HAWAII

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It is difficult to overstate the value of coral reefs to the State of Hawaii. Coral reefs are central to a $700 million and growing marine recreation industry. Coral reefs serve as habitat for many subsistence and commercial fisheries, as well as the basis of a highly diverse ecosystem. Coral reefs protect island shorelines against the destructive forces of storms and high waves. Many island cultural activities are dependent on coral reef resources. In their beauty, isolation and ecological sensitivity, coral reefs are symbolic of larger island vulnerabilities. Their conservation is vital to the state.

Assessment is the first step in protecting and managing coral reef ecosystems. In cooperation with international efforts by the United States to determine the status and health of coral reefs worldwide (The International Coral Reef Initiative — ICRI and the International Year of the Reef — IYOR), a poll of experts and a literature survey of coral reefs in the main Hawaiian Islands were conducted in 1996 and 1997. While the results of this survey indicate that most coral reefs in Hawaii are presently healthy, problems of resource overutilization and environmental degradation are increasing. The most serious problem is overfishing. There is an immediate need for improved fishery management and strengthened enforcement. Stream and non-point source runoff is the cause of eutrophication and sedimentation in some embayments and areas with confined circulation. Improving the water quality of these environments is of economic significance for growing recreational uses by residents and tourists alike. The vitality of Hawaii's healthy reefs must also be maintained to insure their productivity. To accomplish these goals, a major commitment by the State of Hawaii to manage coral reef resources is needed.
INTRODUCTION

Coral reef ecosystems in the Hawaiian Islands represent an extremely valuable natural resource to the state’s economy. The marine recreation industry alone generates over $700 million annually to state revenues. Coral reefs are of further value to the state for the protection they provide to the coastline from waves and destructive storms. Coral reef organisms constitute a major source of sand for Hawaii’s beaches. Coral reefs also are habitat to numerous nearshore fisheries including reef fish, lobsters, and bottom fish, which collectively generate about $20 million in landings annually and are an important source of food for local and restaurant consumption. In addition to species of commercial value, coral reefs are the habitat for 700 species of fish, 400 seaweeds, 1,000 mollusks, and 1,350 invertebrates, including 47 species of reef-building corals (Armstrong 1983; Maragos 1995).

As an ocean state, the shore and nearshore represent one of Hawaii’s greatest natural resources. No point in the state is more than 29 miles from the sea. Hawaii’s peoples are dependent on the marine environment for a diverse array of needs encompassing economic, environmental and cultural values. The protection and sustainable use of the nearshore environment, including coral reef ecosystems in all aspects, is vital to the welfare and quality of life for residents and visitors to the islands.

Growth in both Hawaii’s resident and visitor populations is placing increasing pressure on nearshore coral reef ecosystem resources. The resident population is about 1.2 million and growing at a 1.6% annual rate. Between five and six times this many tourists visit Hawaii every year. Human activities which potentially can affect coral reefs in Hawaii include a variety of land uses such as construction, agriculture, deforestation, and erosion caused by introduced animals, all of which lead to increased runoff and possible impact from sedimentation and non-point source pollution. Activities which have potential negative impact to coral reefs include sewage disposal, land runoff, dredging, and shoreline construction or modification. Other human impacts include fishing (overharvesting), boating (anchor damage) and diving (collecting).

Although numerous studies of coral reef ecosystems in Hawaii have been conducted in recent decades, no systematic survey covering all islands has ever been done and no comprehensive monitoring program of reef resources exists in the state. In view of the value of coral reef resources to Hawaii and the present lack of information concerning their health, a statewide survey of their status and health is of fundamental importance. The opportunity to conduct such a survey in 1997 was presented by international program activities associated with the ICRI and the IYOR. Both programs provided funding to the PSA Scientific Committee on Coral Reefs to conduct a survey. The results of this survey apply to the main Hawaiian Islands (Figure 1) and are presented below.

METHODS

Several agencies in the State of Hawaii and many individuals representing diverse organizations and backgrounds worked together to conduct a statewide survey of the status and health of coral reefs. Informally this effort has been called the Hawaii Coral Reef Initiative. The State Coastal Zone Management Program provided early leadership for the project and linkage with the ICRI program of the U.S. State Department. Volunteer efforts by Dr. Mike Hamnett of the Social Science Research Institute of the University of Hawaii, Dr. Jim Maragos of the East-West Center, David Raney of the Sierra Club, and Peter Rappa of the University of Hawaii Sea Grant College Program were also invaluable in organizing meetings
Figure 1. Map of the Hawaiian Islands.
and compiling information. Other individuals active in helping to gather data and information for the survey are listed in the acknowledgments.

The objectives of the survey were to (1) describe the current status and health of coral reef ecosystems and coral reef resources in the main islands of the State of Hawaii, (2) make this information available to the scientific community and to the public in order to increase awareness of problems facing coral reefs, and (3) generate information necessary to formulate improved management plans and activities for the sustainable use of coral reefs in Hawaii in the future, including monitoring of reefs and designation of additional protected reef areas.

The survey was conducted using a participatory process by holding workshops among invited experts. Meetings were held on all islands during 1996 through 1997. At each meeting, the discussion was led by individuals deemed to be the most knowledgeable in the group. Each island was divided into sectors containing similar habitat and each sector was discussed and evaluated by the group. Data or information generated included (1) a description of naturally controlling factors, (2) an evaluation of the importance of anthropogenic stressors in each sector, and (3) an overall judgment as to the “health of the reef” in that sector. Health was defined as the natural state of the reef minus losses or changes due to anthropogenic stressors. A reef in a perfectly natural state regardless of abundance or diversity of corals and associated organisms was considered pristine. Reefs suffering various degrees of change due to anthropogenic factors were judged to be in a moderate, fair or poor condition. An attempt was made also to estimate the coral cover in all sectors on all islands. In cases where published data were available from the scientific or gray literature, this information was incorporated into the evaluation process (Maragos and Elliott 1985; Grigg et al. 1988).

RESULTS AND DISCUSSION

General Status of Coral Reefs in Hawaii

Coral reefs in Hawaii are characterized by low biodiversity. Only 47 species of reef-building corals have been recorded in the Hawaiian Archipelago (Maragos 1995) compared to over 500 in the Indo-West-Pacific zoogeographic realm. The absence of more species of coral is generally attributed to geographic isolation of the Hawaiian island chain (Kay 1980; Grigg 1988), although unfavorable winter temperatures particularly in the northern half of the chain may also limit some species and contribute to poor reef development.

In general, the growth of coral reefs (carbonate accretion) and the community structure of coral reefs in Hawaii are naturally controlled by wave forces and depth (Grigg, in press; Dollar 1982). Most coastline areas in the state are exposed to the open ocean. Coral reef communities growing in such areas are frequently disturbed by wave-induced mortality caused by breakage, scour and abrasion. Reefs growing at or near the surface are constrained by sea level (depth). The only significant buildups of modern reef carbonates during the Holocene (last 10,000 years) that exist in the main islands are found in areas that are sheltered or partially sheltered from long-period, large, open-ocean swell and at depths not constrained by sea level. Such areas are typically restricted to embayments and are sheltered from wave exposure by nearby or adjacent islands. In all exposed areas, Holocene reefs are thin and transient veneers, at most several meters thick growing on Pleistocene (>10,000 years) foundations. Veneers are no thicker than the height of the largest living colony. In other words, no accretion of living corals is taking place. Living corals are dying as fast as they are being replaced by natural processes. Physical and biological processes of erosion are removing limestone as fast as it accretes.
The community structure of coral reefs in Hawaii is also controlled primarily by wave energy and depth. This does not mean that other natural factors such as sedimentation, turbidity, light, nutrient concentration or biological factors are not important. In some environments, in fact, one or more of these variables might be of overriding significance. The ecological status of any given reef is further complicated by the presence of anthropogenic stressors. The impacts associated with these stressors are superimposed or are additive to the effects of natural controlling factors, and sometimes it is difficult to separate effects when they operate in combination. The distinction between, and deconvolution of, natural versus anthropogenic impacts can be extremely difficult and requires the experience of highly trained ecologists. This problem limits the value of information gathered by volunteers lacking such training.

In cases where the ecology of coral reefs is under the primary and dominant control of wave forces, the potential effects of pollution may be of little consequence except as it relates to aesthetic values or water quality and human health. Impacts related to point and non-point source pollution, therefore, would be expected to be of most significance in wave-sheltered environments or in bodies of water with a high residence time, such as embayments and lagoons. None of the above discussion however, would apply to reef fisheries. The degree of anthropogenic impact to fisheries would be expected to be a function of habitat and fishing pressure irrespective of exposure or shelter to large open ocean long-period swell.

**Oahu**

Much of the open coastline of Oahu is fringed by coral reef habitat with low natural coral cover under the control of wave stress. Most living coral communities are thin veneers growing on fossil beach rock or Pleistocene limestone foundations. The best reef development is found in embayments or areas sheltered (Kaneohe Bay) or partially sheltered (Hanauma Bay) from large, open-ocean, long-period swell. Reef communities are generally healthy except for local areas where usage of the shoreline is high or certain embayments where water circulation is restricted. Many of these environments have been degraded by non-point source runoff containing high sediment loads. Most notable is the south end of Kaneohe Bay where sewage discharge prior to 1976 resulted in a significant decline in coral ecosystem health. Coral communities were largely replaced by filter-feeding organisms (Smith et al. 1981). The bubble algae, *Dictyosphaeria cavernosa*, also overgrew or infiltrated colonies, particularly *Porites compressa*, the dominant coral on patch reefs and fringing reefs in Kaneohe Bay. Sewage discharges in the bay were diverted offshore in 1977 and since that time, the bay has undergone gradual recovery although it is still subject to periodic influxes of fresh water, sediment and nutrients during high rainfall events (Jokiel et al. 1993), and setbacks in recovery have occurred (Hunter and Evans 1995). Other coral habitats in embayments impacted by sediment-laden runoff on Oahu include Pearl Harbor, Kahana Bay, Kewela Bay, Kaiaka and Wailua Bays and the southeast corner of Moanalua Bay at shallow depths (0.5-2.0 m) off Hawaii Kai. Non-point source runoff from the Ewa plain has also altered shallow habitat in shallow water favoring the growth of numerous species of algae. The most significant alteration to nearshore habitat has been off Waikiki and Honolulu where former wetlands and estuaries have been converted to harbors, parks and beaches fronting hotels.

The most serious anthropogenic impact to coral reef ecosystems islandwide is overfishing. Gill netting and spearfishing are the most damaging forms of fishing. State fishery regulations are largely ignored and rarely enforced except in Hanauma Bay, a Marine Life Conservation District.
Notwithstanding these problems, many improvements in coastal environments have occurred. All shallow nearshore sewage discharges have been replaced by deepwater outfalls and former impacts on coral reefs have been eliminated (Grigg 1995). Better land management practices and the curtailment of dredge and fill activities have greatly reduced sedimentation problems to coral reefs islandwide. As a result of the federal Endangered Species Act passed in 1972, the taking of green turtles (*Chelonia mydas*) was banned. This has led to a dramatic comeback in green turtle populations throughout the state although not without new problems. Many green turtles in recent years have been afflicted by external tumors. The cause is unknown. Oahu, being the population center in the State of Hawaii, ranks highest among the main islands in terms of both coral reef resource problems and the need for better longterm management.

**Maui**

Maui, the second largest island in the state, is made up of two large coalesced shield volcanoes, Haleakala and West Maui. Consistent with the other islands, most coral reefs on Maui are under the primary control of wave forces. The best reefs are off Honokowai on the west end and along the stretch of coastline between Olowalu and Papawai Point off the south coast of West Maui, both at depths of 10-20 m. Coral cover in these areas ranges between 50 and 80%. Both of these areas were sheltered from the impact of large swells (up to 5 m) generated by Hurricane Iniki in 1992. Exposed areas, some with reefs containing 50% or more coral cover, were devastated by Iniki resulting in mortality up to 100% (Eric Brown, Pacific Whale Foundation, pers. comm.). Other pristine reefs exist at 30-40 m depth in the Auau Channel and at Molokini Crater where they are totally sheltered from wave stress.

The two most significant environmental problems affecting coral reefs on Maui are overfishing and increases in various species of algae. The only areas not overfished are those least accessible; deep reefs off Hana, Keanae and Kaupo on East Maui and Honokohau on the northwest tip of the island. Outbreaks of algae periodically occur off Spreckelsville to Kanaha, Honokowai and Wai'alea. Their cause is not well understood, but increases of species in shallow water (*Hypnea, Acanthophora, Sargassum, Dictyota*) may be related to the leaching of nutrients from cesspools and non-point source runoff at times of low circulation. The species of *Hypnea* and *Acanthophora* are introduced to Hawaii and their abundance may reflect a lack of natural predators or competitors (Steve Dollar, pers. comm.). Outbreaks in deep water of the algae species *Cladocera* appear to be related to periodic natural upwellings. Increases in algae may also be related to overfishing of herbivorous fishes and the low abundance of echinoids and herbivores. In recent years, turtle nesting has increased at Kaloia Beach near Maalaea.

**Lanai**

Coral reef ecosystems off Lanai appear to be under the control of natural forces. Reefs along the southern half of the island are wave controlled. Those on the northern half are very well developed although natural sediment runoff results in episodic mortality. While limited by these factors, virtually all reefs on Lanai are in a healthy condition. And although all reefs are overfished, none are impacted by pollution. Turtle populations are very high, and nesting is common on sandy beaches along the northwest end of the island.
Molokai

Except for widespread overfishing, the only significant anthropogenic problem for coral reefs on Molokai is sediment laden runoff. Historically, natural runoff has been exacerbated by land erosion caused by overgrazing by alien species (feral ungulates), agricultural practices resulting in loss of ground cover and some construction (earth moving). Natural runoff from 34 perennial streams adds to this problem. The area most seriously affected is about 10 km of fringing reef and lagoon off the southwestern end of the island.

Fifteen historic fishponds exist on the southeastern coast. None are in use today although they may inadvertently help to curtail sediment-laden runoff from entering the nearshore environment. In 1972, an outbreak of the starfish *Acanthaster planci* was discovered off the southeast coast (Branham et al. 1972) on reefs at depths between 15 and 25 m. Although some initial attempt was made to control (eradicate) the outbreak, it appeared to return naturally to a normal abundance level over a period of several years.

The fringing reef off the south coast of Molokai is the largest and longest reef of this kind in the Hawaiian Islands. Its size may be related to wave shelter afforded by the island of Lanai situated south of Molokai (Figure 1).

Kahoolawe

Kahoolawe is the smallest of the eight main Hawaiian Islands. It is also the driest, receiving less than 63 cm (25 inches) of rainfall annually. It has no perennial streams. Its location in the rain shadow of East Maui accounts for its low annual precipitation. For years, the U.S. military used Kahoolawe as a target for live-firing and bombing. This, in addition to land erosion caused by feral ungulates, created significant amounts of sediment that (in spite of low rainfall) was transported by runoff into nearshore environments. However, all of the goats on Kahoolawe have been recently eradicated.

In 1994 the military returned control over the island back to the State of Hawaii and the bombing ceased. Since that time, the reefs have been gradually recovering from conditions caused by previous high rates of sedimentation. Hurricane Iniki in 1992 helped to remove large amounts of sediment from the bottom in shallow water along the southern coast (Paul Jokiel, pers. comm.). Aside from this historical problem, the only other anthropogenic source of impact to the coral reefs of Kahoolawe is overfishing. While small fishes are diverse and abundant, the absence of large fishes and lobsters and few sharks are evidence of high fishing pressure (Ernest Reese, pers. comm.). The best reefs on the island are found off Hakio-awa. Interestingly, little ordnance can be found on any reefs around Kahoolawe today, suggesting rapid overgrowth by coral and/or high accuracy of the military target practice.

Hawaii

Hawaii is the largest and youngest island in the main Hawaiian Islands. It is made up of five large shield volcanoes (Mauna Kea, Mauna Loa, Hualalae, Kilauea and Kohala). A dramatic difference exists between windward and leeward coral reefs on the Big Island. On the entire windward coast, except for Hilo Bay, coral reef communities are under the control of wave forces. Early successional stages dominate and consist of scattered coral colonies or thin crustose veneers growing on basalt foundations (Grigg and Maragos 1974). In contrast, the leeward side of the island is shielded from trade winds and large north and northwest swell. Along the leeward coast, the richest coral reef communities exist near wave base between 15 and 27 m depth. In this zone, climax communities dominated by *P. compressa* are common.
Periodically, however, even this zone is disturbed by large wave events (waves up to 7 m or larger) produced by exceptional kona storms. The return period for storms of this intensity is about 40 years (Dollar 1982). Events of this severity, depending on the magnitude, can and do set back the successional process to time zero (Grigg and Maragos 1974; Grigg 1983; Dollar and Tribble 1994), Figure 2. Consequently, there has been virtually no accretion of a limestone reef foundation off the coast of Hawaii and fringing reefs have not developed.

Figure 2. Theoretical model of succession of coral reef communities and hypothetical case illustrating the effects of various intensities and frequencies of disturbance. From Grigg 1983.

Anthropogenic impacts to coral reefs are superimposed on the effects of natural controlling factors. Four sources of human impact are of particular significance on the island of Hawaii. The oldest source of anthropogenic impact is bagasse and sediment contained in sugarcane waste waters discharged into the sea along the Hamakua Coast. At peak discharge levels in the early 1970s, about 24 km of coastline and reef habitat were severely impacted. Since that time, however, all of the sugar mills along the Hamakua Coast have closed and all areas formerly affected are now under recovery (Grigg 1985; Dollar 1994).

On the leeward coast, overfishing, aquarium fish collecting and groundwater intrusion are the most serious anthropogenic induced impacts to coral reefs. Overfishing is a problem on all islands. Aquarium fish collecting is highly selective and localized; however, competing private interest groups (mainly SCUBA charter companies) claim that impacts are significant. Groundwater intrusion is common along the shoreline and within nearshore shallow reefs. The source is percolation of rainfall or water used for agriculture, golf course or other commercial purposes, through highly porous volcanic soils. Groundwater is often enriched with nutrients including silicate, nitrate and phosphate. Even so, dilution is so great in the receiving waters that the biological responses of the benthos are nil or highly localized (Dollar and Atkinson 1992). Less than 1% of the coastal habitat is altered by intrusion of groundwater. With the exception of significant declines in reef fish biomass, coral reef ecosystems on the Big Island can be described as generally healthy.
Kauai

Kauai is the oldest of the main Hawaiian Islands. Its single shield volcano is estimated to be about 5 million years old. Kauai is also the wettest island. Mount Waialeale receives over 1140 cm (450 inches) of rainfall per year (Armstrong 1983), and is one of the wettest spots in the world. Thirty-eight perennial streams drain upland watersheds and deliver large quantities of sediment-laden water to virtually all coastal environments. This is the most important factor that distinguishes Kauai from the other islands and appears to be responsible for the lack of well developed fringing reefs islandwide. Coral reef habitats in shallow water and embayments with restricted circulation are the most severely impacted. As opposed to the other islands, this may explain why the best shallow reefs on Kauai occur on the northeast and north coasts. Because of wave exposure, the receiving waters off these coastlines are the most vigorously mixed (Don Heacock, per. comm.). Suspended sediment in the nearshore waters along the north and northeast coast rarely settles before it is transported offshore by coastal currents.

The fate of sediment introduced into the ocean from coastal developments (hotels, condominiums and golf courses) is similar. A before/after survey of the coral reef communities off the Princeville development at Anini Beach on the north shore actually showed that small increases in coral cover and diversity occurred after 15 years (Grigg 1995; Figure 3). Increases were attributed to the lack of severe storm wave events during this time frame and the lack of sediment accumulation on the bottom.

![Graphs showing changes in coral, fish, and algal species](image)

Figure 3. Quantitative marine assessment of coral, fish and algal populations along five transects offshore of the Princeville, Kauai, area surveyed in 1980 and 1995. Horizontal scale, 1.5 cm = 1 km.
Water quality is also affected by widespread runoff from Kauai’s 38 perennial streams. In particular, on the southwest coast in shallow water between Kekaha and Port Allen, nearshore environments are dominated by algae. Brown nutrient-rich water is persistent in this area. The lack of echinoids and low abundance of herbivorous fishes also may contribute to conditions favoring algae. As with all the other main Hawaiian Islands, overfishing on Kauai is perceived by fishermen and scientists to be a serious problem.

The best reefs exist in deep water (15-25 m) with the least exposure to sediment-laden runoff from streams. The reefs off Poipu and Makahuena are the best examples, although both areas have been impacted recently by Hurricanes Ewa (1982) and Iniki (1992). Limestone fossil reefs are particularly abundant off the entire southern half of Kauai at depths of 30-70 m. Abundant populations of the black coral *Antipathes dichotoma* are found in this unique habitat.

**CONCLUSIONS**

1. Growth and community structure of coral reefs in the main Hawaiian Islands are primarily under the control of wave forces and depth.

2. With the exception of Kauai, where sediment-laden runoff is a serious limiting factor, the best reefs in the main Hawaiian Islands are found in embayments sheltered or partially sheltered from long-period, large, open-ocean swell.

3. In all areas exposed to large, open-ocean swell, coral reefs in the main Hawaiian Islands consist of thin and transient veneers of modern limestone growing on antecedent foundations. Virtually no accretion has occurred during the entire Holocene (last 10,000 years).

4. Impacts from anthropogenic factors on coral reefs are superimposed on naturally controlling forces. In general, they are only important in environments where wave forces are not the dominant controlling factor. These environments typically are embayments and lagoons or are areas of low water circulation where the residence time of the overlying water column is high. These environments constitute less than 10% of the coastline in the state.

5. All coral reef habitats in the main Hawaiian Islands are overfished in various degrees. It is not likely that this problem will be solved until the enforcement of existing regulations is greatly strengthened and more restrictions in fishing effort and certain gears (particularly gill nets) are imposed.

6. With the exception of overfishing, about 90% of the coral reefs in the main Hawaiian Islands are healthy. Anthropogenic impacts are serious in localized areas where water circulation is restricted. Sedimentation and eutrophication are the most serious general problems. Each main island in the chain is characterized by specific but localized anthropogenic induced problems that are geographically unique.

A major commitment by the State of Hawaii is needed to improve the management of coral reef resources statewide. Overfishing is a serious problem on every island and is in need of remediation. In general, the water quality of embayments and areas of confined circulation is in need of improvement with better control of non-point source runoff. Increasing recreational and commercial uses of coral reef resources and environments is of major economic significance. State government needs to devote more resources for the management of coral reef resources to insure their future health.
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