CHAPTER 9

Restoring Damaged Reefs

GOAL: *Increase the capability of federal and nonfederal managers to efficiently and effectively restore injured or degraded coral reefs.*

Rationale for Action

A well-developed coral reef can represent thousands of years of slow, incremental growth by resident stony corals. Consequently, many corals living today are centuries old. Despite the longevity and apparent natural resilience of corals and the reefs they construct, both are extremely vulnerable to destruction by human activities, either gradually through degraded habitat quality, or suddenly through catastrophic damage from vessel groundings, toxic spills, or habitat destruction. The natural recovery of coral and fish populations can be slow in areas of degraded habitat and in the presence of other stressors, such as pollutants, climate change, high abundances of pest species, exotic species, or species that compete or inhibit the recruitment and growth of native fishes and corals and other

OBJECTIVES

OBJECTIVE 1: Review and evaluate existing reef restoration projects to quantify the benefits gained by the restoration effort and expenditure of the restoration compared to scenarios in which no restoration efforts were undertaken and make recommendations for improvements.

OBJECTIVE 2: Develop and test innovative methods and techniques to expedite reef restoration for all major categories of coral reef injury using a hypothesis-driven approach that involves rigorous, quantitative evaluation.

OBJECTIVE 3: Develop regional restoration plans that identify significant restoration alternatives and weigh the costs and benefits of natural recovery compared with restoration alternatives.

OBJECTIVE 4: Promote cost-effective pilot restoration of selected degraded U.S. reefs, focusing on habitats of high ecological, economic, and social or conservation value.

OBJECTIVE 5: Rehabilitate degraded fish habitat through the deployment of artificial structures and rapid, inexpensive transplant met

OBJECTIVE 6: Transfer proven restoration tools, techniques, and lessons learned to domestic and international partners.

Diadema **(long-spined black urchin), an important herbivore, controls macroalgae in coral reef ecosystems.**

benthic invertebrates. Natural recovery may never occur when the underlying habitat structure is destroyed or when the prevailing environmental conditions have been chronically degraded over time.

The *National Action Plan To Conserve Coral Reefs* (USCRTF 2000) recognizes that preventing the loss of coral reef habitat through proactive conservation measures is preferable to restoring coral reefs after they have already been damaged. However, when reefs have been damaged by human use or misuse, removing or mitigating the anthropogenic stressors responsible for their decline may enhance natural recovery. In specific situations, the USCRTF has facilitated recovery through active restoration efforts, which have shown some success. Most of these efforts have been limited to addressing physical damage to reefs at small spatial scales caused by vessel groundings. This typically involves repairing the reef structure to prevent further degradation or erosion with reattachment of benthic organisms being undertaken secondarily to speed up restoration of high-relief habitat.

Restoration efforts are also exploring the possibility of small-scale targeted efforts to enhance recovery from hurricanes, experimental-scale removal of pest and exotic species, and enhancing recruitment of habitat-forming organisms. Since the practice of coral reef restoration is in its infancy, the USCRTF seeks to strengthen restoration science through the development, testing, and assessment of methods that repair damage caused by human impacts and assist in the natural recovery of coral reef ecosystem structure and function.

Summary of Implementation

As an important adjunct to reducing key threats to coral reef ecosystems, active restoration of coral reefs may help prevent further degradation and advance the natural recovery process in injured or damaged habitats. Through a better understanding of the extent and effects of human and natural disturbances to reefs and their potential to recover naturally, scientists are beginning to apply more practical restoration approaches including novel ecological restoration strategies under conditions where the natural system is out of balance. Critical aspects of the restoration process include building knowledge about possible restoration alternatives, developing effective restoration tools and approaches, and finding ways to gauge the success of restoration activities. The goal is to apply lessons learned toward simple and cost-effective techniques for enhancing restoration functions.

Most previous restoration projects in the United States were a response to ship groundings and efforts to mitigate coral losses due to harbor dredging and other discrete shoreline modification projects. Restoration efforts associated with vessel grounding involve the structural repair of damaged reef frameworks to avoid continued loss of habitat associated with erosion. They also may involve the transplantation of corals and other organisms to speed up ecological recovery. In 2002–2003,

USCRTF members developed guidelines to assess resource injuries, developed and implemented novel restoration projects, and evaluated and monitored existing restoration and mitigation projects in the Pacific and Atlantic. Since coral reef ecosystems are complex and the processes affecting recovery potential are varied (e.g., water quality, local disturbance, habitat structure), USCRTF members are undertaking a multifaceted, research-based approach to developing successful restoration tools and methodologies.

Highlights of Task Force Member Activities

OBJECTIVE 1: Review and evaluate existing reef restoration projects to quantify the benefits gained by the restoration effort and expenditure of the restoration compared to scenarios in which no restoration efforts were undertaken and make recommendations for improvements.

Assessment of Transplanted Corals as Part of a Mitigation Project

NOAA and the University of Hawai'i completed 6 years of monitoring a harbor mitigation project in Kāne'ohe Bay. In the course of the project, all of the scleractinian corals from a small yacht harbor (an area of 38 square meters) were transplanted to a nearby reef that was dredged in 1939 for a seaplane runway. The reef had not recovered due to the persistence of a silt-sand substrate caused by the dredging that inhibited coral recruitment. Researchers found an initial decline in transplanted coral, followed by an average increase in coral cover of 40 percent over 6 years. Through this effort, colonies that would have died in the yacht harbor provided a low-impact source of coral to rehabilitate a degraded reef, which provided habitat for 439 reef fish, with major benefits associated with increasing topographic complexity.

Assessment of Restoration Efforts at Ship Grounding Sites in Florida

The majority of coral reef restoration efforts by NOAA scientists have occurred in the Florida Keys over the past 15 years. A scientifically rigorous monitoring program was initiated at 10 restoration sites damaged by vessels aground or anchored on coral reefs in the Florida Keys National Marine Sanctuary (FKNMS). This restoration monitoring program was designed to evaluate the effects of restoration actions on an injured coral reef community by tracking the condition of key biological variables. Important indicators of reef habitat quality, coral cover, coral density, and coral colony size were compared among the restored sites and undisturbed reference sites. Preliminary results from the baseline monitoring conducted in 2004 showed coral recruitment and coral growth at most of the restoration sites. Other important reef community components such as octocorals, sponges, reef fish, and invertebrates were also observed among the restored reefs.

OBJECTIVE 2: Develop and test innovative methods and techniques to expedite reef restoration for all major categories of coral reef injury using a hypothesis-driven approach that involves rigorous, quantitative evaluation.

Ecological Approaches to Coral Restoration

NOAA scientists have been testing various novel, low-cost ecological approaches to coral restoration. To improve habitat quality and restore ecosystem functions, these approaches emphasize coral

recruitment, reduction of competing algae, and control of corallivorous predators. To evaluate the efficacy of removing targeted predators to mitigate tissue loss to elkhorn coral (*A. palmata*) populations, researchers conducted a pilot experiment in FKNMS involving the removal of coral-eating snails (*Coralliophila abbreviata*) from elkhorn coral colonies. Removing the corallivorous snails preserved 75 percent more live tissue than treatments leaving the snails in place, suggesting predator removal may be an effective conservation measure in situations where the natural system is out of balance.

The reintroduction of wild-caught and laboratory-cultured herbivorous long-spined black sea urchins (*Diadema antillarum*) to a wide variety of habitats in FKNMS is being tested by NOAA scientists and partners to control macroalgae that has proliferated since urchin die-off in 1983–1984. The primary factor limiting sea urchin reintroduction and recovery appears to be predation pressure by fish and large crabs with the laboratory-cultured urchins being more vulnerable. However, surviving urchins are contributing to the successful removal of algae through grazing pressure. Other research is evaluating the differences between structural restoration approaches in FKNMS and the ability to enhance recovery through the natural recruitment of corals, survival and growth of seeded coral larvae, and survival of transplanted fragments. These studies provide insight into factors controlling settlement and post-settlement survival, benefits and drawbacks of different structural restoration approaches, and optimal strategies for fragmenting and transplanting corals.

Coral Nursery Expanded at Biscayne National Park

In 2002, Biscayne National Park near Miami greatly expanded its coral nursery for future restoration projects. Multiple impacts from vessel groundings, storms, coral diseases, and other stressors are requiring scientists and resource managers to develop innovative strategies to restore coral reefs. The coral nursery is a pioneering effort to rebuild damaged coral reefs by using new coral recruits grown in the nursery. Park scientists and volunteers populate the nursery by rescuing coral fragments from grounding sites that would die if not properly tended. They are first taken to the National Marine Fisheries Service Southeast Fisheries Center facility at Virginia Key to be stabilized and later transferred to nursery sites in the Park. The University of North Carolina, students from the University of Miami, and volunteers assist in research and nursery maintenance.

OBJECTIVE 3: Develop regional restoration plans that identify significant restoration alternatives and weigh the costs and benefits of natural recovery compared with restoration alternatives.

Restoration and Assessment of Coral Ecosystems

Recreational and commercial vessel groundings are a major cause of coral and seagrass habitat loss in FKNMS. More than 600 known vessel groundings occur every year within the sanctuary, with a likely equal number going unreported. In 2000, NOAA and the State of Florida began the Restoration and Assessment of Coral Ecosystems (RACE) Program to assess and restore coral resources damaged by small-vessel groundings within the sanctuary. Since its inception, the RACE Program has:

- Developed a set of rapid, cost-effective damage assessment methods using global positioning systems and bathymetric tools to accurately assess the extent of habitat damage;

- Created and calibrated a seagrass model capable of predicting time to recovery following restoration;
- Settled 19 seagrass cases totaling nearly $600,000; and
- Streamlined communication and decisionmaking protocols between NOAA and Florida natural resource managers and law enforcement officers to ensure rapid assessment of injuries, effective case management, and successful restoration.

Juvenile *Diadema* (long-spined black urchin), with mixed coral species.

The successful application of the RACE Program has prompted NOAA and the State of Florida to modify the seagrass restoration process to aid coral reef restoration efforts in the sanctuary.

OBJECTIVE 4: Promote cost-effective pilot restoration of select degraded U.S. reefs, focusing on habitats of high ecological, economic, and social or conservation value.

Transplantation of Coral Fragments to Degraded Reefs

U.S. Geological Survey and National Park Service scientists conducted a small coral transplant project in the Virgin Islands National Park. The project reattached storm-generated *Acropora palmata*, *A. cervicornis*, and *Porites porites* fragments onto a degraded reef using plastic cable ties.

Approximately 20 percent of transplanted *A. palmata* fragments were alive after 4 years. Live fragments exhibited tissue growth over cable ties, fusion with the reef substrate, and growth in the form of new branches. The pilot project demonstrates the feasibility of a low-cost, low-impact method using naturally occurring, storm-generated fragments of fast-growing corals to help restore damaged reefs.

OBJECTIVE 5: Rehabilitate degraded fish habitat through the deployment of artificial structures and rapid, inexpensive transplant methods.

Habitat Restoration on Mona Island, Puerto Rico

In 1997, the *M/V Fortuna Reefer* grounded on Mona Island, Puerto Rico, damaging 6.8 acres (0.03 km^2)

Elkhorn coral fragment seven years after restoration efforts. The coral has produced numerous branches and now has the typical adult morphology.

of shallow *Acropora*-dominated fore-reef habitat. Within 2 months, restoration experts stabilized 1,857 *A. palmata* coral fragments using stainless steel wire to secure fragments to the reef substrate and dead standing elkhorn coral skeletons. Six years after the restoration, 20.3 percent (377) of the restored fragments were living. Most live fragments were cemented to the reef and produced new branches, forming small colonies providing considerable structural relief. Reef fish communities have begun to shift from a dominance of roving herbivores to a more complex community associated with an increase in groupers and snappers. Given the large declines *Acropora* populations have sustained from disease, hurricanes, and other impacts, this restoration effort demonstrates reattaching *Acropora* fragments may be a viable restoration tool in cases where remaining *Acropora* habitat is damaged by ship groundings and hurricanes.

Assessment of Artificial Structures as a Restoration Effort

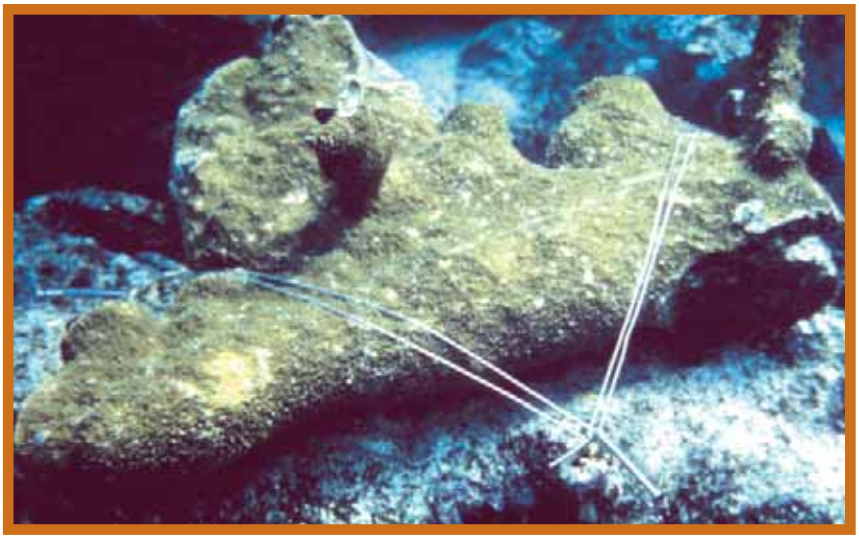
Extending for more than 150 kilometers along the continental shelf off eastern Florida, *Oculina* Banks provides habitat for thousands of reef fish and invertebrates. It also provides spawning grounds for commercially important groupers. Although large portions of the area (*Oculina* Banks Habitat Area of Particular Concern) are protected from fishing, only an estimated 10 percent of the former live reef remains. Restoration efforts, started by NOAA and its partners in 1996 and expanded since 2000, involve deploying artificial structures seeded with fragments of the dominant coral, *Oculina varicosa,* into rubble habitats. Artificial structures appear to enhance the natural colonization of corals through recruitment, with high survivorship rates of transplanted fragments and increased densities of reef fish.

OBJECTIVE 6: Transfer proven restoration tools, techniques, and lessons learned to domestic and international partners.

USCRTF members have actively engaged the international community in the development, implementation, and evaluation of restoration efforts by:

- Convening sessions on coral reef restoration at major international symposia;
- Publishing peer-reviewed articles and technical documents and hosting websites on damage assessment, mitigation, and restoration approaches and the efficacy of various restoration projects; and

- Providing state and territory government partners and consultants with technical expertise to assist with damage assessment, resource valuation, and restoration planning and implementation.



Restoration scientists employ numerous mechanisms to ensure successful coral transplant efforts.

Future Challenges

During the past several years, USCRTF members have improved the ability to conduct injury assessments, and calculate monetary damages; outline primary restoration alternatives; and implement emergency and compensatory restoration projects to mitigate damage, prevent further losses, and restore ecological functions of coral reefs. Efforts to address acute impacts on reefs, such as ship groundings, have exhibited engineering success with restoration structures remaining stable through subsequent disturbances and transplanted corals remaining attached with moderate to high rates of survival and growth. However, restoration efforts often lack rigorous evaluation, and few projects are designed to test how effectively different restoration approaches enhance biological performance or community function.

Future coral reef mitigation and restoration efforts are needed to preserve and restore critical ecological functions within regional ecosystem dynamics. Agencies need to continue to develop and evaluate inexpensive, effective restoration techniques to mitigate human impacts on reefs, including ship groundings, and to possibly address other disturbances. However, managers need to carefully analyze degraded sites before undertaking a restoration project, ensuring the causes of degradation are understood and have been eliminated or mitigated. Other considerations include the proper selection of species for transplantation, impacts on source populations of transplanted fragments, optimal sizes of transplants and methods of attachment, and other factors to enhance survival of corals, minimize damage to source reefs, and maximize rates of ecological recovery. Managers further need to recognize that each proposed restoration needs to be conducted on a case-by-case basis with consideration for variations in species life histories, environmental and physical parameters, and regional differences. The main objectives for future restoration and mitigation efforts include the following:

Continue to evaluate success of restoration projects. A rigorous evaluation of the success of existing reef restoration and mitigation projects should be conducted to identify site- and species-specific approaches that maximize transplant survival and effectively restore ecological function.

Continue to develop cost-effective, ecologically sound restoration methods. Broad, novel, cost-effective ecological restoration strategies are needed to enhance natural recovery and promote survival of critical habitat-forming organisms. Strategies are

needed to improve herbivory, coral recruitment, and coral growth; reduce pest or exotic species; and stabilize rubble and other unstable substrates.

Evaluate the benefits of using vessels as artificial reefs. To reduce diving pressure on natural reefs, the feasibility and ecological benefits of sinking decommissioned U.S. Navy vessels and other artificial substrates should be evaluated. Before vessels and other artificial substrates are sunk, it is critical for all steps to be taken to minimize ecological impacts associated with the sinking process.

Develop sources of coral fragments. Ready sources of coral fragments should be developed for immediate transplantation after ship groundings through coral culture techniques, coral nurseries, and other low-impact coral sources in order to prevent harvesting of natural populations.

Enhance restoration research. Using adaptive management techniques to guide future restorations, a science-based, hypothesis-driven approach should be implemented for future restoration projects to answer questions on what works and why.

Increase community awareness. Local communities can be trained and involved in basic coral reef assessments and restoration techniques to raise awareness and increase the incidence of reporting coral injury to expedite reef recovery.