The State of Coral Reef Ecosystems of the Main Hawaiian Islands

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INTRODUCTION AND SETTING

Hawaii is one of the most isolated archipelagos in the world and as a result, possesses some of the highest marine endemism recorded anywhere on earth. Because they are located in the middle of the Pacific Ocean, Hawaii's coral reefs are exposed to large open ocean swells and strong tradewinds that have a major impact on the structure of these coral reef communities. The archipelago consists of two regions: the Main Hawaiian Islands (MHI) which consists of populated, high volcanic islands with non-structural reef communities and fringing reefs abutting the shore (Figure 9.1), and the Northwestern Hawaiian Islands (NWHI) consisting of mostly uninhabited atolls and banks which are the subject of a separate chapter. This island chain stretches for over 2,500 km from the island of Hawaii in the southeast to Kure Atoll (the world's highest atoll latitudinally) in the northwest.

Coral reefs were important to the ancient Hawaiians for subsistence, culture, and survival. According to the Hawaiian Creation Chant, the kumulipo, the coral polyp was the first creature to emerge from the sea during creation. The early Hawaiians recognized that coral reefs were a building block of the islands and used coral in religious ceremonies to honor and care for ocean resources. Today, Hawaii's coral reef communities provide protection from storm waves, create the large surf that makes Hawaii world famous, provide food for sustenance, and are critically important to the State's approximately $800 million per year marine tourism industry.

Over 70% of the state's 1.2 million people live on Oahu, and are mostly concentrated in the Honolulu metropolitan area. In addition to the resident population, nearly seven million tourists visit Hawaii each year. This concentrated number of people has put pressure on Hawaii's coral reefs through various direct and indirect means. In general, Hawaii's coral reefs are in better condition than many other reefs around the world, although urban areas and embayments have suffered from land-based sources of pollution, overfishing, recreational overuse, and alien and invasive species.

1 NOAA/ NOS/ NCCOS/ Center for Coastal Monitoring and Assessment, Biogeography Program.
2 Oceanic Institute
3 Hawaii Department of Land and Natural Resources, Division of Aquatic Resources
4 National Park Service
5 Bishop Museum
6 University of Hawaii
7 Hawaii Coral Reef Initiative
8 Environmental Protection Agency
9 NOAA/NOS/ Hawaiian Islands Humpback Whale National Marine Sanctuary
10 Hawaii Sea Grant Program
11 U.S. Geological Survey
12 Washington State University

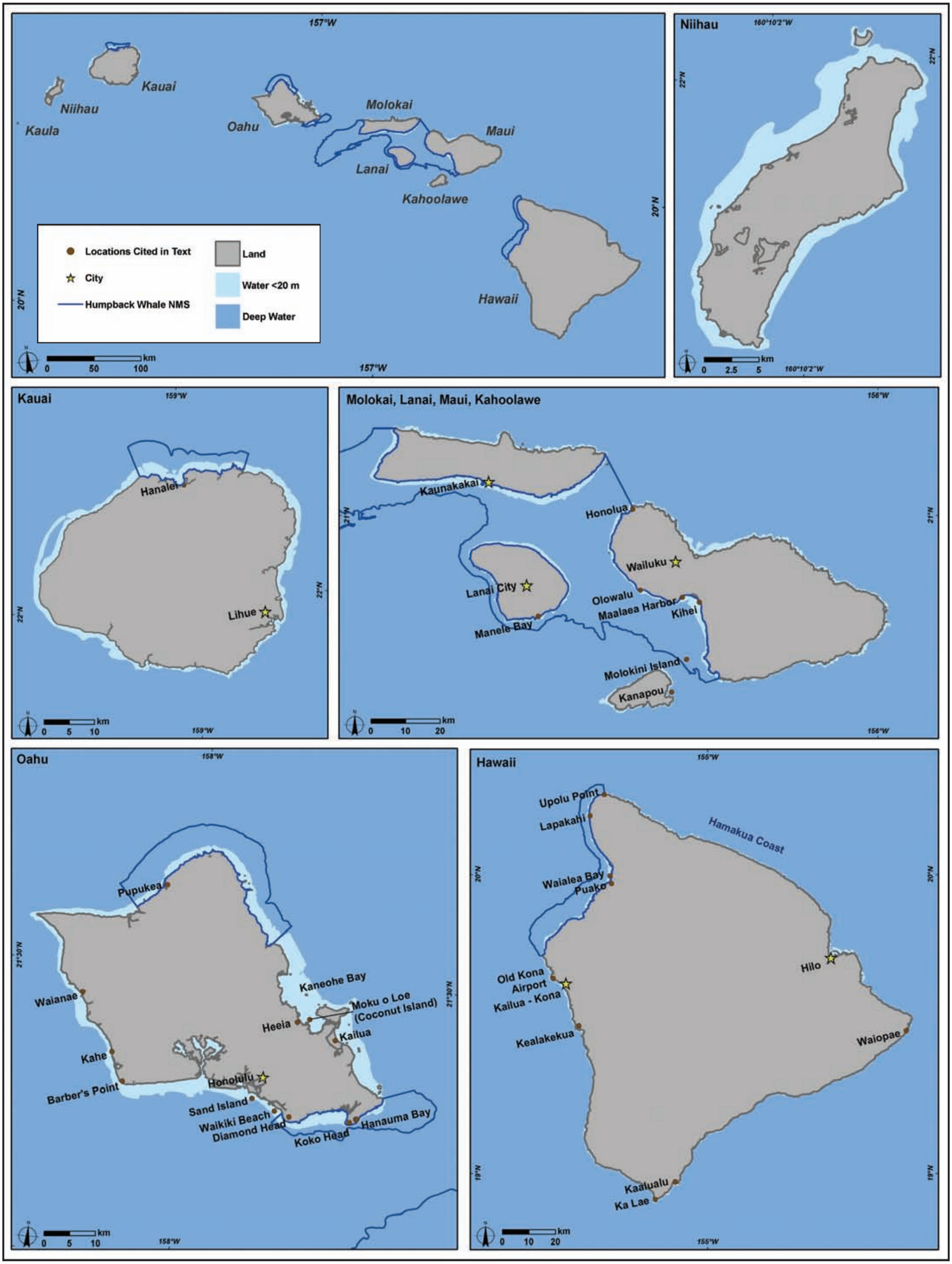

Figure 9.1. Maps of the MHI showing locations mentioned in this chapter. Map: A. Shapiro.

ENVIRONMENTAL AND ANTHROPOGENIC STRESSORS

Climate Change and Coral Bleaching

Hawaiian waters show a trend of increasing temperature over the past several decades (Figure 9.2) that is consistent with observations in other coral reef areas of the world (Coles and Brown, 2003). The first documented multi-locational coral bleaching occurred in Hawaii in late summer of 1996, with a second event in 2002 (Jokiel and Brown, 2004). Although bleaching events may have occurred prior to 1996, there is no quantitative or qualitative record of previous episodes. These documented bleaching events in Hawaii were triggered by a prolonged regional positive oceanic sea surface temperature anomaly greater than 1°C that developed offshore during the time of the annual summer temperature maximum. High solar energy input and low winds further elevated inshore water temperatures by 1-2°C in reef areas with restricted water circulation (e.g., Kaneohe Bay, Oahu) and in areas where mesoscale eddies retain water masses close to shore for prolonged periods of time (Figure 9.3).

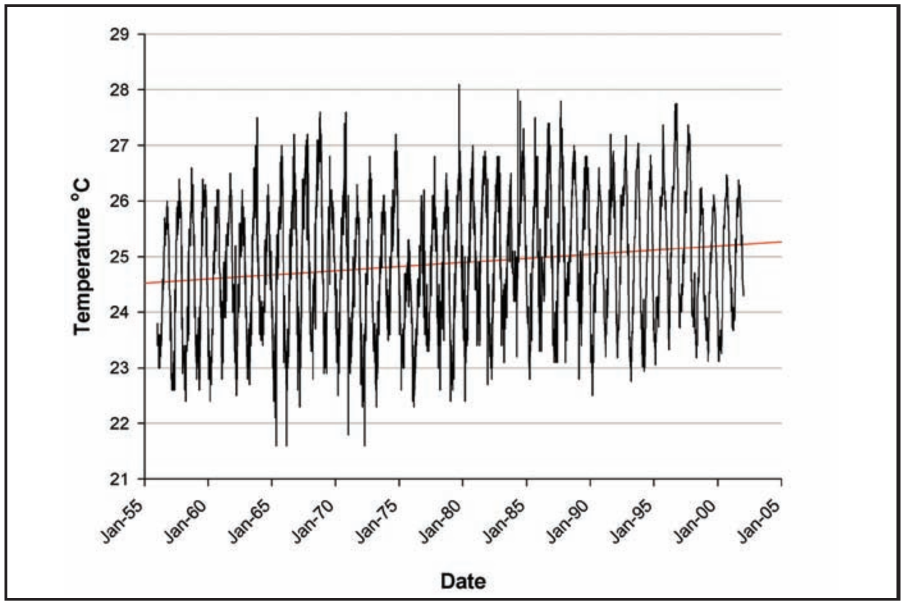

Figure 9.2. Weekly averaged points for NOAA Fisheries temperature series taken at Koko Head, Oahu (21°17'N, 157°41'W) and weekly IGOSS-NMC data series that overlapped temporarily. Data sets were merged. Source: Jokiel and Brown, 2004.

Bleaching was recorded throughout the State of Hawaii in 1996, with the most severe impact observed on Oahu and lesser bleaching reported on Maui and Hawaii. On Maui, weekly temperatures on reefs at eight locations on the southwest coastline showed a range of 28.0-28.5°C in late August and early September, with peak temperatures approaching 29°C. Corals began to bleach at Olowalu, Maui in late August, but the extent and severity of bleaching was minor, with less than 10% of the corals being affected. Recovery occurred after several months.

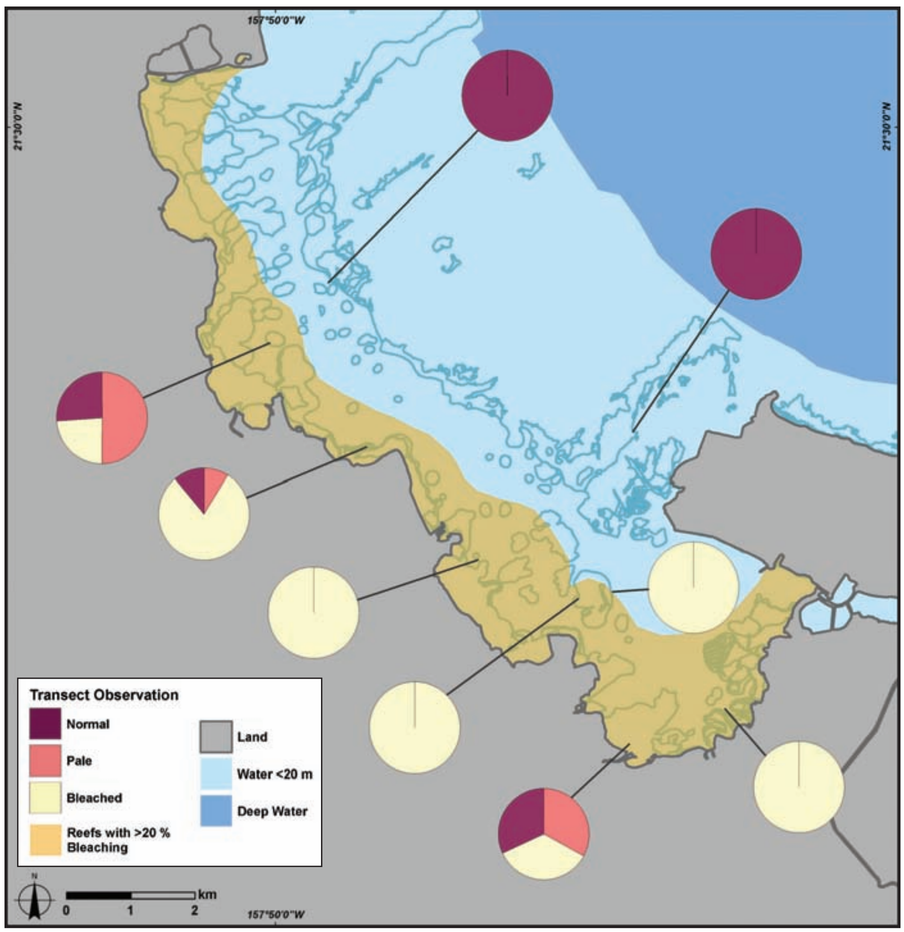

Figure 9.3. Map of Kaneohe Bay, Oahu. Shaded area shows reef areas with a high proportion of bleached corals (>20%) on 31 August 1996. Pie charts show relative portions of bleached, pale and normal coral coverage on transects located throughout Kaneohe Bay at that time. Source: Jokiel and Brown, 2004.

The second major bleaching event in the NWHI transpired during the summer of 2002 (Aeby et al., 2003). A detailed description of this event is provided in the chapter on the NWHI's coral reef ecosystems.

Diseases

Coral populations in the Hawaiian Archipelago continue to be spared from epidemic disease outbreaks unlike many other corals reefs around the world. Baseline surveys for coral disease were recently conducted at 18 sites around Oahu. The average prevalence of disease (no. diseased colonies/total no. colonies) was estimated at 0.95% (range 0-4.4%). Differences in disease prevalence were found among coral genera, with *Porites* having the highest prevalence of disease. The most common condition found on *Porites* was growth anomalies or 'tumors' (Figure 9.4). Prior studies found growth anomalies on *Porites* from both Oahu and Hawaii Island (Hunter, 1999; Work and Rameyer, 2001). Similar growth anomalies have not yet been documented on *Porites* in the NWHI despite intensive coral disease surveys (Aeby, unpublished data). The cause of *Porites* tumors has not yet been elucidated, but the occurrence of tumors on *Porites lobata* is positively correlated with colony size (a broadly generalized proxy for colony age; Hunter, 1999).

Another common disease found in both the MHI and NWHI is *Porites* trematodiasis caused by the larval stage of the digenetic trematode, *Podocotyloides stenometra* (Aeby, 1998; Figure 9.4). The greatest abundance of infected coral has been found on the reefs in Kaneohe Bay on the windward side of Oahu (Aeby, 2003). In Kaneohe Bay, infected corals have been found in all reef zones from the reef flat to the bottom of the reef slope and have persisted on the reefs since the 1970s (Cheng and Wong, 1974; Aeby, 2003). Trematode infection can cause reductions in coral growth of up to 50% (Aeby, 1992).

General coral necroses also commonly occur on Hawaiian reefs. Hunter (1999) found that necrotic patches followed one of three outcomes: 1) complete recovery, 2) successional change from turf to crustose coralline algae on which new coral recruits become established, or 3) persistence of the turf community with a net loss of coral cover.

No major die-off of corals has ever been documented due to disease in Hawaii. However, increasing human usage and the impacts of global climate change are causing concern about the health of Hawaiian reefs. Plans are currently underway to extend baseline disease surveys out to the MHI. The Hawaii Department of Land and Natural Resources - Division of Aquatic Resources (DAR) will also be integrating coral disease assessment into its monitoring program.

The endangered Hawaiian green sea turtle is affected by fibropapillomatosis (FP), a disease that causes external and internal tumors in turtles. Turtles with FP also have significant additional complications including inflammation with vascular flukes, bacterial infections, poor body condition, and necrosis of salt gland (Work et al., in press). Recent evidence suggests the herpes virus as a probable cause or co-factor of FP (Herbst, 1995). In Hawaii, FP has been found in 40-60% of observed turtles, with juvenile turtles constituting most of the cases (Balazs and Pooley, 1991). A recent study found that the majority of stranded turtles were juvenile turtles affected by FP and suggested that FP may detrimentally affect survival in juveniles (Work et al., in press).

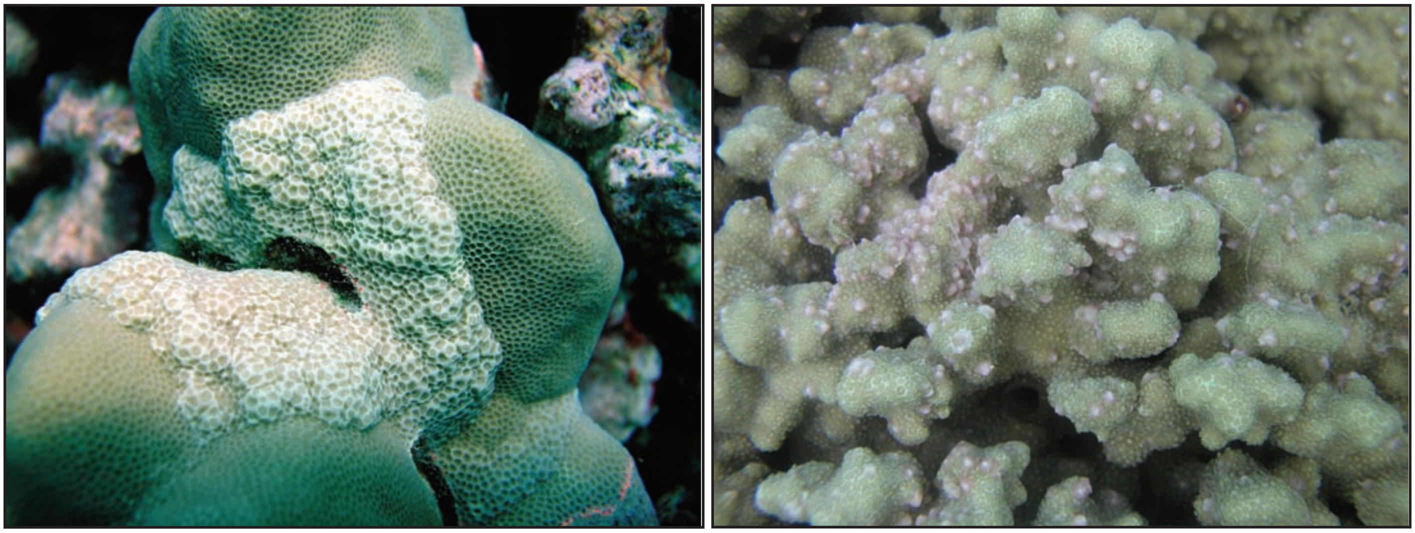

Figure 9.4. Left panel shows *Porites lobata* with tumor. Right panel shows *Porites compressa* with Trematodiasis. Swollen, pink nodules on the coral colony indicate polyps infected with the trematode. Photos: G. Aeby.

As such, FP may pose a significant threat to the long-term survival of the species (Quackenbush et al., 2001).

Figure 9.5. Large winter swells, such as this in Peahi, Maui, impact the structure of coral reef communities in Hawaii. Photo: E. Brown.

Tropical Storms

By virtue of its isolation, the structure of Hawaiian reefs is molded by a unique set of biogeographical factors and physiological tolerances which limit community assemblages to a relatively few hearty species. Another unique aspect of the geographical location of Hawaii is direct exposure to long-period swells emanating from winter storms in both the northern and southern hemispheres (Figure 9.5). Breaking waves from surf generated by Pacific storms is the single most important factor in determining the community structure and composition of exposed reef communities throughout the MHI (Dollar, 1982; Dollar and Tribble, 1993; Dollar and Grigg, 2004; Jokiel et al., 2004). The exception to this general rule is sheltered embayments that make up less than 5% of the coastal areas of the MHI.

Hawaiian coral community structure has been shown to respond to storm wave stresses of varying frequency and intensity as described by the 'intermediate disturbance hypothesis' (Grigg, 1983). Moderate cover and peak diversity is attained as the result of a continual cycle of intermediate intensity disturbances. High coral cover with low species diversity is found in sheltered embayments and areas protected from direct swells (e.g. south Molokai).

Based on the structure of coral communities on dated lava flows on the island of Hawaii, it has been projected that it takes about 50 years for Hawaiian reefs to regain peak diversity following a catastrophic event (Grigg and Maragos, 1974). A 30-year study documenting the impacts of storm waves of varying intensity on the west coast of the island of Hawaii has shown that shallow zones, populated primarily by a pioneering species of cauliflower coral, recovered completely within 20 years to pre-storm conditions, while deep reef slope zones showed only the initial stages of recovery during the same period. In addition, the study showed that recovery might not always result in immediate replacement of the same dominant species in a particular zone (Dollar, 1982; Dollar and Tribble, 1993; Dollar, 2004).

The cycle of repetitive impact and recovery is also a major factor in the present-day lack of reef accretion in exposed areas throughout the Hawaiian Islands. Extensive pre-Holocene (last major glacial epoch, approximately 11,000 years ago) reefs have been noted throughout the Hawaiian chain. This may be due to greater storm wave intensity now relative to earlier periods (Rooney et al., 2004), or an increased resistance of pre-Holocene Hawaiian coral communities to such storms, possibly through species components more adapted to rapid recovery (Dollar and Tribble, 1993). As a result, the only reef accretion that is presently taking place in Hawaii occurs in sheltered embayments or inside barrier reefs that are protected from storm wave impact. A good understanding of the response of reef systems to natural stresses is an important aspect in evaluating the effects of human activities because responses of reef ecosystems to human-induced stress are superimposed on natural cycles of impact and recovery.

The few studies in Hawaii to date that examined the effects of storms on fishes show that surf height and degree of wave exposure have negative relationships with various measures of fish assemblage organization (Friedlander and Parrish, 1998a; Friedlander et al., 2003). This relationship suggests that habitats protected from the highest wave energies maintain larger fish populations with greater richness and diversity of species. Walsh (1983) found that the impacts on the fish assemblage following a large "kona" storm were ameliorated by the presence of deeper water refuges.

Large storms and typhoons can also affect local fisheries by damaging essential fish habitat (Figure 9.6). In recent decades, two major hurricanes (Hurricane Iwa, 1982; Hurricane Iniki, 1992) struck the islands and caused considerable coral and habitat damage on Oahu and Kauai (W. Aila, pers. comm.). Hurricane Iwa damaged extensive inshore reef areas, especially the prime aquarium fishing grounds along Oahu's western and southern coast (DLNR-DAR, undated; Pfeffer and Tribble, 1985). Hurrincane Iniki also impacted coral reef communities on Oahu (Brock, 1996; Coles and Brown, in prep.), but limited evidence suggests the effects may have been less than with Iwa (Miyasaka, 1994a, b).

Fish catch and value declined around Oahu after the hurricanes but rebounded somewhat in the following years (Walsh et al., 2004; Figure 9.7). With the loss of collecting habitat, collectors concentrated their efforts on those sites still relatively intact and economically viable. The net result of storm effects, when combined with overfishing, was a drastic long-term decline in the abundance of key targeted species such as yellow tangs (*Zebrasoma flavescens*) around Oahu (Figure 9.7).

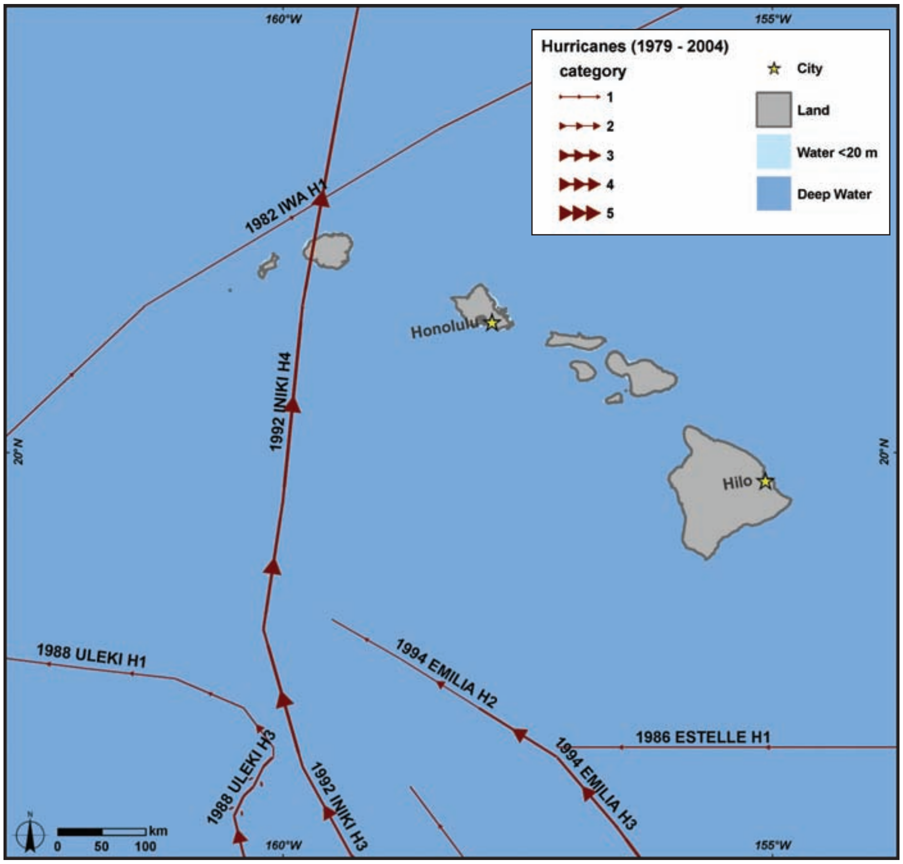

Figure 9.6. A map showing the paths and intensities of tropical storms passing near the MHI from 1979-2004. Year of storm, storm name and storm strength on the Saffir-Simpson scale (H1-5) are indicated for each. Map: A. Shapiro. Source: NOAA Coastal Services Center.

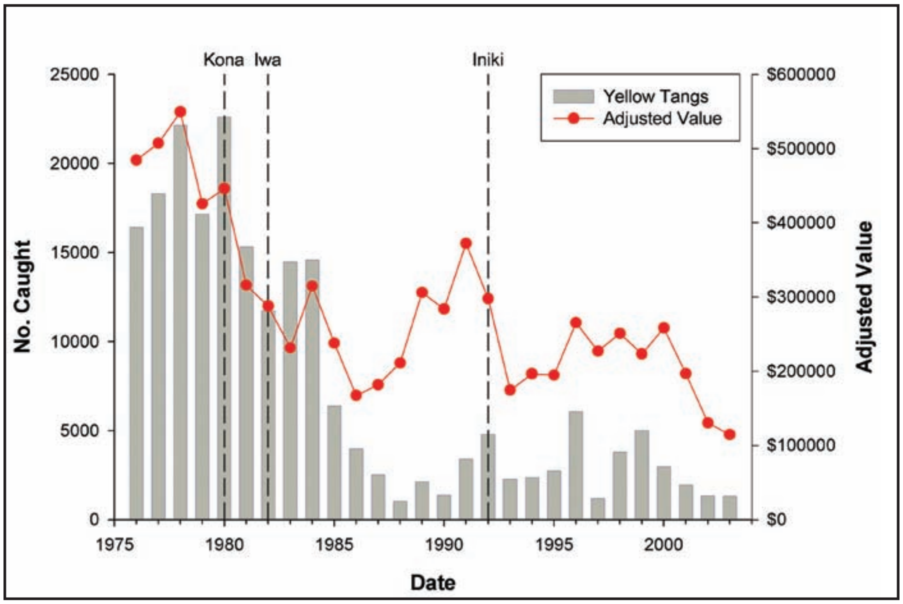

Figure 9.7. Value (adjusted for inflation) of all aquarium fish caught on Oahu and number of yellow tangs caught in primary collecting areas of south and west Oahu. Dashed lines indicate year of major storms. Source: Walsh et al., 2004.

Coastal Development and Runoff

Coastlines of Hawaii continue to be developed for a variety of land uses. On all of the islands, agricultural lands (primarily for sugarcane and pineapple) are changing to residential and resort uses. Coastal development can bring a suite of social and environmental consequences including conflicts over shoreline access and viewplanes, the need for flood water storage and protection, infrastructure demands, and degradation of coastal waters from cumulative increases in runoff and groundwater contamination. Changes in land use from large-scale agriculture, which periodically exposes land to erosion, may result in an overall decrease in sediment delivery to the ocean.

Figure 9.8. This steep roadcut at a construction site on Kauai is vulnerable to erosion and movement of sediments to the beach and nearby coral reef ecosystems. Practices to stabilize the slope include terracing, erosion control matting, hydromulch, and wattles. Photo: W. Wiltse.

Many of Hawaii's low-lying coastal areas were once wetlands and flood plains before being altered for agriculture and development. These areas served as excellent filters, removing sediments and nutrients from streams before the water entered the ocean. Development inevitably increases the amount of impervious surface and runoff. Runoff is generally diverted to storm drain systems that, like underground rivers, transport trash, soil, pathogens, and chemical pollutants to Hawaii's streams and coastal waters (Figure 9.8). As coastal areas are developed, floodplains filled, storm drains constructed, and streams channelized, more sediment is delivered to nearshore waters. For example, Kulanihakoi Stream (Kihei, Maui) was recently channelized near the shoreline as part of a condominium development, removing a coastal wetland that flooded regularly. The new stream channel solved the flooding problem but increased turbidity in coastal waters has resulted.

Harbor facilities on all the MHI are being improved to accommodate new large cruise ships, an inter-island car/cargo ferry, and large container ships. Harbor improvements involve dredging to deepen and widen entrance channels and turning basins, as well as construction of new piers, waterfront work areas, jetties, and breakwalls. The harbor improvements have the potential to impact coral reefs and areas used for recreation, such as surfing and canoeing. Proposed expansions can affect longshore transport and water quality as well. In Kahalui Harbor on Maui, the proposed development and expansion of pier space to accommodate cruise ships may result in displacement of several canoe teams from the harbor, due in part to the added security zones that would also be designated with the expansion and the resulting lack of protected water area for paddling. At Maalaea Harbor on Maui, a $10 million expansion of berthing facilities and reconfiguration of the entrance channel has been planned for 40 years. The preferred design is controversial because it will eliminate 4 acres of coral reef and impact a surf site, while providing over 100 new berths for recreational and commercial boats. No new construction or approval of permits has been considered to date with this proposed project due to the fact that the impacts to the coral reefs and offshore surf site have yet to be adequately addressed.

Coastal Pollution

Point Sources:

In areas near offshore sewage outfalls, long-term studies show little or no effect of water chemistry on coral communities. This was not the case in the period from approximately the 1950s to 1970s when discharge of poorly treated sewage on shallow offshore areas of Sand Island (Dollar, 1979) and in Kaneohe Bay resulted in significant damage to coral reef communities (Smith et al., 1981). In the 1980s, Hawaii took significant action to improve coastal water quality by removing most wastewater outfalls from bays and shallow waters. Moving sewage outfalls to deep offshore waters (~40-75 m) has allowed significant recovery to the previously stressed areas (Dollar and Grigg, 2003). Another reversal of impacts from point source discharges has occurred on the Hamakua Coast of the island of Hawaii, where reef communities that were severely damaged by point source discharges of sugarcane processing waste have recovered following the closure of sugar plantations (S. Dollar, pers. obs.).

Seven major wastewater treatment plants discharge to the coastal ocean in Hawaii (Table 9.1). All but three of these discharge through deepwater outfalls (>40 m). Under terms of a consent decree filed in November 1991 with the Federal district court for violations of the Federal Clean Water Act, the City and County of Honolulu agreed to provide $8 million for a comprehensive water quality study in Mamala Bay, the bight extending from Diamond Head to Barber's Point along the southern coast of Oahu. Several studies were undertaken to determine the impact, if any, of the outfalls on the health of aquatic animals and plants. The conclusion of one study was that "there is no quantitative evidence supporting the view that the discharge of sewage is impacting the shallow reef resources shoreward of the two sewage outfalls" (E.A. Kay, J.H. Bailey-Brock, and R.E. Brock, all of the University of Hawaii). In fact, the authors found that the armor rock placed over the outfall pipe provided excellent habitat for fish and coral communities.

Table 9.1. Wastewater treatment plants that discharge to Hawaii's coastal waters. Source: U.S. EPA.

	LEVEL OF TREATMENT
Deepwater Discharges (>40 m)	
Sand Island, Oahu	Advanced primary
Honouliuli, Oahu	Advanced primary
Waianae, Oahu	Secondary
Kailua, Oahu	Secondary
Hilo, Hawaii	Secondary
Shallow Water Discharges (<40 m)	
East Honolulu, Oahu	Secondary
Ft. Kamehameha, Oahu	Secondary

Other discharges permitted through the National Pollutant Discharge Elimination System (NPDES), such as those from aquaculture facilities, shipyards, and power plants, release waste and cooling water through outfalls into estuaries or coastal waters. Hawaii state law precludes NPDES-permitted facilities from discharging wastes to inland waters such as streams.

A relatively new form of potential point source discharge of nutrients is from open ocean cage aquaculture. The first such venture in Hawaiian waters is located approximately 3 km offshore of Ewa on the southern shoreline of Oahu, and presently consists of three cages in which Pacific threadfin (*Polydactylus sexfilis*) are grown out from fingerlings to a commercially viable size. Continued monitoring of the water column in the vicinity of the cages, which is required for NPDES compliance, has revealed that suspended nutrient subsidies are relatively small and diluted within tens of meters of the cages. Water quality constituents at the boundaries of the elliptical zone of mixing (1,800 m x 1,200 m) centered at the cages have been shown to not differ from control stations (Bailey-Brock, 2004). Monitoring of benthic community structure under the cages has revealed a localized region of markedly different infauna, presumably as a result of particulate delivery to the sediment surface from the cages. The region of altered sediment community composition encompasses an elliptical area extending 400 m alongshore and 100 m in the inshore direction at a water depth of about 40 m (Bailey-Brock, 2004). The Mamala Bay study has documented that the predominant currents in the area during all seasons are easterly-westerly, which carries material offshore. There is not a strong likelihood that particulate material from the aquaculture cages will result in negative effects to inshore coral communities. However, active monitoring of the environmental effects of the aquaculture cages is continuing.

Nonpoint Sources:

Sediment discharge is probably the leading cause of alteration of reef community structure in the MHI. Several major sources of erosion have ceased or are reversing, which will likely lower the potential for negative effects in the future. Examples include the closure of large agricultural plantations, cessation of live fire training on the island of Kahoolawe, and culling programs of feral ungulates on the islands of Lanai and Molokai. Dollar and Grigg (2004) have documented a decrease in coral cover of about 30% in a sheltered embayment on Maui (Honolua Bay), which they attributed to burial by sediment emanating from storm runoff from pineapple fields (Figure 9.9). Planned conversion of these pineapple fields to other land uses (residential, resort, and mixed agriculture) will provide a "natural experiment" to evaluate the relative influence of different land uses on coral reefs in embayments in Hawaii.

In many areas of the Hawaiian Islands, nearshore water chemistry is a mixture of oceanic water and freshwater emanating from both submarine groundwater discharge at or near the shoreline and surface water runoff. Except for the island of Kauai, both groundwater and surface water discharge are equivalent to about 20% of rainfall (Yuen and Associates, 1992). Kauai has a higher percentage owing to greater overall rainfall. Groundwater in Hawaii typically contains two to three orders of magnitude higher concentrations of dissolved nitrogen and phosphorus than seawater. Thus, groundwater nutrients are an important natural factor of nearshore marine water chemistry. The groundwater nitrogen load reflects natural background and anthropogenic sources from wastewater and fertilizers. Calculations using values from U.S. Geological Survey (USGS) groundwater models show that pristine groundwater contributes about 1,800 tons of nitrogen annually to the nearshore ocean along the west coast of the island of Hawaii.

Figure 9.9. Maui shoreline showing nearshore sediment plumes resulting from runoff from pineapple fields after a Kona rainstorm. Photo: USGS.

Monitoring programs seldom demonstrate a conclusive impact to Hawaiian reef communities from nonpoint source inputs. Runoff and groundwater have lower salinity than ocean water and in the absence of turbulent mixing, form a low-density surface layer. As a result, the elevated pollutant concentrations are not in contact with the bottom, hence there is little opportunity for exposure to reef communities.

On neighbor islands, most of the sewage treatment plants discharge secondary treated wastewater into the ground through 15-60 m deep injection wells. In some cases, a portion of the effluent is reused for irrigation, providing additional opportunity for nutrient and particulate removal. Plumes from these injection wells have not been identified and traced. However, models predict that the wastewater plumes mix with groundwater and discharge to the ocean fairly close to the shoreline in water less than 30 m deep.

Cesspools are a potentially harmful source of untreated wastewater, containing nutrients and pathogens that seep into the ocean along the shoreline. Hawaii has an estimated 100,000 cesspools, more than any other state (EPA, unpublished data).

While there is no statewide nutrient budget to assess the total magnitude of anthropogenic nutrient subsidies to groundwater, Soicher and Peterson (1997) developed such a comparison for the relatively small region of West Maui (Figure 9.10). In this region, 91.3% of the nitrogen delivery to the ocean is from factors associated with anthropogenic activities. It is of interest to note that since this estimate was compiled, sugarcane farming has ceased, and the last crops of pineapple are currently being harvested. While there have been no

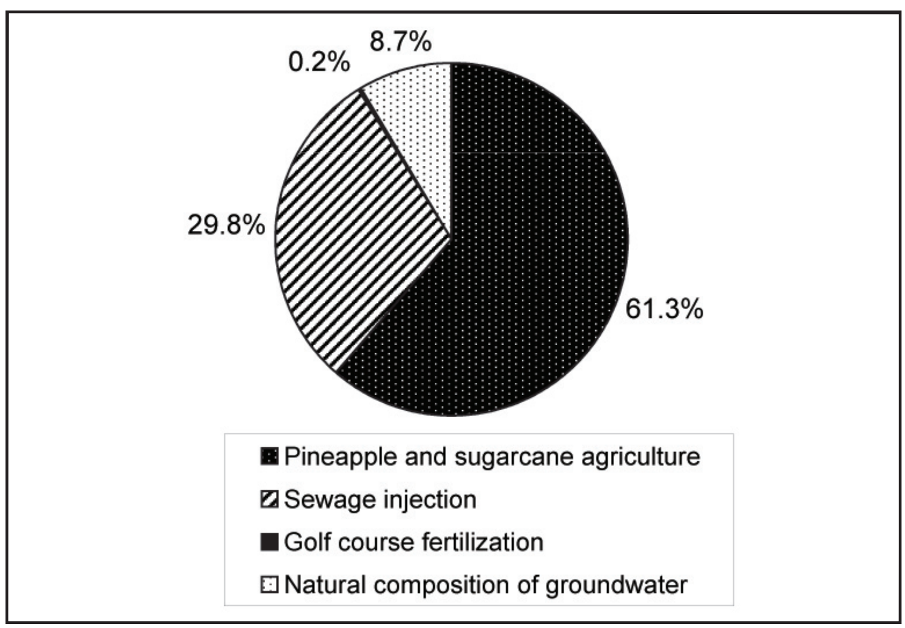

Figure 9.10. Total nitrogen delivery to the ocean from groundwater discharge in 1995 off of west Maui. Source: Soicher and Peterson, 1997.

documented impacts to the reefs in West Maui as a result of the additional nutrients, this coastline is known to have nuisance algal blooms.

Toxic pollutants are seldom measured in Hawaii's marine waters. In southern Kaneohe Bay, Hunter et al. (1995) reported elevated concentrations of lead, copper, chromium, and zinc in oyster tissues near stream mouths. High levels of dieldrin and chlordane were also found in oyster tissues at some sites. In the Hanalei River and Estuary, the USGS (Orazio et al., 2003) reported quite low concentrations of semi-volatile aliphatic hydrocarbons, polyaromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), organochlorine pesticides, certain hydrophobic organics, and metals. Most organic contaminants were below, or slightly above, limits of detection.

The USGS recently completed an assessment of water quality of streams and groundwater on the island of Oahu during 1999-2001 (Anthony et al., 2004). Anthony et al. (2004) found toxic contaminants in streams that drain urban and agricultural lands, and in groundwater supplies (although few chemicals exceeded the drinking water standards in groundwater). In Oahu's urban streams, some of the highest levels of termite-treatment chemicals in the U.S. were reported. The USGS conducted no analyses in the marine environment where ocean mixing and dilution must be considered. Based on the USGS findings, screening of estuaries and coastal waters for toxic contaminants such as chlordane, dieldrin, and diazinon is warranted. Sediment particles containing toxic contaminants are easily transported to the ocean with storm flows and may be deposited at stream mouths and on reef flats.

Kaneohe Bay remains a site of innovative work to establish the links between water quality and effects to reef communities. At present, an instrument array called the Coral Reef Instrumented Monitoring Platform (CRIMP) provides near real-time data at five to 10 minute intervals in order to characterize the biogeochemical and physical conditions of the water column of the coral reef environment of Southern Kaneohe Bay. CRIMP has been able to characterize changes from high intensity, short duration storms that previously were either "averaged" or undetected by manual sampling at longer time intervals (E. DeCarlo, pers. comm.). Results to date show that there are significant spikes in water chemistry constituents following storm events, but the elevated concentrations rapidly return to background levels following the storm. The model will be used to examine the timing and magnitude of fluxes of terrestrial materials to reef biota.

Tourism and Recreation

Tourism is Hawaii's primary industry with state projections estimating about 6.7 million visitors arriving in 2004 and spending more than $11.4 billion. An increase in tourism since 2003 is partially the result of the return of Asian travelers and the launching of a new Hawaii-based inter-island cruise ship with a passenger capacity of over 2,000 per trip. Between 1982 and 2002, there was a 66% increase in tourism representing a growth of over 2 million visitors (Hawaii DBEDT, 2003).

There are over 1,000 ocean tourism companies, generating an estimated $700 million in gross revenues annually (Clark and Gulko, 1999). Over 80% of Hawaii's tourists participate in some form of ocean recreation, from sunbathing and swimming, to snorkeling and surfing, to jet skiing and parasailing (Hawaii DBEDT, 2002). Most, if not all, of this activity occurs around Hawaii's coral reefs that generate almost $364 million each year in added value (Cesar and van Beukering, 2004).

Hawaii also consistently ranks as one of the top dive destinations in diver surveys conducted annually by Rodale's Scuba Diving magazine. Nearly 52% of all visitors participate in diving or snorkeling activities during their stay in Hawaii (Hawaii DBEDT, 2002). Other than beach going, snorkeling and scuba diving activities outrank all other forms of recreational activities participated in by both U.S and Japanese visitors to Hawaii (Hawaii DBEDT, 2002).

Hawaii's marine life conservation districts (MLCDs) and other calm water locations are highly sought after locations in which to dive and snorkel and are marketed by the visitor industry as "must see destinations" (Clark and Gulko, 1999; Figure 9.11). Popular sites have high visitation and high economic value (Table 9.2). Hanauma Bay, a 41 ha marine protected area (MPA), and the surrounding City Nature Preserve generates over $31 million each year in added value (van Beukering and Cesar, 2004). Over the next 50 years, this translates to nearly $2 billion in total benefits from this one site alone.

Often the most popular sites are lacking in or have minimal shore side facilities, which increase the potential for impacts affecting the nearshore resources. As popularity increases, management agencies are faced with continuous and growing challenges to define the appropriate levels of use and how to gauge and monitor impacts.

Recent studies have shown that extensive damage to corals can occur in shallow, calm water sites with high levels of human use (Rodgers and Cox, 2003). Trampling can occur in shallow nearshore reef flats which often possess fragile and delicate coral species. The greatest concentrations of human-substrate contacts occurred at shoreline access points where people stood or waded as they enter and exit the water (Holland and Meyers, 2003).

In both the trampling study (Rodgers and Cox, 2003) and the human use impacts study (Holland and Meyer, 2003), results indicated that patrons who were provided a brief orientation and given flotation devices for snorkeling were less likely to impact the reef than those visitors with no interpretive information or training. Mandatory education efforts at Hanauma Bay each year help conserve reefs statewide since visitors generally go to two or three additional sites during their stay and residents snorkel or dive at 10 sites per year. The cumulative effect of educating visitors and residents has resulted in improved behavior at sites across the state (Davidson et al., 2003).

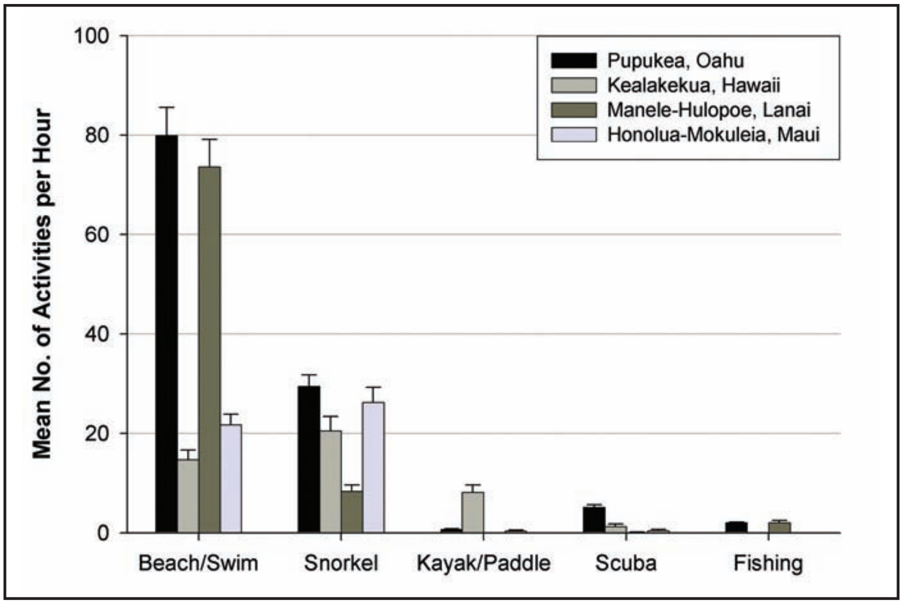

Figure 9.11. Patterns and types of use at four MPAs in Hawaii. Fishing is prohibited or restricted in all of these areas. Source: Holland and Meyer, 2003.

Table 9.2. Summaries of annual human use at various locations in Hawaii. All locations except Waikiki Beach are MLCDs.

LOCATION	NO. OF VISITORS
Waikiki Beach, Oahu	8,355,448[1]
Hanauma Bay, Oahu	1,751,318[1]
Pupukea, Oahu	177,600[2, 3]
Manele/Hulapoe Bays, Lanai	277,400[2]
Molokini Shoal, Maui	400,000[4]
Honolua/Mokuleia Bays, Maui	160,000[2]
Kealakekua Bay, Hawaii	189,800[2]

[1] DBEDT State Data Book, 2002.
[2] Adapted from Holland and Meyer, 2003 (based on mean hourly usage).
[3] Reflects only summer use for five months, as there is minimal use in the winter.
[4] Estimation by S. Hau, pers. comm.
* MLCDs are marine protected areas established to conserve and protect marine resources.

In a recent assessment of the economic benefits and costs of marine managed areas in Hawaii, a total of 1,380 divers, snorkelers, and beachgoers at six sites where surveyed regarding their willingness to pay a coral reef conservation fee for more active management. More than 75% indicated that they would be willing to pay for reef conservation and the average payment indicated by respondents was $3.77 per experience. Based on these results, management improvements could be provided for a small fee including basic facilities, enforcement compliance, education/awareness, assessment and monitoring, and infrastructure (e.g., parking, moorings, etc.). These fees would result in significant benefits to the sites and a decrease in visitor impacts. Other mechanisms to define and determine appropriate levels of use are still needed as efforts continue to minimize the impacts from use while maintain the health of the ecosystem.

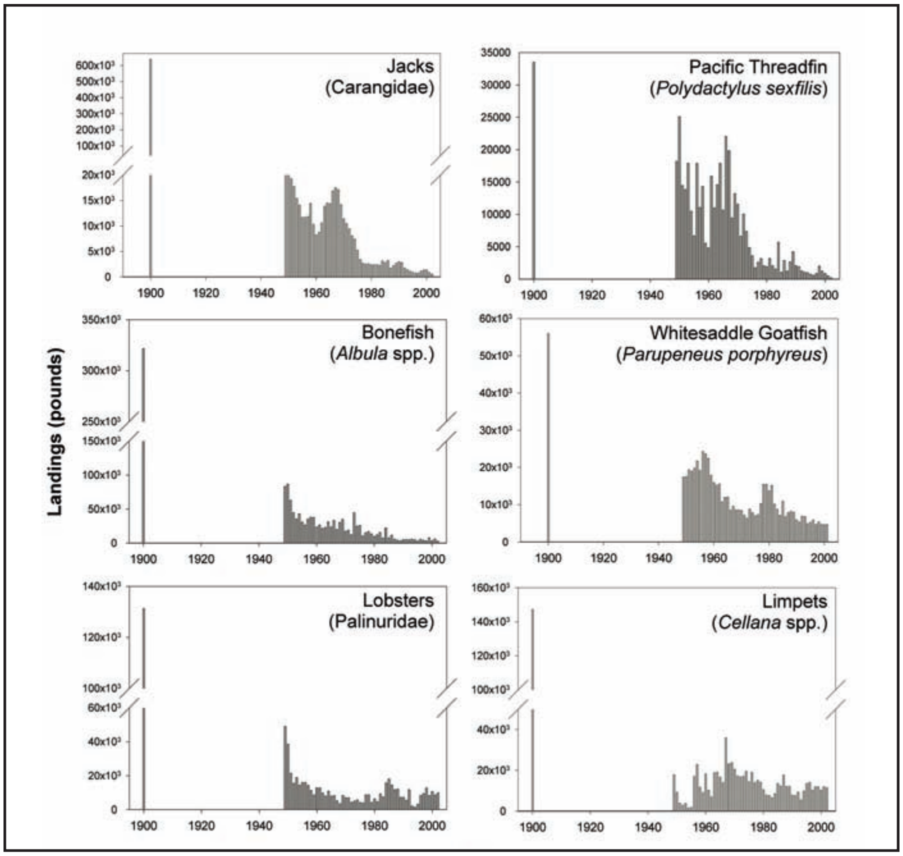

Figure 9.12. Commercial catch data from Hawaii DAR from 1948 to present. 1900 data from statewide market surveys conducted by the United States Fish Commission. Sources: Cobb, 1905; DAR Commercial Landings Database.

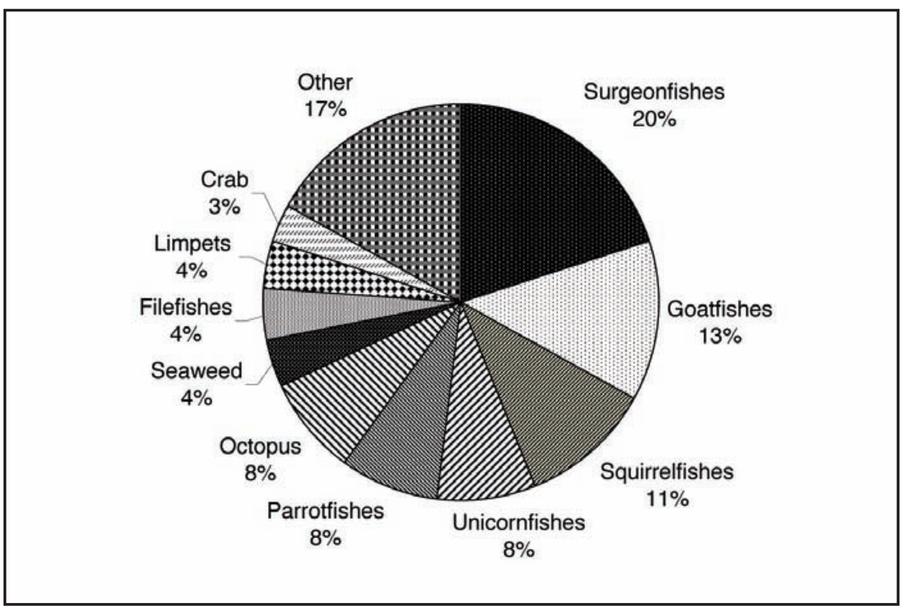

Figure 9.13. Top 10 taxa of commercially harvested coral reef organisms excluding coastal pelagic fish from 2001 commercial catch data. Source: DeMello, 2004.

Fishing

Fishing has been a way of life for Hawaii's people for centuries, with fish and shellfish providing the major protein source for the Hawaiian people (Kamakau, 1839; Titcomb, 1972). The traditional system in Hawaii emphasized social and cultural controls on fishing with a code of conduct that was strictly enforced (Friedlander et al., 2002a; Poepoe et al., in press). After western contact, a breakdown of the traditional kapu system and the demise of the watershed as a management unit led to the virtual elimination of traditional Hawaiian fisheries management practices (Smith and Pai, 1992; Lowe, 2004).

Over the past 100 years, the coastal fisheries in Hawaii have undergone enormous changes (Shomura, 1987; Friedlander, 2004). Overfishing is cited as the primary reason for the declining resources both by general users (DLNR-DAR, 1988) and commercial fishers (Harman and Katekaru, 1988). Factors contribut- the decline of inshore fisheries include a growing human population, destruction or disturbance to habitat, introduction of new fishing techniques inexpensive monofilament gill scuba equipment, geographic positioning systems, power boats, fish finders), and loss of tradi- conservation practices (Lowe, Birkeland and Friedlander,

Commercial landings for a number important species have shown dramatic declines since the 1900s (Figure 9.12). With the exception of which have been associated ciguatera poisoning, consumer demand and wholesale prices to fish- alone do not explain the dramatic decline in landings. The number of commercial fishers participating in the coral reef fishery rose from 282 in 1966 to a peak of 1,178 in 1996, with the current level at 925 commercial fishers (DeMello, 2004). Excluding coastal pelagic fishes, which account for 80% of the nearshore commercial catch, 139.500 kg of coral reef fish were landed in 2001, consisting mainly of surgeonfishes, goatfishes, soldierfishes, unicornfishes, parrotfishes, and octopus (Figure 9.13; DeMello, 2004).

Underreporting by commercial fishers and the existence of a large number of recreational and subsistence fishers without licensing or reporting requirements have resulted in uncertainty in actual fisheries catch statistics for the state (Lowe, 1996). The nearshore recreational and subsistence catch is likely equal to or greater than the nearshore commercial fisheries catch, and recreational and subsistence fishers take more species using a wider range of fishing gear (Friedlander and Parrish, 1997; Everson and Friedlander, 2004).

The proliferation of long and inexpensive gill nets has allowed new fishers to enter the fishery and set nets deeper and in locations not previously harvested (Clark and Gulko, 1999). Intensive fishing pressure on highly prized and vulnerable species has led to substantial declines in catch and size as well as raised concerns about the long-term sustainability of these stocks (Smith, 1993; Friedlander and Parrish, 1997; Friedlander and DeMartini, 2002). Pacific threadfin is considered one of the premier Hawaiian food fishes and was reserved for the ruling chiefs in ancient Hawaii. The mean size of threadfin in all sexual categories has declined significantly since the 1960s, while the proportion of juveniles has increased from 6% to 40% of the catch during this time period (Friedlander and Ziemann, 2003; Figure 9.14).

Fishers frequently cite the lack of adequate enforcement of fishing and marine resource laws as one of their major concerns (Harman and Katekaru, 1988; DLNR-DAR, 1998). The Hawaii Division of Conservation and Resources Enforcement (DOCARE) is the state's primary agency for enforcement of natural resource regulations. Although the number of enforcement officers has increased substantially over the past 50 years, the number of fishing citations for freshwater and saltwater issued per officer has declined over time to 2.3 citations per officer per year (Figure 9.15).

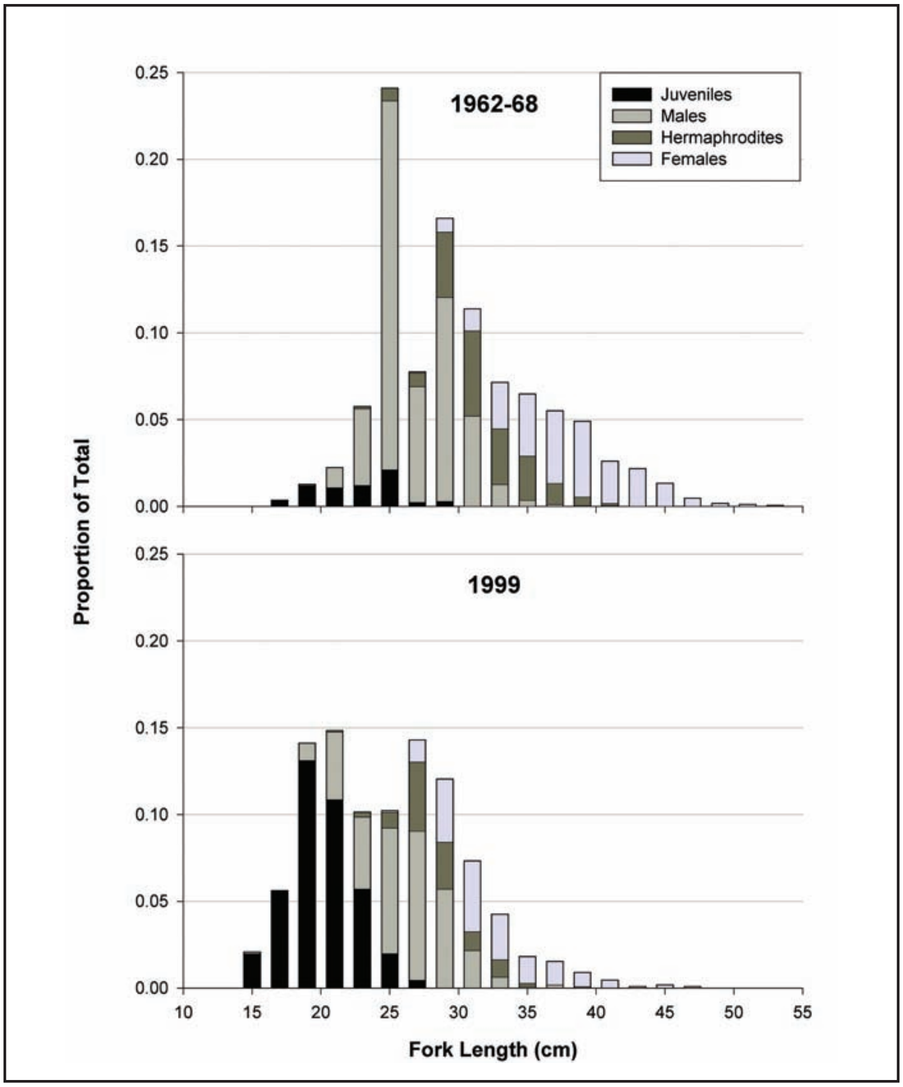

Figure 9.14. Proportion of juveniles, males, hermaphrodites, and females for Pacific threadfin (*Polydactylus sexfilis*) on windward Oahu from 1962 to 1968 (upper panel) and during 1999 (lower panel). Source: Friedlander and Ziemann, 2003.

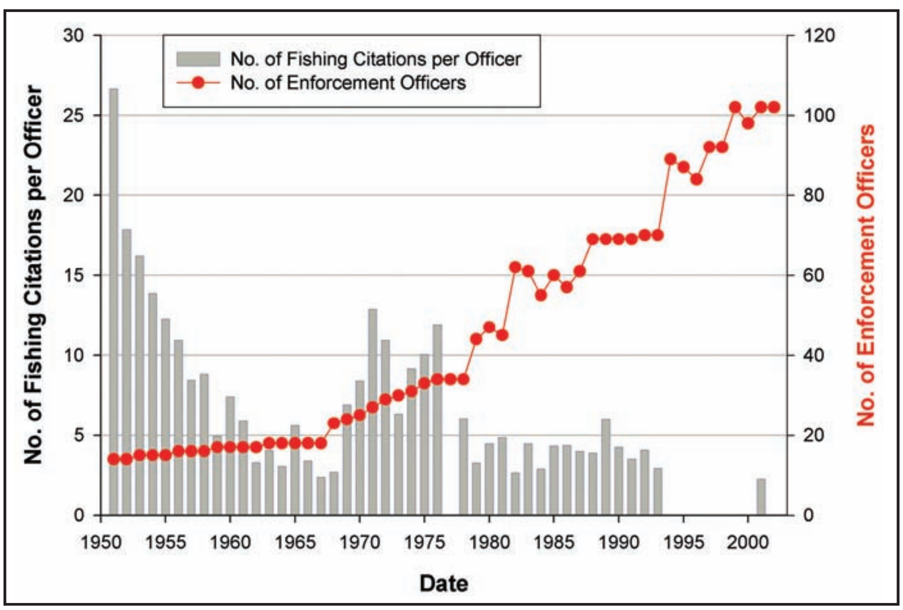

Figure 9.15. Number of fishing citations (including arrests) issued per DOCARE officer, and the number of officers over time. Gap in data due to unavailability of information. Source: DOCARE Database.

In 1981, Hawaii's legislature expanded DOCARE's traditional enforcement duties to include non-natural resource issues. Although legislation stipulated that the primary duty of enforcement officers would be the enforcement of conservation and resource laws, the proportion of citations (including arrests) related to natural resource violations (primarily hunting and fishing) has decreased in recent years and presently constitutes only 33% of total DOCARE citations. However, DOCARE's responsibilities also increased substantially in 1991, when the Division of Boating and Ocean Recreation was created within Hawaii's Department of Land and Natural Resources, and the agency found that it must now also enforce all boating safety, small boat harbor, and ocean recreation regulations. A DOCARE volunteer officer program created in 1973 has similarly declined and the number of volunteer officers in the program is presently only 20% of what it was 20 years ago.

In contrast to some other states, Hawaii DOCARE officers are presently prohibited from inspecting the bags, containers (e.g., coolers), or vehicles of any recreational fisher unless they have probable cause that a violation has taken place (HRS Title 12, subtitle 5). With the increase in responsibilities to enforce both natural resource and other laws, and the limitations on inspections and funding, it is unlikely that enforcement of existing and future rules and regulations will increase substantially.

Trade in Coral and Live Reef Species

It is against Hawaii state law to take or sell stony coral or live rock (i.e., marine substrate where living material is visibly attached). A number of recent enforcement cases have documented trafficking in Hawaiian corals, including one conviction resulting in over $1 million in fines and seven convictions resulting in jail time as long as seven months.

The commercial aquarium fishery in Hawaii has developed over the last 50 years into one of the state's major inshore fisheries, with landings of over 708,000 specimens with a reported value of $1.06 million (Walsh et al., 2004). As the aquarium industry is composed of both independent contractors (collectors) and wholesalers, which may or may not be collectors themselves, the overall economic value of the aquarium fishery is estimated to be substantially higher than the reported value. Cesar et al. (2002) estimated industry gross sales at $3.2 million and industry profits at $1.2 million. A 1993 analysis based on export figures by an aquarium trade group calculated total sales of Hawaiian fish (inclusive of freight and packing) at $4,909,654 (Hawaii Tropical Fish Association, unpublished data). DAR reported the total average fishery value for fiscal year 1993-1994 as only $819,957 (Miyasaka 1994a, b).

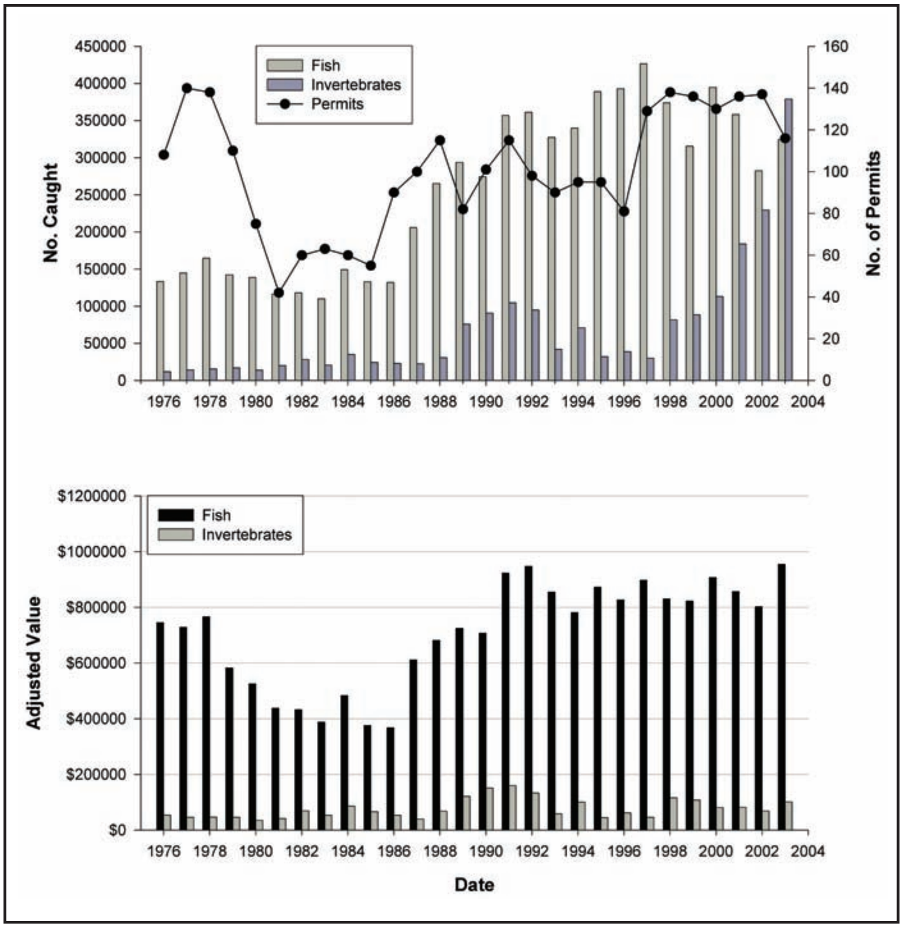

Figure 9.16. Upper panel shows the number of commercial aquarium permits issued statewide and the numbers of fish and invertebrates reported caught. Lower panel shows dollar value of commercially caught fish and invertebrate aquarium specimens. Value is adjusted for inflation by means of Honolulu Consumer Price Index (Hawaii Dept. of Labor and Industrial Relations). Source: Walsh et al., 2004.

While the overall economic value and total catch of the aquarium fishery in the state has been relatively stable over the last decade (Figure 9.16), there have been substantial changes in value on each of the islands (Figure 9.17). The value (adjusted for inflation) of the Oahu aquarium fish catch in fiscal year 2003 has declined by 76% while that of Hawaii Island has increased 282%.

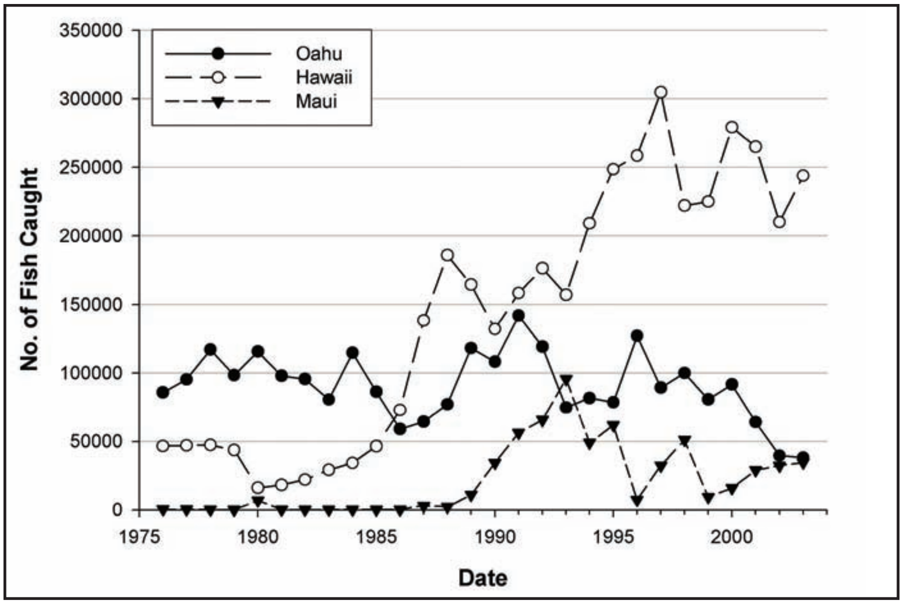

Figure 9.17. Number of aquarium fish caught on each island per fiscal year. Kauai catch omitted due to low numbers. Source: Walsh et al., 2004.

The overall aquarium catch has been diverse, comprising 235 taxa of fish and 37 taxa of invertebrates. A relatively small number of species dominates the catch; the top 10 species constitute 73.3% of the total historical catch (Walsh et al., 2004; Table 9.3). Surgeonfishes, butterflyfishes, and wrasses are the most commonly caught fish species, while feather duster worms, hermit crabs, and shrimp predominate among the invertebrates. The yellow tang (*Zebrasoma flavescens*) accounts for 37% of the total catch.

Table 9.3. Top 10 taxa of collected animals from FY 1976-2003. Source: Walsh et al., 2004.

TAXA	COMMON NAME	TOTAL CAUGHT	% OF TOTAL
Zebrasoma flavescens	Yellow tang	3,386,860	37.2
Sabellastarte sanctijosephi	Feather duster worm	741,949	8.1
Hermit crabs	Hermit crabs	707,654	7.8
Ctenochaetus strigosus	Goldring surgeonfish	346,944	3.8
Acanthurus achilles	Achilles tang	337,781	3.7
Naso lituratus	Orangespine unicornfish	298,884	3.3
Centropyge potteri	Potter's angelfish	287,668	3.2
Forcipiger flavissimus	Forcepsfish	251,523	2.8
Zanclus cornutus	Moorish idol	187,662	2.1
Halichoeres ornatissimus	Ornate wrasse	121,766	1.3

Subsequent to the overall contraction of the aquarium fishery in the late 1970s and early 1980s due to a downturn in the economy (Figure 9.7), there has been an increasing trend in the number of commercial fishery permits on all islands (Figure 9.16). In the early days of the fishery, most collecting activity was centered on the island of Oahu, which accounted for between 64% (1976) and 84% (1981) of the fish catch. This fishery has declined over the years due to hurricane impacts and localized overfishing, with the current catch from Oahu accounting for only 12% of the total catch. Low-value invertebrates are increasingly replacing fishes. In contrast to Oahu, the aquarium fishery on the island of Hawaii has experienced a 645% increase over the last two decades and now accounts for 55% of the catch and 68% of the total state fisheries value. The expansion on Hawaii was due to both an influx of new collectors and the relocation of collectors from Oahu.

Recent research shows that collecting activities in Hawaii can significantly affect targeted species (Tissot and Hallacher, 2003). A network of fish replenishment areas (FRAs) has been established on the island of Hawaii to ensure sustainability of the aquarium fishery and to reduce user conflicts. Four years after implementation of the FRAs in 2000, there were significant increases in the abundance of several targeted species, and the overall value of the fishery is at an all-time high. Catch report compliance is low on the island of Hawaii and likely elsewhere within the state. Actual aquarium catch is thought to be underreported, but specific management actions are increasing reporting compliance by collectors.

Ships, Boats, and Groundings

More than 16,000 recreational and commercial vessels are currently registered in Hawaii. On average, three to five ship groundings are reported each year in the MHI, but these values are likely an underestimate as many recreational vessel groundings go unreported. In most cases, responsible parties have not had to cover the cost for vessel salvage, and restitution for damage is rarely made. Cruise ships currently make over 400 port calls annually in Hawaii, and this figure is expected to triple in the next few years. The limited port facilities have raised concerns about anchoring areas and potential reef damage. In February 2005, a 550-ft bulk carrier freighter ran aground off SW Oahu causing considerable damage to corals to a depth of 70 ft.

Marine Debris

Each year, thousands of kilograms of debris wash onto Hawaii's shorelines. This debris poses entanglement and ingestion threats to endangered Hawaiian monk seals, sea turtles, and sea birds (Henderson, 1984; Balazs, 1985). Fishing gear can snag on a reef, leading to the damage and breakage of coral heads and eventually mortality (Donohue et al., 2001; Yoshikawa and Asoh, 2004).

Several efforts are made each year to clean up marine debris. One such effort is the National Marine Debris Monitoring Program (NMDMP), which is coordinated by the Ocean Conservancy and for which trained NMDMP volunteers monitor selected beaches across the state and conduct monthly beach cleanups. Another effort is the "Get the Drift and Bag It" event, part of the Ocean Conservancy's International Coastal Cleanup, which is coordinated locally by the Hawaii Sea Grant Program. In 2002, nearly 2,000 volunteers across the state collected over 13,000 kg of marine debris along 151 km of shoreline in this one-day event. Over 100 divers removed 590 kg of underwater debris from 38 km of underwater area. The majority (54%) of the collected debris was derived from shoreline and recreational activities, with the remainder comprised of debris from smoking related (37%) and ocean/waterway activities (7%). Of all the debris types noted, cigarettes, plates, utensils, caps, and lids were the most common, accounting for over half of all debris collected (The Ocean Conservancy, 2002). Debris from ocean and waterway activities (i.e., fishing line and nets) are the most common types of entangling debris and many times do not wash ashore.

In 2003, in conjunction with the International Coastal Cleanup, two focused cleanup events were conducted in remote areas that are impacted almost entirely by ocean-borne debris. At Kanapou Beach, Kahoolawe, staff and volunteers cleaned almost 2,700 kg of marine debris (primarily plastics) from this particular area in a one-day effort on a half kilometer strip of beach. At Kaalualu Bay, on the south coast of the island of Hawaii, over 100 volunteers cleaned approximately three km of coastline in two days. Over 36,000 kg of marine debris, mostly ocean-borne plastic and nets, were removed.

While statewide coastal cleanup events have documented that the majority of Hawaii's debris is from land-based sources, there is a substantial amount of marine debris that washes ashore from sources outside Hawaii, particularly at more remote coastlines. Therefore, efforts are needed not only to continue the ongoing, local volunteer activities, but also to address this issue on the high seas and with Pacific Rim communities that share the impacts and responsibility for this marine pollution.

Aquatic Invasive Species

The coral reef communities surrounding the Hawaiian Islands have been inundated with alien species over the last century (Coles and Eldregde, 2002; Coles et al., 1999a; Eldredge and Smith, 2001; Friedlander et al., 2002b). Due to extreme isolation and subsequent high levels of endemism, alien invaders pose a significant threat to the native diversity of these unique marine environments. Perhaps because Hawaii lies in the middle of the Pacific Ocean and is located on shipping routes across the Pacific, the islands have intercepted more nonindigenous marine species (NIMS) than other tropical locations (Carlton, 1987). The estimated number of NIMS in Hawaii includes 287 invertebrates, 20 algae, 20 fish, and 12 flowering plant species (Eldredge and Smith, 2001). While the majority of NIMS in Hawaii are invertebrates, many of these species are cryptic and/or have remained in highly disturbed harbors and other fouling environments. These factors have made it difficult to determine the impacts and interactions that the invaders may be having on native marine flora and fauna. However, the larger and more conspicuous nonindigenous marine algae (NIMA) have become increasingly more common along Hawaiian shores over the last several decades (Smith et al., 2002; Smith et al., 2004; Smith, 2003).

Out of the 20 or more species of NIMA introduced to Hawaii since the mid-1950s, recent surveys indicate that at least five of these have become well established (Smith et al., 2002). Several species of the red algal genera *Kappaphycus* and *Eucheuma* were introduced to open reef cultures in Kaneohe Bay, Oahu in the 1970s for experimental aquaculture for the carrageenen industry. Following experimental manipulations, plants were left on the reef. Some 30 years later, at least two of these species (*Kappaphycus alvarezii* and *Eucheuma denticulatum*) have spread throughout Kaneohe Bay and are beginning to appear on reefs outside of the bay (Woo et al., 1999; Rodgers and Cox, 1999; Smith et al., 2002; Smith, 2003). These species are particularly threatening to the integrity of Hawaiian reefs, as they are able to overgrow, smother, shade, and kill reef-building corals (Figure 9.18; Smith, 2003). These species generally grow in large three-dimensional mats that monopolize the benthos. Not only do these invaders kill coral, but they denude the three-dimensional complexity or rugosity (i.e., roughness) on a reef, thus posing negative cascading effects to the entire reef community.

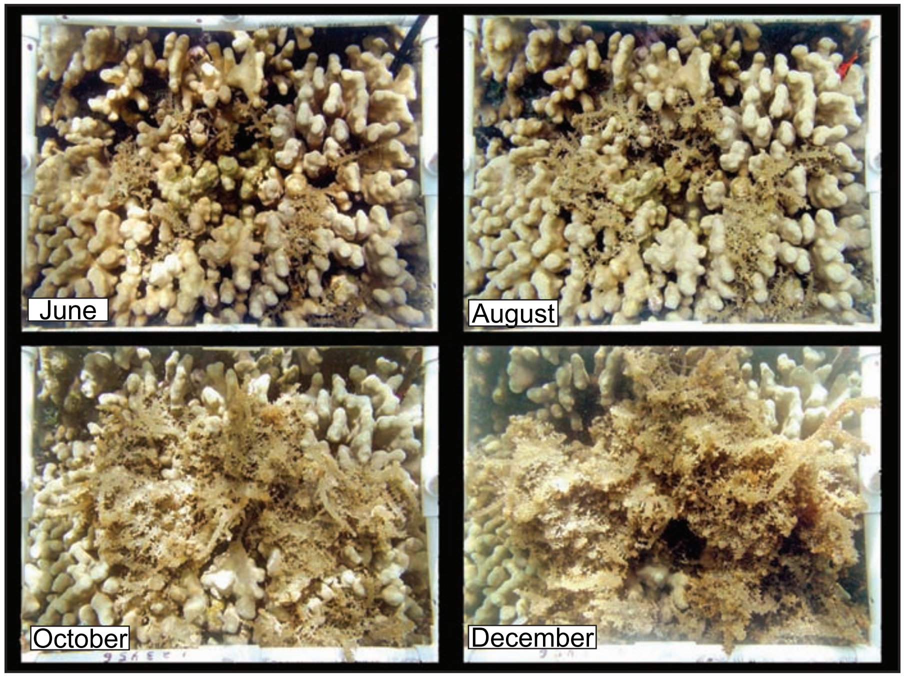

Figure 9.18. Representative photographic sequence showing the invasion of the red alga *Eucheuma denticulatum* into a live *Porites compressa* colony on a patch reef in Kaneohe Bay, Oahu, 2002. Several quadrats were permanently marked on a variety of reefs using steel pins and photographs were taken monthly for one year to monitor algal invasion and coral growth. Source: Smith, 2003.

Hypnea musciformis was introduced from Florida to Kaneohe Bay, Oahu in 1974. This species is now the second most widespread of the NIMA species in Hawaii and is found on all of the MHI except the island of Hawaii. This alga forms massive blooms on the shallow reef flats on the island of Maui (Hodgson, 1994). A recent economic evaluation has estimated that because of these blooms, the State of Hawaii suffers net losses of over $20 million per year due to reduced occupancy rates in hotels and condominiums, reduced property value in the impacted area, and direct costs associated with removing rotting seaweed from beaches (Figure 9.19; van Beukering and Cesar, 2004).

Figure 9.19. The introduced seaweed, *Hypnea musciformis*, forms massive blooms that have negative ecological and economic impacts. Photo: J. Smith.

Gracilaria salicornia was introduced to Waikiki and Kaneohe Bay for experimental aquaculture in 1971 and 1978, respectively. The source population had been known to exist on the island of Hawaii prior to the 1950s.

There is some support for the idea that this population on the island of Hawaii was an early 20th century introduction from ship ballasts originating in the Philippines, where *G. salicornia* is native (I. Abbott, pers. comm.). In 1999, *G. salicornia* still had a distinct and localized distribution (Smith et al., 2002). However, more recent surveys indicate that *G. salicornia* has become increasingly common on the island of Oahu (Smith et al., 2004). It is the most common species in the shallow reef areas off of Waikiki and readily overgrows and kills reef-building coral. Coral cover has declined significantly in Kaneohe Bay and Waikiki as a result of the *G. salicornia* invasion. At the same time, new populations continue to emerge across the state.

Acanthophora spicifera, another red alga, was accidentally introduced to Honolulu Harbor in the 1950s on a heavily fouled barge originating from Guam. This species has now spread throughout the MHI and can be considered naturalized. While it is now a common component of the intertidal community, it generally does not form large monospecific blooms. However, high abundances have been recently documented from the reef slope area at numerous locations on West Maui (J. Smith, unpublished data).

Avrainvillea amadelpha, a green alga, is currently considered to be a cryptogenic (i.e., of uncertain origin) species. It was first documented on Oahu in the 1980s and has since become highly abundant on Oahu's south shore. It is unclear how this species got to Hawaii or even where it originated from specifically, but it is likely to have been a home aquarium introduction through the dumping of live rock. This species appears to be competing with Hawaii's native seagrasses. Very little is known about the impacts and interactions of *A. amadelpha* on Hawaii's reefs, but it is currently the subject of active research (K. Peyton, unpublished data).

Only three invasive or potentially invasive species of invertebrates occur on Hawaiian coral reefs. The Philippine mantis shrimp (*Gonodactylaceus falcatus*) is common in Kaneohe Bay (Coles et al., 2002a), where it has displaced the native shrimp (*Pseudosquilla ciliate*) from coral rubble habitats (Kinzie, 1968), and in Waikiki (Coles et al., 2002b). The snowflake coral (*Carijoa riisei*) can occur in high densities from the intertidal zone (Coles et al., 2002b) to over 100 m deep where optimal growth conditions are provided by reduced light and moderate current. It occurs under ledges and in caves at many reef sites throughout the MHI and overgrows black coral beds off Maui between 75 m and 100 m that may be important source populations for shallow water black coral assemblages (Grigg, 2003). Other observations suggest that *C. riisei*, which was first reported in Hawaii in Pearl Harbor in 1972 (Evans et al., 1974; Devaney and Eldredge, 1977), is highly fecund and has a rapid growth rate (S. Kahng, pers. comm.), resulting in the proliferation of this species.

A third introduced invertebrate recently designated as potentially invasive (Coles et al., 2004) is the orange keyhole sponge (*Mycale armata* Thiele). This sponge was observed at five of 41 rapid assessment sites, but at all sites other than in Kaneohe Bay, it was a minor component of the sessile benthos and appeared neither abundant nor invasive. However, in Kaneohe Bay and especially on reefs on or near Coconut Island, this sponge has become abundant and is growing at a sufficient rate to overgrow the dominant corals *Porites compressa* and *Montipora capitata.* The spatial extent and degree of competition among *M. armata* and other corals has not been established at present.

Previous studies of the presence and impact of nonindigenous (introduced or alien) and cryptogenic marine species, collectively termed NIS, in Oahu's harbors and embayments have indicated that 15-23% of the total biota in these enclosed or semi-enclosed areas is composed of confirmed or putative introductions (Table 9.4). Earlier surveys have not indicated a substantial presence of NIS on surveyed Hawaiian coral reefs except in Kaneohe Bay and at Waikiki where NIS comprised 14.5 and 6.9%, respectively, of total biota identified (Table 9.3). Remote areas such as Kahoolawe, the NWHI and Johnston Atoll showed NIS to be a minor component of the reef total biota, comprising 0.3-1.5% of the total identified biota.

At least 13 species of introduced marine fishes have become established in Hawaii (Eldredge, 1994). The Marquesan sardine (*Sardinella marquesensis*) was intentionally introduced as a tuna baitfish in the 1950s, while the gold spot herring (*Herklotsichthys quadrimaculatus*) was an accidental baitfish introduction that has proliferated at the expense of a local endemic silverside (*Atherinomorus insularum*; DeMartini et al., 1999). A mullet (*Valamugil engeli*) and goatfish (*Upeneus vittatus*) were unintentional introductions that arrived with the Marquesan sardine (Randall, 1987). The mullet is not important in the local fishery, but may be displacing the

Table 9.4. Numbers of marine nonindigenous (N), cryptogenic (C), nonindigenous plus cryptic (NIS), and total species in Hawaii and Johnston Atoll.

LOCATION	(N)	(C)	TOTAL NIS	TOTAL SPECIES	% N + C	SOURCE
Hawaiian Islands						
Oahu, Pearl Harbor	69	26	95	419	23	Coles et al., 1997, 1999a
Oahu, South Shore Commercial Harbors	73	27	100	585	17	Coles et al., 1999b
Kaneohe Bay	82	34	116	617	14.5	Coles et al., 2002a
Waikiki	33	19	52	749	6.9	Coles et al., 2002b
Kahoolawe	3	0	3	298	1	Coles et al., 1998
Midway	4	0	4	444	1.5	DeFelice et al., 1998
French Frigate Shoals	2	0	2	617	0.3	DeFelice et al., 2002
41 additional sites	18	8	26	486	5.3	Coles et al., 2004
Johnston Atoll	5	5	10	668	1.5	Coles et al., 2001

more valuable native mullet (*Mugil cephalus*). Several introduced tilapia species are also thought to reduce the abundance of the valuable native mullets through competition for food and other resources (Randall, 1987; Eldredge, 1994).

Between 1951 and 1961, 11 demersal fish species (six groupers, four snappers, and one emperor) were intentionally introduced into Hawaii (Oda and Parrish, 1981; Randall, 1987). Of these species, the blacktail snapper (*Lutjanus fulvus*), bluestripe snapper (*Lutjanus kasmira*), and peacock grouper (*Cephalopholis argus*) have established viable breeding populations in the state. The latter two species have proven to be particularly controversial because they have adapted well to Hawaiian waters and are often blamed for depletion of desirable species due to competition or predation.

Bluestripe snappers have been by far the most successful fish introduction to the Hawaiian coral reef ecosystem. From some 3,200 individuals introduced on the island of Oahu, the population has expanded its range as far north as Midway in the NWHI (~2,400 km). These records suggest a dispersal rate of about 33-130 km/yr and attest to the interconnectedness of the entire archipelago. Recent research suggests that the purported impact on native species may be substantially less than what fishers commonly believe. A study of the interactions of bluestripe snappers with native deepwater snappers found little habitat or dietary overlap with native deepwater snappers (Parrish et. al., 2000). Preliminary results of feeding interactions between bluestripe snapper and shallow-water reef fishes do not suggest predatory effects on native populations by the introduced snapper, or vice versa (Schmacker and Parrish, 2004). Likewise, state fisheries data do not suggest a strong negative impact of this snapper on landings of deepwater snappers.

Similarly, studies of bluestripe snappers in shallow water environments have not detected direct negative impacts on other fish species. Friedlander et al. (2002b) found that while bluestripe snappers associated with many native species, no clear and consistent relationships were observed that would suggest strong common dependence on an important, limited resource (e.g., space, shelter, food, and foraging grounds). Oda and Parrish (1981) reported that commercially important fish species were not eaten by bluestripe snapper nor did they appear to have diet overlap with food fish such as goatfishes (Mullidae) or soldierfishes (Holocentridae).

Of the six species of groupers introduced to Hawaii, only peacock groupers (*Cephalopholis argus*) have become established. Peacock grouper now occur on all of the MHI and in low numbers on some of the NWHI. Increases in abundance have been noted at several locations since the early 1990s (Figure 9.20). Although this species was introduced to augment declining populations of food and game fishes, it has not been well received by most Hawaii fishers due to concerns about ciguatera poisoning. Peacock grouper have been blamed for a multitude of problems on the reefs, most notably a decline in important aquarium fish such as the yellow tang (*Zebrasoma flavescens*). Ongoing feeding studies have failed to find yellow tangs in the stomachs of peacock grouper (J. Dierking, pers. comm.; Walsh, pers. obs.). Peacock grouper appear to be omnivorous,

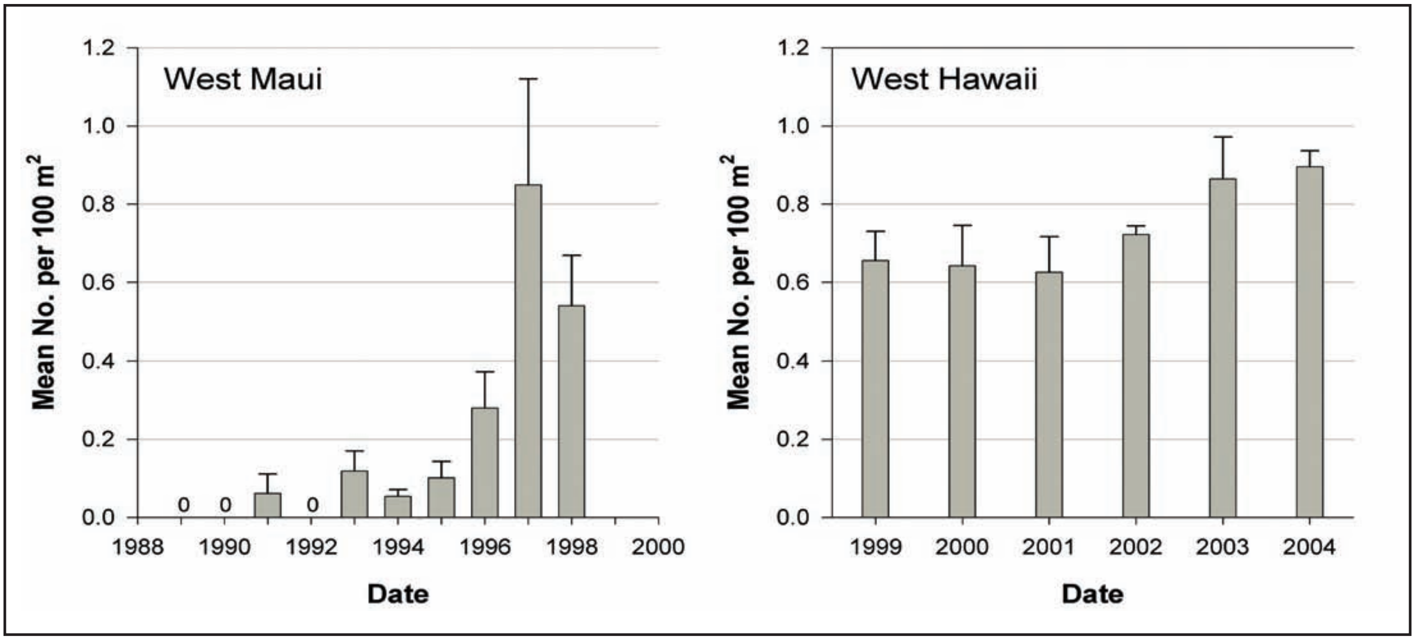

Figure 9.20. Mean abundance of peacock grouper on transects along West Maui (left panel) and West Hawaii (right panel). Source: E. Brown, unpublished data; West Hawaii Aquarium Project, unpublished data.

feeding on both invertebrates and a range of fish types (diurnal/nocturnal), rather than targeting certain types of prey. Studies to date have not found any relationship between peacock grouper densities and species richness (i.e., number of species per transect), number of fishes, or recruitment, suggesting that they may not be having the dramatic impact on reef fish populations that has been attributed to them. In fact, Peacock grouper were found to have a positive relationship with other piscivores, which suggests that they are not outcompeting or otherwise negatively impacting these piscivores.

Security Training Activities

In Hawaii, the extensive presence of U.S. air force, army, coast guard, marine and naval installations makes the military the second largest economic activity in the state. Many of these areas are closed to fishing and this prohibition has resulted in high abundance of some targeted resource species. Large jacks are not frequently encountered around Oahu but large individuals and high numbers of these species have been observed in Pearl Harbor, likely due to restrictions on fishing at the facility (R. Brock, pers. comm.). The island of Kahoolawe was used as a military bombing target until 1990, and fishing restrictions resulted in certain sites having the highest biomass of reef fish and greatest number of predators compared to other sites around the MHI (Friedlander and DeMartini, 2002). Kaula Rock, a live-fire and bombing target 35 km southwest of Niihau, is also closed to harvest and is noted for its abundance of jacks and other large species. Recent surveys around Kaneohe Bay Marine Corp Base, Oahu have noted greater abundance and larger sizes for many reef fishes compared with other areas around Oahu.

Negative impacts on coral reefs resulting from military activities include unexploded ordinance, pollution, and vessel groundings. Unexploded ordnance have been observed at all of the above mentioned locations as well as numerous other areas around the MHI that were previously used as bombing targets and live-fire training areas. The approximately 2,024 hectares of sediments (e.g., mud and sand) comprising the bottom of Pearl Harbor act as a sink or repository for many of the chemicals entering the harbor. Chemical contaminants found in the harbor have led State of Hawaii, U.S. Navy, and other Federal officials to notify the public and issue warnings to alert fishers not to eat any fish caught in the harbor. Amphibious training exercises have resulted in groundings and reef damage on several occasions.

Offshore Oil and Gas Exploration

No offshore oil and gas exploration occurs in Hawaiian waters.

Other

Crown-of-thorns starfish *(Acanthaster planci)*

At present, outbreaks of crown-of-thorns starfish (COTS; Figure 9.21), *Acanthaster planci*, do not appear to be a problem in Hawaii except in isolated incidents. The last reported large-scale occurrence of COTS was in August 1969 when approximately 20,000 COTS were observed off the south shore of Molokai (Branham et al., 1971). There have only been scattered reports of COTS aggregations since this time and all have been of considerably lesser magnitude.

Figure 9.21. A crown-of-thorns starfish, *Acanthaster planci*, consuming its prey. Photo: S. Holst.

CORAL REEF ECOSYSTEMS—DATA GATHERING ACTIVITIES AND RESOURCE CONDITION

Current coral reef monitoring, research, and assessment activities, including those that are represented in this report, are summarized in Table 9.5. Monitoring locations are shown in Figure 9.22.

Table 9.5. Extant monitoring programs investigating coral reef ecosystems in the MHI.

PROGRAM	OBJECTIVES	START DATE	FUNDING	PARTNERS
Hawaii Coral Reef Assessment and Monitoring Program (CRAMP)	Long-term monitoring of benthos and fishes across a statewide network of sites	1997	HCRI, USGS, EPA	UH-Manoa, NOAA, DAR, USGS
West Hawaii Aquariumfish Project (WHAP)	Assess aquarium fish collecting and MPA effectiveness	1998	HCRI, DAR	Washington State Univ., DAR, Oregon State, UH-Hilo
Spread of alien algae in Kaneohe Bay, Oahu	Examine spread of alien algae and assoc. fish assemblages	1999	HCRI	UH-Manoa
Fish Habitat Utilization Program (FHUP)	Examine fish habitat utilization patterns and MPA effectiveness statewide	2002	NOAA	DAR, NOAA, UH-Manoa, UH-Hilo, HIMB, NPS
Physical factors and biological processes affecting nuisance algae in W. Maui	Examine linkages of physical and biological related to nuisance algae	2003	NOAA, HCRI	NOAA, DAR, UH-Manoa, USGS, DOH
DAR statewide marine research and surveys of fish and habitat	Habitat and species status relative to recreationally fished species	1970s	USFWS	DAR
Hanalei Bay Marine Communities Investigation	Long-term trends in benthic and fish	1992	NOAA, DAR, USGS, Hanalei Heritage River	NOAA, DAR, Hanalei Heritage River Hui, HIMB, USGS
Reefcheck	Volunteer, community-based monitoring protocol to measure the health of coral reefs on a global scale.	1996	NOAA, CZM, DAR	Oceanwide Sci. Instit., Waikiki Aquarium, Windward C.C., Hawaii Pacific Univ., Hanauma Bay Edu. Center, MOP
The Reef Environmental Education Foundation (REEF)	Volunteer scuba divers and snorkelers collect information on marine fish populations	2001	CZM, NFWF, PADI – Project Aware, NOAA, NMSP	Maui Community College MOP, Project SEA-Link, Hawaii Coral Reef Network, DAR
Kahe Point Coral monitoring	Long-term trends in coral community	1973	HECO	HECO, AECOS, Sea Engineering
Reef Watchers Program	Volunteers monitor and provide data on near shore and intertidal sites	1999	HCRI, CZM/DBEDT, NFWF, NOAA, Harold Castle Foundation, HCF, TNC, CCN	DAR, TNC, CCN, DOE, UH-Hilo, Washington State University and West Hawaii participating residents
Kapoho Reef Watch	Monitor human use, water quality, and marine biota around Waiopae tide pools	2003	HCF, NFWF, VHCA, Kapoho Kai Water Assoc.	Cape Kumukahi Foundation, UH-Hilo, DAR, DOCARE, NOAA
USGS Study of Coral Reefs in the Pacific Ocean	Mapping, monitoring, remote sensing, sediment transport studies, and collection of tide, wave, and current data from remote stations.	2000	USGS	USGS, UH-Manoa, HIMB, DAR, NPS
DAR Coral Reef Monitoring	Benthic and fish monitoring	2003	NOAA, HCRI	UH-Hilo, UH-Manoa, NPS
Oahu Offshore Islets Surveys	Assessment of resources at offshore islets around Oahu	2004	NOAA	DAR, UH, NOAA, USFWS

AECOS – AECOS Inc. Environmental Consulting Company
CCN – Community Conservation Network
CZM – Hawaii Coastal Zone Management
DAR – Hawaii Department of Land and Natural Resources, Division of Aquatic Resources
DOE – Hawaii Department of Education
DOH – Hawaii Department of Health
EPA – Environmental Protection Agency
HCF – Hawaii Community Foundation
HCRI – Hawaii Coral Reef Initiative Program
HECO – Hawaii Electric Company
HIMB – Hawaii Institute of Marine Biology
MOP – Univ. of Hawaii Marine Options Program
NOAA – National Oceanic and Atmospheric Administration
NFWF - National Fish and Wildlife Foundation
NMSP – National Marine Sanctuary Program
NPS – National Park Service
PADI – Professional Association of Diving Instructors
UH – University of Hawaii
USFWS – U.S. Fish and Wildlife Service
USGS – U.S. Geological Survey
VHCA – Vacationland Hawaii Community Association

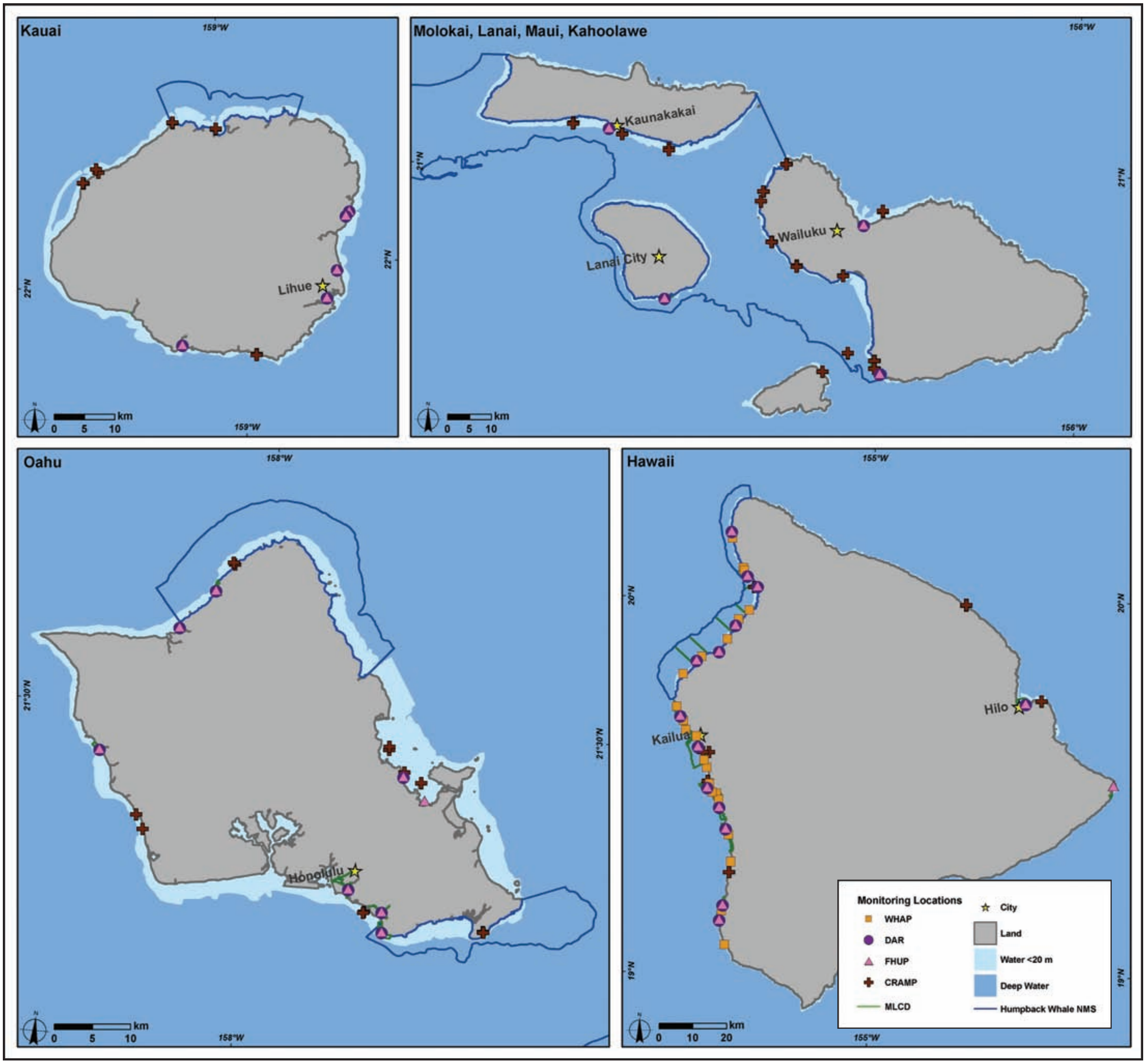

Figure 9.22. Monitoring locations in the MHI. Map: A. Shapiro.

The monitoring programs presented in Figure 9.22 represent the major programs with the greatest spatial and temporal coverage in the MHI. In addition, there have been numerous studies and monitoring programs of short duration or limited spatial scope that extend back nearly 100 years.

The DAR has been collecting data on fish and habitat at all of the state's MLCDs since the 1970s. This is the longest running extant monitoring program in Hawaii and occurs on all major islands. The Hawaii Coral Reef Assessment and Monitoring Program (CRAMP) examines spatial and temporal changes at sites on Oahu, Kauai, Maui, Hawaii, Molokai, and Kahoolawe which encompass broad spectrum of environments and management regimes. Several monitoring sites sampled in the 1970s and 1980s were incorporated into the current CRAMP monitoring program, thus providing a 30-year time span at some locations. The West Hawaii Aquariumfish Project (WHAP) was established to monitor aquariumfish along the west Hawaii coastline. This program covers a broad spatial scale (~150 km) and includes a robust sampling design that evaluates various levels of fisheries management. The National Oceanic and Atmospheric Administration's (NOAA) Center for Coastal Monitoring and Assessment - Biogeography Team (CCMA-BT) has developed digital benthic habitat maps for much of the MHI. Using these maps, CCMA-BT has been conducting an extensive evaluation of Hawaii's MLCDs and adjacent areas in cooperation with DAR and the University of Hawaii.

WATER QUALITY

There are no statewide comprehensive water quality monitoring programs assessing sediment or chemical impacts to coral reef areas in Hawaii. Water quality at beaches is monitored for bacteria that indicate a risk to human health. Pollutant concentrations normally decrease sharply with distance from shore, and offshore water quality in Hawaii is generally good.

Hawaii's Department of Health (DOH) regularly monitors indicator bacteria (*Enterococcus*) at swimming beaches. In recent years, DOH has also collected data on turbidity, nutrients, and chlorophyll a at specified shoreline stations (knee-deep water) and in perennial streams. DOH uses these data, and other available data that meet specific quality criteria, to identify streams and coastal segments that are "water quality impaired" (i.e., where state water quality criteria (Hawaii Administrative Rules, Title 11, Chapter 54; http://www.hawaii.gov/health/about/rules/admrules.html, Accessed 1/19/05) are regularly exceeded. A list of impaired waters is reported to the U.S. Environmental Protection Agency (EPA) every two years, as required by the Federal Clean Water Act (33 USC § 1251 et seq.) Section 303(d). Although the listings are a function of available data rather than the result of a comprehensive statewide sampling design, it is not surprising that the number of listed waters corresponds, roughly, with island population size (Table 9.6).

The impaired coastal waters are primarily harbors, semi-enclosed bays, and protected shorelines, where mixing is reduced and resident time of pollutants is long when compared with exposed coasts. Several bays that have coral reefs, such as Kaneohe Bay and Pearl Harbor (Oahu), Nawiliwili Bay (Kauai), and Hilo Bay (Hawaii), are included on the list. Because offshore water quality is generally good and few data sets are available to characterize water quality around reefs, deeper and offshore waters where coral reefs occur are generally not included on the list. The most widely distributed coastal pollutants are nutrients, sediments, and *Enterococcus* (Table 9.6).

Table 9.6. Number of waterbodies by island where ambient pollutant concentrations regularly exceed State water quality criteria. ND = No Data.

POLLUTANTS	HAWAII	KAUAI	MAUI	MOLOKAI	OAHU
Sediments	14	7	41	2	45
Enterococcus	8	9	3	ND	23
Nutrients	4	5	11	1	54
Chlorophyll a	8	2	22	ND	34
Toxics: Metals, pesticides, PCBs	ND	ND	ND	ND	3
Total Coastal Stations Listed	20	16	41	2	61
Population Size	148,677	876,156	58,463	128,241	7,404

A source of information on offshore water quality is the multitude of ongoing water quality monitoring programs associated with permit requirements for specific activities (Table 9.7). These include the assessment of point source discharges, such as sewage outfalls and cooling water discharges, required for NDPES permits. Results for NPDES permit monitoring are submitted to the DOH. Nonpoint source inputs from land-based sources, such as resorts and golf courses, are monitored through a variety of state and local permit requirements. Data generally include constituents listed in the State of Hawaii Water Quality Standards: dissolved inorganic nutrients (nitrate + nitrite [NO_3^- + NO_2^-]), ammonium [NH_4^+], orthophosphate [PO_4^{3-}], and silica [Si]), chlorophyll a, salinity, turbidity, pH, temperature, and dissolved oxygen. In total, approximately 3,000 ocean water samples are analyzed annually by private entities as required by permit conditions. These permit-related data have not been synthesized by island or region into a comprehensive database or report.

Table 9.7. Long-term water quality monitoring programs in the main Hawaiian Islands.

ISLAND	LOCATION	PROJECT	PERMIT REQUIREMENT	DURATION	FREQUENCY	SAMPLES PER SURVEY
Kauai	Port Allen	Kauai Island Utilities Coop	NPDES	1990-	Quarterly	50
	Kekaha	Agribusiness Devel. Corp.	NPDES	2000-	Bi-Annual	15
	Kekaha	Ceatech USA	NPDES	1998-	Quarterly	27
Oahu	Sandy Beach	East Honolulu WWTP	NPDES	1965-	Semi-Monthly	18
	Ewa	Ocean Pointe	DLNR	1990-	Quarterly	60
	Barbers Point	Chevron USA	NPDES	1985-	Quarterly	20
	Ewa	Cates International	NPDES	2000-	Quarterly	21
Lanai	Hulopoe Bay	Castle & Cooke	Maui Co. LUC	1989-	Quarterly	21
Maui	Honolua	Kapalua Land Co.	None	1990	Annual	32
	Honokohua	Kapalua Land Co.	None	2001	Annual	32
	Napili	Kapalua Land Co.	None	2001	Annual	16
	Kaanapali	North Beach	Maui Co.			
	Makena	Makena Resort	LUC, DOH	1990	Bi-Annual	50
Hawaii	Keahole Point	NELHA	DOH, Hawaii Co.	1987-	Quarterly	72
	Hilo Bay	Hilo WWTP	NPDES	1985-	Monthly	18
	Hamakua	Papaiko WWTP	NPDES	1985	Semi-Annual	6
	Hamakua	Kulaimano	NPDES	1985	Semi-Annual	5
	Hokulia	Oceanside 250	DOH, Hawaii Co.	1989-	Quarterly	47
	Kukio	Kukio Resorts	DOH, Hawaii Co.	1989-	Quarterly	37
	Maniniowali	Kukio Resorts	DOH, Hawaii Co.	2000-	Quarterly	21
	Waikoloa	Waikoloa Land Co.	DOH, Hawaii Co.	1987-	Quarterly	26

NPDES – National Pollutant Discharge Elimination System
DLNR – Department of Land and Natural Resources
LUC – Land Use Commission
DOH – Department of Health

BENTHIC HABITATS

CCMA-BT Benthic Habitat Mapping

The CCMA-BT initiated a nearshore benthic habitat mapping program for the MHI in 2000. A NOAA Citation jet collected aerial photographs and hyperspectral imagery which was used to delineate habitat polygons in a geographic information system (GIS). Habitat polygons were defined and described according to a hierarchical habitat classification system consisting of 27 discreet habitat types. The project, which was completed in 2003, mapped 774 km^2 of nearshore habitat in the islands and produced a series of 87 maps that are currently being distributed via a print atlas, a CD-ROM, and on-line at http://biogeo.nos.noaa.gov/products/hawaii_atlas, Accessed 02/28/05. The benthic habitat maps are depicted in Figure 9.23.

Hawaii Coral Reef Assessment and Monitoring Program

The CRAMP was established in 1998 and produced a comprehensive description of the spatial differences and the temporal changes in coral reef communities in the MHI. Spatial information described the major ecological factors controlling the status of reef coral communities in the MHI. Temporal trends documented patterns of reef decline, recovery, and stability.

Methods

The CRAMP monitoring sites were selected to give a cross-section of locations that differed in perceived environmental degradation, level of management protection, quantity of previous data, and extent of wave exposure. Two reef areas, a shallow (generally 3 m) and a deep (generally 10 m) station, were surveyed at each of the 30 statewide sites at least twice since 1999. Digital video transects, fixed photoquadrats, visual belt fish transects (Brock, 1954), substrate rugosity, sediment samples and additional qualitative data were collected at various times over the study period. Detailed methods and data analysis are described in Brown et al. (2004) and Jokiel et al. (2004). Total mean percent coral cover by station, mean percent coral cover by species within a station, and species richness and diversity (Shannon-Weiner Index) were documented. The monitoring site data were supplemented in the spatial dimension using a rapid assessment technique (RAT). The RAT is an abbreviated version of the CRAMP monitoring protocol, using a single 10 m transect to describe benthic cover, rugosity, and sediments. The RAT, however, is not designed to produce the type of data needed to detect temporal change. Other data sources included U.S. Navy WAM models (for wave direction and height) and the State of Hawaii GIS database (for data on population demographics, watershed characteristics, and precipitation levels).

Results and Discussion

Average coral coverage for all 152 reef stations (CRAMP plus RAT) combined was 20.8% ± 1.7 standard error (SE), with six species accounting for most of the coverage (20.3%). The six dominant species were: *Porites lobata* (6.1%), *Porites compressa* (4.5%), *Montipora capitata* (3.9%), *Montipora patula* (2.7%), *Pocillopora meandrina* (2.4%), and *Montipora flabellata* (0.7%).

Spatial patterns:

The spatial data set (CRAMP plus RAT) revealed that various biological parameters (i.e., coral cover, coral species richness, and coral diversity) showed a significant relationship with physical factors such as the geologic age of the islands, mean wave height, mean wave direction, rugosity, sediment composition, and rainfall. These observations are consistent with and amplify the findings of previous studies:

• Geologic age is a major factor influencing reef coral community structure. The Hawaiian Islands formed over a hot spot located near the southeast end of the archipelago and have gradually moved to the northwest on the Pacific plate over millions of years. The islands are thus moving to higher latitude over time so there is a high correlation (r=0.95) between island age and latitude. Light and temperature conditions favorable to coral growth diminish with increasing latitude and increasing island age. Grigg (1983) previously demonstrated this trend over the range from the island of Hawaii (19˚N) to Kure Atoll (28.5˚N). The present study was conducted over a smaller latitudinal range (19˚N to 22˚N), but with a much more extensive sample size and validated these observations.

• Sites exposed to the larger west and northwest swells on the older islands (e.g., Kauai and Oahu) generally

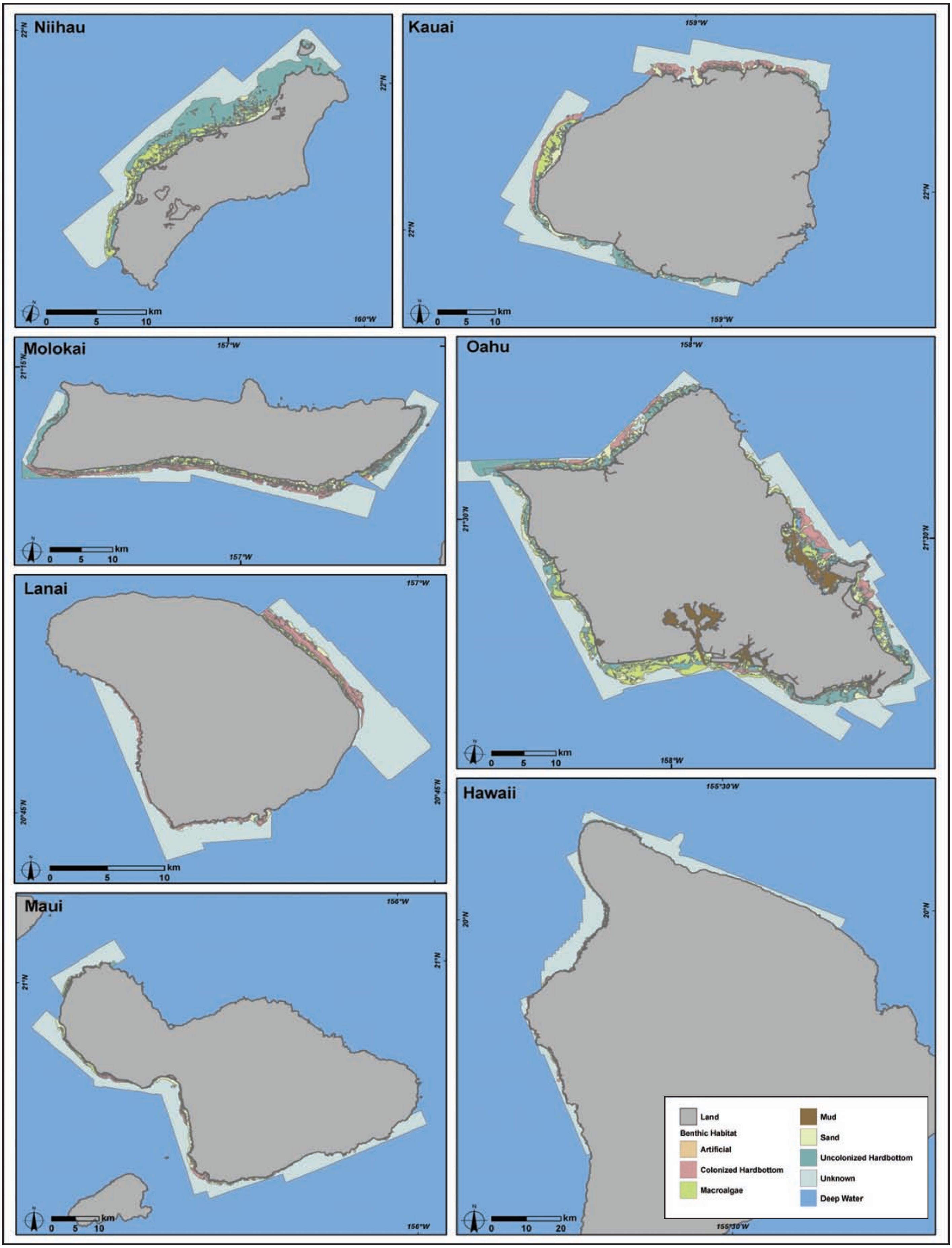

Figure 9.23 Nearshore benthic habitat maps were developed in 2003 by CCMA-BT based on visual interpretation of aerial photography and hyperspectral imagery. For more info, see: http://biogeo.nos.noaa.gov. Map: A. Shapiro.

had lower coral coverage, species richness, and diversity. Mean wave direction (expressed as compass bearing) showed a negative relationship with coral cover, species richness, and diversity. This is because major storm surf in Hawaii arrives along a gradient that roughly diminishes in a counter clockwise direction from the north (Moberly and Chamberlain, 1964). The largest and most frequent storm surf arrives during the winter from the north Pacific swell (bearing 315^o) with the less frequent and less damaging storm waves during the summer from the south swell (bearing 190^o) and trade wind swell (bearing 45^o). Storlazzi et al. (2003) showed that waves in Hawaii can reach destructive levels that will damage corals and restrict species distribution patterns.

• Rugosity measurements showed that areas of antecedent high rugosity allow corals to attach and grow on higher substrata not influenced by sand and sediment movement along the bottom. Rogers et al. (1984) found that coral larvae preferentially recruited to vertical surfaces and suggested that this pattern also applied to areas of higher rugosity. As coral reef communities develop, the structure and continued accretion of the coral skeletons further increase rugosity. Thus both physical and biological components are involved in development of high rugosity environments.

• Sediment components played a role in explaining variation in the coral assemblage characteristics. Percent organics, an indicator of terrigenous input, showed negative relationships with coral species richness and diversity. Higher percent organic content was also important in explaining decline in coral cover over time. Other studies have determined that increased terrigenous input has an adverse impact on reef communities (e.g., Acevedo and Morelock, 1988). Continuing work by the USGS in Hawaii is helping to define the influence of sediment on reef development.

• Higher levels of rainfall in a watershed corresponded to lower levels of coral cover on adjacent reefs. Jokiel et al. (1993) described the negative impacts of low salinity water on coral reef assemblages in Kaneohe Bay, Oahu.

Temporal trends:

• Coral cover at most stations changed less than 10% (absolute) over the three-year period. A total of 29 of 60 stations experienced a statistically significant change in coral cover from the initial baseline survey to the last survey conducted (Figure 9.24). Sixteen stations showed a significant decline in coral cover, with the greatest drop of 19% occurring at the Kamalo 3-m station on Molokai. In contrast, 13 stations increased in coral cover, with the greatest increase of 14% at the Papaula Point 4-m station on Maui. One problematical site (2-m station at Kaalaea, Oahu), showed high fluctuations between samplings. This appeared to be due to several slumping events involving large sections of reef which moved the marking pins and blocks of live coral between the pins.

• Patterns of change in coral cover observed in the CRAMP investigation are consistent with observations of other studies in Hawaii. For example, coral coverage declined at monitoring sites in Kaneohe Bay in the past three years, which continues a trend documented during the previous 20 years (Hunter and Evans, 1995).

• The downward trend on Hawaiian coral reefs as measured in this study appears to be most prevalent in the central portion of the archipelago on the islands of Oahu, Molokai, and Maui (Figure 9.25). Most of the human population of Hawaii resides on Oahu (72%) and Maui (10%). Molokai has a lower human population, but suffers from extreme erosion and sedimentation of reefs along the south shore due to inadequate watershed management (Roberts, 2000). Maui also suffers from impaired watersheds and population centers that are adjacent to major reef areas (West Maui Watershed Management Advisory Committee, 1997). The islands of Kauai and Hawaii have relatively low human population and show an increase in coral reef coverage. At Kahoolawe, a former military target island, the condition of sediment-impacted reefs have held steady following the removal of all grazing animals, cessation of bombing, and a massive program of revegetation.

• Temporal trends should be interpreted with caution over the relatively short time span of the study. This study did identify six reefs (10% of the total) that had major shifts in absolute coral cover (>10%), warranting further experimental investigation and more detailed observations in the future.

Environmental variables that explained changes in coral cover included rugosity, mean wave height, and watershed area (Jokiel et al., 2004).

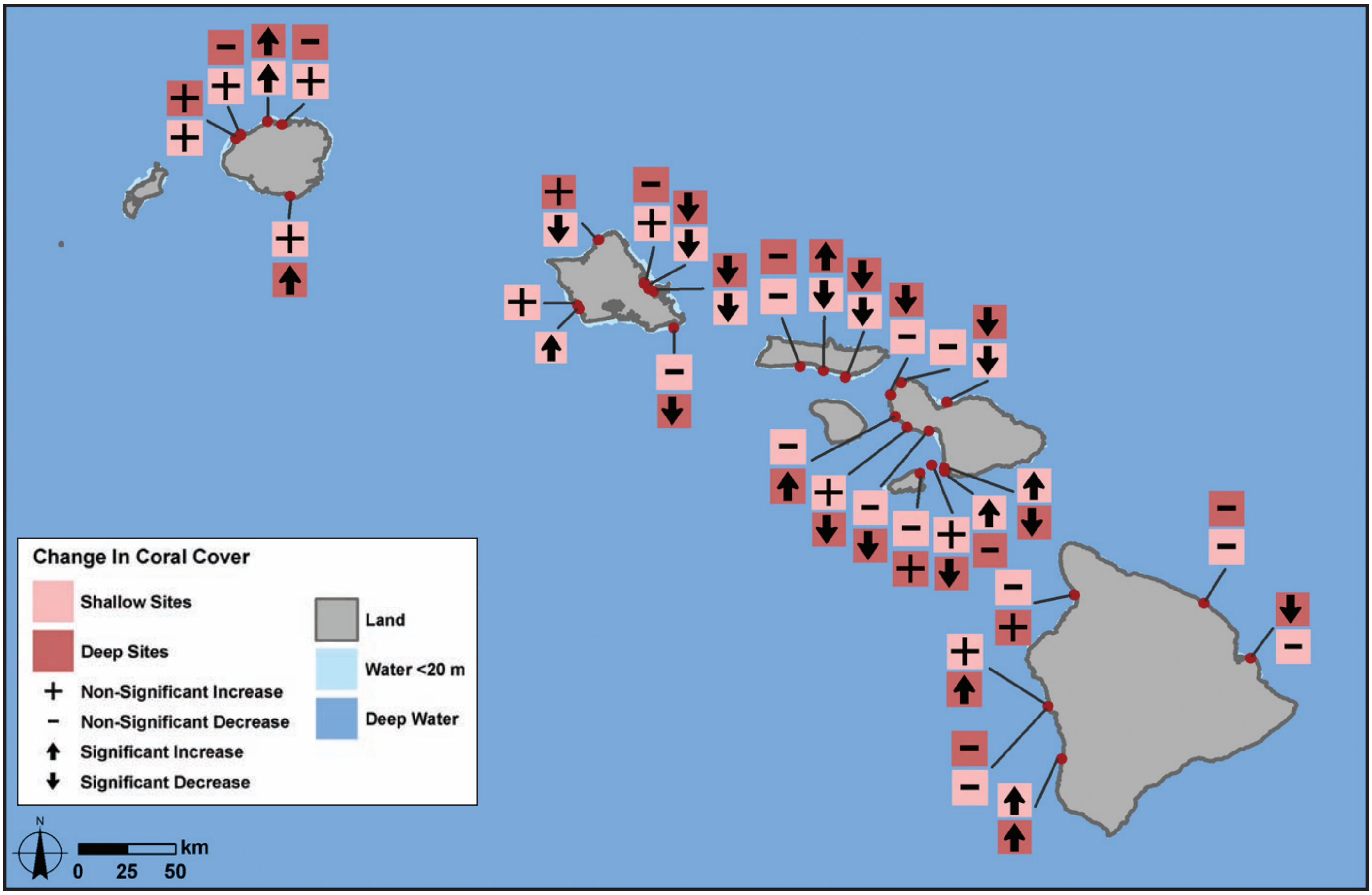

Figure 9.24. Results of CRAMP monitoring efforts since 1999 show trends in coral cover at sites across the state. Shallow sites (3 m) are shown in light pink and deeper sites (8 m) are shown in dark pink. Source: Jokiel et al., 2004.

• Stations with higher rugosity or more topographical complexity experienced greater declines in coral cover.

• In contrast, stations exposed to higher mean wave height or situated adjacent to larger watersheds had significant increases in coral cover.

Turgeon

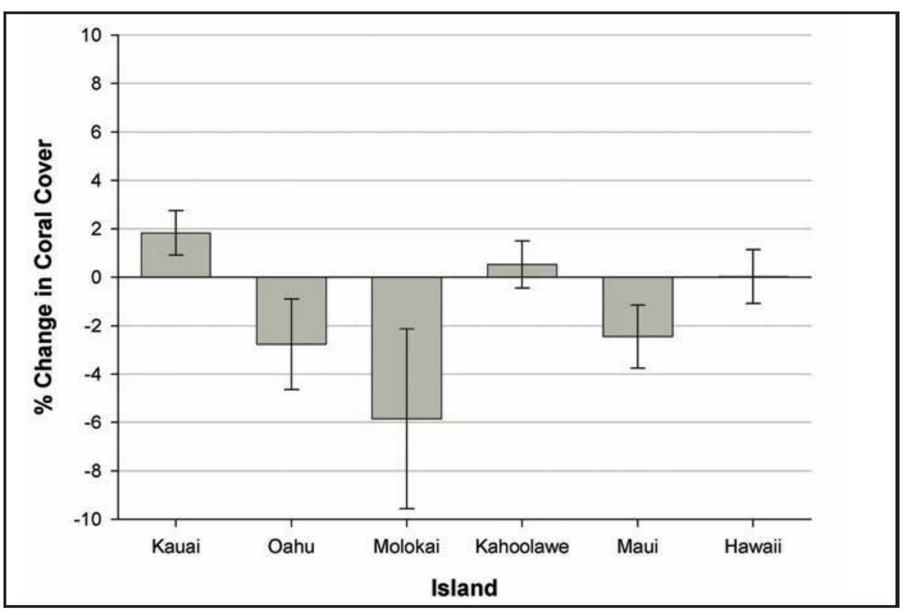

Figure 9.25. Trends in coral cover between 1999-2002 at CRAMP sites show a decline for the islands of Oahu, Molokai, and Maui. Source: Jokiel et al., 2004.

ecologists is that, with a few exceptions, the health of the near-shore reefs around the MHI remains relatively good." On the other hand, some researchers, local fishers and recreational divers with long-term experience observe that reefs in many areas of Hawaii have declined over past decades. For example, Jokiel and Cox (1996) have noted degradation of Hawaiian reefs due to human population growth, urbanization, and coastal development. Absence of the catastrophic short-term reef declines that have been noted in other geographic areas (e.g., Hughes, 1994) can lead to the impression that Hawaiian reefs are in good condition. Slow rates of decline, however, will eventually result in severely degraded reefs. The spatial patterns and temporal change of coral reef community structure in relation to human population that were observed in this study suggest that the rapidly growing human population of Hawaii may be having a negative effect on the reefs. Long-term monitoring will be required to differentiate the observed short-term declines in coral cover from natural oscillations (Done, 1992) in Hawaiian reef community structure (Hughes and Connell, 1999).

Long-Term Monitoring at Selected Sites

Selected sites throughout Hawaii have been monitored over a longer time period (>10 years) and were incorporated into CRAMP to extend the historical perspective including one site on Kauai, five on Oahu, and two on Maui (Table 9.8). Puako, Hawaii, which is not part of CRAMP, is included because it has also been surveyed for over 10 years. Coral cover at several stations within each site has been surveyed sporadically over the years (Table 9.8). Different methods have been used but studies that have compared methods produced similar results (e.g., Brown, 2004). For comparative purposes, only transects or quadrats that sampled the same spatial habitat as CRAMP were utilized.

The selected sites may not be representative of wave exposed reefs around Hawaii because six of the nine sites (12 of 15 stations) are located in protected embayments. Sites such as Hanauma Bay, Honolua Bay, and Olowalu, however, are high human use areas and changes at these reefs have important management implications. In addition, long-term data sets on coral cover are uncommon and provide benchmarks for future comparisons. Temporal results for all of the sites are listed in Table 9.8.

Table 9.8. Average percent coral cover at selected sites that have been surveyed at time periods spanning 10 or more years. Overall percent change (Δ) from the initial survey to the last survey is shown in the last column. Data sources for each station are listed below. * indicates locations within Kaneohe Bay.

ISLAND	SITE	STATION	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	Δ
Kauai	Hanalei Bay	3m[1,2]																								15						16	26		17	17	2
		8m[1,2]																								20						28	30		26	36	16
Oahu	Kahe Point	3m[2,3]												19	19	15	16	16	18	22	20	18	17	12	10	5	5	4	5	9	7	12	13	15	15		-4
	Pili o Kahe	3m[2,3]												19	12	10	10	9	8	10	11	12	18	17	16	14	11	9	8	8	7	9	7	10	11		-8
	Kaalaea*	2m[2,4,5]		92												82							79									62	51	49	67	59	-33
		8m[2,4,5]		7												11							9									3	2	4	3	3	-4
	Heeia*	2m[2,4,5]		33												64							62									36	23	18	24	22	-11
		8m[2,4,5]		1												15							2									8	7	7	5	7	6
	Moku o Loe*	2m[2,4,5]		6												45							21									30	20	16	13	14	9
		9m[2,4,5]		0												4							3									8	7	6	4	9	9
	Hanauma Bay	3m[2,6,7]							28																47	28		28		28	33	24	26		22		-6
		10m[2,6,7]							38																40	36		33		32	25	27	27		22		-15
Maui	Honolua Bay	North 3m[2,7,8,9,10,11]					39					23												51	56		41	35	28	28	24	15	17	15	14		-25
		South 3m[2,7,8,9,10,11]					43					36															42	42	38	33	28	21	27	23	24		-19
	Olowalu	3m[2,10,12]																			31						32	30	23	30	30	23	25	22	23		-8
		8m[2,10,12]																									55	56	47	57	51	55	54	53	51		-4
Hawaii	Puako	3m[7,13]											66											42	42	43		47		58	60						-5
		10m[7,13]											63											46	41	43		44		59	45						-18

DATA SOURCES

1 Friedlander et al., 1997
2 Jokiel et al., 2004
3 Coles, 1998
4 Maragos, 1972
5 Hunter and Evans, 1995
6 Anderson, 1978
7 Hunter, 1999
8 Environmental Consultants, 1974
9 Torricer et al., 1979
10 Brown, 1999
11 Dollar and Grigg, 2004
12 Ambrose et al., 1988
13 Hayes et al., 1982

Statewide Trends

Hanalei Bay, Kauai

Total coral cover at the 3-m station appears to be holding steady while total coral cover at the 8-m station has increased nearly 17% (84% relative increase).

Kahe Point and Pili o Kahe, Oahu

Both stations appear to be undergoing 12-13 year oscillations in total coral cover. The temporal patterns, however, do not coincide. Pili o Kahe reached a low point in coral cover in 1986 (8% ± 1% SE) and 1998 (7% ± 2% SE). In contrast, coral cover at Kahe Point declined in 1983 to 15% ± 2% SE and to 4% ± 1% SE in 1995.

Kaalaea, Kaneohe Bay, Oahu

The Kaalaea 2-m station has experienced a decline in total coral cover of 34% (36% relative decrease). Total coral cover at the 8-m station was higher in 1983 (7%) compared to 1971 (11%-68% relative increase), but then decreased to 3% (72% relative decrease) by 2003. Much of the decrease in coral cover was attributed to slumping of the reef slope (Jokiel et al., 2004).

Heeia, Kaneohe Bay, Oahu

The Heeia 2-m station followed a similar pattern to the Kaalaea 8-m station with higher total coral cover in 1983 (64%) compared to 1971 (33%-93% relative increase). By 2003, coral cover declined to 22% (66% relative decrease). The percent cover at the 8-m station appears to have increased since 1971, but has fluctuated in the interim.

Moku o Loe, Kaneohe Bay, Oahu

At Moku o Loe, coral cover increased in 1983 at the 2-m station by 39% (680% relative increase), but subsequently declined to 14% in 2003 (68% relative decrease). In comparison, coral cover at the 9-m station has slowly increased from 0% to almost 9% since 1971.

Hanauma Bay, Oahu

The Hanauma Bay 3-m station experienced an 18% increase (65% relative increase) in coral cover from 1976 to 1992. Subsequently, coral cover steadily declined to 22% (25% absolute decline, 53% relative) by 2002. The Hanauma Bay 10-m station had similar total coral cover values in 1976 (38%) and 1992 (40%), and then declined to 22% (18% absolute, 45% relative decrease) by 2002.

Honolua Bay, Maui

The 3-m stations on the north and south reefs appeared to be relatively stable from 1974 until 1994. From 1994 to 1998, coral cover declined from 41% to 14% (66% relative decrease) at the north station and from 43% to 24% (44% relative decrease) at the south station. Since 1999, coral cover has stabilized at both stations.

Olowalu, Maui

The Olowalu 3-m station showed a gradual decline in coral cover of 8% (26% relative decrease) since 1998. In contrast, the Olowalu 8-m station has remained relatively stable from 1994 to 2002, with total coral cover between 51-55%.

Puako, Hawaii

Total coral cover appears to be increasing at the Puako 3-m station (18% absolute increase, 43% relative increase) to 1982 levels, after an initial drop of 23% (36% relative decline) from 1982 to 1991. In comparison, total coral cover at the 10-m station was 63% in 1982 and only 46% in 1991. This was a 17% decline (27% relative decline) that increased to 58% (12% absolute increase, 27% relative increase) in 1997 and subsequently decreased to 45% in 1998. The increase in coral cover at the 10-m stations was mirrored at the 3-m station until 1998 when trends diverged at the two stations.

Summary

The long-term trends at the selected sites show that the majority of the stations (13 out of 18) have declined since the first survey. Several of these stations (e.g., Kahe Point 3-m station) have experienced minor decreases in coral cover that can be explained by measurement error and therefore are not ecologically relevant. Explanations for the major declines (>10%) include reef slumping (e.g., Kaalaea; Jokiel et al., 2004) and sedimentation (e.g., Honolua Bay; Dollar and Grigg, 2004). Dollar and Grigg (2004) have suggested that embayments with restricted circulation, such as many of the sites previously listed, are more susceptible to anthropogenic stresses. Intermittent sampling, however, confounds most of the monitoring studies. As shown in the Kahe data, oscillations in coral cover may be occurring that are not detected from the sporadic sampling at the other stations. Therefore, inferring that the selected sites are in fact declining should be interpreted with caution. At present, however, these data sets are the best indicators of long-term trends in Hawaiian coral reefs.

ASSOCIATED BIOLOGICAL COMMUNITIES

West Hawaii Aquariumfish Project

In response to longstanding concern and controversy over marine aquarium collecting in West Hawaii, the nineteenth Hawaiian legislature passed Act 306 in 1998 which established the West Hawaii Regional Fisheries Management Area in the nearshore waters from Upolu Point (North Kohala) to Ka Lae (Kau). One of the primary goals of the legislation was to improve management of fish resources by designating a minimum of 30% of the West Hawaii coastline as FRAs where aquarium fish collecting was prohibited.

Methods

Study sites were established in early 1999 in six existing reference areas, eight open areas adjacent to FRAs, and all nine FRAs. Using stainless-steel bolts cemented into the bottom, four permanent 25-m transects were established in a H-shaped pattern at each of the study sites.

Fish densities were estimated by a pair of divers who conducted visual surveys along each transect. Divers swam side by side and surveyed a column 2 m wide (4 m total width). On the outward-bound leg, larger planktivores and wide-ranging fishes were recorded. On the return leg, fishes closely associated with the bottom, new recruits, and fishes hiding in cracks and crevices were recorded.

Power analysis of preliminary fish transect data indicated that the observational design would detect 10–160% changes in the abundance of the principal targeted aquarium fishes in West Hawaii during the first year using reasonable error rates ($\alpha=\beta=0.10$).

Results and Discussion

Over the course of the four years of the WHAP study, overall aquarium fish abundance (top 10 species) has been increasing (linear regression, $p<0.05$) in FRAs, including control and open sites (Figure 9.26). Notably, FRAs have become quite comparable to pre-existing MPAs that have been in existence for 13 years or more. Although there was a tendency for non-aquarium species to increase during this period, the trend was not significant ($p=0.07$). Three years after closure of the FRAs, there were significant increases in the overall abundance of fishes targeted by collectors. Interestingly, the estimated increase in abundance (26%) is the same amount as the estimated re-

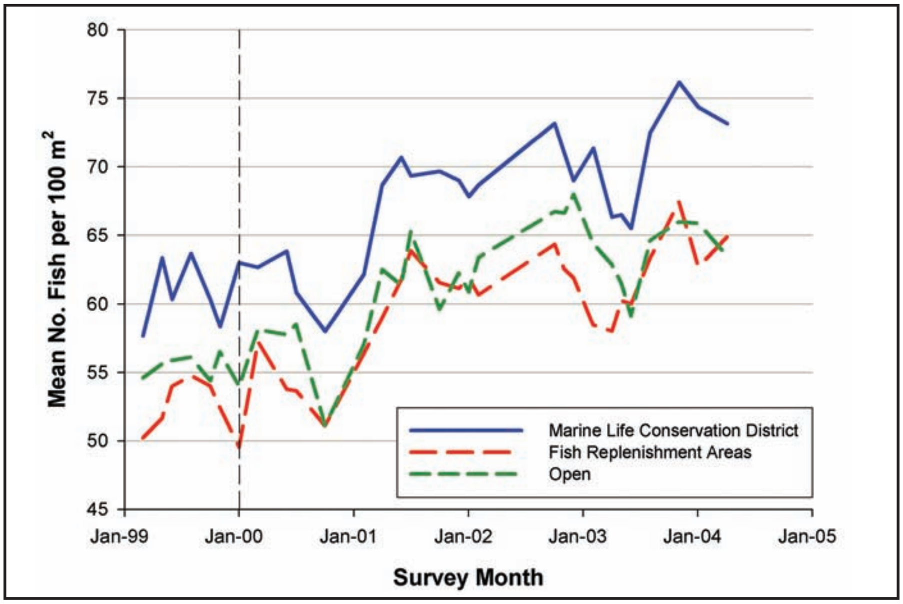

Figure 9.26. Overall abundance through time of top 10 most collected aquarium fishes. Dashed line represents FRA establishment. Source: Tissot et al., 2004; WHAP, unpublished data.

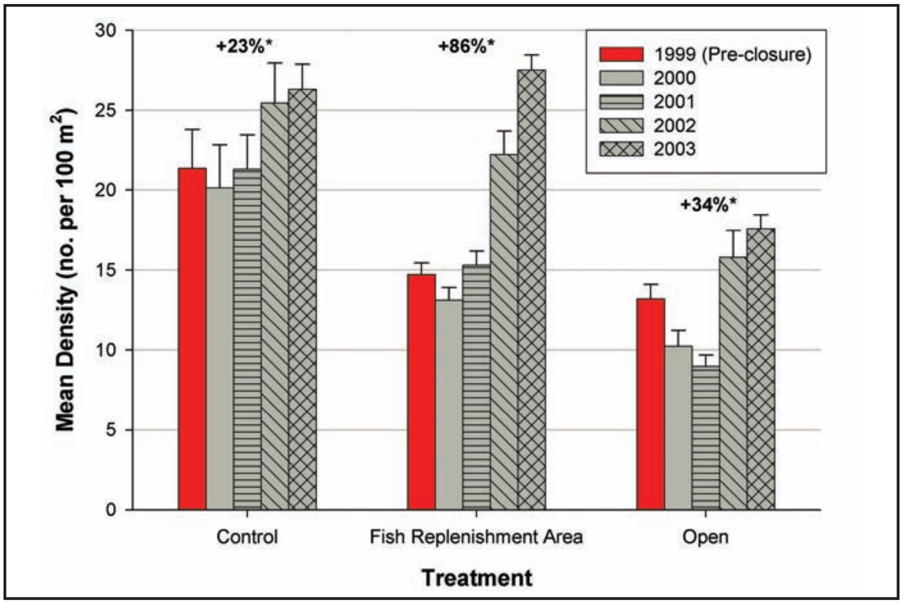

Figure 9.27. Comparison of yellow tang (*Zebrasoma flavescens*) abundance in pre-closure (1999) and post-closure years (2000-2003). Percentages are two sample comparisons between 1999 and 2003 (*values are significant using a two sample t-test at α=0.05). Source: Tissot et al., 2004; WHAP, unpublished data.

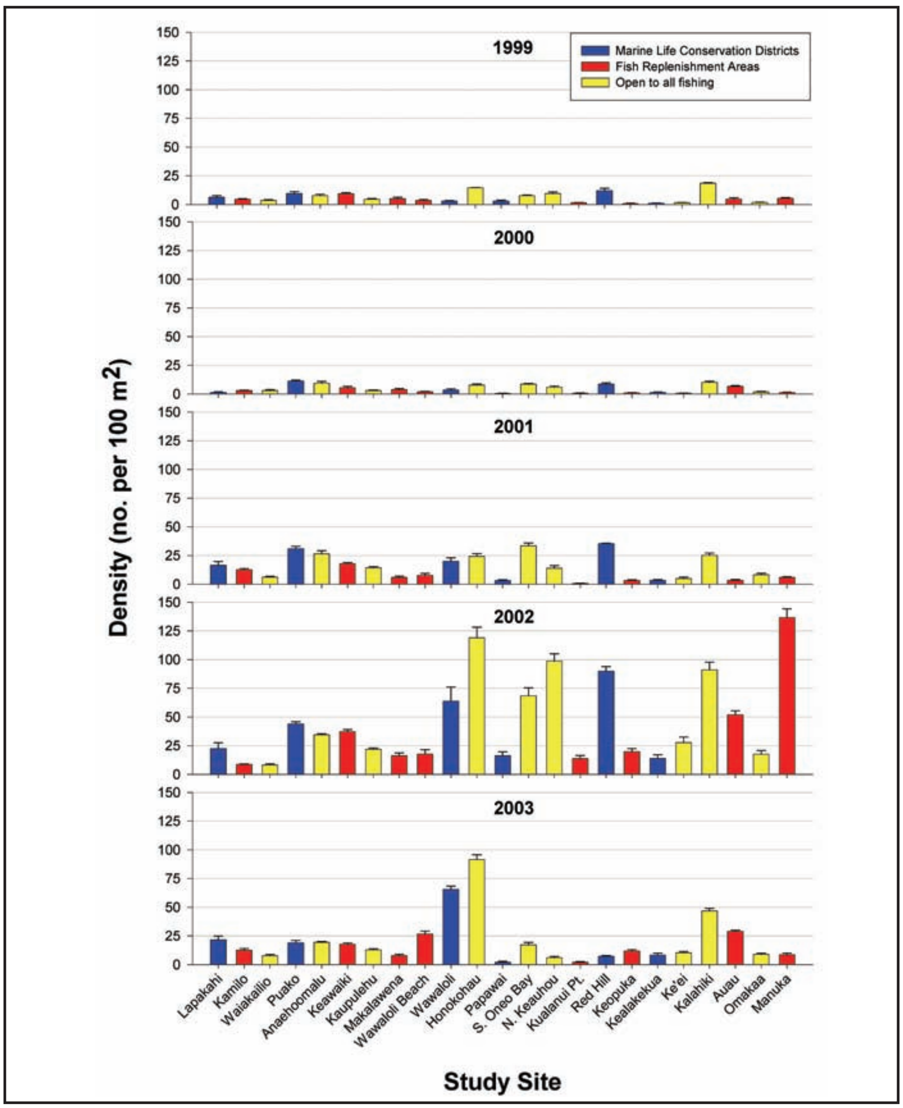

Figure 9.28. Density of *Zebrasoma flavescens* young-of-year at all study sites during 1999-2003. Source: Tissot et al., 2004; WHAP, unpublished data.

duction due to collectors prior to FRA closure, suggesting that as a group, these fishes may have increased to their pre-exploitation levels (Tissot et al., 2004). Yellow tangs (*Zebrasoma flavescens*) increased in density by 86% within FRAs between 1999 and 2003, or about 12.2 fish/100 m^2 (Figure 9.27). The yellow tang is by far the most heavily collected fish in West Hawaii, accounting for 79% of the total catch. The recovery of yellow tang populations was undoubtedly related to the high number of newly recruited fishes observed in 2001-2002 (Figure 9.28). Large recruitment events are uncommon in West Hawaii but are likely to be an important factor determining the effectiveness of MPAs to help replenish depleted fish populations.

There were no significant changes among non-collected species within FRAs or in aquarium and non-aquarium species in areas outside of FRAs. Furthermore, no aquarium fishes declined in abundance in open areas as might be expected if the intensity of harvesting increased outside of the FRAs.

Although specific FRAs varied in their degree of effectiveness, the overall results demonstrate that MPAs can promote recovery of fish stocks depleted by fishing pressures in Hawaii, at least in heavily exploited species, without significant declines outside of MPAs. Overall, FRAs have successfully reduced conflicts between collectors and other resource users, promoted a sustainable fishery, and enhanced aquarium fish populations. The success of the FRAs in West Hawaii is likely to increase as aquarium fishes grow and mature within these MPAs and further replenish nearshore reefs.

Hanalei Bay Marine Communities Investigation

In 1992, the DAR's MHI Marine Resource Investigation Program identified Hanalei Bay, Kauai as one of five key sites upon which to focus extensive field research programs. This Program provides a broad base for understanding the state's living marine systems and is directed towards more effective management (Friedlander and Parrish, 1998a; Friedlander, unpublished data). Hanalei Bay is one of the largest embayments on the island of Kauai and serves as a major recreational area for residents of many north shore communities and neighboring areas. The recent designation of the Hanalei River as an American Heritage River has increased the community's awareness and involvement in protecting its marine environment.

Methods

Abundance of fishes on hard substratum was assessed using standard underwater visual belt transect survey methods. Twenty-two transects (25 m x 5 m) were permanently established in a wide variety of habitats throughout the bay to assess fish and associated benthic communities (Friedlander and Parrish, 1998a, b).

Retrospective analysis of Hanalei data

Monthly visual fish censuses of transects from December 1992 to November 1994 showed that surf height and degree of wave exposure were negatively correlated with several measures of assemblage organization (Friedlander and Parrish, 1998a). Most measures of fish assemblage structure were lower during the winter months when large north Pacific swells and heavy rainfall, coupled with high river discharge, impacted the bay.

Fish censuses were conducted at 20 of the 22 permanent sites in June 1999, September 2003, and June 2004. Species richness, biomass, and diversity have all either increased or were constant during this time period (Figure 9.29).

Three introduced fish species (bluestripe snapper, blacktail snapper, and peacock grouper) have become well established in Hanalei Bay (Friedlander et al., 2002b) and their contribution to total fish biomass has increased from 15% in 1993 to as high as 39% in 1999 (Figure 9.30). The bluestripe snapper is the most important, currently accounting for 23% of total fish biomass in the bay. The blacktail snapper appeared in large numbers in 1999 but was not observed in high abundance in 2003 or 2004. A large rain event just prior to the 1999 sample date may have caused blacktail snappers to move out onto the reef temporally. The pea-

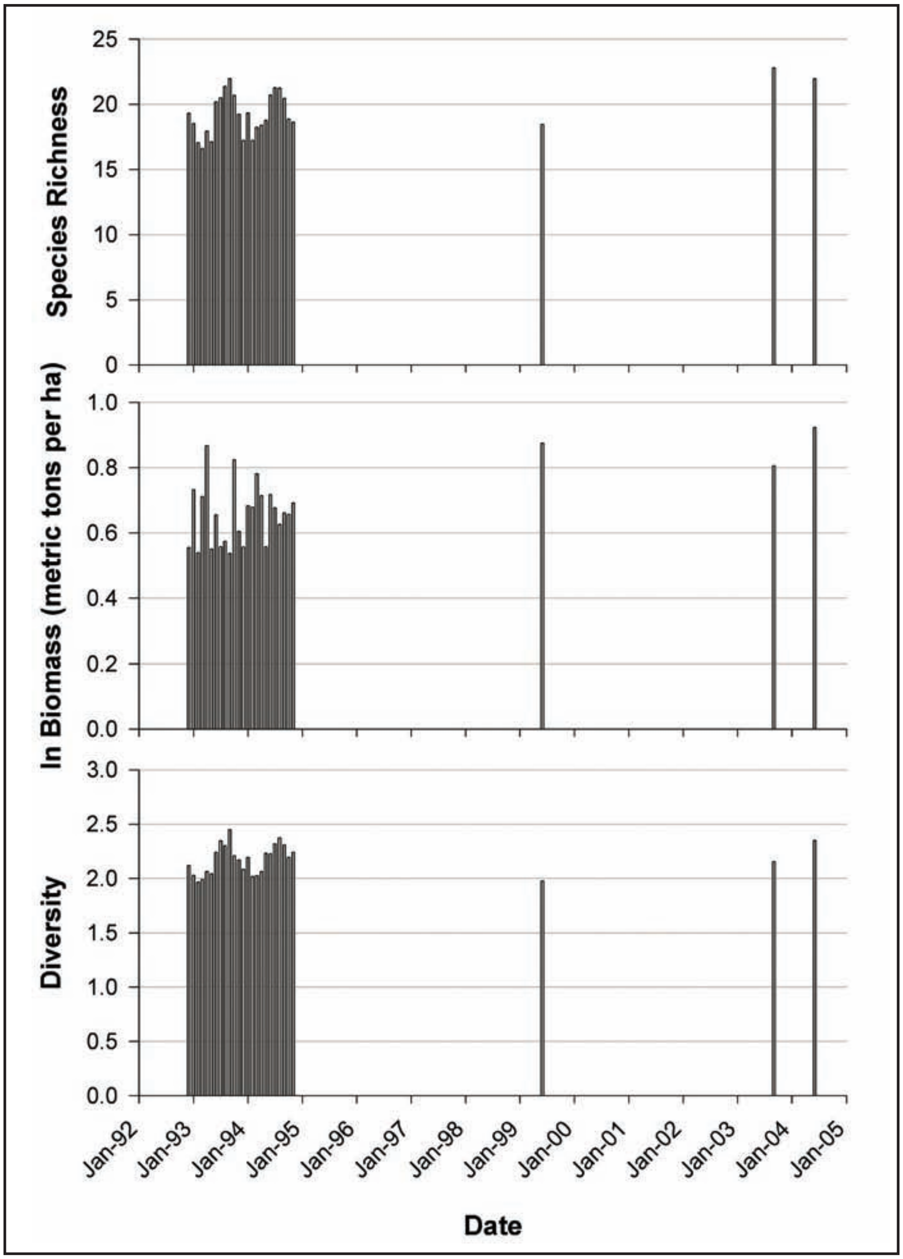

Figure 9.29. Mean fish species richness (upper panel), mean fish biomass (middle panel), and mean fish diversity (lower panel) in Hanalei Bay, Kauai. Note natural log scale for graph of mean fish biomass (middle panel). Source: Friedlander and Parrish, 1998a; Friedlander, unpublished data.

cock grouper has steadily increased in importance from less than 1% of fish biomass in 1993 to nearly 7% in 2004. Increases in total fish biomass since the early 1990s cannot be attributed solely to introduced species, as other elements of the fish assemblage have also increased over this time period. Reduced fishing pressure has been cited as one potential reason for these trends.

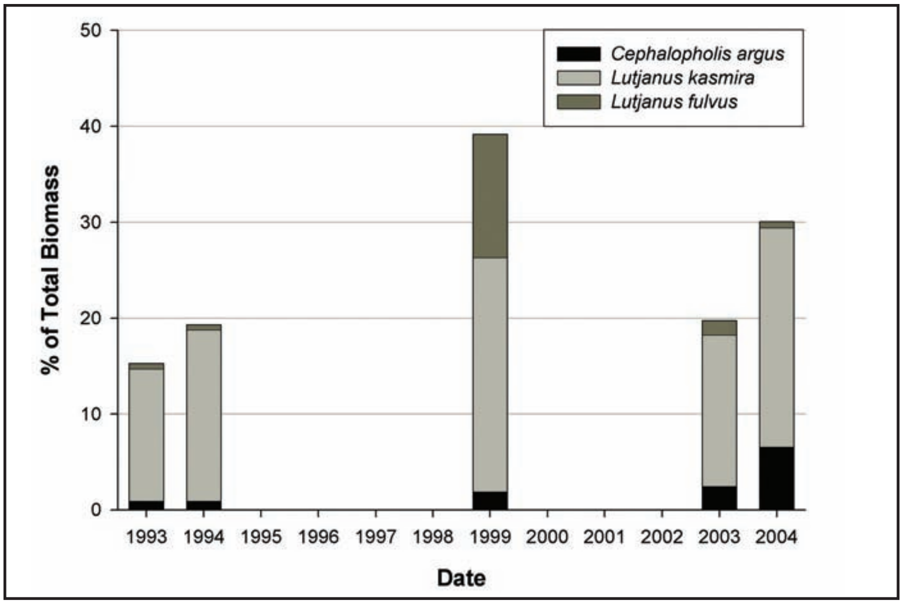

Figure 9.30. Percent contribution of introduced species, peacock grouper (*Cephalopholis argus*), bluestripe snapper (*Lutjanus kasmira*), and blacktail snapper (*L. fulvus*), to total fish biomass in Hanalei Bay, Kauai. Source: Friedlander and Parrish, 1998a; Friedlander, unpublished data.

Waikiki-Diamondhead FMA – Results of a rotational closure

Unique among Hawaiian marine managed areas, a rotational closure strategy has been applied in the Waikiki Diamond Head Fishery Management Area (FMA). Created in 1978, the FMA initially operated on a four-year cycle: two years of closure followed by two years in which fishing was permitted. In 1988, a portion of the FMA was converted to a permanently closed area by becoming the Waikiki MLCD, and the rotational cycle in the remaining area was changed to one year open followed by one year closed.

As part of the DAR's reef monitoring program, fish populations in the FMA, including the 'Kapahulu' portion of the FMA which subsequently became the MLCD, have been monitored since 1978. Overall trends in biomass of fishery-target species in the FMA and MLCD are displayed in Figure 31. Within the FMA, biomass of fishery-target species has tended to increase during periods of closure, but such increases have been insufficient to compensate for declines occurring during open periods. Overall, there has been a striking decline in biomass of fishery-target species in the FMA from 40-50 g per m^2 in the early years after its creation to around 10 g per m^2 in recent years (Figure 31).

Assessment of the effects of fishing and closure on the FMA and the adjacent fully-closed MLCD has been complicated by declines in habitat quality, particularly within the MLCD. Beginning in the early 1990s, habitat quality was degraded by, among other things, the gradual overgrowth of much of the reef by the alien algae, *Gracilaria salicornia*. However, the initial effect of full closure was a dramatic reversal of the previous downward trend in fish biomass (Figure 9.31, B); during the first three years of full closure, biomass of target species averaged nearly 40 g per m^2 more in the MCLD than in the adjacent FMA ($p<0.05$, paired t-test). The impact of habitat decline on fish populations appears to have been much more severe within the MLCD than in the FMA, but even in the post habitat-decline period (Figure 9.31, C), biomass of target species within the MLCD is nearly double that in the FMA (paired t-test $p<0.05$).

Within the FMA, substantial reductions in the size of the largest fishes observed during surveys coincided with the downward trend in biomass. In the early 1980s, 40-50 cm and larger acanthurids and scarids were commonly observed during fish-counts, but in recent years, the maximum size recorded per survey has averaged around 30 cm for acanthurids and less than 20 cm for scarids. Very large scarids, which were regularly encountered between 1979 and 1985 (seen during 115 of 376 surveys), have virtually disappeared from the FMA; individuals of that size have been recorded in only three of 78 surveys conducted since 1990. Less dramatic but still significant declines in maximum size have also occurred in other commonly targeted fish families, such as mullids and carangids. In contrast, there have been no declines or downward trends in the maximum size of any of the previously mentioned families within the Waikiki MLCD.

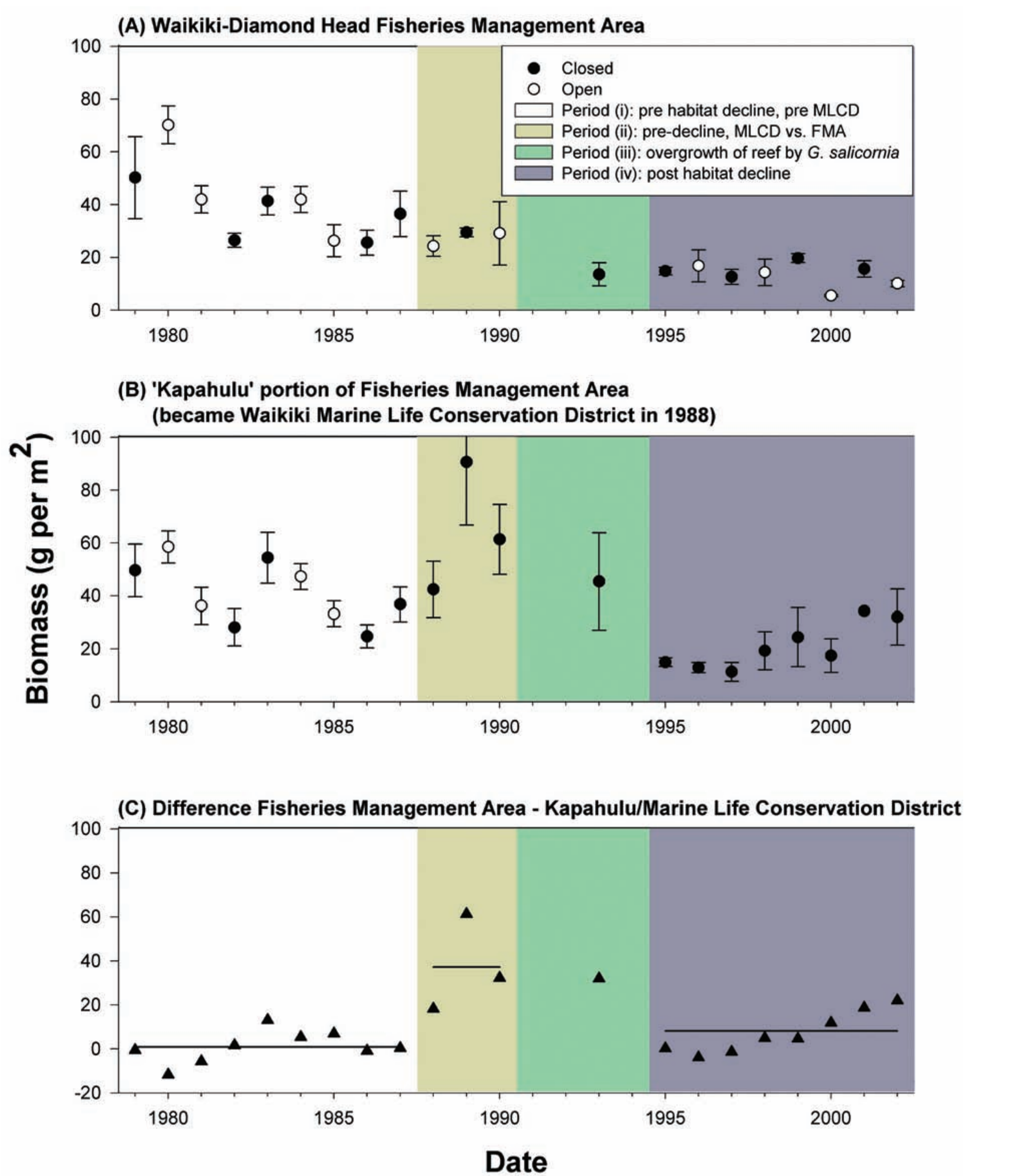

Figure 9.31. Annual mean biomass and SE (g/m^2) of main fishery-target species in Waikiki Diamond Head FMA (upper panel) and Kapahulu/Waikiki MLCD (middle panel). Lower panel indicates mean differences between FMA and Kapahlu/MLCD over four periods: (i) 1978-1987, when both were within original boundaries of the FMA; (ii) 1988-1990, immediately after creation of the MLCD, when (A) was rotationally managed and (B) fully-closed; (iii) 1990-1995, a period of significant algal overgrowth and habitat degradation; and (iv) 1995-2002, post habitat degradation in FMA and MLCD. Closed circles represent years when fishing was prohibited, open circles represent years when fishing was permitted. Source: Williams et al., in review.

Both the FMA and MLCD now largely consist of low quality coral reef habitat, with shallow areas dominated by fleshy algaes and patchy coral cover. In the absence of any long-term habitat data, it is difficult to unequivocally determine the relative impacts of fishing or protection compared to habitat declines, but significant differences between the FMA and immediately adjacent MLCD indicate that rotational closure has been much less effective than permanent closure as a means of conserving fish populations.

CRAMP Management Regime Comparison Study

The CRAMP sampled the fish and benthic communities at 60 locations around the MHI in 2000 (Friedlander et al., 2003). Of these 60 locations surveyed, 18 had some level of protection from fishing associated with them. No-take areas (Hanauma Bay MLCD, Honolua Bay MLCD, Molokini Crater MLCD, and Moku o Loe (Coconut Island-Hawaii Marine Laboratory Refuge)) had the highest values for most fish assemblage characteristics, followed by areas under customary stewardship (Kaho‘olawe Island Reserve and Ahihi-Kinau Natural Area Reserve). Locations under community-based management with customary stewardship harbored fish biomass that was equal to or greater than that of no-take MPAs, although light fishing pressure and the remoteness of these locations may also contribute to the high biomass observed (Figure 9.32).

General linear models were used to assess the importance of various environmental parameters and fisheries management regimes on fish assemblage characteristics (Table 9.9). Locations with protected status explained significant portions of variation in species richness (p=0.001), biomass (p=0.01), and diversity (p=0.008). For each of these characteristics, locations protected from fishing (no-take and customary stewardship) had higher numbers of species, greater biomass, and higher diversity

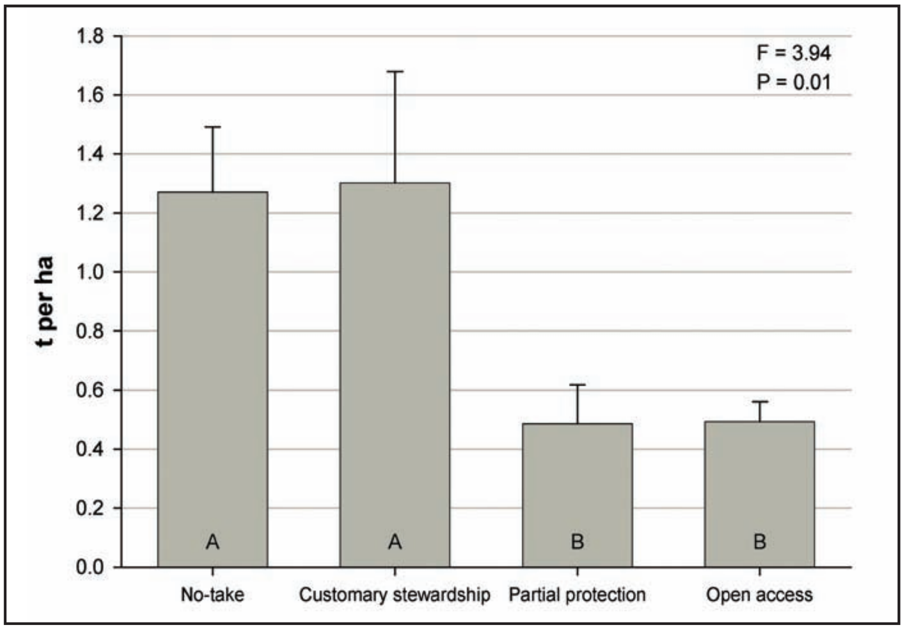

Figure 9.32. Comparisons of fish biomass (t ha-1) under various levels of protection from fishing. Error bars are standard error of the mean. Statistical results of one-way ANOVA are shown. Levels of fishing protection with the same letter designation are not significantly different (Tukey HSD multiple comparisons test, a=0.05). Source: adapted from Friedlander et al., 2003.

The variability in species richness was explained by rugosity, live lobate coral cover, and areas protected from fishing which were all significant parameters ($F_{8,51}$=6.73, p<0.001). The variability in the number of individuals was explained by rugosity, live branching and lobate coral cover which were all significant parameters ($F_{8,51}$=5.57, p<0.001). Rugosity and protected status were significant in explaining the variability in biomass ($F_{8,51}$=4.86, p<0.001). Diversity was explained by rugosity, the degree of wave exposure (exposed, sheltered, and embayments), and protected status ($F_{8,51}$=7.42, p<0.001).

Areas with limited protection from fishing had values for fish assemblage characteristics that were lower

Table 9.9. Influence of various environmental variables and management regimes on fish assemblage characteristics in the MHI base on results of multiple regression models (GLM). Significant statistical results in bold. Source: Friedlander et al., 2003.

PARAMETERS	SPECIES		NUMBER		BIOMASS		DIVERSITY	
	F	p	F	p	F	p	F	p
PHYSICAL								
Depth	0.02	0.893	3.39	0.072	0.63	0.431	1.16	0.287
Rugosity	**7.70**	**0.007**	**4.62**	**0.036**	**4.92**	**0.031**	**4.11**	**0.048**
Wave Exposure	2.8	0.080	0.65	0.526	0.06	0.945	**11.5**	**<0.001**
BIOTIC								
Coral cover (plate)	2.31	0.135	0.71	0.402	1.42	0.239	<0.01	0.955
Coral cover (branching)	2.03	0.161	6.14	0.017	2.71	0.106	1.3	0.260
Coral cover (lobate)	**5.48**	**0.023**	**5.42**	**0.024**	3.09	0.085	1.02	0.319
MANAGEMENT REGIME								
Protected Status	**11.70**	**0.001**	2.40	0.128	**7.02**	**0.011**	**7.58**	**0.008**

than areas where fishing was restricted, and similar to areas completely open to fishing. The Pupukea MLCD is a partially protected area that has recently received additional protection through the expansion of existing boundaries and the restriction of most fishing activities within the reserve. The existing data will help to serve as a baseline in determining whether these new regulations enhance the fish assemblage within the reserve over time. MPAs in the MHI with high habitat complexity, moderate wave disturbance, a high percentage of branching and/or lobate coral, coupled with legal protection from fishing pressure, had higher values for most fish assemblage characteristics.

CURRENT CONSERVATION MANAGEMENT ACTIVITIES

Addressing Alien Species

The 2003 Hawaii legislature and Hawaii Governor Linda Lingle established the Hawaii Invasive Species Council to address gaps in Hawaii's current invasive species prevention and response measures. Governor Lingle introduced legislation in 2004 requesting $5 million from state general funds for alien species prevention, response, research, and education. Three million dollars was appropriated by the State legislature to begin to address this problem. One of the integrated elements of this larger initiative is the focus on aquatic invasive species (AIS).

In December 2003, with guidance from the Federal Aquatic Nuisance Species Task Force as well as input from representatives of state and Federal agencies, industry, non-governmental organizations, and other stakeholders, the State of Hawaii AIS Management Plan was developed to comprehensively address AIS issues throughout Hawaii. The plan focuses on marine and freshwater alien species of concern and outlines a coordinated approach to minimize the harmful ecological, economic, and human health impacts of AIS. The plan calls for the prevention and management of their introduction, expansion, and dispersal into, within, and from Hawaii. It is the first comprehensive plan for aquatic nuisance species that has been developed for a tropical marine ecosystem.

Water Quality

Bare soils at coastal construction sites are very vulnerable to erosion. Construction projects >1 acre are required by DOH (via NPDES permit authorization) and Hawaiian counties (via grading permits) to use best management practices to control erosion. Nevertheless, heavy rainfall at development sites on Hawaii and Kauai has resulted in significant sediment discharge to the ocean. In both cases, lawsuits and enforcement actions delayed the work and cost the developer millions of dollars in remediation, penalties, and legal fees.

Stormwater runoff in major urban areas of Oahu is regulated by the City and County of Honolulu's (CCH) NPDES permit issued by DOH. The permit requires CCH to monitor stormwater quality and use best management practices (e.g., street cleaning, inlet maintenance) to improve water quality. The other counties are not subject to stormwater permits.

Many communities are organizing integrated watershed management projects to address polluted runoff and other water concerns. These watershed projects have many parallels with traditional Hawaiian watershed management. Hawaii's local action strategy (LAS) for addressing pollution threats to coral reefs is a multi-agency partnership building upon ongoing land management efforts and coral ecosystem monitoring in three watersheds: Hanalei, Kauai; Honolua, Maui; and Kawela to Kamalo, Molokai. Pollution control projects are being implemented on land, ranging from cesspool upgrades to erosion control. At the same time, coral reef monitoring programs are being designed specifically to assess pollution impacts. To date, $1.3 million has been identified for LAS projects, which include feral animal control, fire management, technical assistance for areas transitioning from agricultural to residential use and a workshop to identify indicators of impacts to coral reefs across the Pacific.

To address public health and environmental risks from untreated wastewater in cesspools, EPA has banned large-capacity cesspools serving 20 or more people per day. Construction of new large-capacity cesspools was banned on April 5, 2000 and existing ones must be upgraded or closed by April 5, 2005. Approximately 30,000 large-capacity cesspools in Hawaii will be affected by this ban.

One outcome of current land development pressures is a movement on all of the islands to preserve open space and beaches. The counties, along with local land trusts and conservation organizations, have purchased and preserved major coastal land parcels.

Addressing Overfishing
The DAR has undertaken a number of measures to improve the management of fisheries resources, including changes to minimum size limits for certain resource species, initiation of marine recreational fisheries surveys, evaluation and expansion of MPAs, and changes to commercial reporting forms. Other management measures have included the use of stock enhancement based on aquaculture for a few highly prized species and artificial reefs to improve the catch of some coastal fisheries species in a few select locations. A tag-and-release program initiated by DAR has involved over 850 volunteer anglers and has increased public awareness about fish biology and conservation.

DAR has begun discussions on revisions to the bag limits for certain species and has held a series of public meetings to discuss the regulation of gill nets. DAR is also considering size and harvest regulations for additional species. Additional work and revisions to the MPA program are also being proposed to enhance fisheries resources.

DAR and NOAA Fisheries are leading the effort to create a three-year LAS for coral reef fisheries. The LAS incorporates stakeholder input and defines the state's strategy for coral reef fisheries management. LAS projects include stock assessment, life cycle studies, refinement of data collection and analysis, and outreach and education. The LAS will be used as a starting point to create a coral reef fisheries management plan for Hawaii's nearshore reefs. The goal of the LAS is to work towards the development of an integrated fishery management plan to promote sustainable harvest using an ecosystem-based approach.

DLNR has been creating MPAs for over 35 years. The types of MPAs vary greatly, as do the biological and management considerations that were used to create these sites. State MPAs include:

- 11 MLCDs
- 18 FMAs
- 18 Bottomfish Restricted Fishing Areas
- Hawaii Institute of Marine Biology Research Reserve
- Ahihi Kinau Natural Area Reserve
- Kahoolawe Island Reserve

DAR administers the state's MLCD program, which is designed to conserve and replenish marine resources statewide (DLNR-DAR 1992; Table 9.10). DAR also manages the FMAs, Bottomfish Restricted Fishing Areas, and the Biology Research Reserve. Most of these sites were established to regulate the use of certain gear types and to limit conflicting uses. DAR initiated a regulatory review of current sites and will propose a new set of social/economic and biological criteria to manage existing sites and designate new sites through a public participation process.

Assessment of Efficacy of MLCDs
In order to properly assess the efficacy of existing MLCDs in Hawaii, it is necessary to: 1) map the distribution and characteristics (quality) of benthic habitats; 2) inventory and map the distribution of macroinvertebrates and fishes; and 3) define species habitat affinities in space and time. The CCMA-BT has developed digital benthic habitat maps (Figure 9.23) for most MLCDs and adjacent habitats that are being used to evaluate the efficacy of existing MLCDs, as well as develop criteria for future MLCD design (Friedlander and Brown, 2003a). The integrated mapping and monitoring of coral reef ecosystems and reef fish habitat utilization patterns have been conducted to support the Federally mandated MPA and essential fish habitat (EFH) initiatives. Using GIS technologies to couple the distribution of habitats and species habitat affinities enables the elucidation of species habitat utilization patterns for assemblages of animals at a scale that is commensurate with ecosystem processes. This integrated approach is useful in quantitatively defining EFH and defining biologically relevant boundaries of MPAs.

Of the six MLCDs examined to date, all have nominally higher fish biomass than similar adjacent hard bottom

Table 9.10. Summary of Hawaii MLCD characteristics. Levels of human use as classified by DAR (1992). Protection from fishing based on regulations, not on enforcement of these regulations. Source: Friedlander and Brown, 2003b.

MLCD	HECTARES	YEAR ESTAB.	USE	PROTECTION FROM FISHING	PERMITTED ACTIVITIES
OAHU					
Hanauma Bay	41	1967	High	High	Complete no-take
Pupukea[1]	71	2000	High	Mod	Pole and line from shore (2 lines only) Harvest of limu (seaweed) up to 2 lbs. Surround net for mackerel scad (Aug/Sep) Surround net for bigeye scad (Nov/Dec)
Waikiki	31	1988	High	High	Complete no-take
HAWAII					
Kealakekua Bay	127	1969	High	Mod	Pole and line – 60% of MLCD Thrownet – 60% of MLCD Mackerel and bigeye scad – 60% of MLCD Crustaceans – 60% MLCD
Wai Opae Tidepools	34	2003	High	High	Complete no-take No commercial activity
Lapakahi	59	1979	Low	Low	Pole and line – 90% of MLCD Throw net – 90% of MLCD Lift net for mackerel scad– 90% of MLCD
Waialea Bay	14	1985	Low	Low	Pole and line; Netting
Old Kona Airport	88	1992	Mod	Mod	Throw net from shore Pole & line from shore
LANAI					
Manele-Hulopoe	125	1976	Mod	Mod	Hook & line (shore) – 100% of MLCD All fishing except spear, trap, and net (other than thrownet) – 50% of MLCD
MAUI					
Molokini Shoal	31	1977	High	High	Trolling in 60% of MLCD
Honolua-Mokuleia Bays	18	1978	Mod	High	Complete no-take
Pupukea[1] – Established 1983, amended 2000					

habitats (Figure 9.33). The MLCDs also had higher values for most other fish assemblage characteristics (e.g., species richness, size, diversity), illustrating the effectiveness of these closures in conserving fish populations within these management units. Habitat complexity, quality, and size were important determinates of the effectiveness of these MLCDs with respect to their associated fish assemblages.

Recreational Use

A LAS is being developed to address the overuse and misuse of Hawaii's reefs by non-consumptive users. Statewide scoping meetings are soliciting input on the issues that should be addressed in the LAS. Develop-

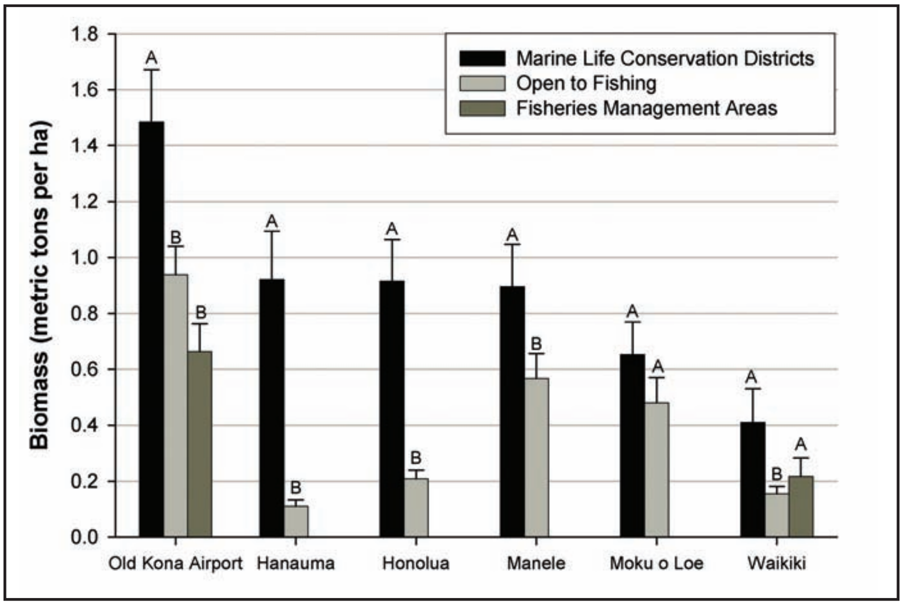

Figure 9.33. Comparison of fish biomass in MLCDs, FMAs, and areas open to fishing in the MHI. Management regimes with the same letter are not significantly different ($\alpha = 0.05$). Source: adapted from Friedlander and Brown, 2003a.

Main Hawaiian Islands

ment and implementation of the LAS will be overseen by a cooperative state/Federal steering committee. Additionally, DAR has undertaken a series of studies to assess the impacts of recreational use on the most heavily used sites to begin to better understand management actions needed to address these impacts.

OVERALL STATE/TERRITORIAL CONCLUSIONS AND RECOMMENDATIONS

Coral ecosystems in the MHI range from fair to excellent condition but are threatened by continued population growth, overfishing, urbanization, runoff, and development. Ocean outfalls, urban growth, and coastal developments (i.e., hotels, golf courses, etc.) are focal points for potential coral reef degradation. New technologies for extraction, offshore aquaculture, and bioprospecting raise concerns about the continued ability of management agencies to keep ahead of impacts to coral reef resources. There is clear evidence of overexploitation of many target food fishes and invertebrates. Key marine aquarium trade species have been heavily exploited with potential underreporting of harvest levels and insufficient enforcement, which compound problems for resource managers. Introduced aquatic alien species now threaten the structure and function of Hawaii's reefs and may outcompete endemic species. These introductions have caused complete phase shifts on some reefs.

However, significant progress has been made in mapping, monitoring, researching, and managing Hawaii's reefs. Habitat maps of the majority of the MHI provide a baseline for understanding the most critical areas for biodiversity and fisheries productivity. Research studies are improving the understanding of land-water interactions and how various stressors affect coral reefs, as well as which land-based mitigation measures are most effective. Monitoring programs are now documenting management effectiveness and improvements in ecosystem health and function. Improved socio-economic valuations of Hawaiian reef resources are fundamental for management and in seeking compensation for detrimental land-based activities (e.g., those causing sediment runoff) and/or ocean activities (e.g., ship groundings). Much of the data needed for decision-making has been obtained in recent years. Problems still remain with marine debris, but the local community is more aware and cooperative in removing it, especially from the MHI. Over the past several years, there has been tremendous success in removing a large portion (480 metric tons) of marine debris from the NWHI. The challenges of how to control the spread of alien species and eradicate them from Hawaiian reefs are just starting to be addressed, but the awareness of this threat has grown substantially in the past few years and funding is being made available to address this threat.

Studies have demonstrated that Hawaiian MPAs can effectively promote recovery of heavily exploited fish stocks without significant declines in areas outside of MPAs. FRAs along the West Hawaii coastline have successfully reduced conflicts between collectors and other resource users, promoted a sustainable fishery, and enhanced aquarium fish populations. The success of the FRAs in West Hawaii is likely to increase as aquarium fishes grow and mature within these protected areas and further replenish nearby reefs.

A new outreach campaign called Hawaii's Living Reef Program launched in 2004 is raising the public awareness of the importance of healthy coral reefs (Figure 9.34). Similar initiatives are underway to address impacts from land-based sources of pollution through Federal, state and community partnerships. The partnerships between management agencies, academia, non-governmental organizations, and user communities continue to develop, but will need ongoing financial and political support to succeed within the complex pattern of different coral reef habitats and human communities in the Hawaiian Archipelago.

Figure 9.34. Hawaii's Living Reef Program aims to raise public awareness of the importance of healthy coral reefs. As part of the campaign, educational slides like this will be shown at movie theaters around the state. Source: DAR.

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