and uplift to describe and forecast shoreline change and associated ecosystem and human vulnerabilities.

Reef history.—As corals grow, they record environmental data in their skeletons. USGS scientists use long-lived corals and coral fossils to reconstruct past environmental conditions that put recent coral reef declines in historical context and enable the development of reliable forecasting tools. The physical characteristics (such as growth bands) and chemical composition of coral skeletons record changes in ocean temperatures, salinity, pH, productivity, sedimentation, and rates of sea-level change. Combined with climate models, these records are providing clues to understanding the future condition of marine systems broadly and coral reefs specifically.

Atmospheric dust.—Billions of tons of soils are eroded from the Earth's surface each year, transported sometimes thousands of miles by prevailing global wind systems, and eventually deposited at downwind locations. This natural process fertilizes both ocean and terrestrial ecosystems with growth-enhancing nutrients, but the dust also carries living microorganisms, as well as pollutants and contaminants, some of which are synthetic and new. Hotter and dryer conditions related to climate change in Africa, Asia, and other source regions may be increasing rates of soil erosion and downwind deposition. USGS scientists and collaborators are studying how these complex mixtures of soil particles, microbes, and chemicals influence coral reef processes. Potential relations between coral disease and algal growth in response to various constituents in the dust (including microbial pathogens and micronutrients such as iron) are of particular interest.

Land-derived impacts.—Coral reefs are affected by the runoff of sediments and associated chemicals and pollutants from nearby landmasses (fig. 4). To understand linkages between land-use changes in watersheds and their effects on runoff and adjacent coral reefs, USGS researchers and colleagues used an integrated approach to study the reefs of Moloka`i, Hawaii, combining geology, oceanography, and biology. These efforts resulted in a landmark publication (Field and others, 2008), which includes insights about watershed management. The approach used in the Moloka`i study is now being applied to other sites in Hawaii and the Pacific that have similar management needs.

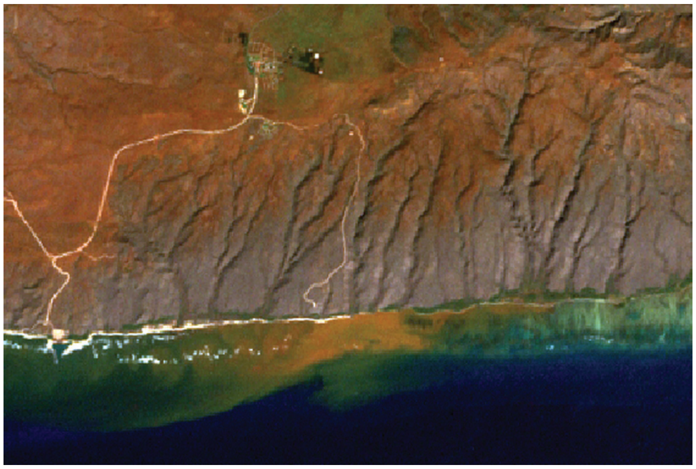


Figure 4. Image of Moloka`i, Hawaii, showing runoff from the land; sediments, pollutants, and contaminants in the runoff degrade coral reefs. Image by Susan Cochran (USGS) from a data image supplied by the National Aeronautics and Space Administration (NASA).

Pathogens and disease.—Although disease is known to be a major cause of coral mortality (fig. 5), the transition from healthy to distressed and diseased states in corals is poorly understood. Specialists have characterized many coral diseases, but few pathogens have been proven as causative agents. The USGS is comparing coral-associated microbial communities in healthy and diseased colonies and testing how various disease states may relate to physical, chemical, and biological stressors that potentially include high temperatures, pH, pollutants, contaminants, predators, and parasites.

Overfishing and ecological integrity.—Unsustainable fishing activities are recognized as severe threats to the integrity of coral reefs; such activities include overfishing and practices that destroy reef structure, remove keystone species (predators and herbivores), and damage coral communities (and connected mangrove and seagrass habitats). The concept of ecological integrity has been variously defined but may be quantified in terms of basic reef structure, functions, and processes such as

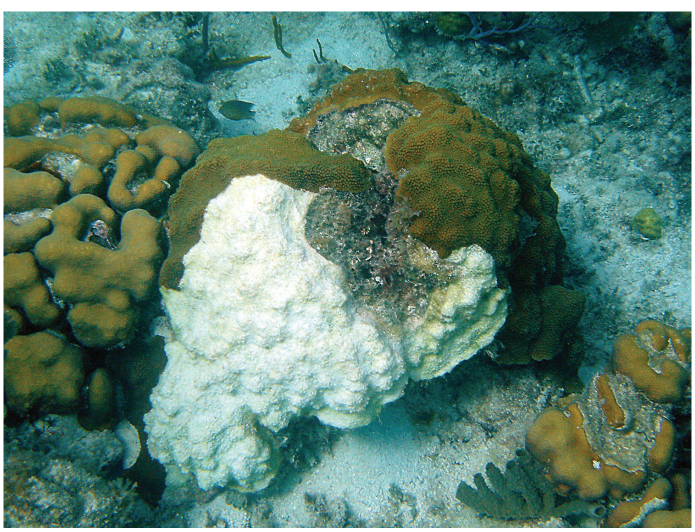


Figure 5. White plague disease affecting coral in the U.S. Virgin Islands. The disease has killed many reef-building corals in Florida and the Caribbean. Photograph by Caroline Rogers, USGS.

reef growth, calcification, photosynthesis, and respiration; plant and animal abundance and biodiversity; biomass production; rugosity; and measures of ecosystem services. Quantifying reef health in terms of such functionality is an important aspect of ongoing monitoring and research by the USGS and its collaborators. This topic also relates directly to ongoing studies of the role and function of marine reserves (designated no-fishing or limited-fishing zones) being conducted by the USGS in partnership with the National Park Service. These efforts, in turn, relate to understanding reef status and trends, ecological linkages and dependencies (such as for sea turtles and as fish nurseries), habitat connectivity, herbivore and predator/prey interactions, resiliency, and recovery from disturbance. Such comprehensive information is being acquired at targeted study sites in Hawaii, American Samoa, Palmyra Atoll, Florida, Puerto Rico, and the U.S. Virgin Islands. These primary study sites will allow scientists to compare reef function in areas having various kinds and levels of human disturbance and, ultimately, to identify environmental thresholds and tipping points when a reef's ecosystem becomes so severely compromised that recovery is prevented.

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Banner on p. 1: Collage by Gary Brewer, USGS.

Contact Information

For further information about USGS coral ecosystem research programs, contact Dr. Gary D. Brewer at gbrewer@usgs.gov or visit http://marine.usgs.gov.