CHAPTER 5

Reef Corals and the Coral Reefs of South Moloka‘i

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Rich and diverse marine benthic habitats exist along much of the south Moloka‘i coral reef, as demonstrated by maps of the area (see Cochran, this vol., chap. 9 for a complete discussion of benthic habitats). Habitats that support corals generally contain a characteristic assemblage of coral species that can be referred to as a “coral community.” Composition of each coral community is controlled by numerous environmental factors that influence recruitment, growth, and mortality of each component species. Different species show different adaptations to various environmental conditions, which enable some species to thrive in certain habitats but not others.

Corals that develop framework reefs in tropical waters are long-lived sedentary organisms that have a very narrow range of tolerance to temperature, salinity, water clarity, sedimentation, and nutrients. Therefore, corals can serve as excellent indicator species. Data on coral abundance and species composition allow evaluation of prevailing environmental conditions and changes over time. Corals are the keystone species that form the reef framework through secretion of limestone skeletons. The abundance and diversity of reef fish are directly related to coral community development (see Friedlander and Rodgers, this vol., chap. 7 for a complete discussion of reef fish on Moloka‘i). The ecological importance, economic value, and environmental sensitivity of corals make them ideal subjects for monitoring and assessment efforts. Brown and others (this vol., chap. 6) discuss results from several years of monitoring of coral growth off south Moloka‘i.

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The Corals of South Moloka‘i

Distinguishing among the hundreds of species of reef corals in the world is based largely on microscopic features of the coral skeleton as well as on skeletal growth form. However, the number of coral species in Hawai‘i is small, and they are relatively easy to distinguish from each other in the field (Maragos, 1977; Fenner, 2005). There are five dominant species of reef-forming corals on the reefs of south Moloka‘i. They are the “rice corals” *Montipora capitata* (previously known as *Montipora verrucosa*), and *Montipora patula*; the “finger coral” *Porites compressa*; the massive “lobe coral” *Porites lobata*; and the “cauliflower coral” *Pocillopora meandrina*. South Moloka‘i reefs are also inhabited by a number of other species of reef-forming and soft corals that range in abundance from rare to common. These species increase biodiversity, have great aesthetic value, and are of basic scientific interest, but they account for only a small percentage of the total living coral cover.

Abundant Species of Hard Corals

Montipora capitata (figs. 1, 2, 4) is clearly the most widespread species off south Moloka‘i. It is highly variable in growth form and occurs in all coral habitats, including isolated rocks on the muddy inner reef flat. Its range extends to a depth of more than 30 m (100 ft) on the deepest portions of the offshore fore reef, where it takes on a frail and highly branched growth form reminiscent of a finely branched *Anacropora*. Vaughan (1907)

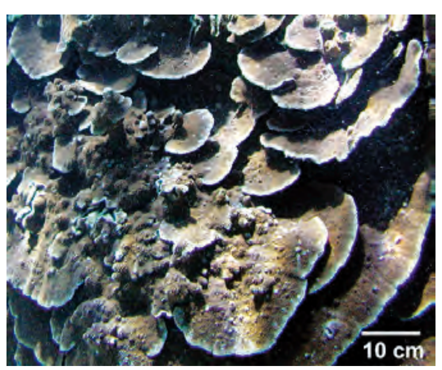

Figure 1. Encrusting and platelike growth forms of *Montipora capitata* dominate vertical faces and overhangs on the fore reef. Photograph taken at depth of 5 m (15 ft) at Pālā‘au, Moloka‘i.

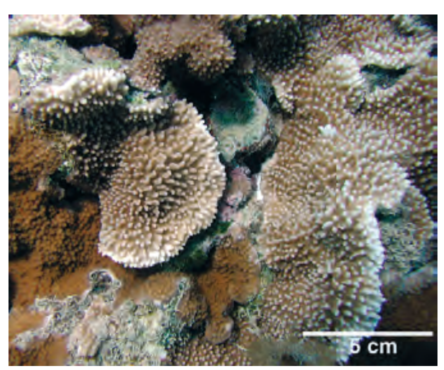

Figure 2. Platelike and encrusting growth forms of *Montipora capitata* (on the right) and encrusting *Montipora patula* (darker colony on the left) at a depth of 3 m (10 ft) on the shallow fore reef at Pālā‘au, Moloka‘i.

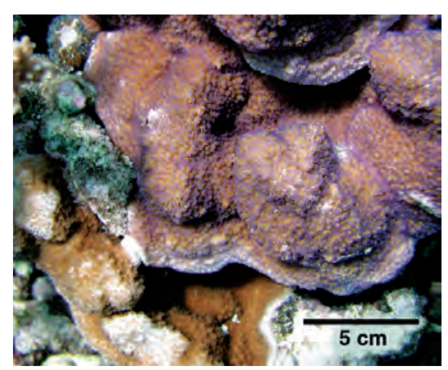

Figure 3. Purple-polyp form of *Montipora patula* (top of photograph) compared to brown variety at a depth of 3 m (10 ft) on the fore reef at Pālā‘au, Moloka‘i. The purple-polyp form of *M. patula* should not be confused with *Montipora flabellata*, which has a deep blue coloration throughout the colony.

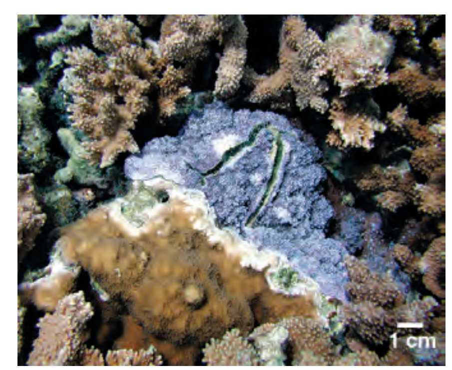

Figure 4. The three dominant species of *Montipora* compete for space on shallow reef off Kamalō, Moloka‘i. The blue species *Montipora flabellata* (upper center) struggles to overgrow the brown encrusting species *Montipora patula* (lower center). The branching growth form of *Montipora capitata* surrounds the two encrusting species in this photograph.

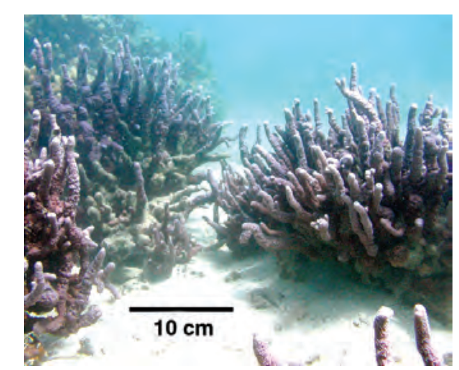

Figure 5. *Montipora flabellata* assumes a very unusual branched form on the reef flat of south Moloka‘i though symbiosis with a small shrimp known as *Gammaropsis* sp. (see text).

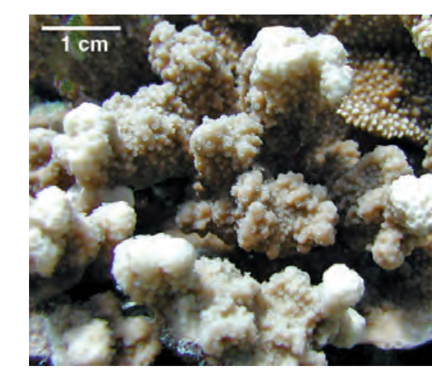

Figure 6. *Montipora studeri* (= *Montipora incrassata*) at depth of 3 m (10 ft) at Kamalō, Moloka‘i, with a small plate of *Montipora capitata* showing in the upper right.

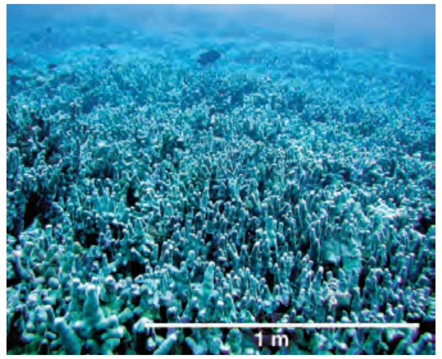

Figure 7. The deep fore reef is dominated by the “finger coral” *Porites compressa* along much of the south Moloka‘i coastline that is not affected by large waves. Photograph at 10-m (30-ft) depth off Pālā‘au, Moloka‘i.

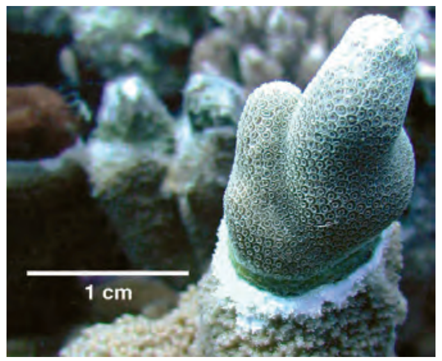

Figure 8. The “finger coral” *Porites compressa* (top) must grow vertically at a rate faster than the encrusting competitor *Montipora capitata* in order to survive. Photograph taken at depth of 10 m (30 ft) at Kamalō, Moloka‘i.

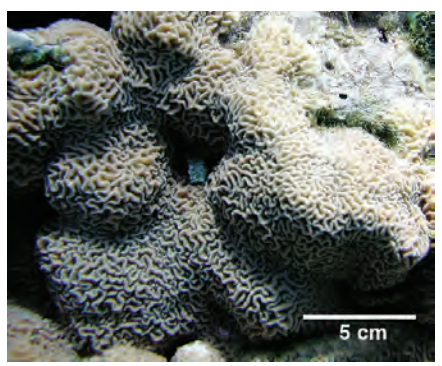

Figure 9. *Pavona varians* is an encrusting coral often found in shaded environments.

reported that *M. capitata* (which he called *Montipora verrucosa*) had the most variable growth form of any coral species. In shaded environments *M. capitata* forms large platelike structures; in calm-water environments it assumes a branched morphology; and in areas of high wave action it takes on an encrusting growth form.

Montipora patula (figs. 2, 3, 4) is an encrusting and plate-forming species that does not have a branching growth form. *M. patula* is somewhat more restricted in range than *M. capitata*, being more common in environments of higher wave energy and less abundant in environments subject to high sedimentation rates.

Montipora flabellata (figs. 4, 5) is a blue encrusting species commonly found in shallow, high-wave-energy environments (Jokiel and others, 2004). This species does not normally have a branching growth form and, by itself, cannot compete with branched species. However, unique branched colonies of *M. flabellata* occur on the outer reef flat at south Moloka‘i that have not been reported from other locations in Hawai‘i. The unusual branched morphology is the result of a mutualistic symbiosis between the coral and a small shrimp. The shrimp is an unidentified species of gammarid amphipod in the genus *Gammaropsis*. The shrimp forms a tube, and as the tube grows outward, the coral skeleton grows and encrusts the tube. Each branch of the coral thus has a hollow tube running up the center and an opening at the tip that provides a home for this small crustacean. In this way the coral is able to form a branched colony while the amphipod is given the protection of the coral skeleton (fig. 5). To the casual observer the opening at the end of the branch resembles a terminal polyp, and this growth form could easily be mistaken for a member of the genus *Acropora*.

Montipora studeri (fig. 6) is uncommon and generally found in wave-disturbed habitats, but isolated colonies have been observed as deep as 10 m (30 ft) along the south Moloka‘i coastline. Fenner (2005) recently revised this species name to *Montipora incrassata* Dana, 1846.

Porites compressa is a conspicuous coral and occurs in abundance at depths of 10–30 m (30–90 ft) on the fore reef (fig. 7) and can be found in most environments at lower abundance. The species is also successful in many shallow calm-water environments, such as along the rim of “blue holes” and in the shallows off Kamalō Pier. *P. compressa* is endemic to the Hawaiian Archipelago (Veron, 2000) and is an important framework coral. Its highly branched growth form provides cryptic habitats and cover for many species.

Porites compressa is most abundant in deeper areas on platforms and on the tops of ridges where wave energy is low (Dollar, 1982). This species can outgrow most other corals for space through rapid vertical growth of branches. Several encrusting species of coral are associated with this community, but they are generally forced to live in the spaces between the *P. compressa* branches because of the ability of this branched species to outgrow the encrusting forms. Occasionally some encrusting species can gain the upper hand. For example, *Montipora patula* can be seen overgrowing a branch of *P. compressa* (fig. 8) in some environments. Other encrusting species, such as *Pavona varians* (fig. 9), can be found deeper within the branches of *P. compressa* as well as in cryptic habitats, such as under ledges or in crevices. *Pavona maldivensis* (fig. 10) also follows this pattern, but is rare off south Moloka‘i.

The species in the genus *Porites* with more massive growth habits are ultimately classified by microscopic structures of the skeleton, but they can be distinguished from each other in the field off south Moloka‘i by certain diagnostic features. *Porites lobata* is the most common species of *Porites*. This species is generally yellow in color and forms massive to encrusting colonies. *P. lobata* is a long-lived species able to withstand periodic storm waves that remove the fast-growing and more delicate branching species that would otherwise overgrow the colonies (Grigg, 1983). Some shallow environments are dominated by colonies of *P. lobata* measuring 5 to 10 m in diameter (fig. 11). The polyps of this species are located in deep

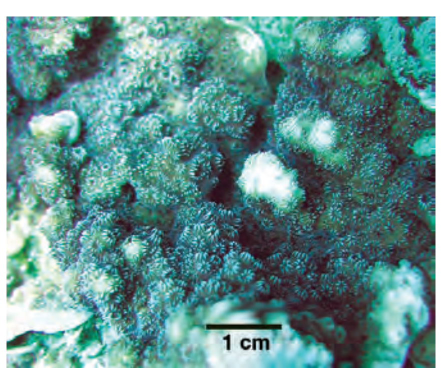

Figure 10. The encrusting coral *Pavona maldivensis* grows in crevices and under ledges.

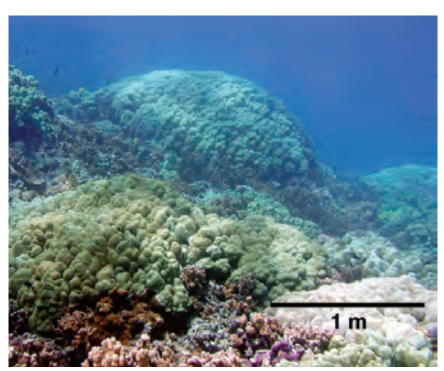

Figure 11. The shallow fore reef is commonly dominated by large yellow colonies of *Porites lobata*. Photograph taken at depth of 2 m (6 ft) at Kamalō, Moloka‘i.

Figure 12. *Porites evermanni* at a depth of 2 m (6 ft) at Kamalō, Moloka‘i.

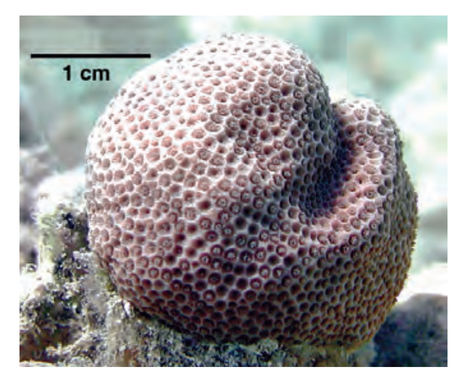

Figure 13. *Porites brighami* on the shallow reef flat near Pālā‘au, Moloka‘i. Note the deep calices in comparison to *Porites evermanni* (fig. 12).

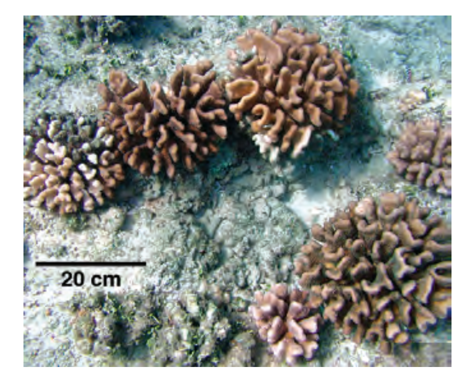

Figure 14. The shallow fore reef and reef crest are commonly dominated by the rose or cauliflower coral *Pocillopora meandrina*. Photograph taken at depth of 2 m (6 ft) off Kamiloloa, Moloka‘i.

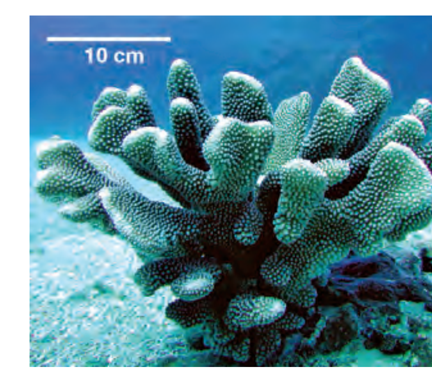

Figure 15. *Pocillopora eydouxi* growing at a depth of 10 m (30 ft) off Pālā‘au, Moloka‘i.

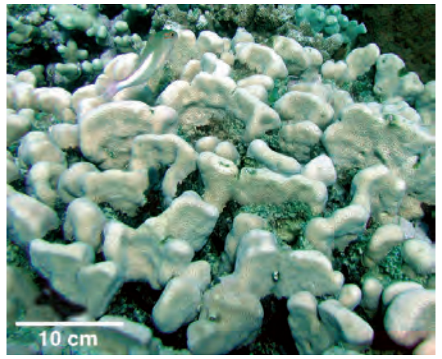

Figure 16. *Pavona duerdeni* colony growing in shallow fore reef area at Pālā‘au, Moloka‘i.

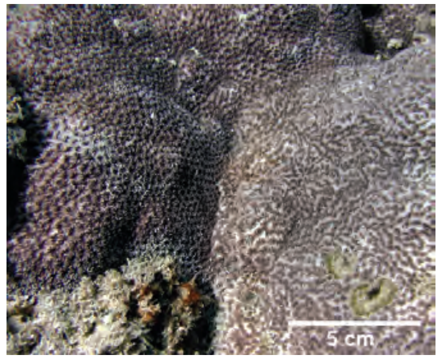

Figure 17. The encrusting reef coral *Leptastrea purpurea* at Pālā‘au, Moloka‘i.

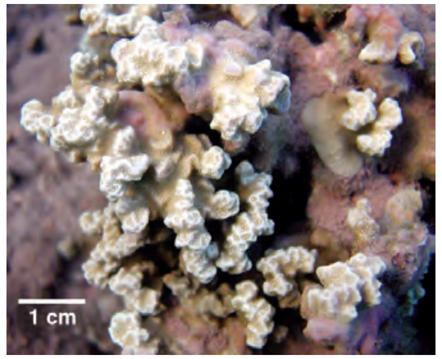

Figure 18. *Porites rus* on the reef crest at Kamiloloa, Moloka‘i.

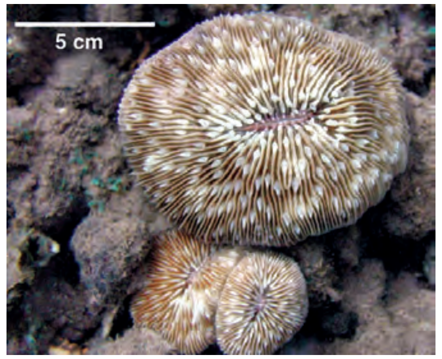

Figure 19. “Mushroom coral” *Fungia scutaria* on outer reef flat at Kamiloloa, Moloka‘i.

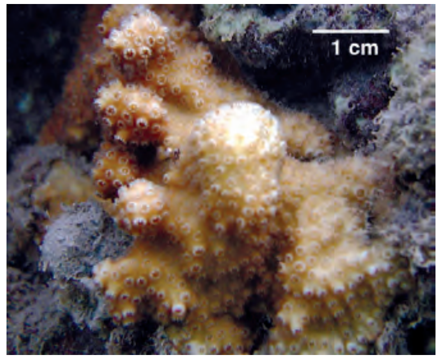

Figure 20. *Cyphastrea ocellina* on outer reef flat at Kamiloloa, Moloka‘i.

Figure 21. *Porites lichen* (= *Porites* cf. *bernardi*) on outer reef flat off Kamiloloa, Moloka‘i.

calices (Veron, 2000). By comparison, the closely related species *Porites evermanni* has very shallow calices (fig. 12). At Moloka‘i, *P. evermanni* is uncommon and is light blue-grey in color. It can form large massive colonies but is generally restricted to water depths of less than 1–2 m (3–6 ft) off south Moloka‘i. This coral has been classified as *Porites lutea* by Fenner (2005) because the two cannot be distinguished from each other, and *P. lutea* is the older name. A third species, *Porites brighami*, has very deep calices (fig. 13) and forms very small colonies that seldom exceed 5 cm (2 in) in diameter. *P. brighami* is relatively rare off south Moloka‘i and only occurs in shallow, high-wave environments, such as the reef crest or outer reef flat.

Pocillopora meandrina has a dense, hard skeleton that resists breakage (Rodgers and others, 2003) and thus is able to dominate shallow areas characterized by high wave energy where other species cannot persist (fig. 14). *Pocillopora ligulata* is a species closely related to *P. meandrina*, which occurs in environments of high wave energy. It has the general appearance of *P. meandrina* but with very thin and ragged branches. *Pocillopora eydouxi* is similar to *P. meandrina* but with thick large branches (fig. 15). This species occurs from the reef flat through the shallow fore reef at depths of 1–10 m (3–30 ft), generally as isolated large colonies. *P. eydouxi* is very vulnerable to extreme storm surge because of its large size.

Less Common Species of Hard Corals

Pavona duerdeni (fig. 16) has a very dense skeleton that can form very massive colonies with ridgelike structures. In the Hawaiian Islands this species is more common on south-facing shores. This species is typically found on the upper fore reef, reef crest, and seaward edge of the reef flat.

The encrusting coral *Lepastrea purpurea* (fig. 17), which has a hard, dense skeleton that resists abrasion, is commonly found on the reef crest and outer reef flat.

Porites rus is uncommon on most Hawaiian reefs. Scattered colonies occur on the reef crest on south Moloka‘i in the Kaunakakai region (fig. 18). An unusual situation occurs on the outer shallow reef flat and shallow fore reef on the west side of the Kaunakakai channel. This area is dominated by an extremely large population of *P. rus* colonies that covers an acre or more.

The solitary, free-living coral *Fungia scutaria* (fig. 19) is an easily recognized hard coral. This species is typically found tucked into crevices in the reef. Although not common in Hawai‘i, *F. scutaria* can be locally abundant.

Cyphastrea ocellina (fig. 20) can be found on reef flats, the reef crest, and the shallow fore reef. *Porites lichen* is another species with a similar distribution (fig. 21) with small greenish cryptic colonies less than 1 in (2.5 cm) in diameter. The calices of this species are often aligned to form rows. *P. lichen* reported from Hawai‘i is not the same species as *P. lichen* found in other areas of the Pacific, where they commonly grow to a much larger size. Therefore, this Hawaiian species has recently been reclassified as *Porites* cf. *bernardi* Vaughan, 1907 by Fenner (2005).

Pocillopora damicornis is a finely branched species typically found in shallow, calm-water environments. Off south Moloka‘i, *P. damicornis* is found on the reef flat, despite muddy sediment and competition from macroalgae (fig. 22). *Psammocora stellata* (fig. 23) occupies the same reef-flat habitats as *Pocillopora damicornis*, but it is less abundant. This species occurs primarily on the shallow reef flat and is often found growing on rocks and rubble very close to shore.

Soft Corals and Octocorals

Several “soft corals” and an octocoral are found on the reefs of south Moloka‘i. These do not contribute to the formation of the reef, because they do not form a calcium carbonate (limestone) skeleton. Although these species are uncommon off south Moloka‘i, they are interesting organisms that contribute much to the biodiversity and beauty of the reefs. The soft coral *Sinularia molokensis* is extremely rare (fig. 24). Only a few colonies are known to exist in the world, and all of these are recorded

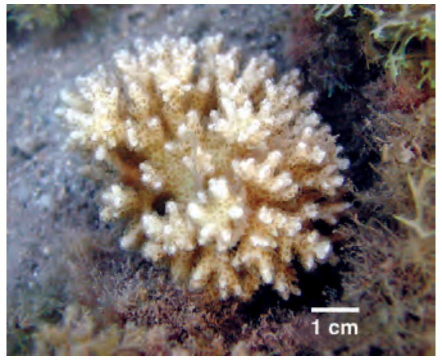

Figure 22. *Pocillopora damicornis* on inner reef flat off Kamiloloa, Moloka‘i.

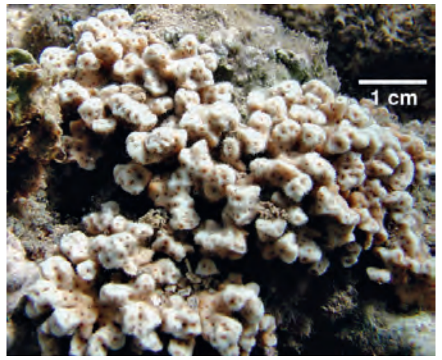

Figure 23. *Psammocora stellata* on shallow inner reef flat at Kamiloloa, Moloka‘i.

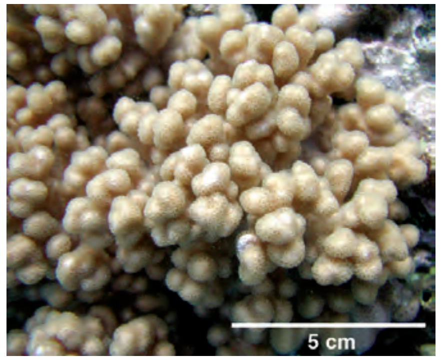

Figure 24. *Sinularia molokensis* is a very rare soft coral and known only from a few colonies that occur on Moloka‘i.

from Moloka‘i. *S. molokensis* occurs on the fore reef at depths of 1–6 m (3–20 ft). *Palythoa tuberculosa* is found in shallow, high-wave-energy environments on the reef crests (fig. 25), but this species rarely occurs on the deeper reefs. *Zoanthus pacificus* is uncommon on the reefs of south Moloka‘i, but it has been observed in shallow water at the east end of the island and in water as deep as 10 m (30 ft) off Pālā‘au (fig. 26). *Anthelia edmondsoni* is a small endemic octocoral that is common in shallow, high-wave environments off many of the Hawaiian Islands but rare off south Moloka‘i. Note the presence of eight tentacles (fig. 27). Colonies of this species are generally velvetlike and of purple color in shallow water and more brownish in deep water.

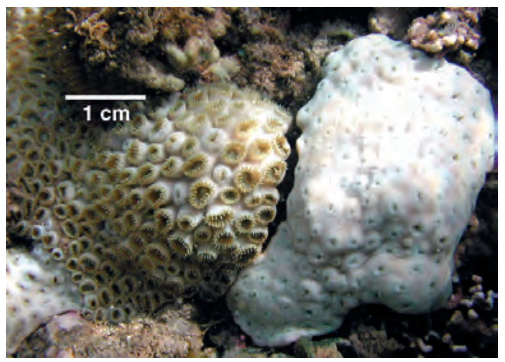

Figure 25. *Palythoa tuberculosa* with polyps expanded (far left) and contracted (near right) on the reef crest at Kamiloloa, Moloka‘i.

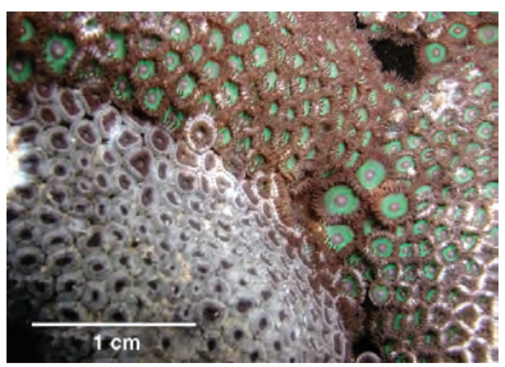

Figure 26. *Zoanthus pacificus* is uncommon off south Moloka‘i but is found on shallow areas near the east end of Moloka‘i and more rarely in deeper water along the rest of the coastline.

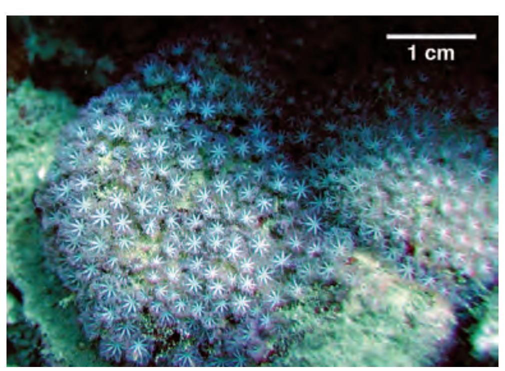

Figure 27. This small colony of *Anthelia edmondsoni* was photographed at a depth of 10 m (30 ft) off Pālā‘au, Moloka‘i.

Major Environmental Factors Affecting Coral Community Structure off South Moloka‘i

Physical Factors

Currents and Waves

Wave energy is an important factor controlling development of coral reef communities (Storlazzi and others, this vol., chap. 11; Grigg, 1983). Anomalous and extreme wave events such as hurricanes can pulverize corals, but such catastrophic events are very infrequent, so the prevailing wave regime is of greater importance over the long run. Many fast-growing species do not recruit, grow, or survive in high-wave-energy regimes. Corals adapted to strong water motion cannot compete effectively in environments of weak water motion. Each major reef-building species modifies its morphology to fit environmental conditions; thus the prevailing wave regime shapes the structure of the coral community. For example, the growth form of the coral *Montipora capitata* is delicate and branching in calm water, but becomes encrusting in areas with strong water motion.

In extreme situations, wave impact retards or prevents establishment of reef coral communities. The large North Pacific swell that strikes the north coast of Moloka‘i during the winter can move boulders the size of trucks (fig. 28). Such waves can fragment and abrade all except the most wave-resistant coral species, which persist on isolated outcrops and in protected, recessed areas where wave force and abrasion are minimized. The elongate east-to-west orientation of Moloka‘i shields much of the reef along the south coast from the North Pacific swell. North Pacific swell wraps around the extreme east and west ends of the island, influencing reef development in these areas (see Storlazzi and others, this vol., chap. 11 for more information on waves). The southeast coast from Kamalō to Hālawa is severely affected by the large northeast trade wind swell passing through the Pailolo Channel. The south coast of Moloka‘i falls into the “wave shadow” of surrounding islands, but it is potentially vulnerable to the infrequent storm waves associated with hurricanes or “Kona” storms from the south. Hurricane Iwa caused extensive damage to the Kaunakakai wharf during late November 1982 and presumably damaged the surrounding fragile reefs (Capt. Joe Reich, oral commun., 2001). A paradox is that such extreme events can also remove years of accumulated sediment and thereby rejuvenate coral growth on a reef.

Figure 28. The force of large storm waves from the North Pacific prevents development of a reef framework off the north coast of Moloka‘i. Note diver in the lower portion of the figure. Photograph taken at Kalaupapa on the north coast of Moloka‘i.

Light

Light is absolutely necessary for reef growth. Corals are plant-animal symbioses that require sunlight as a primary source of energy. Therefore, their lower depth distribution is set by light penetration. Waters above the ocean reefs off south Moloka‘i are of sufficient clarity to permit development of rich *Porites compressa* communities to depths of 30 m (100 ft). At greater depths, the substrate is unsuitable for corals, and the reef gives way to a sand terrace dominated by the alga *Halimeda* (see Smith and others, this vol., chap. 8 for more discussion of alga distribution). High turbidity inshore because of fine sediment from land runoff dramatically reduces light penetration on the shallow reef flats. The impact and processes that influence sediment runoff and turbidity are discussed in more detail in chapters 17 through 21.

Temperature

Temperature is a primary physical factor governing reef coral distribution (Wells, 1957). The optimum growth temperature for Hawaiian reef corals is 27°C (81°F), although they can tolerate prolonged temperature of from 20°C to 29°C (68–84°F) and short exposure to temperatures of 18°C to 31°C (64–88°F). Under calm sunny periods during the summer months, temperature on the inner reef flat can approach the upper lethal temperature for these reef corals.

Salinity

Reef corals have been described as having very narrow salinity tolerance (Wells, 1957), but corals and coral reefs are known to occur under natural conditions at salinities ranging from 25 parts per thousand (ppt) to 42 ppt (Coles and Jokiel, 1992). Reef kills caused by low salinity associated with flood events have been reported throughout the world, as well as from Hawai‘i (Jokiel and others, 1993). Salinity on the reefs of south Moloka‘i is generally close to that of the open ocean, which is on the order of 34–35 ppt (Ogston and others, this vol., chap. 20). Hawaiian corals can tolerate salinity of 15 ppt for several days without dying. This represents a 50-percent dilution of seawater with freshwater. During extreme floods, such low salinity can occur near stream mouths on the reef flat, but the freshwater is rapidly mixed with seawater that is pushed over the reef crest by wave action. Freshwater is much less dense than seawater, so it often forms a surface layer that does not reach corals in deeper water. Rising and falling tides further flush the reef flat. Thus, live coral can be found scattered across the shallow reef flat even close to shore. Floods definitely represent a major but episodic stress for corals on the Moloka‘i reef flats, but corals continue to persist in this environment.

Substrate Type

Reef corals generally require a hard substratum. A substratum of sand and mud is unsuitable for coral settlement and growth. Corals can, however, develop in these areas through initial settlement on isolated outcrops of hard rock. Accretion of skeletal material over many generations of coral will produce larger coral mounds or ridges surrounded by mud or sand. The solitary coral *Fungia scutaria* (see fig. 19) can persist on unstable rubble substrate because of unique hydrodynamic properties (Jokiel and Cowdin, 1976).

Figure 29. Movement of sediment across the bottom can smother and later uncover large coral colonies, as well as new coral settlements. Photographs of live *Pocillopora meandrina* (top) a buried colony (middle) and an uncovered dead colony (bottom) were taken at a depth of 3 m (10 ft) off Kamiloloa, Moloka‘i.

Figure 30. The coral *Pocillopora meandrina* (center of picture) is being overgrown by the fast-growing purple *Montipora flabellata* (bottom of picture) and by the branching growth form of *Montipora capitata* (top of picture). Photograph taken at depth of 3 m (10 ft).

Sand and mud are transported onto and off the reef in response to currents and waves (see Bothner and others, this vol., chap. 19 and Ogston and others, this vol., chap. 20). Passage of sediment through coral communities can smother new coral settlements and encrusting corals and can even bury large coral colonies (fig. 29), which are killed and sometimes uncovered later by subsequent erosion.

Depth

Depth of water is an important factor for corals, mainly because light and water motion diminish with depth. Deeper corals are subjected to less risk from wave energy under normal conditions. However, these corals are limited by lower light intensity, which causes a reduction in growth.

Land Impact

Terrigenous runoff carries freshwater, fine sediment, and nutrients onto the reef (Field and others, this vol., chap. 21; and Roberts and Field, this vol., chap. 15). The shallow inshore reefs of Moloka‘i have been profoundly affected by increased runoff and sediment from two centuries of improper land-management practices. A major impact to the inshore is the extreme sedimentation of fine mud.

Biological Factors

Competition

The limited amount of space available on a coral reef results in competition. Corals compete with each other as well as with other organisms for this resource. In optimal environments (for example, high light and moderate water motion), the fast-growing encrusting or branching species have the advantage. They have lightly constructed skeletons that allow them to rapidly overgrow other species (fig. 30). This eventually leads to total dominance by the single most successful competitor (see example in fig. 7). Such weak skeletons, however, cannot persist in high-wave environments, where the slower growing corals with dense skeletons have the advantage.

Predators and Parasites

Numerous organisms feed directly on coral tissue. Various butterfly fish feed exclusively on coral polyps, and large parrotfish will occasionally scrape tissue and underlying skeletal material from live corals (Brock, 1979). The nudibranch mollusk *Phestella sibogae* feeds on *Porites* coral. The snail *Drupella*, and the “cushion starfish” *Culcita* feed directly on a variety of corals. The flatworm *Prosthiostomium montiporae* feeds on the coral *Montipora*. Generally, coral predators and parasites do not inflict severe damage on coral colonies. A notable exception is the “crown of thorns starfish” (*Acanthaster planci*), which will eat the tissue off of entire coral colonies (fig. 31).

During 1969–70, a large aggregation estimated to consist of 20,000 *Acanthaster planci* was observed off south Moloka‘i (Branham and others, 1971). They were feeding selectively on *Montipora capitata*. The infestation occurred on the rich coral reefs between Kawela and Kamalō. At that time the coral cover in the area was estimated visually and was reported to consist of approximately 90 percent *Porites compressa* and about 5 percent *Montipora capitata*. The area of uniform coral cover was reported to be approximately 1 km wide and extended to depths of 30 m (100 ft), where the bottom becomes a sandy slope. This description generally fits conditions that exist today, suggesting that major changes have not occurred in the reefs over the 1971–2004 time period. The State of Hawai‘i Department of Fish and Game undertook extensive surveys and eradication efforts after discovery of the infestation (Onizuka, 1979). Divers killed a total of approximately 26,000 starfish between 1970 and 1975 by injecting them with ammonium hydroxide. Additional surveys were conducted throughout the State of Hawai‘i, but no other infestations were detected at that time.

Disease

All organisms are subject to disease, and corals are no exception. However, little is known about the diseases of corals. Recently, interest in this area has grown tremendously because of serious outbreaks of coral disease in many parts of the world (Richardson, 1998). Off south Moloka‘i, very few diseased corals have been observed on the fore reef, where conditions

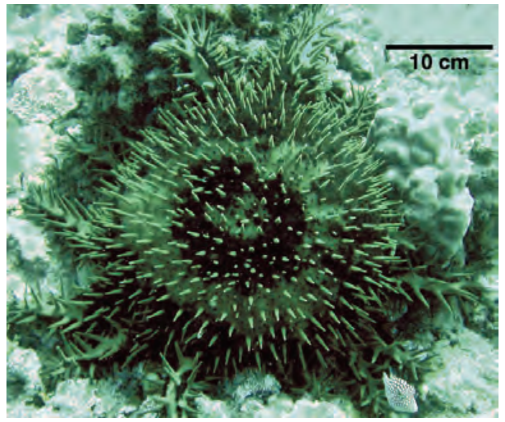

Figure 31. Adult *Acanthaster planci* or “crown of thorns starfish” off Kamiloloa, Moloka‘i, feeding on the coral *Montipora capitata*. The starfish is approximately 25 cm (10 in) in diameter.

are very favorable to coral growth (fig. 32). Dead and dying corals are more common on the highly stressful reef flat and the damaged fore reef off Kamiloloa. Corals that are weakened by adverse environmental conditions, such as high sediment loading, high organic input, and reduced light availability, are under stress. Increased environmental stress makes corals more prone to disease, as is the case with other organisms.

Bioerosion

Along with the physical forces of wave action, organisms play a significant role in abrading the reef framework. The rasping action of grazing fish (fig. 33) and urchins wears away carbonate rock (Brock, 1979). Boring sponges and boring mollusks degrade and weaken coral skeletons (Hutchings and Peyrot-Clausade, 2002).

Herbivorous Fish

Herbivorous fish crop competitive algae, to the advantage of reef corals (Karlson, 1999). Overfishing can reduce the number of herbivores on a reef and thereby tip the balance in favor of the algae (Hughes, 1994). A healthy population of these fish off south Moloka‘i (Friedlander and Rodgers, this vol., chap. 7) will keep competitive algae under control.

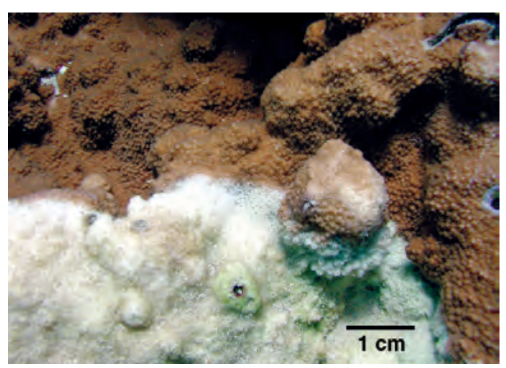

Figure 32. Coral *Montipora patula* at Kamalō, Moloka‘i, showing rapid death of diseased tissue exposing a white coral skeleton.

Figure 33. Parrotfish rasp away encrusting organisms along with carbonate substratum on the reef crest at Pālā‘au. Grazing by fish and urchins is a major erosive force on the reefs of south Moloka‘i, producing carbonate sand and fine carbonate mud in the process.

Distribution of Corals on South Moloka‘i Reefs

Coral Zonation from Deep Ocean to Shore

Deep Fore Reef

The deep fore reef (fig. 34) extends from a depth of approximately 10 m (30 ft) out to the sand shelf at 30–40 m (90–120 ft). This zone consists of coral platforms bisected by sand channels. In areas of high coral coverage, the tops of the platforms are dominated by a *Porites compressa* community, whereas the vertical sides are dominated by a *Montipora* spp. community.

Shallow Fore Reef

The shallow fore reef extends from a depth of approximately 2 m (6 ft) to a depth of approximately 10 m (30 ft). This zone is characterized by spur-and-groove morphology consisting of sand channels, ridges, and buttresses (Cochran, this vol., chap. 9). In many places there is a shallow shelf extending seaward that receives the brunt of the wave action.

Reef Crest

Diverse wave-resistant coral species and encrusting coralline algae characterize the reef crest. This area receives extremely heavy wave impact, resulting in low coral cover. Diversity of coral species, however, can be relatively high. Dominant species, such as *Porites compressa*, *Montipora flabellata*, small *Pocillopora meandrina*, *Pocillopora ligulata*, and *Montipora studeri* are often found in this zone, as well as in the shallow fore reef and the seaward edge of the reef flat. *Leptastrea purpurea* is an encrusting species with a hard skeleton that is found on the reef crest, shallow fore reef and outer reef flat, but with a somewhat scattered distribution. *Pavona duerdeni* occurs on the reef crest and extends deeper into the shallow fore reef. This species has a hard dense skeleton and is resistant to waves and sediment abrasion.

Reef Flat

Shoreward of the reef crest there is a strong environmental gradient on the shallow reef flats of south Moloka‘i. The seaward edge of the reef flat is subjected to waves breaking over the reef crest and to strong currents. Small carbonate rock outcrops surrounded by coral rubble characterize the seaward reef flat. Depth diminishes shoreward of the reef crest. Wave energy is dissipated as the water decreases in depth moving toward the shoreline (Denny, 1988). Toward shore the substrate becomes sandy with scattered rocks. Near the shoreline the sand grades into mud.

The coral community on the outer reef flat is characterized by high coral diversity and low coral cover. Wave disturbance prevents the dominance of substratum by the more rapidly growing species, so many other species

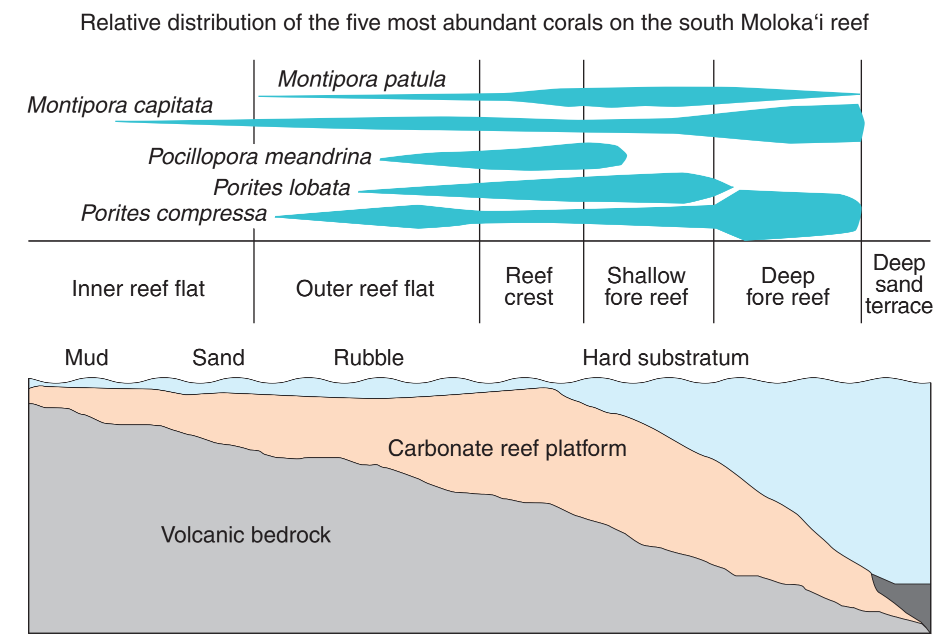

Figure 34. This generalized profile shows the distribution of the five most abundant species of corals along a typical section of reef between Kamalō and Kawela, Moloka‘i. Relative abundance of each species at each point along the cross section is represented by the thickness of the color bar.

Figure 35. This aerial image shows the portion of the south Moloka‘i coast from Kawela (left) to Kamalō (center) and U‘alapu‘e (right). The areas of darker blue on the image on the reef flat are channels and “blue holes.” The straight-edged hole in the reef flat (right center, near shore) is from a dredging operation in the late 1960s. Distance across the image is approximately 7 km.

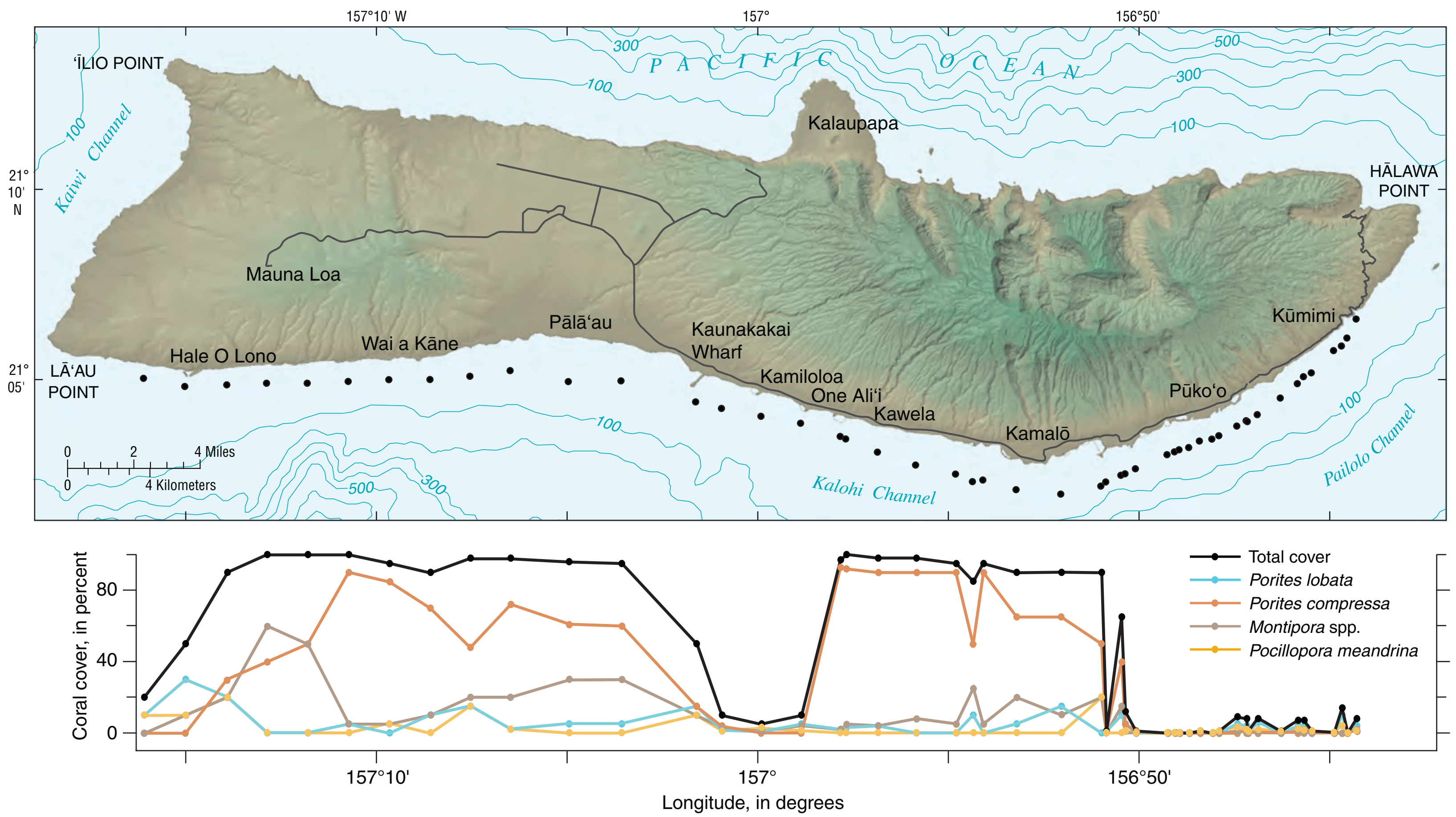

Figure 36. Distribution of reef corals along the fore reef of south Moloka‘i at a depth of 10 m (30 ft). Map shows sampling sites (black circles); depth contours in meters.

rarely found in deeper water occur on the outer reef flat. All of the common species are found here, mixed with several species not common in deeper water. The mushroom coral *Fungia scutaria* is a solitary free-living coral that is not attached to the reef. This coral can live on the unstable rubble and fore reef. *Porites* cf. *bernardi* (previously known in Hawai‘i as *Porites lichen*) is a small encrusting species that is characteristically apple green in color with calices arranged in rows. Colonies are generally less than 2 cm (1 in) in diameter and are found hidden in crevices and under overhangs on the carbonate outcrops. *Cyphastrea ocellina* is another common encrusting species that occurs here in similar habitats.

One of the unique features of the south Moloka‘i reef is the system of deep “blue holes” that lie to the east of Kamalō (fig. 35). This portion of the reef is cut by areas of deeper water. The holes are partly in alignment and may be remnants of submerged stream valleys that have been cut off and partly filled in by reef growth. Perhaps the remaining holes are areas where reef development was retarded by freshwater and sediment discharged from Kamalō Gulch. Another hypothesis is that the blue holes are karst features caused by ground-water dissolution with consequent undermining of the carbonate reef structure (Grossman and others, this vol., chap. 13). The coral community growing along the edges of the blue holes is similar in composition to the coral communities found in Kāne‘ohe Bay, O‘ahu. The dominant coral is *Porites compressa*, with small amounts of *Pocillopora damicornis*, *Cyphastrea ocellina*, and *Montipora* spp.

Distribution of Corals Along the South Moloka‘i Fore Reef

Estimated coral cover, by dominant species, along the 10-m (30-ft) depth contour is shown in figure 36. These data were obtained by visual estimates from the surface rather than by detailed transects. Data recorded by the type of visual survey used in this chapter can show a slightly higher total coverage, biased in favor of the branched species, when compared to the digital methodology used for the monitoring stations (Brown and others, this vol., chap. 6). Estimation of coral over a wide area by the visual method has a resolution of from 20 to 40 cm, whereas the digital methodology has a resolution of a few millimeters. Furthermore, there is a parallax effect when viewing a large area by the visual method from the surface, which results in seeing the sides of the branching finger corals and not the intervening spaces between branches. The visual method does not account for the small dead areas between the branches, nor will it record coverage by the small cryptic encrusting species. Nevertheless, a recent comparison study by Jokiel and others (2005) has demonstrated that the various coral survey methods commonly used in Hawai‘i yield very similar estimates for coral cover.

It is apparent that the coral distribution along the 10-m (30-ft) depth contour is bimodal, with two areas having high coral cover and three areas having very low coral cover. On the western end of the south Moloka‘i reef, the extremely high wave energy from the North Pacific swell wraps around Lā‘au Point and suppresses coral development (Storlazzi and others, 2002, 2003). Coral coverage increases rapidly to the east of Hale O Lono and remains high along the coastline to Kaunakakai, where a sharp decrease is observed. Coral cover from Kaunakakai to Kawela is quite low. Coverage increases sharply between Kawela and Kamalō, where the coastline turns northeast and another sharp decrease is noted. Low coral coverage along the southeast coast from Kamalō to Hālawa on the east can be attributed to the destructive wave impact of the northeast trade wind swell (Storlazzi and others, this vol., chap. 11). The existence of low coral cover between Kaunakakai and Kawela is not easily explained.

Damage Along the Kaunakakai-Kawela Sector

A detailed visual survey was conducted by teams of scuba divers from Kaunakakai to Kawela along a series of transects run perpendicular to shore from depths of 30 m (100 ft) to 10 m (30 ft) (fig. 37). West of Kaunakakai and east of Kawela the coral cover is very high at all depths. Between Kaunakakai and Kawela, however, is an area of damaged reef with low to nonexistent coral cover. Two important features of the coral distribution were noted. First, damage increases westward with depth from Kawela to Kaunakakai. Second, the distribution is essentially bimodal, with either low coverage (0–20 percent) or high coral coverage (80–100 percent), separated by a very sharp intervening boundary.

Damage Along the Coast from Kamalō to the East End of Moloka‘i

The drop in coral cover between Kamalō and the east end of the island can easily be explained by high wave stress due to northeast trade wind swell (Storlazzi and others 2003; Storlazzi and others, this vol., chap. 11). The break in both coral cover and wave stress is remarkably sharp.

Anthropogenic Change: Man and Corals of the South Moloka‘i Reef

Over the past two centuries, improper land-use practices have led to accelerated erosion of the watersheds, with increased sediment and nutrient input onto the coral reefs (Roberts and Field, this vol., chap. 15). Initially the problem was overgrazing by cattle and sheep, but overgrazing continues to

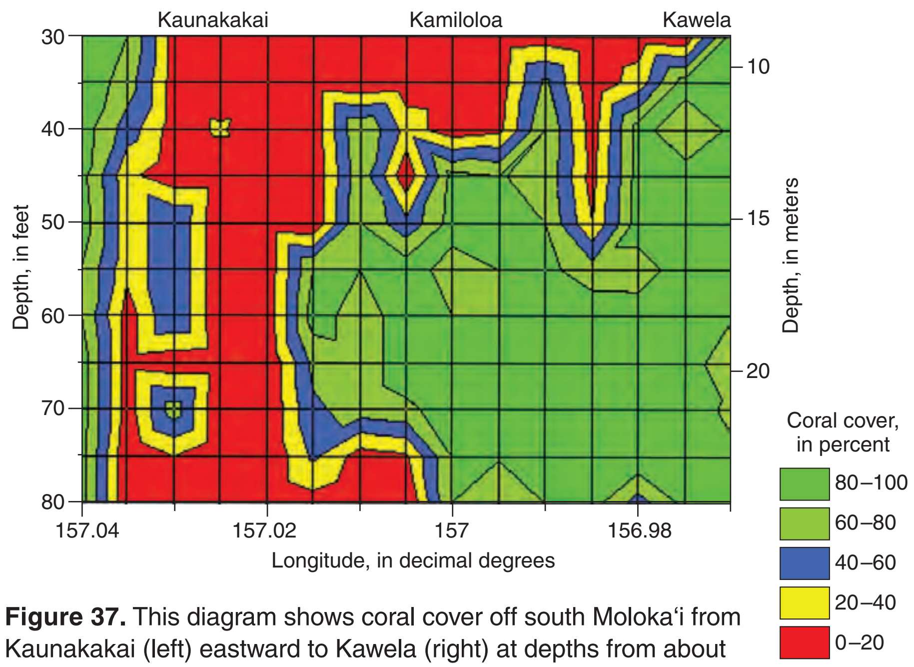

Figure 37. This diagram shows coral cover off south Moloka‘i from Kaunakakai (left) eastward to Kawela (right) at depths from about 10 m (30 ft) to about 25 m (80 ft). The figure represents coral cover on the reef face as viewed from seaward.

this day as a result of uncontrolled feral ungulates (deer, pigs, and goats) that are rapidly increasing in number on the watersheds. Initial cattle- and sheep-ranching operations were followed by extensive development of plantation agriculture (sugar cane and pineapple), which further contributed to the sediment and runoff problem (Roberts and Field, this vol., chap. 15). More recently, there are reports of introduced algae, which could negatively affect the shallow inshore reef communities (Smith and Field, this vol., chap. 8).

Fishing is an important activity on the reefs of south Moloka‘i, but the low human population has less impact on the reefs than what is observed on the more populated Hawaiian Islands (Friedlander and Rodgers, this vol., chap. 7). Effects of future climate change on the coral reefs of south Moloka‘i could be disastrous if current warming trends continue (Hughes and others, 2003). Hawaiian reefs have already begun to experience the impact of mass bleaching events (Jokiel and Brown, 2004).

Some of the impacts of coastal construction were discussed previously in this chapter. Damage due to dredging has also occurred on the reefs of south Moloka‘i. Kamalō was a prime fishing area with extensive coral cover before a series of aborted dredging operations in the area that began in the late 1960s. The dredging occurred on the inner reef flat east of Kamalō near Kalaeloa Harbor. The prevailing westward currents carried silt from the dredge operation down the coast and well past Kamalō (fig. 38). The fine silt covered reefs downcurrent, killing the coral. The area took on the appearance of a wasteland—everything was covered with fine silt, and the fish left the area (Capt. Joe Reich, oral commun., 2001). Even after the company went bankrupt and abandoned the dredging operation, the fine sediment continued to remobilize whenever the wind speed and wave heights increased. Chronic turbidity and sedimentation prevented any recovery of the reefs for many years. As fine sediment was winnowed out and transported offshore, the area slowly began to improve. These reefs showed signs of recovery by mid 1970s. Recovery was well underway by the early 1980s, with full recovery by 1990. The reefs off Kamalō presently appear to be “pristine,” but much of the area actually represents a regenerated reef that was heavily damaged by siltation.

Conclusion

The coral reefs off south Moloka‘i represent a great living treasure that has been damaged by increased sedimentation resulting from improper land-use practices and from coastal construction. Nevertheless, a large portion of the fore reef to the east of Kaunakakai and to the west of One Ali‘i remains relatively pristine. Diverse habitats in this area support rich coral reef communities. The reefs of south Moloka‘i represent a significant source of sustenance, recreation, and inspiration to all and must be managed carefully to prevent further decline.

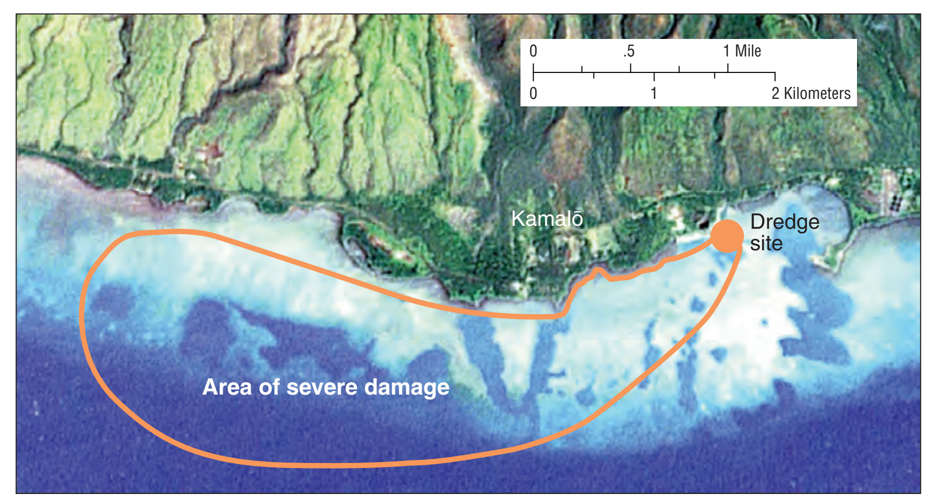

Figure 38. This map shows the area of damage near Kamalō resulting from a dredging project in the late 1960s.

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