SUMMARY

The Moloka‘i Coral Reef Today, and Alternatives for the Future

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From the contributions collected in this publication have emerged two important observations that have significance locally, nationally, and internationally. First, the fringing coral reef along the south coast of Moloka‘i is one of the most extensive and luxuriant reefs in the eight main Hawaiian Islands. It is longer and more continuous and has denser coral cover than reefs at any of the other islands—this alone makes it a state and national treasure worthy of study and protection. The second observation is more sobering: sections of the south Moloka‘i reef have been damaged in the past by sedimentation ultimately caused by human activities in adjacent watersheds. Although some of those activities are no longer taking place, their lingering effects are still being felt in the form of excess sediment runoff. We here review the basis for each of these observations, discuss how sedimentation affects the reef, and summarize the choices that are faced by the people of Moloka‘i and the State of Hawai‘i with regard to the reef's future.

The Magnificent Coral Reef of South Moloka‘i

The early chapters of this book describe the expansiveness, diversity, and beauty of the fringing reef off south Moloka‘i. Except for Moloka‘i locals, infrequent scuba divers, and occasional visiting marine scientists, few people have understood the nature and importance of the reef. As a result of recent studies, we now know a great deal more about the reef—from lidar bathymetric surveys, aerial photographs, diver inventories, and instrument measurements. The south Moloka‘i reef is a living, growing structure stretching along most of the island's south coast, from Hale O Lono on the west to Kamalō on the east, a distance of 40 km (25 mi). This stretch of coast is sheltered from the North Pacific swell by the island itself. Observations and mapping presented in this publication (see in particular Jokiel and others, this vol., chap. 5, and Cochran, this vol., chap. 9) document that much of the reef is an exceedingly rich and diverse marine benthic habitat, as exemplified by figure 1. Nearly all of the coral species known from the Hawaiian Islands, as well as several soft corals and an octocoral, are present on the Moloka‘i reef.

The Moloka‘i reef is a classic fringing coral reef with a wide, shallow reef flat; a well-developed reef crest at the seaward edge of the reef flat; and a biologically rich fore reef reaching to depths of 27 to 32 m (90 to 105 ft). As noted by Jokiel and others (this vol., chap. 5), the Moloka‘i coral reef hosts a rich and diverse marine benthic community dominated by five reef-forming corals: *Montipora capitata*, *Montipora patula*, *Porites compressa, Porites lobata*, and *Pocillopora meandrina*. The fore reef consists of coral ridges, or "spurs," separated by sand channels, or "grooves," In areas of dense coral coverage, the tops of the spurs are dominated by a *Porites compressa* (finger coral) community and the steep sides are dominated by a *Montipora* spp. community. Live coral is abundant on the fore reef, and the highest percentages, commonly in excess of 70 percent, are found at depths between 5 and 15 m (16 to 50 ft) along the entire reef and locally at depths between 20 and 25 m (66 to 82 ft).

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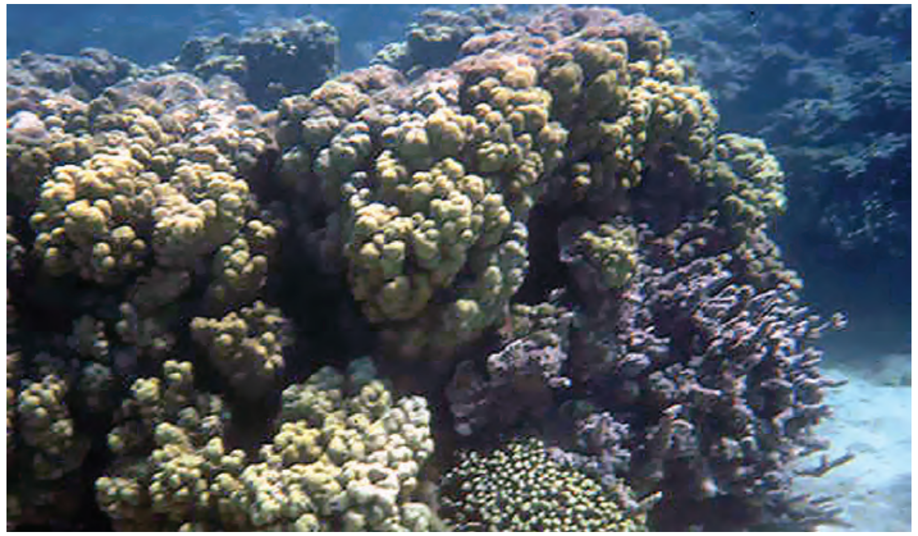

Figure 1. Underwater photograph taken off Kamalō, south Moloka‘i, showing a healthy fore reef. The coral colonies are multicolored (a sign that they are alive), and algae and fine sediment are noticeably absent.

The "blue holes" that characterize the Moloka‘i reef east of Kamalō appear to be unique within the main Hawaiian Islands. Some of these blue holes are open on one side toward the deep ocean, and others occur in the middle of the reef and thus are isolated from direct oceanic flow. Many blue holes, which are rimmed at the surface by *Porites compressa*, extend from near the water surface to depths of 25 m (83 ft) or more. The steep walls that form the perimeter of the blue holes are commonly covered by a lush coral growth and a vertically zoned habitat unique to these formations.

Many fishes observed in residence on Hawaiian reefs are important to the overall health of the coral reefs and ultimately of the islands. As Friedlander and Rodgers (this vol., chap. 7) point out, "fish provide food, cultural identity, and commerce to a broad majority of the local population of Moloka‘i and are an integral component of the marine environment." Both the herbivorous fish that feed on algae and the predatory fish that feed on other fishes are critical to the overall health of the Moloka‘i coral reef. The herbivores help in the prevention of algal overgrowth on corals and the spread of alien and harmful algae. Predators play an important role in maintaining turnover rates and overall productivity. Finally, a comment by Friedlander and Rodgers (this vol., chap. 7) is particularly relevant to the present state of the reef:

> The broad reef fringing the south shore of Moloka‘i is probably the most productive reef flat in the main Hawaiian Islands for the harvest of reef fishes and invertebrates. The fish assemblage represents a diverse fauna that is healthier than those in more heavily exploited urban areas around the state, but it has shown signs of decline in overall health and quality over time.

There are many factors that can cause fish declines on coral reefs. For the Moloka‘i reef, one such factor may be the decline in the overall condition of the reef because of sedimentation.

Sediment as a Primary Threat to the Reef

As with most coral reefs around the world, the long-term health of the reef off south Moloka‘i faces numerous threats, most of which are induced by humans. On many Pacific and Caribbean coral reefs, rising sea-surface temperatures cause bleaching and enhance disease, overfishing alters the food web and allows competing algae to thrive and smother coral, and nutrification from runoff and from sewage-contaminated ground water also supports algal growth at the expense of coral growth (see, for example, Rogers, 1990; Hughes and others, 2003; Pandolfi and others, 2003; Richmond and others, 2007).

Degradation of coral reefs, as pointed out by Pollnac (2007), Pandolfi and others (2003), and other authors, is often related directly to human habitation (fig. 2). Progressive degradation has occurred throughout reefs in the Pacific Ocean, Red Sea, and Caribbean Sea as nearby societies have shifted from subsistence agriculture to colonial development to modern development. In the analysis by Pandolfi and others (2003), reefs of the eight main Hawaiian Islands are identified as being nearly 60 percent degraded (fig. 3).

Figure 2. This graphic diagrammatically portrays the interplay between human civilization and coral reefs through time. As societies have grown and spread throughout tropical regions, there has been a corresponding decline in reef health, including depletion of larger fish stock from overfishing, and degradation from runoff of sediment and other anthropogenic pollutants has occurred. The path to recovery is uncertain. Few truly pristine coral reefs remain in the world today, some of which reside in the Northwestern Hawaiian Islands (from Pandolfi and others, 2005; image credit Mary Parrish).

At Molokaʻi, the damage from sediment-laden runoff from the land ranks as a first-order cause of reef degradation. By blocking light needed for photosynthesis, covering sites of potential coral growth, providing nutrients for harmful algae, and directly smothering coral polyps, sediment inhibits or prevents coral growth. However, even on this reef, where turbid red-brown water along the central coast of south Molokaʻi is considered the norm by locals and visitors alike, the linkage to declining coral health on the fore reef is not easily established. On the reef flat, though, the linkage is better defined.

Monitoring on the fore reef at depths of 3 m (10 ft) and 10 m (33 ft) for the past five years has produced confusing results. Monitoring sites on the reef along the Molokaʻi south shore have both some of the highest and some of the lowest levels of coral cover found in Hawaiʻi. Brown and others (this vol., chap. 6) and Jokiel and others (2004) document that sections of the reef around Kamalō contain some of the most densely packed coral communities in Hawaiʻi. However, they also point out that the Molokaʻi reef, judging from the sites that were surveyed, may not be faring as well as other sites in the State. The six Coral Reef Assessment and Monitoring Program (CRAMP) stations at Molokaʻi experienced the largest decline in coral cover (by island) between 2000 and 2002, compared to the other 54 CRAMP stations on Kauaʻi, Oʻahu, Kahoʻolawe, Maui, and Hawaiʻi (Brown and others, this vol., chap. 6; Jokiel and others, 2004). Declines on other Hawaiian Islands can be roughly correlated with rising human population, but on Molokaʻi the population is relatively low and stable. Here, the impacts to watersheds from farming, ranching, feral grazers, and other causes of soil loss (Roberts and Field, this vol., chap. 15) are a strong indication that sediment yield is a cause of coral decline at selected locations on the fore reef.

Visual surveys of the reef condition and estimates of coral cover were made along the fore reef by Jokiel and others (this vol., chap. 5) and are reproduced here in figure 4 because of the importance of this survey to understanding the condition of the reef. Previous work has determined that in most places on the Molokaʻi reef, coral growth is continuous from the base of the reef at depths of about 27 m (90 ft) up to shallow depths near the reef crest. Between the Kaunakakai Wharf and One Aliʻi, however, the pattern is distinctly different: coral was severely degraded or absent at all water depths in a 1-km swath off the wharf; and for the entire distance from the wharf to One Aliʻi, coral cover was absent or nearly absent on the upper fore reef at depths of 5 to 10 m (16 to 33 ft) (fig. 4*A*). Recent observations in 2007 (fig. 4*B*) established that at even shallower depths (< 5 m) coral was very sparse or absent, the bottom consisted of bare rock, reef rubble, and sand, and the water was chronically turbid. Observations west of the Kaunakakai Wharf and east of One Aliʻi show that coral is relatively abundant and the water clear at those same depths. The coral-poor area between the Kaunakakai Wharf and One Aliʻi coincides with the movement of chronically turbid waters westward and off the reef flat (Ogston and others, this vol., chap 20; Ogston and others 2004; Presto and others, 2006).

The link between coral health and sedimentation is more evident on the expansive reef flat bordering south Molokaʻi. The entire reef flat between Pālāʻau and Kamalō bears evidence of damage from sedimentation. West of Pālāʻau, the reef flat has healthy coral growth within 50 m of the shoreline and, on the very west end of the island, the limiting factors appear to be wave stresses and abrasion from the Southern swell and North Pacific swell. East of Kamalō, the coast and reef are more exposed to waves, and the less extensive coral cover appears to be a consequence of waves breaking on the reef flat. (Storlazzi and others, this vol., chap.11).

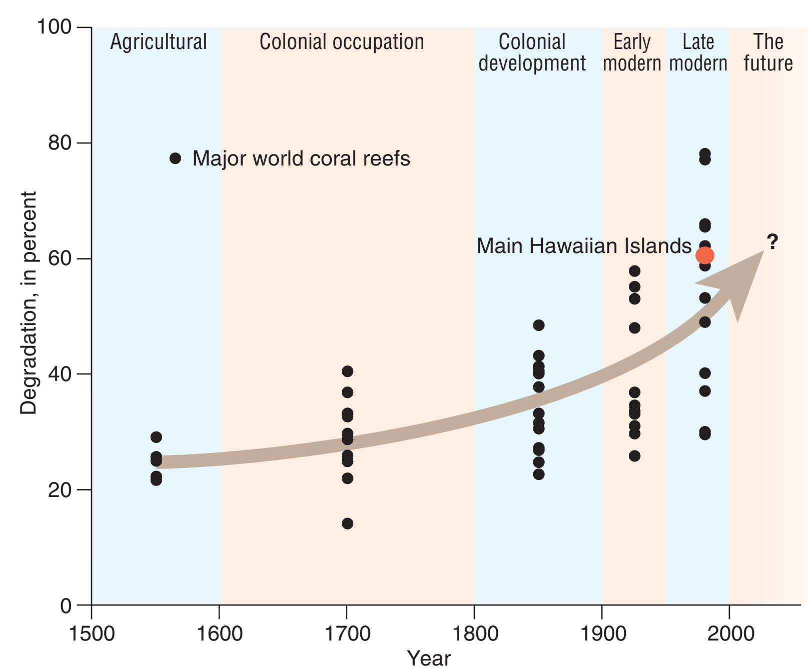

Figure 3. Trends in ecosystem conditions over the past five centuries for coral reefs in the Pacific Ocean, Caribbean Sea, and Red Sea (modified from Pandolfi and others, 2005). The arrow shows the general trend, from 20 to 30 percent degraded in the 16th century to 30 to 70 percent degraded at present. Note that the main Hawaiian Islands are now summarized as being nearly 60 percent degraded.

The evidence for sediment damage on the central Molokaʻi reef flat between Pālāʻau and Kamalō is both circumstantial and direct. The circumstantial evidence consists of observations of relatively thick deposits of muddy sand along the inner reef flat, photographs and measurements of turbid water, and an apparent lack of coral. The connection between these characteristics seems clear, but without direct documentation of poor coral condition caused by excess sediment, it remains circumstantial. The direct evidence comes from measurements of those factors, specifically coral cover and suspended sediment concentrations, made in April 2005 between the Kaunakakai Wharf and Kamalō (fig. 5*A*,*B*). Within 300 m of the shoreline, sediment concentrations greatly exceeded 10 mg/L, a number commonly used as the upper limit for turbidity for maintaining healthy corals (Rogers, 1990). Concentrations at many of the inshore sites exceed 20 mg/L, a level found to be lethal at other reefs (Hodgson, 1997; Hodgson and Dixon, 1992). Another factor is time — even low concentrations of suspended sediment over extended time periods can cause coral death (Hubbard, 1997). Virtually no coral is present within 300 m of the shoreline between the Kaunakakai Wharf and Kamalō. The first measurable coral cover, about 2 percent, appears about 400 m from shore, and coral cover gradually increases to about 10 percent (still a low level) on the central to outer reef flat 600 m from shore (Rodgers and others, 2005).

The low to absent coral on the inner reef flat between the Kaunakakai Wharf and Kamalō is striking. Evidence presented in earlier chapters on the abundance of algae and the low abundance of fish, when combined with the information on low coral cover and chronic high levels of sedimentation, makes it clear that this magnificent reef has been degraded and faces ongoing threats to its well-being as an ecosystem.

Why the Well-Being of the Reef Matters

Our comments above have sought to recognize that the Molokaʻi coral reef has major significance in terms of its intrinsic beauty, biodiversity, cultural importance, and as a local food resource. We have also endeavored to summarize findings that we and our colleagues interpret as evidence that parts of the reef are impacted by sediment, and that other parts (conceivably the entire reef) are threatened by sediment runoff from the land. Degradation of coral reefs is not limited to Molokaʻi, nor is it limited to Hawaiʻi — it is occurring on a global scale (Brown, 1997; Hughes and others, 2003a). Sediment runoff is one of the major causes of global reef decline (Pandolfi and others, 2003; Bellwood and others, 2004; Fabricius, 2005; Richmond and others, 2007). Our comments here are intended to place the potential loss of the Molokaʻi reef in perspective, for loss of the living reef would forever alter Molokaʻi. Coral constructs a complex reef that hosts a diverse biota, protects the shoreline from erosive waves, and provides food for locals. When coral dies in significant quantities, the food web shrinks, erosion of the old reef reduces its effectiveness as a barrier, and what once was a thriving complex ecosystem becomes a surface dominated by alga and sediment.

Although no one would argue that the survival of people on Molokaʻi is dependent upon actions taken in the watershed and on the reef, the situation

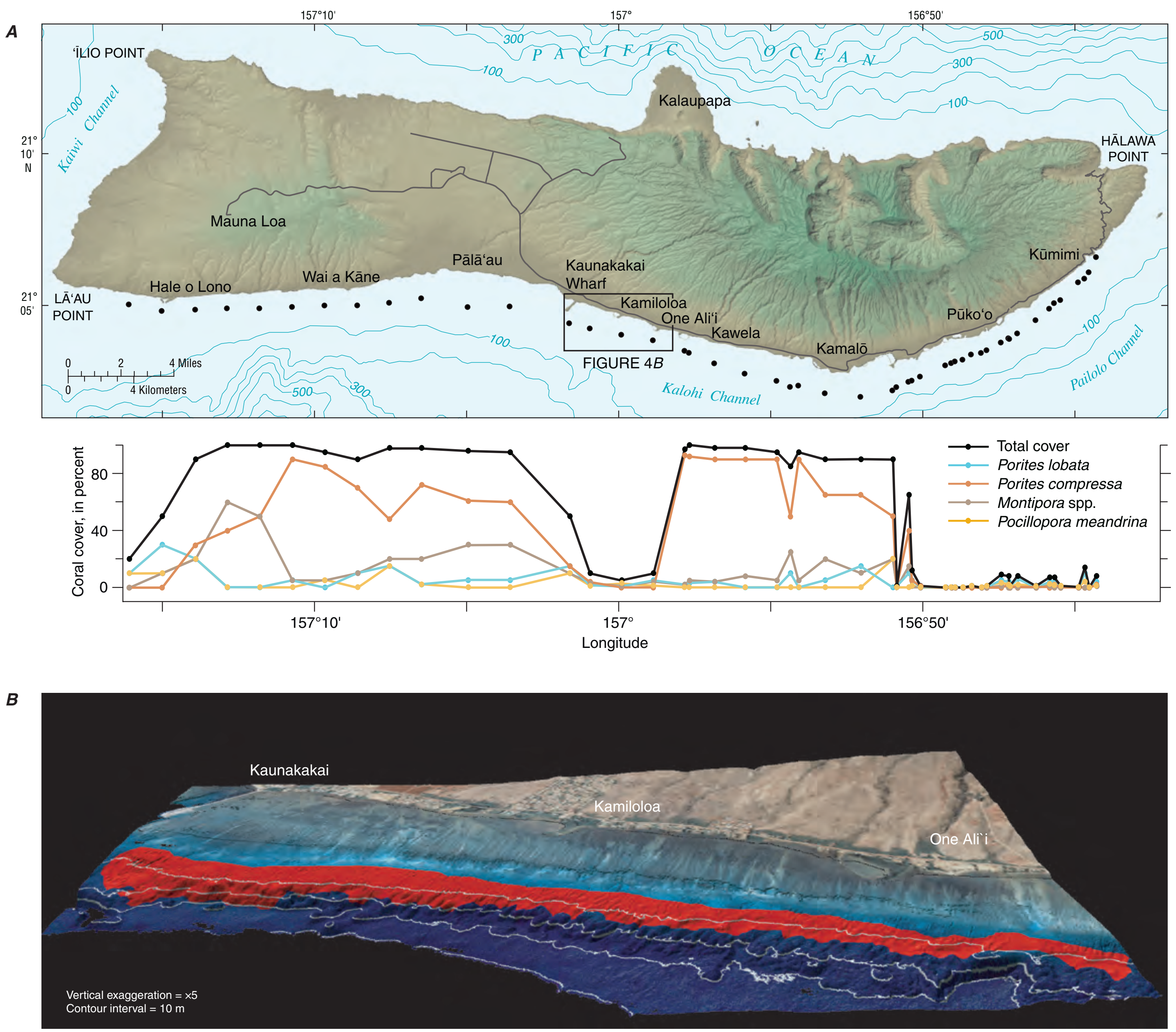

Figure 4. Variation of coral abundance along the south Moloka'i reef. *A*, Coral abundance on the fore reef along the south shore of Moloka'i in 2001, based on single point observations (dots in upper panel) in about 10 m (33 ft) of water every 2 km (1.24 mi) along the length of the reef (Jokiel and others, this vol., chap. 5). Note the very high total coral abundance from Hale O Lono on the west end of the island to east of Kamalō, with the pronounced drop in coral cover between the Kaunakakai Wharf and Kawela. *B*, An aerial photograph overlaid on shaded topography gives a 3D perspective view of the Moloka'i reef between Kaunakakai and One Ali'i and shows results of detailed follow-up surveys in 2002 and 2007. Observations made on scuba dives in the area of low coral cover from the 2001 survey showed that the entire upper fore reef at depths of 10 m (33 ft) in this area has low coral cover of ~15 percent (shown in red on the image). Coral cover in deeper water is high (>80 percent), except off the 3-km reef segment east of the wharf at Kaunakakai, where coral is degraded or absent. Distance along bottom of image is about 6.5 km (about 4 mi).

might be different if the island were isolated geographically, culturally, and economically from other human populations. Moloka'i is part of the county of Maui, the State of Hawai'i, and the United States. As such, even if the reef were to be totally destroyed, the Moloka'i community would remain intact, at a reasonable standard of living. But the community of Moloka'i and all of Hawai'i would be far poorer—culturally and biologically—from the loss of this reef. The most intractable issue is the question of habitat damage and potential loss of a resource that has immeasurable intrinsic and cultural value.

In his seminal book, "Collapse: How Societies Choose to Fail or Succeed," Jared Diamond (2005) identifies four ways that societies fail to respond to ecological damage:

> First of all, a group may fail to anticipate a problem before that problem actually arrives. Second, when the problem does arrive, the group may fail to perceive it. Then, after they perceive it, they may fail even to try to solve it. Finally, they may even try to solve it but may not succeed. (p. 421)

How then do Diamond's four categories apply to Moloka'i? Gradual landscape change is difficult to detect, and it is likely that early Hawaiians did not anticipate or recognize changes in watershed processes and the downstream effects that resulted from cutting hardwood trees and cultivating crops. It may be that the problem was perceived during the last century, but that few actions were taken to remediate the effects from these activities (planting of mangroves at Pālā'au was one such action). Finally, it may be that some actions were undertaken to offset soil erosion and loss, but that these actions largely failed because of the complex nature of the problem.

The key issue for avoiding environmental disasters is the recognition that change is occurring. Such recognition is often difficult—perceptions by residents of an area tend to be distorted by "shifting baselines" (Pauly and others, 1998) or "creeping normalcy" (Diamond, 2005), slow trends that are masked by large and irregular year-to-year variations. For example, a 75-year-old resident of Moloka'i may recall reef waters off Kamiloloa as being clearer in his youth, but 45-year-old and 15-year-old residents will probably disagree with each other and with the older resident about what is "normal." Over time and through generations, humans tend to develop "landscape amnesia" (Diamond, 2005), forgetting original environmental conditions because change is gradual. Thus the potential exists for people to accept the degraded coral, depleted fishery, abundant algae, and turbid water as normal.

It need not be so, and there is encouraging evidence that, with enough will and local support, the condition of the reef can improve. The introduction of mangroves at Moloka'i in 1902—itself an action with its own environmental consequences—is direct evidence that successful actions can be taken to preserve and protect the reef. What future actions will be taken, and will they be successful?

What's Next for the Moloka'i Coral Reef?

Alternative scenarios are possible for the future of the reef, besides continued decline. The inhabitants of Moloka'i, along with resource managers at the State and Federal levels, share responsibility for the protection and restoration of the reef. The sheltered setting of south Moloka'i and the variety and abundance of bottom types—pinnacles, fore reef, channels, blue holes, reef flat—

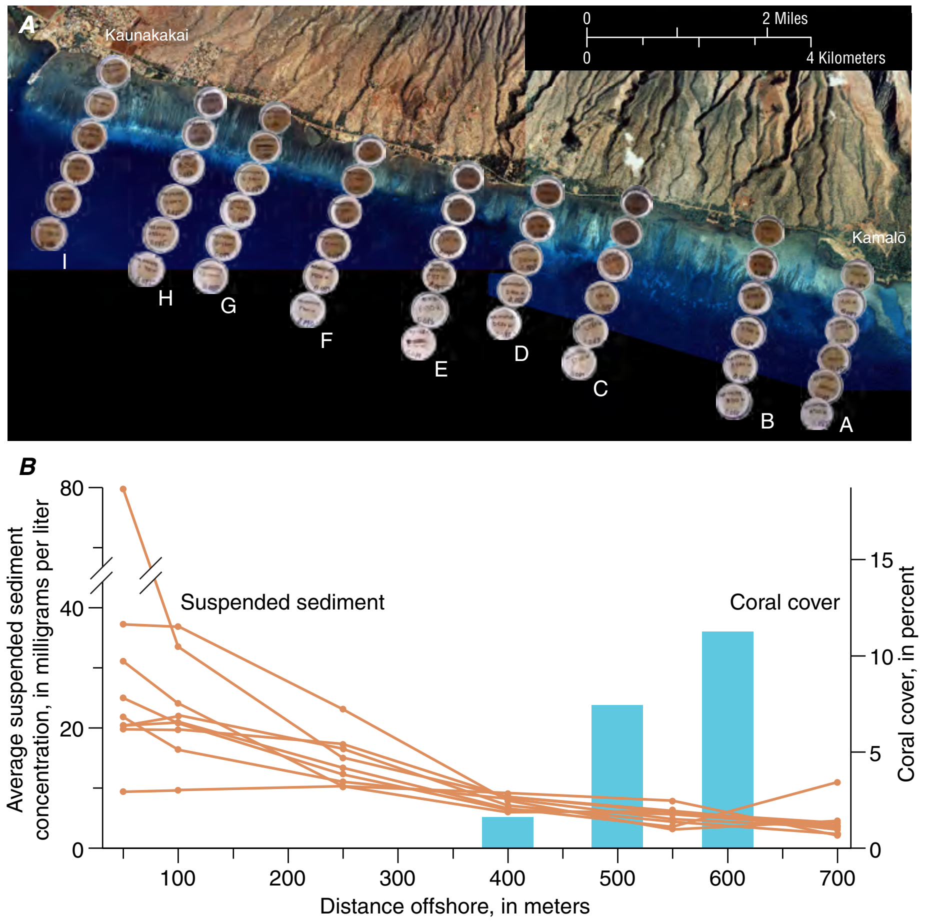

Figure 5. Turbidity of water on the south Moloka‘i reef flat and its relation to coral cover. *A*, Aerial mosaic of the central south Moloka‘i reef flat, between the Kaunakakai Wharf and Kamalō, with superimposed images of round filter papers containing the residue from filtering 1 to 2 liters (~1 to 2 quarts) of water. Samples were collected on April 7, 2005, at distances of 50, 100, 250, 400, 550, and 700 m from the shoreline. The filter papers are arranged on the image from nearshore to offshore along the sampling transects, but are shown non-overlapping for visual purposes. The darker brown color indicates that the nearshore waters contain relatively high levels of silt particles, which are derived from the island slopes (as confirmed by chemical tests). The highest concentrations of land-derived particles are on the inner reef flat. *B*, Concentrations of sediment in water on the Moloka‘i reef flat between the Kaunakakai Wharf and Kamalō, and their relation to coral cover, from field surveys and samples collected in April 2005. Suspended sediment concentrations are high near the shoreline (typically 20 to 70 mg/L) and decrease to 10 mg/L or less about 400 m from the shoreline. A concentration of 10 mg/L is considered the upper limit at which coral can grow successfully (Rogers, 1990). Also shown on this figure is the average coral cover on the reef flat, as mapped by Rodgers and others (2005). No appreciable coral exists within ~400 m of the shoreline, and at 400 m it is less than 5 percent. Coral cover gradually increases seaward to values of ~10 percent, which are still low compared with most other places on the reef.

have given rise to a rich coral setting. As Jokiel and others (this vol., chap 5) observe, diverse habitats in this area support rich coral reef communities.

The reef of south Moloka‘i has long served as a food, cultural, and recreational resource for the people of Moloka‘i, but its ability to do so in the future is not guaranteed. Many residents have noted that the nearshore waters are browner and the food resources reduced compared to earlier years. Friedlander and Rodgers (this vol., chap. 7) noted that fish resources are fewer and that management starting at the very local level was required:

> In addition, the men and women of the fishing community have expressed concern about the declining size and abundance of several important resource species such as kūmū and moana kale (blue goatfish, *Parupeneus cyclostomus*).

The coral reef off south Moloka‘i has been damaged—in some places severely—by excess sediment runoff from the land, particularly between the Kaunakakai Wharf and Kawela. Without protection of the reef from overuse and from excess sedimentation, its future is in jeopardy. Brown and others (this vol., chap. 6) point out that only 5 percent of Hawaiian reefs are in a threatened stage at this time but that portions of the Moloka‘i reef make up a significant part of the threatened group. Continued overuse of the reef for food sources, along with sediment influx from the land, will lead to continued degradation of the Moloka‘i coral reef ecosystem.

The fate of reefs receiving large quantities of sediment from adjacent landmasses is well studied. Woolfe and Larcombe (1998, 1999) discuss how reefs transform from healthy, accreting reefs to ones marked by declining health because of increased sediment input. The positions of the Moloka‘i reef flat and fore reef in such a scenario are well known at present, but the future pathway will depend on whether sedimentation continues unchecked or whether local actions are successful in significantly reducing the amount of land-derived sediment reaching the reef.

As long as large quantities of sediment are delivered annually onto the Moloka‘i reef flat, and as long as the reef is unprotected from overfishing, anchor damage, and other local stresses, it will be at risk. Climate change will likely place additional stresses on the coral communities through more acidic and warmer ocean waters (Hoegh-Guldberg and others, 2007), but that is a factor that cannot be controlled locally. The other stressors can be controlled locally, through strong sediment-management methods and establishment of large marine protected areas on the reef. As Hoegh-Guldberg and others (2007) point out, one important approach for offsetting the impacts of climate change on reefs is to reduce the influence of local stressors, such as suspended sediment in overlying waters.

Some steps are being taken locally to limit the impact of sediment on the reef. The Moloka‘i Watershed Advisory Group, The Nature Conservancy, the Hawai‘i Local Action Strategy of the U.S. Coral Reef Task Force, the U.S. Geological Survey, and other groups and agencies have all made concerted efforts to understand the factors that cause significant sediment runoff to the reef and to implement measures to limit the runoff. Eliminating feral goats, limiting wildfires, and guarding against harmful coastal and watershed construction activities all help to improve the situation, but these measures by themselves are not enough.

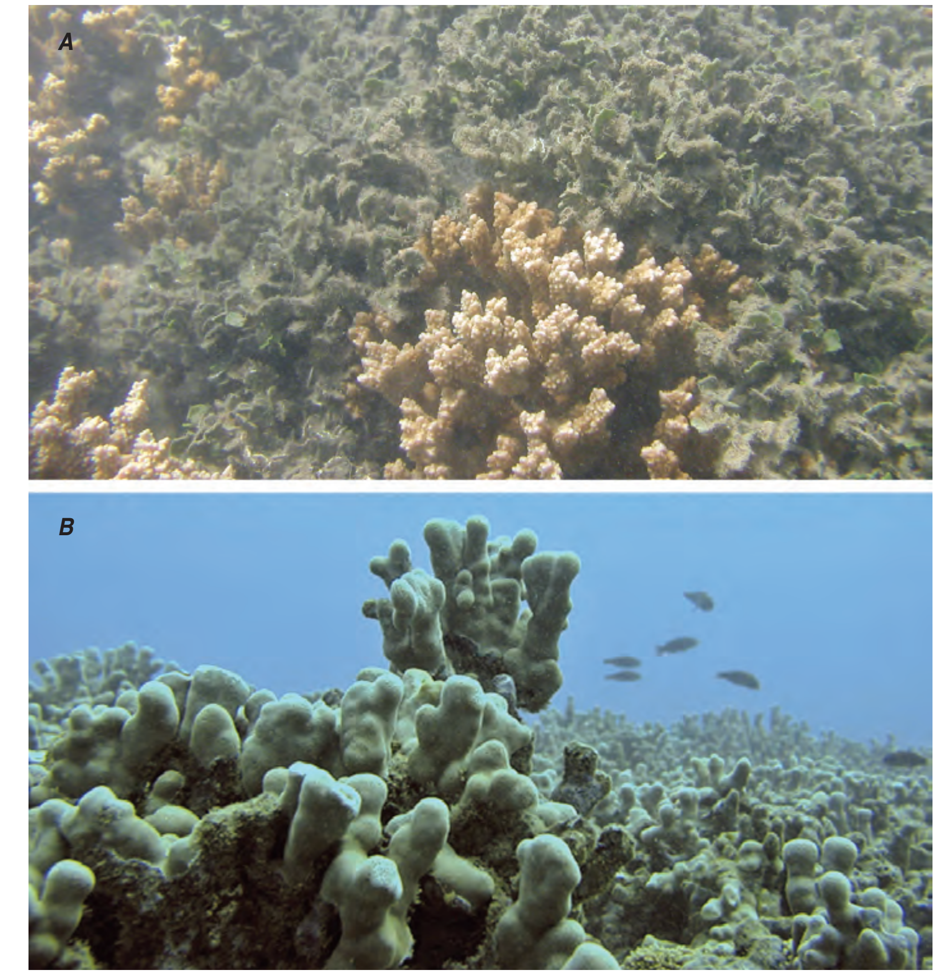

Figure 6. Two photographs of coral habitats that represent alternative pathways for the future of the Moloka‘i reef. *A*, Sediment and algae covering the surface have led to a decline in coral growth and its demise in places such as shown here, most notably on the reef flat and upper fore reef off central Moloka‘i. If land use and sediment runoff are not controlled, this may be the fate of large portions of the reef. *B*, Much of the Moloka‘i reef today remains healthy, as seen in this photograph. Reduction in sediment loads to the reef will help preserve this type of setting—and perhaps allow damaged areas to recover to a healthier state.

The ultimate fate of the coral reef off south Moloka‘i has not yet been determined (fig. 6). It is for the people of Moloka‘i, along with appropriate support at the county, State, and Federal levels, to take the necessary measures to safeguard this very special place—the reef of south Moloka‘i—for future generations. First steps could include support of efforts by nongovernmental and government groups to control fires, goats, and other factors that contribute to excess sediment runoff. Preserving the reef for generations of Moloka‘i and Hawai‘i residents can ultimately be best achieved by designating a large section of the reef as a marine protected area, one that is shielded from abuse by overfishing, sediment runoff, and other impacts.

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