Pp. 393 – 409 In: Marine Conservation Biology, The Science of Maintaining the Sea's Biodiversity. E.A. Norse and L.B. Crowder, Eds. Island Press 2005. 470 pages

Chapter 23

Recovering Populations and Restoring Ecosystems:

Restoration of Coral Reefs and Related Marine Communities

Robert H. Richmond

Kewalo Marine Laboratory

University of Hawaii at Manoa

Honolulu, Hawaii (USA)

Richmond@hawaii.edu

Introduction

Ecosystems throughout the world have been degraded as a result of human activities. Burgeoning human populations have impacted biological communities on a global scale, and even remote areas have been affected. Many marine communities adjacent to population centers have been dramatically altered and even once-isolated marine ecosystems have suffered from overfishing and destructive fishing practices due to the ability of fishing fleets to travel far from their home bases. Eutrophication of coastal marine waters through both the removal of filter-feeding organisms as well as nutrient-laden runoff has resulted in chronic and widespread toxic algal blooms. Coral reefs thousands of kilometers from industrialized centers have been devastated by extensive bleaching events tied to global climate change. It is increasingly clear that environmental damage and degradation must not only be stopped, but be reversed if future generations are to have natural resources for their enjoyment and use. Restoration ecology has recently emerged as a biological sub-discipline in response to habitat loss and population depletion, and holds promise for reversing some of the damage that has occurred. However, there are also some concerns raised by recovery-directed activities and there is a need for a careful examination of potential pitfalls, limitations, and alternatives.

Restoration is a term that has several definitions, all of which suggest an act of returning something to its original state, or fixing something that is damaged. The *Oxford Dictionary* includes the definition: "to return to *supposed* original form." For old houses, faded art, and broken jaws, restoration objectives are pretty clear, and most people would agree on the end product. For ecosystems, the objectives and acceptable end points are much harder to define. Part of the problem lies in what we "suppose" is the original form, with the understanding that the baseline most present-day ecologists, resource managers or stakeholders use as a reference is undoubtedly far different from the baseline state of a previous period as recent as a decade ago. The value of historical marine ecology and marine environmental history is evident in determining previous conditions and subsequent trends (Jackson 1997; Jackson et al. 2001). While we know that human influences generally result in environmental degradation, we must recognize that cycles of natural disturbance can also cause a high degree of variation among years, and that ecological succession is a natural process of change that affects biological communities over space and time. Attempts at ecosystem restoration and recovering populations of organisms require us to understand that the target is often moving.

Ecosystem restoration efforts to date have usually been the result of government intervention and regulatory compensation, with differing goals depending on a participant's role. For a developer and/or environmental consultant, the goal might be to meet the minimum mitigation requirements set by an agency. For an agency, it might be to fulfill its regulatory obligations and to compensate for losses. For an ecologist, it might be to study ecosystem response, and for others, it might be to have back what once was. Without making any value judgments, it is clear that the objectives of restoration efforts can vary widely on a single project, and that the perception of success can be highly subjective.

I have concerns about restoration discussions, as there is an inherent implication that a damaged ecosystem can be repaired, and hence, that biological communities can be temporarily destroyed, only to be replaced at a later date. Restoration used as part of the planning or permitting process for projects also implies we fully understand all of the interactions, services, and functions that occur within the affected biological communities. The danger increases when decision makers use restoration as a justification for approving activities known to cause extensive environmental degradation. Bold statements on the efficacy of restoration technologies can make for good press and capture the attention of potential funding sources, but might ultimately add to already unacceptable levels of environmental degradation; it is important for scientists, resource managers and journalists to clearly and explicitly present the limitations of their findings

Ecologists, with the benefit of both education and experience in biology, are capable of drawing some questionable conclusions when viewing biological communities as a cluster of interconnected boxes, including one each for the various trophic levels of producers, consumers, herbivores, carnivores, and bacteria. In an article on theoretical aspects of community restoration ecology, (Palmer et al. 1997) the authors discuss replacing functional groups or suites of species and suggest that for grasslands, other ungulates could replace bison, as they both act as grazers. The ("Larson-esque") vision of camera-toting tourists stalking the wild dairy cows of the Serengeti is sufficient to appreciate that there are a number of issues that need to be considered in developing guidelines for recovery activities. A holistic and pragmatic view of ecosystem structure, function and value is clearly needed before restoration efforts are mounted.

Pp. 393 – 409 In: Marine Conservation Biology, The Science of Maintaining the Sea's Biodiversity. E.A. Norse and L.B. Crowder, Eds. Island Press 2005. 470 pages

The realities of habitat loss, population declines, and species extinctions mandate that we take specific actions that not only stop the damage, but support recovery. We need to review alternatives and develop a framework for decision making that includes an honest assessment of costs versus benefits if there is any hope of effective and positive outcomes. In this chapter, I discuss some basic underlying concepts that need to be addressed when considering recovery and restoration efforts. I review several case histories, paying particular attention to coral reefs, as that is the area of my expertise and coral reefs are presently the focus of heightened international attention with substantial financial and human resources directed towards restoration and recovery. The lessons learned from coral reef restoration efforts are broadly applicable to other marine and terrestrial ecosystems because, while the species assemblages might differ, the underlying ecological principles are the same. I conclude with a discussion of options, applications, and suggestions for dealing with mounting pressures on a variety of marine ecosystems resulting from human activities and associated stresses. My goal is to identify important questions that need to be asked, and focus more attention on prevention and alleviation of stresses as key elements of restoration and recovery plans.

What is Ecological Restoration?

Restoration can encompass a wide variety of activities, from transplantation of some species to the eradication of others. There have been suggestions that organisms providing similar ecological services can be interchanged, and landscapes can be modified to create artificial ecosystems. In such discussions, it is critical to step back and recognize that biological communities are more than simply a group of individual species occupying a specific space but that complex interactions (e.g. predator-prey and symbioses) are ecological and evolutionary governing factors. For many species of benthic invertebrates, grazing herbivores are critical in opening spaces for recruitment of larvae. Furthermore, for larvae that respond to specific metamorphic inducers, the presence of conspecifics, particular prey species, or certain species of crustose coralline algae might be necessary for settlement, metamorphosis, and the replenishment of populations (Morse 1990; Morse and Morse 1991). Re-establishing populations with a sufficient number of individuals is also an important target. Having too few individuals within an area can lead to future reproductive failure in spawning creatures, as gamete interactions might be limited (the Allee Effect; see Levitan and McGovern, Chapter 4). A clear goal of restoration efforts must be to restore the ability of populations to grow without continuous intervention.

Establishing Targets: Original Condition and Baselines

There are few, if any, areas left on Earth that can be considered pristine. Defining a baseline for ecosystem integrity and community composition is a realistic, albeit challenging, starting point for restoration efforts, recognizing that at some point in time, every species in an ecosystem was introduced as the result of vicariance and dispersal or through evolutionary speciation events. Ecological rather than geological time scales (10^0 to 10^3 vs. 10^4 to 10^9 yrs) are appropriate for such discussions, and archeological, as well as historical written and photographic records, can be valuable sources of baseline information (Jackson et al. 2001). Humans are an integral part of modern ecological landscapes, and the driving force behind restoration and recovery efforts. Hence, the economic and social aspects of recovery-related activities are important concerns in determining how far we can expect to set the clock back, how big an area can be addressed, how many species and how much recovery we can realistically expect. Because overfishing is one of the greatest threats in the marine environment, affecting both commercially valuable species as well as nontarget species from bycatch, "restorationists" must develop biologically based population size goals, with an understanding that fishing will undoubtedly resume once populations exceed a certain size. In all cases, establishing criteria for determining the baseline or goal for restoration efforts is a critical step in the process.

Restoration Goals

The goal of restoration and recovery efforts follows from the definition: to replace that which has been lost. Several approaches can be taken. The focus can be on an individual species (e.g., green turtles, rock oysters), a group of interacting organisms (e.g., herbivorous grazing fishes and sea urchins), an ecosystem (e.g., coral reefs) or a suite of interconnected biological communities (e.g., upland forests, grasslands, wetlands, mangrove swamps, seagrass beds, and coral reefs in high island tropical ecosystems). Restoration of ecological services is another area of application, as exemplified by wetland mitigation efforts directed towards filtering watershed discharges to protect coastal marine communities from sedimentation and pollution from runoff, or the restoration of filter-feeding oyster populations to reduce the effects of hypoxia from eutrophication (Lenihan and Peterson 1998; Lenihan et al., 2001). Restoring populations in support of ecotourism opportunities has also occurred, for example, where the museum value of a coral reef can far exceed the commodity value of the resources present. One famous dive site in Palau, the Blue Corner, generates an estimated $2.8 to $3.5 million per year on dives alone, yet the value of the fishes and corals that could be collected from the area and sold represent an estimated market value of only a few tens of thousands of dollars. Protection of specific trophic levels (e.g., filter-feeding bivalves to control algal blooms, herbivores on coral reefs to crop fleshy algae, sharks to serve as top predators) and associated population recovery is another potential goal. In addition to the biological goals, there can be other considerations that make recovery efforts worthwhile. Community education and awareness are important goals, and public participation in recovery-based activities is an appropriate objective. In these cases, failures can actually be successes. The inability to restore an ecosystem or biological community can send a clear message that environmental destruction is not an acceptable alternative in the planning process and help develop much-needed political will and support for conservation efforts.

Why Are Restoration and Recovery Activities Necessary?

A critical question that needs to be addressed is why restoration and recovery activities are necessary in the first place. If the answer is "in response to environmental degradation and population depletion," it follows that the specific causes must be identified and understood before remediation can be undertaken. The top five reasons why restoration of marine ecosystems is needed include:

1) Overfishing
2) Marine/coastal pollution (including runoff, sedimentation, and eutrophication)
3) Habitat destruction (dredging, bottom trawling and other destructive fishing practices, coastal construction, ship groundings)
4) Elevated seawater temperatures associated with global climate change (a special case for coral reefs through massive bleaching events)
5) Invasive species

Overfishing continues to be a major problem throughout the world's oceans. The problem stems from a combination of gear efficiency, on-board storage capabilities, high levels of bycatch, and ineffective regulations (e.g., the US Magnuson-Stevens Fishery Conservation and Management Act that uses single-species demographics rather than ecological and habitat information for determining exploitation levels). Whereas maritime activities including oil spills and ship groundings have been obvious sources of marine pollution (e.g., the Exxon Valdez), coastal pollution often originates from land-based sources and poor land-use practices. Agricultural and urban runoff, coupled with the depletion of filter-feeding oysters, have contributed to hypoxia in Chesapeake Bay as well as other estuaries along the East Coast of the USA. Chemical discharges into streams and rivers from specific industrial sources account for a portion of coastal pollution problems, but more often "nonpoint source" pollution that originates from broad areas within watersheds is the major culprit. Sedimentation is particularly problematic for coastal coral reefs adjacent to high islands and landmasses, and is largely the result of poor land-use planning including engineering practices that design systems to drain runoff into the ocean as quickly as possible. Such practices can be defensible in temperate waters with upwelling and nutrient-driven trophic webs, but are unacceptable to receiving waters supporting coral animal-algal symbioses that are dependent on clear water and sunlight penetration. Additional causes of marine habitat destruction include dredging, sand mining, trawling, and vessel groundings. Invasive species can also be a problem in the marine environment; for example, the fish *Lutjanus kasmira* and the alga *Kappaphycus striatum* in Hawaii (Eldredge 1994), or the alga *Codium fragile* in New England that displace indigenous species and upset the ecological interactions that are critical elements of marine communities.

Attempts at ecological restoration have usually been in response to anthropogenic disturbances, either those that have already occurred or those that are planned. Anthropogenic disturbances tend to be more chronic in nature than natural disturbances, especially in areas adjacent to population centers. Chronic stresses generally prevent natural recovery, and hence, will also limit the effectiveness of restoration efforts (Richmond 1993). If restoration and recovery initiatives are to be pursued, the cause(s) of the problem clearly must be addressed first; that is, if chronic or repeated episodic pollution is the major cause of population depletion in an aquatic ecosystem, it makes no sense to attempt to restore populations of organisms until the sources are eliminated.

What Restoration Options Exist?

There are a variety of actions and activities that can be considered under the broad category of population recovery and ecosystem restoration. These range from full intervention (eradication and transplantation) to "passive rehabilitation," which focuses on the reduction of stressors (Woodley and Clark 1989). On one end of the spectrum, educational campaigns to reduce point and nonpoint source pollution can be employed to support improved coastal water quality. Establishment of marine protected areas to counteract overfishing requires a higher degree of effort and stakeholder support. Replenishment and/or replacement of specific functional groups (e.g., filter-feeding oysters in the Chesapeake Bay, or herbivores on coral reefs) can be both time consuming and costly. Removal of invasive species, coupled with habitat repair and augmentation of populations of indigenous species, represents the highest end of restoration-directed intervention. Efforts at removing feral animals (goats, deer, sheep, pigs) from high islands can cost hundreds of thousands of dollars and take years to accomplish, yet could be an essential element in the overall success of restoration efforts for both terrestrial and downstream coastal marine communities. Integrated watershed management, specifically erosion control, is terrestrially based but often a prerequisite to restoration of coastal marine communities affected by runoff and sedimentation.

Transplantation/reseeding/reintroduction of individuals is often at the center of restoration efforts. The source of the material and life history characteristics of the organisms are important considerations. For organisms capable of asexual propagation, seed stock can be relatively easy to generate with minimal impacts to source populations. For colonial benthic invertebrates, including corals, colony fragments can be harvested for transplantation. Individual organisms, both juvenile and mature, can be used as restoration stock. Finally, collection of gametes with the subsequent release of larvae might also be attempted. In some cases, replenishment of populations of organisms can require more than just reseeding, such as the control of pathogens (e.g., for the recommended re-establishment of oyster reefs in the Chesapeake Bay; see Jackson et al. 2001), improvements in ambient water quality, or reestablishment of suitable habitat features. The choice of methodologies is dependent on local conditions and requires an accurate cost-benefit analysis.

There are several concerns in restoration efforts involving transplantation. The first is the source of the restoration material. It is important to ensure that pathogens and parasites are not introduced along with the target organisms. When the giant clam *Tridacna gigas* was cultivated and shipped to islands as part of a reintroduction/aquaculture campaign, a pyramidellid predatory gastropod, *Tathrella iredalei*, was accidentally included in some of the shipments and nonindigenous to several of the recipient sites (Eldredge 1994). Additionally, when "borrowing from Peter to pay Paul," restorers can harm the source population with little or no benefit to the area being rehabilitated. Some organisms always die in transplantation exercises and the reduction of populations at the donor site may be too costly in the big picture. Finally, restoration programs should include efforts to maintain and promote genetic variability. If there is insufficient genetic diversity in seed material, rare alleles might be absent, leading to an increased risk of future extinctions under changing conditions or in response to pathogens, an "Irish Potato Famine" effect (Helenurm and Parsons 1997).

Removal of stresses is an important option to consider, with the goal being to return the ambient conditions to those favoring natural recovery. Examples for marine and aquatic ecosystems include closure of fisheries and other extractive activities, cessation of destructive fishing practices, integrated watershed management, pollution abatement, and improved treatment of sewage and heated effluent (power plant) discharges. Many ecosystems are resilient, and if stresses are removed, they can recover. Of course, the most effective and efficient option is to prevent damage and resource depletion in the first place.

In addition to biological tools, several legal tools can provide much-needed funding for restoration activities. For example, the US Oil Pollution Act of 1990 (**OPA-90**) has provisions that support restoration following oil spills and ship groundings that can be applied with a degree of flexibility, including efforts at prevention.

Coral Reef Ecosystem Restoration

Coral reefs provide a good set of examples for the upsides and downsides of restoration and recovery efforts. At the National Oceans Conference held in Monterey, California in 1998, President Clinton signed Executive Order 13089 titled "Coral Reef Protection." Included in this directive, which established the US Coral Reef Task Force, were sections identifying restoration of degraded reefs as a specific goal: "Sec 5(b) Research - This research shall include fundamental scientific research to provide a sound framework for the restoration and conservation of coral reef ecosystems worldwide; and Sec. 5(c) Conservation, Mitigation and Restoration - The Task

Force… shall develop, recommend and seek or secure implementation of measures necessary to reduce and mitigate coral reef ecosystem degradation and to restore damaged coral reefs..." Is this a realistic and attainable goal?

Coral reefs are diverse and productive marine ecosystems found primarily in shallow and coastal tropical marine environments. They are generally on the high end of marine biodiversity, and are also relatively stenotopic (possessing a narrow range of tolerances) when compared to temperate and upwelling-driven marine ecosystems. As with other marine communities, there are a number of factors and disturbances that affect coral reef ecosystems, both anthropogenic and natural (Table 23.1). Typhoons in the Central and Indo-west Pacific can dramatically alter coral reef community structure, yet data collected over periods from years to decades demonstrate that reefs can recover if substratum and water quality return to the pre-disturbance state. The coral-eating crown-of-thorns starfish, *Acanthaster planci*, has been responsible for large-scale reef loss during periods of outbreaks in the Pacific Ocean, yet areas can recover in 12 to15 years through a combination of growth of remaining live sections of corals and recruitment of larvae onto suitable carbonate substrata (Brown 1997). Following the 1998 bleaching events in the western Pacific, researchers are now reporting moderate levels of recruitment and recovery on selected reefs (Personal communication with S. Victor, Palau International Coral Reef Center, Palau) while other areas have not recovered from the *Acanthaster* outbreaks of the 1970s (personal communication with C. Birkeland, University of Hawaii, USA). Whereas both *Acanthaster* outbreaks and coral bleaching events associated with elevated seawater temperatures have been considered "natural" disturbances in the past, there are strong indications that both are influenced by human activities (nutrient input and global warming, respectively) affecting the frequency, magnitude, and duration of the disturbances (Birkeland and Lucas 1990; Glynn 1993).

Pp. 393 – 409 In: Marine Conservation Biology, The Science of Maintaining the Sea's Biodiversity. E.A. Norse and L.B. Crowder, Eds. Island Press 2005. 470 pages

As in other marine ecosystems, overfishing and destructive fishing practices are among the greatest threats to coral reefs. The depletion of herbivorous fishes (and invertebrates) can drastically alter community structure (Done 1992; Hay 1981). *Muro ami* fishing, which involves the use of weighted objects (e.g. stones and metal pipes) to pound the sea floor and chase fish into large nets, has been used extensively in the Philippines, pulverizing substantial areas of coral reef and resulting in the death of corals, associated organisms and even the young boys employed in this destructive fishery (Bengwayan 2001). The use of dynamite, cyanide (used to capture live grouper and aquarium fishes), bleach, and other toxins negatively affects many nontarget organisms and can result in extensive habitat destruction.

Oftentimes, coral reefs subjected to chronic, terrigenous runoff, sedimentation, eutrophication, and water pollution do not recover from these stresses, and larval recruitment will not occur until appropriate ambient conditions return (Figure 23.1). Reefs where an alternate stable state has been reached (e.g., domination by fleshy algae; Hatcher 1984) are among those that have not recovered from previous mortality events. Furthermore, reefs suffering from human-induced stress are less resilient and more susceptible to diseases and mortality from the synergistic effects of natural disturbances.

Coral Reef Restoration: A Closer Look

Views on the value of coral reef restoration efforts differ greatly among practitioners, managers, researchers, agency representatives, consultants, and stakeholders. It is important to understand that major differences exist among coral reefs, and hence, what works in one location might not necessarily be applicable in another. For example, Caribbean coral reefs, while every bit as beautiful to the beholder and valuable to the stakeholders as Indo-west Pacific reefs are to their users, contain an order of magnitude less coral, invertebrate, algal, and fish diversity (Paulay 1997). It is far more reasonable to pursue transplantation when only 20 species of corals are being considered (with only 5 or 6 dominant types) than in a site with over 100 species of reef-building corals. As species diversity increases, the effectiveness of interventional restoration decreases. Coral reef restoration is an area where we have to ask the question: Are humans capable of creating, within a span of months to years, what nature has taken centuries to millennia to create? While the answer to this is clearly "no," restoration and recovery efforts may still be of value when replacement of the original is not feasible and spatial scales are limited.

Transplantation

Restoration activities following ship groundings off Florida have had some degree of success (Gittings et al. 1994; Hudson and Diaz 1988; Precht 1998). Mitigation efforts consisted of stabilizing the damaged corals and rubble, "rebuilding" topographic relief by moving large coral heads and dislodged reef material into the areas scraped clean by the grounded vessel, and transplanting both hard and soft corals to the site. In one study (Hudson and Diaz 1988), a total of 11 scleractinian corals representing 8 species, as well as 30 soft coral colonies representing 12 species, were transplanted. The hard coral transplants were reported to have done well, but storm damage later caused a 50 percent loss of soft corals. There was recruitment of coral larvae (predominantly from brooding species), but the coral cover remained low after five years (Gittings et al. 1994).

A similar effort was mounted on Guam following a localized physical disturbance. In January 1989, the Navy Public Works Center installed a mooring buoy in Apra Harbor and dragged the anchor chain across a submerged patch reef, damaging an area of approximately 720

m^2 (University of Guam Marine Lab unpublished report; Figure 23.2). While the Navy claimed legal jurisdiction over the area where the coral damage took place, Guam's Attorney General's office determined the resources that were damaged belonged to the people of Guam. At the threat of a lawsuit the Navy agreed to assist in a recovery effort in cooperation with local resource agencies and institutions. The primary activity included righting the overturned corals, stabilizing live fragments and rubble, and removing debris. The area was mapped, with some plots left alone and others seeded with the damaged corals. Approximately 40 percent of the fragments did reattach and survive over 2 to 3year monitoring period (primarily *Porites [Synarea] rus*). Mortality was highest among the smallest fragments. The top of the damaged reef was at a depth of 17 m, and below normal wave base, so much of the reseeded material remained in place. After five years, the damage was still evident, but some natural recruitment had occurred and some of the diversity was recovered. Had the damaged reef been in shallower water and in a more exposed area, more work would have been required to stabilize the loose material. The corals used were from this reef, and hence, were already acclimatized to the local conditions. One of the effective lessons learned from this exercise is the mere threat of having to attempt to restore an area damaged by negligence serves as an incentive to concentrate on future prevention.

I have personally observed several efforts to create "enhanced" areas, primarily for the tourist trade on Guam. Stony corals, anemones, sea fans, and sponges were transplanted at three sites associated with tourist operations (a tourist submarine route and a popular dive site in Apra Harbor, and on trays under the windows of an underwater observatory). In all cases, mortality of transplanted organisms occurred, especially when they were collected from habitats with different ambient conditions of water circulation, depth, and water quality. A local diving company responded to the results of a typhoon by gathering up all of the living coral fragments distributed over a relatively large area, and concentrated them in a small plot. While the area that received the fragments was aesthetically pleasing, the surrounding areas were essentially stripped of seed material that would normally attach and regenerate over time. Although the economics of such efforts might be considered reasonable in the short term, the biological needs of the organisms must be considered, and such efforts closely scrutinized. In such cases, cultivating organisms for enhancement projects is recommended over the transplantation of wild stock.

Other efforts at coral transplantation have been carried out in response to both natural coral mortality and construction activities. Guzmàn (1991) reported 79 percent to 83 percent survivorship of transplanted fragments of *Pocillopora* spp. after 3 years, following a massive temperature-related mortality event off the Pacific coast of Costa Rica. Jokiel et al. (1998) reported a high survivorship of corals following initial transplantation at a harbor site in Hawaii, but a gradual loss over time due to waves, storms, burial, and overgrowth with algae. For species that fragment easily and normally recruit via asexual processes, efforts might be successful over limited areas. Harriot and Fisk (1988) reviewed several studies on coral transplantation and came to the conclusion that such efforts are costly, time consuming, and only applicable in areas of high commercial, recreational or aesthetic value.

While transplantation efforts to date have been limited in scope and actual effect, they have established a baseline for continued improvement, and apparent failures can actually provide a valuable lesson: that transplantation cannot effectively restore a coral reef ecosystem within years. As resources are always a limiting factor in conservation efforts, it is prudent to consider where efforts should be focused. In the case of ship groundings, it is far more effective to put funds into prevention, like improved navigational aids and locally trained pilots than into recovery activities. A strict ban on destructive fishing practices with adequate resources for enforcement can be demonstrated to be economically as well as environmentally sound policy. It is also important to point out that a 400-year old coral cannot be replaced in less than 400 years the same way a giant redwood tree cannot be replaced by a sapling.

Coral Cultivation and Larval Seeding

While I have discussed several examples that highlight practical concerns and limitations, it is important to realize that restoration science is a very young field and there have been promising advances. Researchers in Guam, as well as in Australia, the Philippines, and Hawaii, have developed, improved, and simplified techniques for coral cultivation and transplantation. Data exist on the reproductive timing of corals in many geographical areas (Harrison and Wallace 1990; Richmond 1997) and allow for the production of thousands of larvae that can be cultivated as material for reseeding and restoration at virtually no cost to the wild stock. The easiest corals to work with are brooding species that release fully developed planula larvae. Mature coral colonies can be placed into containers receiving fresh seawater that overflow into larval collectors constructed from plastic beakers with walls of 50μ plankton netting. The collected larvae can be settled onto natural or artificial substrata conditioned with diatomaceous films or crustose coralline algae, depending on the metamorphic induction requirements of the particular species. Most scleractinian corals are simultaneous hermaphroditic spawners that release combined egg-sperm clusters. We have developed a simplified technique for coral cultivation as follows:

1) Collect several gravid colonies of the same species one week before the predicted spawning event.
2) On the night of spawning, collect 50 to100 egg-sperm clusters from each of 2 colonies of the same species, and place these into 1,000 ml of filtered seawater with aeration.
3) Check for fertilization after 12 hours, and if successful, siphon 800 ml of the water from the bottom of the vessel and replace with 800 ml of filtered seawater.
4) After the planula become free-swimming and head to the bottom of the vessel, pour the larvae into a 20+ liter glass aquarium with appropriate settlement substrata. Pieces of rubble coated with the crustose coralline alga *Hydrolithon reinboldii* work well for a wide variety of Pacific acroporid, pocilloporid, and favid corals. Move substrata with coral recruits into a flowing seawater system containing adult colonies of the same species as sources of zooxanthellae (the algal symbionts of reef-building corals).
5) Transplant the young corals into the field using a mixture of seven parts plaster of Paris: one part cement that can be pre-measured into small plastic bags in dry form and mixed with a small amount of seawater while underwater to make a putty.

Coral larvae can also be induced to settle in the field using larval seeders attached to appropriate substrata (Figure 23.3). This technique has been successful over very limited areas, with coral recruits attaching to the substratum within the area covered by the seeder (Figure 23.4). At one site, the recruitment rate was relatively high (above 70 percent of the larvae) but all of the recruits were subsequently smothered by sediment and fleshy algae following the onset of the rainy season and the impacts of associated runoff. The techniques briefly outlined above require little more than gravid corals, glass jars, eyedroppers, PVC pipes, and a source of seawater. A group in Australia has pursued larval seeding on a grander scale, using the larvae collected from spawning slicks within the Great Barrier Reef, and pumping these into tents covering larger areas of substratum. Their results were similarly positive.

Since the chance of a single coral egg being fertilized during a spawning event is relatively low and the chances of the developing larvae finding an appropriate recruitment site even lower, these types of enhancement activities are worth pursuing and deserve further attention. These techniques can be applied in areas where larval supply is low or water quality is a limiting factor for successful reproduction, as egg-sperm interactions are highly sensitive to pollution. Use of the products of laboratory cultivation can also be applied in areas where coral population densities are reduced to the point where the Allee effect poses a problem. However, these efforts can only be applied over very restricted areas, and the corals that do recruit will suffer high rates of mortality and will take years to grow to reproductive size and large enough to provide suitable fish habitat. For now, the primary applications of coral cultivation technologies are for producing numbers of corals for bioassays, monitoring, and for the growing aquarium trade as an alternative to the collection of wild stock. I fully expect continued research and experimentation with cultivation and restoration techniques will lead to more success and increase the effectiveness of such efforts.

Artificial Reefs

Pp. 393 – 409 In: Marine Conservation Biology, The Science of Maintaining the Sea's Biodiversity. E.A. Norse and L.B. Crowder, Eds. Island Press 2005. 470 pages

Artificial reefs have been built for a variety of reasons including seashore protection, to enhance fishing, as diving attractions, for creating wave breaks for surfing, as well as for mitigation and restoration projects following overfishing or damage to natural systems. I believe this is another tool for which specific questions need to be addressed:

1) Is the substratum/habitat being deployed a limiting factor (e.g., solid, three-dimensional) rather than larval supply and recruitment?
2) Are the artificial reef materials and structural design being used suitable for supporting population recovery?
3) Will the structure leach metals and other toxic compounds (ships and other vessels are often used with lead-based paints on upper surfaces, anti-fouling bottom paints containing copper, Tributyl tin and other toxins, and hydrocarbons including fuel and oil are often present)?
4) Will the artificial structure eventually break up, collapse, and/or move from wave action, causing damage to natural reefs other biological communities?
5) Will the artificial reef simply aggregate fish and other marine organisms, making them easier to catch, or will the reef be used to provide additional protected habitat for resource replenishment?

Decisions to employ artificial reefs should be based on expected benefits and not simply be used as a convenient method to dispose of abandoned cars, vessel hulls, and other debris. In the 1970s and '80s, numerous artificial reefs were built from old tires, abandoned cars, and scuttled boats. In New York's (USA) coastal waters, experiments were performed using stabilized coal waste and fly ash from coal-burning power plants (CWARP, the Coal Waste

Artificial Reef Program). The Guam Division of Aquatic and Wildlife Resources (DAWR) had several projects using tires, cars, and a decommissioned barge. The Guam projects were funded as a habitat improvement of inshore lagoon project under the Sport Fish Restoration Program (funds provided by the US Dingell-Johnson Act). Monitoring of the reefs found that fishes did aggregate, but the overall value to local fishermen was limited, many of the fish attracted were planktivores and not the larger reef carnivores that fishermen seek, and that recruitment of corals and other benthic creatures was low. These projects raised concerns about potential damage to natural reefs during typhoons, and the projects were eventually abandoned and cleanups performed (DAWR 1977, 1978; Personal communication with G. Davis, Division of Aquatic and Wildlife Resources, Guam Department of Agriculture, Guam (USA)). In Rota, Commonwealth of the Northern Mariana Islands, a grounded vessel was sunk as an artificial reef as mitigation for the damage that occurred to the reef flat, with the primary goal of providing a new dive attraction. Ironically, the detonations from the explosives used to sink the ship killed the population of garden eels at the site as well as numerous reef fish in the area.

In Eilat, Israel, artificial reefs have been used as a tool to protect existing coral reefs and related resources. The amount of coral reef area belonging to Israel in the Red Sea is very limited, and the existing reefs are under stress from local sources of pollution as well as from the high numbers of visiting scuba divers. Artificial structures were placed in accessible areas and seeded with propagules grown from larvae collected in the laboratory and from others that recruited to settlement plates in the field (Oren and Benayahu 1997). In this example where habitat is limited, the artificial reefs have taken pressure off of natural reefs and some of the seed material was cultivated. Such projects do provide important data that can be applied to other projects. New approaches to artificial reefs that are underway use environmentally benign materials (concrete, ceramic) and structures that are specifically designed as marine life habitat. The Reef Ball Development Group, LTD. (http://www.reefball.com) rents and sells molds that can be used for artificial reef development. Another group, EcoReefs (http://www.ecoreefs.com) is also developing new types of artificial reefs, and we can expect such efforts to improve the effectiveness of this approach as a restoration tool.

I believe that each situation needs to be individually examined to determine if artificial reefs are an appropriate course of action to address resource depletion and degradation. In sandy areas devoid of structure, artificial reefs will surely attract fish and benthic organisms and are best used in areas protected from wave damage. The aggregation of organisms can help overcome the Allee Effect of reproductive failure at low population densities, provide an area for fishing as a trade-off for other areas to be closed as marine protected areas, and can serve as diving attractions, perhaps removing pressure from natural reef systems. However, in areas where larvae, rather than substrata, are the limiting factor, larvae (and juveniles and adults) might recruit to the artificial reef instead of reseeding the natural formations, robbing natural reefs of recruits. Moreover, new surfaces might provide settlement substrata for the opportunistic benthic dinoflagellate *Gambierdiscus toxicus*, which is responsible for localized outbreaks of Ciguatera poisoning. Steel, rubber, cement, and other materials have different characteristics than calcium carbonate, and it should be recognized that artificial structures made of artificial materials will end up supporting faunas reflecting these differences (e.g., the community of boring organisms).

Finally, artificial reefs can become dislodged or shed debris during storms, damaging the natural reefs that are more wave-resistant

Restoration of Appropriate Conditions

Of the options available, I feel the best choice is to work towards restoration of those conditions that allow natural recovery of populations to occur. In the real world this might be difficult over large spatial scales, yet is clearly the most functional response. Coral reefs, like many biological systems, are resilient ecosystems that have rebounded from catastrophic events over both ecological and geological time scales (Pearson 1981). They are robust, and can survive a number of individual stresses. Problems arise when multiple stressors act on these ecosystems in concert (Hughes and Connell 1999). If anthropogenic disturbances can be reduced and eventually removed, natural recovery can and usually will occur.

I am presently involved in a joint "restoration" project on Guam that is a partnership among researchers, government resource managers, the private sector, and local stakeholders and that serves as an example of the challenges and potential pitfalls of restoration activities. Tumon Bay is the main tourist center for the island, with over 20 hotels located along a 3-km stretch of beach. The bay is set off from the open ocean by a fringing reef, and has restricted water circulation with two small passes. It has been the receptacle for both surface runoff and aquifer discharge from the airport, main road, and an industrial park, with additional inputs from leaky sewer pipes servicing the hotels. Accumulations of the fleshy green alga *Enteromorpha* sp. (an indicator of eutrophication) line the beach most of the year, and there is an annual red tide in the north portion of the bay. While both have occurred historically, the problem appears to have grown more chronic and extensive during the past two decades.

In 1998 I was approached by members of the Guam Visitors Bureau to determine if the bay could be restored with abundant corals and associated marine life. My first suggestion was to purchase plastic animals (ducks, flamingos, etc), which raised eyebrows throughout the room, and caused some to question my sanity. My defense was simple: Why would anyone attempt to put sensitive living creatures back into an area where it has been clearly demonstrated that the present conditions cannot support their existence? After some consideration, the conversation turned in the direction of asking what needed to be done to restore appropriate conditions. The Tumon Bay Educational Outreach and Restoration Program was born.

The group developed several objectives, including to improve the vitality, and hence the fauna of the bay, improve the bay's water quality, provide a positive environmental and cultural educational experience for both visitors and local residents, and to determine whether specific management initiatives were effective. Several phases were developed, the first being the establishment of the area as a marine reserve. This was a cornerstone of the project and has already raised the numbers of herbivorous fishes in the bay, which has, as expected, cut back on some of the algal build-up. A drainage plan was developed along with an upgrade for the infrastructure. A grass turf management plan was suggested to guide the use of agrochemicals on the grounds of the hotels adjacent to the bay. A set of surveys of the marine flora and fauna were performed. Cultivated juvenile corals were transplanted to a selected site to serve as sentinels of water quality (the proverbial canaries in the cage). This was done with assistance from local high school students as an educational outreach component. As one resource manager pointed out, even a failure (100 percent coral mortality) would be a success as an educational tool on how difficult it is to attempt to restore a reef, and that more would have to be done to reverse the problems that accumulated over years of neglect and poor planning. The project is ongoing, and there is optimism that some of the objectives will be reached in the short term, and recovery of the bay will occur over the longer term. The intervention in this case is primarily stress abatement.

Environmental Clean-ups

Removal of debris from reefs and adjacent ecosystems is an activity that can promote recovery as well as prevent additional damage and degradation. Following Supertyphoon Paka, which hit Guam in December 1997, tons of anthropogenic debris were deposited on coastal reefs. These materials ranged from galvanized roofing tin to clothes, and damage to reef corals continued when post-Paka waves and storm surge resuspended these items. There are reports of metals, particularly iron, inhibiting recruitment of larvae of corals and other benthic organisms downstream from grounded vessels and refuse. Following the removal of metal products from an abandoned, submerged dumpsite on southern Guam, recruitment of benthic organisms improved over a period of months (Personal communication with G. Davis, Division of Aquatic and Wildlife Resources, Guam Department of Agriculture, Guam (USA). The post-Paka cleanup effort enhanced reef recovery by improving recruitment prospects and preventing further damage.

Pp. 393 – 409 In: Marine Conservation Biology, The Science of Maintaining the Sea's Biodiversity. E.A. Norse and L.B. Crowder, Eds. Island Press 2005. 470 pages

Related and Adjacent Ecosystems

Coral reefs are often affected by the state of adjacent ecosystems, including seagrass beds, mangrove communities, and the terrestrial communities within nearby watersheds. Degradation of one ecosystem may have effects on others downstream. Forests, grasslands, wetlands, mangrove systems, and seagrass beds all serve to buffer the effects of runoff and sedimentation on coastal marine communities. These ecosystems serve as both physical and biological filters. Furthermore, mangroves and seagrass beds provide important habitats for specific life history stages of coral reef organisms, specifically refuges and nurseries for juvenile fishes. The terrestrial and shallow-water coastal ecosystems are easier to work in than the marine realm, where time is a severely limiting a factor due to the dependence on scuba, and the related concerns of time, depth, pressure, and sea state. Activities that serve to protect and restore the above biological communities also provide benefits to coral reefs and other marine ecosystems. Watershed restoration is a necessary prelude to any attempt to restore coral reef ecosystems adjacent to land masses with topographic relief.

Summary and Conclusions

Although I have presented a number of concerns raised by restoration and recovery programs, I do feel there are tangible benefits to such efforts, as long as it is understood that humans do not possess the ability to fully repair the damage caused by the combination of anthropogenic and natural disturbance (Elliot 2000). It is critical to treat the disease (environmental degradation) and not just the symptoms (species and habitat losses). Restoration can be considered as a continuum of activities that can be undertaken, in order of preference: prevention, protection, alleviation of stresses, and intervention. When intervention is a chosen path, there are levels from passive rehabilitation that supports natural recovery, to full on, labor-intensive transplantation exercises. Decisions must be based on cost/benefit analyses, as financial and human resources dedicated to conservation will always be limited, and the proper allocation of these is critical if present and future generations are to have natural resources to use and enjoy. Such efforts require a multidisciplinary approach, combining the skills of natural and social scientists with economists, as it's really not ecosystems that can be managed, but rather, the human activities that affect them. Triage, the assigning of priority order on the basis of how resources can best be used, is a suitable approach for selecting areas for restoration and recovery. In the case of coral reefs, the most damaging problems including sedimentation, runoff, eutrophication, physical impacts (ship groundings, anchor damage), overfishing, and destructive fishing methods can be reduced substantially through integrated watershed management, appropriate land use and agricultural practices, navigational aids, mooring buoys, marine protected areas (with enforcement capabilities), and education, respectively. Family planning, the politically correct phrase for population control should also be considered as part of the big picture, even if most politicians inappropriately choose to disconnect this issue from environmental preservation.

Restoration and recovery programs should not be used as justification for environmental destruction, and false promises in the name of positive public relations are simply unacceptable. We need only look at the history of wetland restoration in the USA to recognize that unrealistic goals were set and, predictably, never met. It is always hoped that restoration and recovery efforts will be successful in reversing some of the damage that has been done and replacing some of the losses. Specific benefits beyond possible biodiversity recovery that can be expected from restoration activities include an improved knowledge of the ecosystem under study. Such activities may also provide an opportunity to educate stakeholders through their direct participation, and help develop political will in support of conservation policies and initiatives. Scientists and researchers have not generally been effective in translating their findings to the public and into policies. Restoration activities can provide a suitable opportunity for positive interactions among researchers, agencies, managers, businesses, and the community at large. In such cases, the failure to fully restore an ecosystem has value in educating all involved about the need for better preventive practices, measures and cooperation. Transplanted organisms can be used as indicators to test if conditions are actually improving, and to test the effectiveness of specific management actions on the target organisms.

In conclusion, while restoration ecology is a relatively young field, it holds a great deal of promise. I, like many conservation-minded people (who also happen to be parents), view natural resources as a checking account in the name of future generations. It appears that our present rate of expenditure will bankrupt the account, leaving our children with a serious debt to pay. I really believe that if our legacy to future generations is the global environment in its present state, we have failed a critical test as a society. Restoration and recovery efforts, in the broadest context that includes actions for the restoration of conditions that support natural recovery, are a viable means to turn things around and reverse some of the damage that has been done.

Pp. 393 – 409 In: Marine Conservation Biology, The Science of Maintaining the Sea's Biodiversity. E.A. Norse and L.B. Crowder, Eds. Island Press 2005. 470 pages

Acknowledgements

The author gratefully acknowledges research support from the US Environmental Protection Agency STAR Ecological Indicators and Water and Watershed programs, the National Institutes of Health Minority Biomedical Research Support program, the National Oceanic and Atmospheric Administration Coastal Oceans Program, and the Dept. of the Interior Office of Insular Affairs/MAREPAC. I thank my colleagues and students including G. Davis, S. Romano, S. McKenna, Y. Golbuu, S. Victor, N. Idechong, M. Hadfield, and S. Leota. I am also grateful to my wife, Cynthia, and daughter, Keana, for their continuous encouragement and support. This is contribution # 472 of the University of Guam Marine Laboratory.

Literature Cited

Bengwayan, M.A. (2001). Fishing with dead young boys. *Asia Observer*: May 23, 2001

Birkeland, C.E. (1997). Introduction. pp. 1-12 in C.E. Birkeland, ed. *Life and Death of Coral Reefs.* Chapman and Hall, New York, New York (USA)

Birkeland, C.E. and J.S. Lucas (1990). Acanthaster plancii*: Major Management Problem of Coral Reefs.* CRC Press, Boca Raton, Florida (USA)

Brown, B.E. (1997). Disturbances to reefs in recent times. pp. 354–379 in C.E. Birkeland, ed.

Life and Death of Coral Reefs. Chapman and Hall, New York, New York (USA)

Connell, J. (1978). Diversity in tropical rainforests and coral reefs. *Science* 199:1302-1310

Division of Aquatic and Wildlife Resources, Guam Department of Agriculture (1977). Job Progress Report, Research Project Segment. Guam Fish and Wildlife Investigations, Habitat Improvement of Inshore Lagoons. Project No. FW-2R-16.

Division of Aquatic and Wildlife Resources, Guam Department of Agriculture (1978). Job Progress Report, Research Project Segment. Guam Fish and Wildlife Investigations, Habitat Improvement of Inshore Lagoons. Project No. FW-2R-16.

Done, T.J. (1992). Phase shifts in coral reef communities and their ecological significance. *Hydrobiologia* 247:121-132

Eldredge, L.G. (1994). *Perspectives in Aquatic Exotic Species Management in the Pacific Islands, Volume 1.* South Pacific Commission, Noumea (New Caledonia)

Elliot, R. (2000) Faking nature. pp. 71-82 in W. Throop, ed. *Environmental Restoration: Ethics, Theory and Practice*. Humanity Books, Amherst, New York (USA)

Gittings, S.R., T.J. Bright, and D.K. Hagman (1994). The M/V Wellwood and other large vessel groundings: Coral reef damage and recovery. pp. 174-187 in R.N. Ginsburg, ed. *Proceedings of the Colloquium on Global Aspects of Coral Reefs: Health, Hazards and History, 1993.* University of Miami, Miami, Florida (USA)

Glynn, P.W. (1993). Coral reef bleaching: Ecological perspectives. *Coral Reefs* 12:1-17

Guzmán, H.M. (1991). Restoration of coral reefs in Pacific Costa Rica. *Conservation Biology* 5(2):189-195

Harriot, V.J. and D.A. Fisk (1988). Coral transplantation as a reef management option. pp. 375-379 in *Proceedings of the Sixth International Coral Reef Symposium, Volume 2*. Sixth International Coral Reef Symposium Executive Committee, Townsville (Australia)

Harrison, P.L. and C.C. Wallace (1990). Coral reproduction. pp. 133-208 in Z. Dubinsky, ed. *Ecosystems of the World: Coral Reefs*. Elsevier Science Publishers, Amsterdam, New York (USA)

Hatcher, B.G. (1984). A maritime accident provides evidence for alternate stable states in benthic communities on coral reefs. *Coral Reefs* 3:199-204

Hay, M.E. (1981). Spatial patterns of grazing intensity on a Caribbean barrier reef: Herbivory and algal distribution. *Aquatic Botany* 11:97-109

Helenurm, K. and L.S. Parsons (1997). Genetic variation and the reintroduction of *Cordylanthus maritimus* ssp. *maritimus* to Sweetwater Marsh, California. *Restoration Ecology* 5(3):236-244

Hudson, J.H. and R. Diaz (1988). Damage survey and restoration of M/V Wellwood grounding site, Molasses Reef, Key Largo National Marine Sanctuary, Florida. pp. 231-236 in *Proceedings of the Sixth International Coral Reef Symposium, Volume 2*. Sixth International Coral Reef Symposium Executive Committee, Townsville (Australia)

Hughes, T.P. and J.H. Connell (1999). Multiple stressors on coral reefs: A long-term perspective. *Limnology and Oceanography* 44(3, part 2):932-940.

Jackson, J.B.C. (1997). Reefs since Columbus. pp.97-106 in *Proceedings of the Eighth International Coral Reef Symposium*. Panama City (Panama)

Jackson, J.B.C., M.X. Kirby, W.H. Berger, K.A. Bjorndal, L.W. Botsford, B.J. Bourque, R.H. Bradbury, R. Cooke, J. Erlandson, J.A. Estes, T.P. Hughes, S. Kidwell, C.B. Lange, H.S. Lenihan, J.M. Pandolfi, C.H. Peterson, R.S. Steneck, M.J. Tegner, and R.R. Warner (2001). Historical overfishing and the recent collapse of coastal ecosystems. *Science* 293:629-638

Jokiel, P.L., E.F. Cox, F.T. Te, and D. Irons (1998). *Mitigation of Reef Damage at Kawaihae Harbor through Transplantation of Reef Corals Final Report.* US Fish and Wildlife Service, Pacific Islands Ecoregion, Honolulu, Hawaii (USA)

Lenihan, H.S. and C.H. Peterson (1998). How habitat degradation through fishery disturbance enhances impacts of hypoxia on oyster reefs. *Ecological Applications* 8,128-140.

Lenihan, H. S., C. H. Peterson, J. E. Byers, J. H. Grabowski, G. W. Thayer, and D. R Colby (2001). Cascading of habitat degradation: oyster reefs invaded by refugee fishes escaping stress. *Ecological Applications* 11:764-782.

Morse, D.E. (1990). Recent progress in larval settlement and metamorphosis: Closing the gaps between molecular biology and ecology. *Bulletin of Marine Science* 46:465-483

Morse, D.E. and A.N.C. Morse (1991). Enzymatic characterization of the morphogen recognized by *Agaricia humilis* (scleractinian coral) larvae. *Biological Bulletin* 181:104-122

Oren, U. and Y. Benayahu (1997). Transplantation of juvenile corals: A new approach for enhancing colonization of artificial reefs. *Marine Biology* 127: 499-505

Pp. 393 – 409 In: Marine Conservation Biology, The Science of Maintaining the Sea's Biodiversity. E.A. Norse and L.B. Crowder, Eds. Island Press 2005. 470 pages

Palmer, M.A., R.F. Ambrose, and N. LeRoy (1997). Ecological theory and community restoration ecology. *Restoration Ecology* 4:291-300

Paulay, G. (1997). Diversity and distribution of reef organisms. pp. 298-353 in C.E. Birkeland, ed. *Life and Death of Coral Reefs.* Chapman and Hall, New York, New York (USA)

Pearson, R.G. (1981). Recovery and recolonization of coral reefs. *Marine Ecology Progress Series* 4:105-122

Precht, W.F. (1998). The art and science of reef restoration. *Geotimes* 43(1):16-20

Richmond, R.H. (1993). Coral reefs: Present problems and future concerns resulting from anthropogenic disturbance. *American Zoologist* 33:524-536

Richmond, R.H. (1997). Reproduction and recruitment in corals: Critical links in the persistence of reefs. pp. 175-197 in C.E. Birkeland, ed. *Life and Death of Coral Reefs.* Chapman and Hall, New York, New York (USA)

Woodley, J.D. and J.R. Clark (1989). Rehabilitation of degraded coral reefs. pp. 3059-3075 in O.T. Magoon et al., eds. *Proceedings of Coastal Zone 1989*. Charleston, South Carolina (USA)

Pp. 393 – 409 In: Marine Conservation Biology, The Science of Maintaining the Sea's Biodiversity. E.A. Norse and L.B. Crowder, Eds. Island Press 2005. 470 pages

Tables

Table 23.1. Factors Affecting Corals Reefs and Suggested Actions

Factor	Cause	Scale	Suggested Prevention/Recovery Action
Sedimentation	A/N	L	watershed management/erosion control
Runoff/chemical pollution/eutrophication	A	L	watershed management/pollution controls/deep outfalls/improved agricultural practices
Sewage	A	L	improved treatment/deep outfalls
Dredging/construction	A	L	choose sites away from reefs, down stream
Ship groundings	A	L	Navigational aids/damage bonds/pilots/careful removal of hull and associated debris
Typhoons/Hurricanes	N	R	Reduce anthropogenic stress to support natural recovery
Thermal stress	A/N	L/R	Control local discharges/global emissions
Diseases	A/N	L/R	Reduce anthropogenic stress

Overfishing	A	L	Marine protected areas with enforcement, regulations on species, size and numbers
Destructive fishing practices	A	L	Regulations, education, enforcement, development of economic alternatives
Recreational damage (anchors, divers)	A	L	Mooring buoys, diver training, education
Collection for curios and the aquarium trade	A	L/R	regulate industry to non-destructive standards, phase out wild stock, phase in cultivated products
Crown-of -Thorns starfish and other corallivore outbreaks	A/N	L/R	Reduce nutrient input, protect natural predators, reduce anthropogenic stress to support natural recovery, seed with cultivated larvae & corals

Legend: A = anthropogenic; N = natural; L = local; R = regional

Figure Legends

Figure 23.1 Coral recruit (*Acropora* sp.) on specific crustose coralline algae (*Hydrolithon reinboldi).* Coral planulae cannot successfully recruit to substrata covered by sediment, cyanobacteria or thick accumulations of fleshy algae.

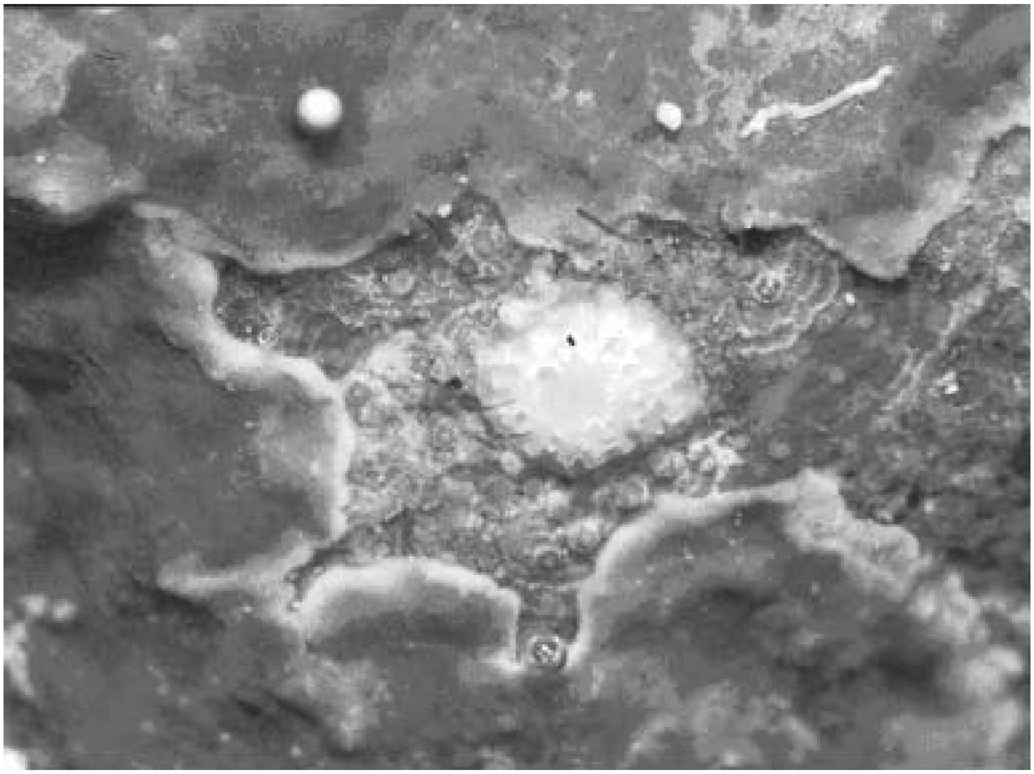

Figure 23.2 Restoration efforts on a reef in Apra Harbor, Guam, damaged by a mooring chain.

Small fragments died quickly, while reattached larger fragments of *Porites rus* survived.

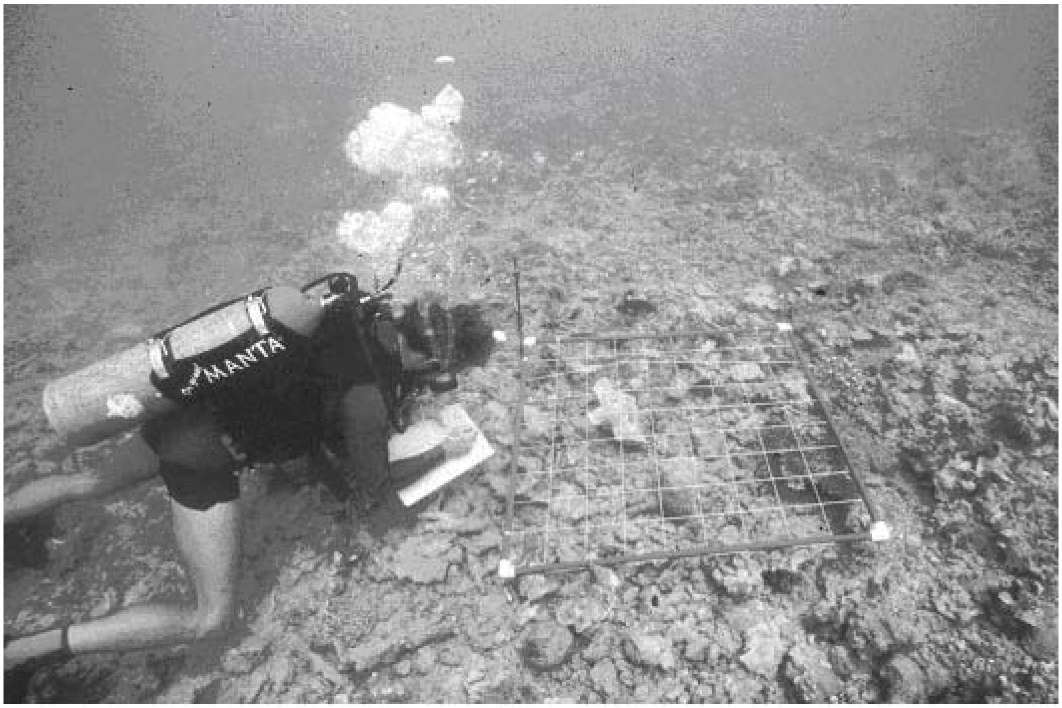

Figure 23.3 Coral seeder. Competent coral planula larvae were injected into the seeder, which was secured over appropriate crustose coralline algae. Reseeding small patches has been successful, but this area previously had corals over three hundred years old.

Pp. 393 – 409 In: Marine Conservation Biology, The Science of Maintaining the Sea's Biodiversity. E.A. Norse and L.B. Crowder, Eds. Island Press 2005. 470 pages

Figure 23.4 Cultivated coral recruits exhibiting aggregation and fusion. While such techniques hold promise, questions of species and genetic diversity remain.

Pp. 393 – 409 In: Marine Conservation Biology, The Science of Maintaining the Sea's Biodiversity. E.A. Norse and L.B. Crowder, Eds. Island Press 2005. 470 pages