Coral transplanting as part of restoration activities in Pago Pago, American Samoa, 1999 (NOAA OR&R).

CHAPTER 5. CORAL REEF RESTORATION

Key points

- Ship groundings on coral reefs physically damage the reef framework, increasing erosion and reef degradation.
- Reef crust and loose rubble should be stabilized as soon as possible after they are physically damaged.
- Damaged coral reefs may take decades to centuries to fully recover.
- Coral transplanting can expedite coral recolonization of damaged areas, especially in protected areas.
- Massive corals survive transplanting better than branched corals, but are very slow-growing. Soft corals are difficult to transplant successfully.
- Physical surroundings affect how fast coral regrows.
- The recovered reef may be different from the original.
- Recovery is more likely after acute, rather than chronic disturbances.
- Delaying restoration may significantly increase restoration costs, increase recovery time, and decrease likelihood of full recovery.

Most work to restore coral reefs to date has focused on restoring physical injuries caused by vessel groundings rather than injury resulting from oil or chemical exposure. Grounding impacts are, in many cases, the main injuries inflicted on coral reefs from "potential" spills or spills of small to moderate quantities of oil. The initial grounding itself and subsequent attempts to free the vessel may physically damage the reef framework and resident marine organisms. Direct grounding damage is often later exacerbated by associated mobile debris. Grounding of vessels of all types on reefs continues to be a significant source of injury to coral reefs around the world.

Accretive and destructive (or erosive) forces act continuously upon coral reefs in relative steady state. Damage to a coral reef framework opens the door for destructive forces to gain ground and degrade the reef. Once this reef framework, or "crust," is breached, for example by the hull of a grounded vessel, ship propellers, anchors, or towlines, the unconsolidated material beneath the surface is exposed. The breached area, if not repaired, will expand over time, especially during storms or hurricanes. Furthermore, the exposed coral rubble can be mobilized during storms and cause collateral reef damage. Structural restoration of the damaged reef framework, including stabilizing loose rubble, is essential before either natural or enhanced recovery of the live reef community can occur. Reef framework restoration should be conducted as soon as possible after a vessel grounding to minimize mortality of reef biota and risk of additional injury during storms. Delaying restoration may significantly increase restoration costs, increase recovery time, and decrease likelihood of full recovery.

Restoration through prevention

Even under the best restoration efforts, coral reefs, once injured, may take decades, if not centuries, to recover. In some cases, injured reefs may never recover. The best strategy is to prevent reef injury in the first place through effective vessel management. Designating "areas to be avoided" by large commercial vessels is one way to help maximize vessel safety and minimize physical and biological damage to reefs in areas such as National Marine Sanctuaries. However, large commercial vessels are a small component of a chronic problem. In the Florida Keys National Marine Sanctuary there are over 580 reported groundings a year, with 40-50% of these on coral and the rest on seagrass and hard-bottom habitats. A significant number of these incidents results in small spills of refrigerants, lube oils, and diesel fuels. Improved navigational technology and education for mariners can also help prevent vessel groundings. Nevertheless, it is likely that groundings, like oil spills, will continue. Consequently, restoring the physical and biological integrity of damaged coral reefs will continue to play an important role in the maintenance of healthy coral reef ecosystems in the U.S.

Coral transplanting

Coral recruitment onto either intact reef framework or structurally restored reef framework may be limited due to scarcity of coral larvae or due to chronic anthropogenic disturbances and influences that inhibit successful settlement of larvae. In such cases, transplanting coral can help expedite coral recolonization of damaged reef areas.

Transplanted corals often survive and grow in low-energy areas, although damage and mortality from wave action is common in less protected locations. Staghorn corals and other branching corals of the genus *Acropora* show good survival and rapid growth after transplanting, but their branching growth form and small area of attachment seem to make them particularly vulnerable to damage from strong wave action. Thus, using staghorn corals for transplanting may be limited to more sheltered areas. Coral species with massive growth forms are more resilient to wave action but are very slow-growing, which may make them less suitable for transplanting where rapid recolonization is desired.

Soft corals are more difficult than hard corals to relocate without injuring the delicate holdfast tissue, which often eventually kills the transplant. If coral for transplanting is not available from the damaged area, such as coral broken off or mobilized from vessel groundings, extreme caution must be exercised to prevent injury to donor populations. In addition to transplanting, reattachment of broken or toppled corals using quick-setting lime cement or epoxies has been used to successfully restore some species of damaged corals, as described by Hudson and Goodwin (1997).

Coral reef recovery rates

Corals are long-lived and recover slowly from disturbances, whether these are natural, such as hurricanes, or human-caused, such as ship groundings or exposure to pollutants. How fast and how well a coral reef recovers depends on the extent and type of damage, the location, species affected, suitable habitat, and many other parameters. Severe and repeated impacts delay recovery, while ongoing pollution and other chronic stresses may postpone it indefinitely.

Recovery is commonly measured using percent coral cover, species diversity, mean colony height, and overall coral color and health. Disturbed areas are compared with nearby areas that have not been impacted, or with data collected from the same area before the disturbance. Coral on damaged reefs recover by regenerating from partially damaged colonies, by reestablishing broken coral fragments, and through settlement of coral larvae carried by ocean currents.

If corals are injured but not killed, survivors regrow as the primary recovery mechanism. If most of the coral is killed, recovery will depend almost entirely on recruitment and growth of propagules from elsewhere, which will be much slower. A physically damaged reef recovers more slowly, and may need restoration. For example, vessel groundings fragment coral skeletons, producing loose rubble and fine sediments that inhibit successful recolonization of hard corals. When destruction is localized and small-scale, coral reef communities usually recover in less than ten years, if major sectors of the community are left intact and the area involved is not already marginal for coral growth. Reefs damaged by major natural disasters may take up to 20 years or longer for full recovery of affected areas. Where destruction has been particularly severe, complete reef recovery may take several decades or perhaps over a century. Corals of the Great Barrier Reef devastated by Crown of Thorns starfish may require 20 to 40 years for full recovery if the bulk of hard coral cover has been lost. Recovery may be delayed indefinitely if starfish infestations recur or if reefs are subsequently impacted by other natural or human-induced disturbances.

Recovery may also be delayed if the exposed substrate is resettled by fleshy seaweeds instead of coral or coralline algae. The situation can be exacerbated further if the algae are alien species. Given the right environmental conditions, a seaweed may be able to gain a foothold at a grounding site and then spread outwards over previously unimpacted reef.

Recovery time depends on the type and intensity of the disturbance. From observing coral communities in the Great Barrier Reef over a 30-year period, Connell et al. (1997) found that coral assemblages usually recovered from acute disturbances, though rates were slower if disturbances altered the physical environment than if they simply killed or damaged corals. In contrast, corals did not recover from chronic disturbances of either natural or human origins, or from gradual declines. Thus, recovery was more likely if disturbances were acute rather than chronic, since recovery will be continually interrupted or set back by repeated, chronic disturbances.

When a coral ecosystem has completely collapsed or the reef environment has changed permanently, making conditions unsuitable for coral, there may be no significant recovery. In areas that are marginal for coral growth, disturbances may result in algae replacing coral completely. Where recovery does occur, the reef may differ from the original in species composition, biological assemblages, and reef building capacity.

Physical characteristics such as exposure can significantly influence the process and rate of recovery for impacted reefs. For example, areas decimated by lava flows in Hawai'i took about 20 years to recover in exposed areas and more than 50 years in sheltered areas. For reefs in Hawai'i and the Eastern Pacific, which are physically controlled coral communities, recovery rates are related to the degree of exposure to sea and swell. Exposed areas require less time for recovery since coral is naturally less abundant in exposed areas and less growth is required for a reef to completely recover to background conditions. Growth rates of some corals are higher in exposed areas, which may be related to differences in circulation or food supply. However, recovery patterns may be different in more biologically accommodated coral reef communities, such as those in the Caribbean and Red Sea.

Recovery from oil exposure

Coral communities may recover more rapidly from oil exposure alone than from mechanical damage. Coral reefs exposed to crude oil and chemically dispersed crude oil in field experiments conducted in Panama showed recovery, with no significant differences between the exposed and control sites, after ten years. Short-term bioassays of corals exposed to oil have revealed temporary effects followed by recovery generally within one week.

Recovery of coral reefs after oil exposure, however, may depend partly on the recovery of associated communities that may be more seriously affected, such as mangroves and seagrass beds. As described in the case study, the 1986 Bahía las Minas oil spill in Panama impacted mangrove and seagrass communities, as well as corals. Death and injury of these habitat-structuring organisms physically destroyed habitats. The secondary biological effects of erosion and redeposition of oily sediments included greatly increased levels of injuries and decreased growth and sexual reproduction for surviving subtidal reef corals in Bahía Las Minas compared to coral reefs outside the bay. The entire Bahía Las Minas ecosystem became more vulnerable to subsequent natural or anthropogenic disturbances. It has been estimated that recovery of the dominant reef-building corals may require at least a century or more to reach the size of many of the colonies killed by this spill.

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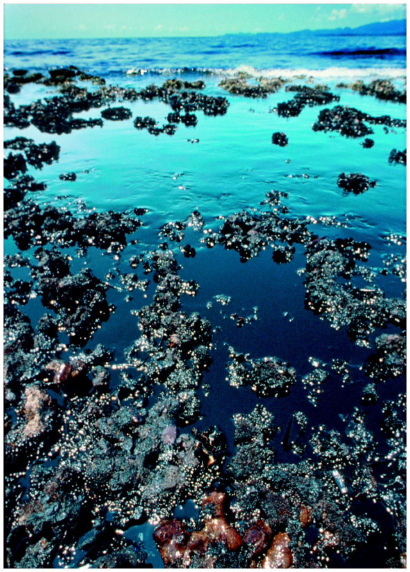

Oiled coral exposed at low tide, Bahía Las Minas, Panama (Carl Hansen)