The first four years:

Hawaii Coral Reef Initiative Research Program

1998-2002

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GLOSSARY AND CREDITS

A message from the director

Michael P. Hamnett, Ph.D.
Director, Hawaii Coral Reef Initiative Research Program.
(Jeremiah Christiansen).

During the 1990s, resource managers, scientists, and those whose livelihoods depend on coral reefs began to recognize that these vitally important natural resources were threatened worldwide by human and environmental impacts and required more effective management.

The Hawaii Coral Reef Initiative Research Program was established as a joint venture of the state's Department of Land and Natural Resources and the University of Hawaii to support research and monitoring to increase capacity to manage reef ecosystems. A Management Committee composed of scientists and resource managers governs the program. This structure brings together different perspectives, allowing for a well-rounded view of the threats faced by Hawaii's coral reefs and resource management issues.

This book summarizes the results from the first four years of HCRI-RP sponsored projects in the main Hawaiian Islands. The website accompanying this report describes each project in greater depth.

The Management Committee hopes that the research profiled in this volume will become an important source of information about Hawaii's reefs for resource managers and others. This book is a companion to the *Coral Reef Ecosystems of the Northwestern Hawaiian Islands* (2001), which can be downloaded from our website at: www.hawaii.edu/ssri/hcri.

Unfortunately, shifts in budget priorities on the state and federal levels have made continued funding for coral reef management uncertain. Without sustained funding to identify and mitigate threats to coral reefs, and to plan, implement, and monitor new management efforts, the value and natural beauty of Hawaii's reefs will continue to degrade. The loss of coral reefs undoubtedly holds serious environmental, economic, and cultural implications for Hawaii and the world.

HCRI-RP is at a vital stage in its evolution. We have established a strong foundation of research and cooperative management, giving us the tools needed to significantly improve the state of Hawaii's coral reefs. Additional effort is needed to continue identifying emerging threats and to understand the impacts of specific threats on the dynamic relationships among coral, algae, fish, and other reef organisms.

THE HCRI RESEARCH PROGRAM

Hawaiian Corals (Jennifer Smith). *Due to geographic isolation, 25% of the state's corals are found nowhere else on earth. Both of these species, however, are found throughout the Pacific.*

The International Year of the Reef in 1997 signaled the world's growing understanding of the importance of coral reef ecosystems. The scientific community and resource managers recognized reefs faced a suite of problems and were degrading at an alarming rate worldwide. In 1998, the Hawaii Coral Reef Initiative Research Program (HCRI-RP) was established to support scientific research and monitoring to enhance the state's capacity to manage its coral reef resources.

In addition to research and monitoring, the program supports public awareness efforts, briefings for legislators and decision-makers, and internships and fellowships. A competitive, peer-reviewed process is used annually to select HCRI-RP projects that address priorities set by its Management Committee.

Rigorous peer reviews of the overall program are conducted each year through NOAA's Coastal Ocean Program. Reviewer comments are addressed as necessary by HCRI-RP to resolve concerns and appropriately redirect project activities as recommended by the scientific community. HCRI-RP also frequently hosts workshops with resource managers, scientists, and stakeholders to discuss potential priorities, the program, and specific topics of interest.

This document summarizes the management-oriented research and monitoring projects supported by HCRI-RP during its first four years.

The initial section begins with an overview of the importance of Hawaii's reefs.

Kallymenia (Isabella Abbott). *This algal species naturally occurs with a dark, purple-red color.*

Padina (Isabella Abbott).
A calcified brown alga.

The narrative underscores the challenges state and local resource managers face in carrying out their mandated duties. This is followed by a summary of the rationale, results, and recommendations from monitoring projects sponsored by the program and research on the threats facing Hawaii's reefs. This first section concludes with a discussion of future actions and directions for the program.

The next section provides more detailed abstracts of monitoring and research projects funded by HCRI-RP. These abstracts are written by each principal investigator. As such, this portion is similar to an edited volume. It starts with a description of the *Economic Value of Hawaii's Reefs* project, which is the first effort to assess the coral reef ecosystems' contribution to Hawaii's economy. This is followed by highlights of monitoring activities sponsored by the program. The section ends with summaries of research projects aimed at: identifying threats to Hawaii's coral reef ecosystem; understanding the impacts of those threats; and assessing the effectiveness of management measures to mitigate the threats.

Puako, Hawaii (Jennifer Smith).
Shallow reef flats are threatened by human activities in nearshore environments.

HCRI-RP MANAGEMENT AND FUNDING

HCRI-RP is jointly managed by Hawaii's Department of Land and Natural Resources/Division of Aquatic Resources (DAR) and the University of Hawaii (UH) through a Management Committee. At present, the Committee has three representatives from DAR, one from the US Fish and Wildlife Service, two from the University of Hawaii, and one from the Pacific Science Association/Bishop Museum.

HCRI-RP sponsors monitoring of the state's coral reefs and research on the major threats to them. Results provide resource managers with information to help effectively and efficiently manage Hawaii's coral reefs. Over its first four years, the program received nearly $3 million in Congressional funding through the National Oceanic and Atmospheric Administration's Center for Sponsored Coastal Ocean Research (NOAA/CSCOR), home of the Coastal Ocean Program (NOAA/COP). NOAA/COP is part of the National Ocean Service (NOAA/NOS) and the National Centers for Coastal Ocean Science (NOAA/NCCOS).

RAINFORESTS OF THE SEA

Leaf Fish (Jennifer Smith).
Mimics of natural floating debris, these camouflage fish sway gently in the current.

Geographic isolation is a blessing to Hawaii's unique reef ecosystems. This isolation fosters the development of life forms found nowhere else on earth. It also protects Hawaii's coral reefs from many of the threats faced in other parts of the United States and the world.

Hawaii's reefs are seriously threatened by fishing pressure, alien species, and localized sediment and nutrient runoff. Intensive coastal development, pollution, and ocean recreation also can negatively impact Hawaii's coral reef ecosystems.

Vertical Reef (Jennifer Smith).
Vertical reefs challenge managers and researchers to devise techniques that can effectively monitor and assess them.

The Economic Value of Hawaii's Reefs project (2001-2002) calculates Hawaii's coastal reefs generate about $364 million each year in added value for the state's economy. Over two generations, reefs surrounding the main Hawaiian Islands will have contributed over $18 billion. This number is based on the summation of added value for: resident and visitor snorkeling and diving ($304 million); property value ($40 million); fisheries ($2.5 million); and research ($10 million). Preservation value and multiplier effects round out the total. Intangible factors, such as ecological or socio-cultural values, are difficult to measure in monetary terms and are not included in the total.

Coral reefs have been characterized as rainforests of the sea.A damaged coastal reef can spell disaster for those who depend on it. The most obvious threat is to tourism, the lifeblood of Hawaii.

Without a healthy reef, Hawaii's most important assets – beaches, huge surf swells, and opportunities for snorkeling and diving – will deteriorate.

The diversity in these unique marine ecosystems is becoming more vital as researchers turn to the sea in search of cures for cancer and other human diseases.

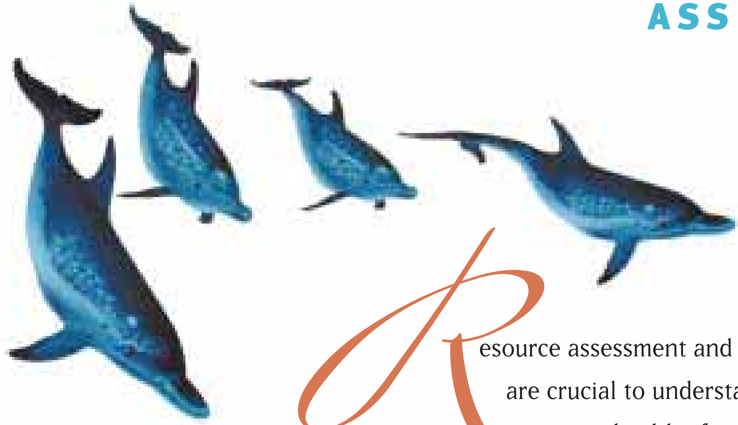
Hawaii's reefs are also critically important to the Hawaiian culture and way of life. Ancient Hawaiians, in their creation chant, placed the coral reef as the foundation of life. In many ways, it still is. Coral reef ecosystems have provided sustenance and medicine for more than 1600 years to the native people of Hawaii.

We live in a time of burgeoning and conflicting needs and diminished resources. The state government faces large budget deficits and increasing social and economic needs. Protecting natural resources must compete with other priorities.

Proactive management is needed to sustain our coastal reef ecosystem. The world has already lost about 30% of its reefs. We cannot afford to lose more.

We must continue to support the study of our coral reef ecosystems to intelligently manage these precious resources. This will require us to better manage our financial resources and continue to match human skills with new, emerging problems. These steps are essential to insure the health of Hawaiian reefs for future generations.

ASSESSMENT AND MONITORING



Resource assessment and monitoring are crucial to understanding the health of coral reef ecosystems. Assessments gather information at one moment in time, giving a snapshot of the reef's health. Monitoring collects data over an extended timeframe, measuring ecological changes. Both define key characteristics of reef ecosystems and can be used to identify resource management needs and to assess the effectiveness of specific management measures.

Monitoring methods effective for one component of an ecosystem may not apply to another. Methods to estimate coral cover are not easily transferred to algae. Therefore, different techniques need to be employed, with continual review and revision.

RESOURCE MANAGEMENT CHALLENGES

Managing coral reef resources is a complex task. Each ecological community has unique characteristics, influencing the type of management required. A coral-dominated community with great species diversity and a high number of recreational users requires different management than a soft-bottom community with few marine species.

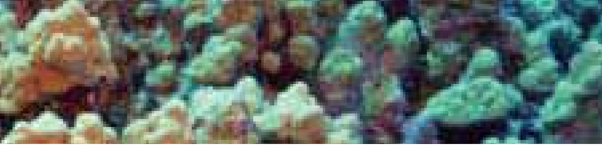
Conflicting stakeholder goals present daunting challenges. Should an area be managed to protect public health? ...to protect a pristine ecosystem? ... to maximize economic benefits? ... to provide ocean recreation opportunities for tourists and residents? ... to provide marine science resources for research and education?

It is possible for a particular reef to meet two or more goals. Hanauma Bay is managed to protect the ecosystem and to promote recreational opportunities. Each reef community's different characteristics make it impossible to apply a one-size-fits-all management scheme across the state.

Resource managers must often make unpopular decisions: requiring additional environmental review for land development; requiring more erosion prevention at construction sites to address non-point source pollution; limiting recreational access; restricting the size and amount of fish caught; closing areas to fishing; requiring educational classes before use of a resource.

Public education becomes essential, not only for gaining understanding of what is at stake, but to nurture voluntary compliance. Without voluntary compliance, new management measures become an even bigger enforcement problem than they are now.

Broad-based community involvement is key, starting from the initial identification of the problem to setting goals and selecting actions. Working together, scientists, resource managers, informed legislators, and an educated and caring public can make the changes needed to preserve the resources that define Hawaii.



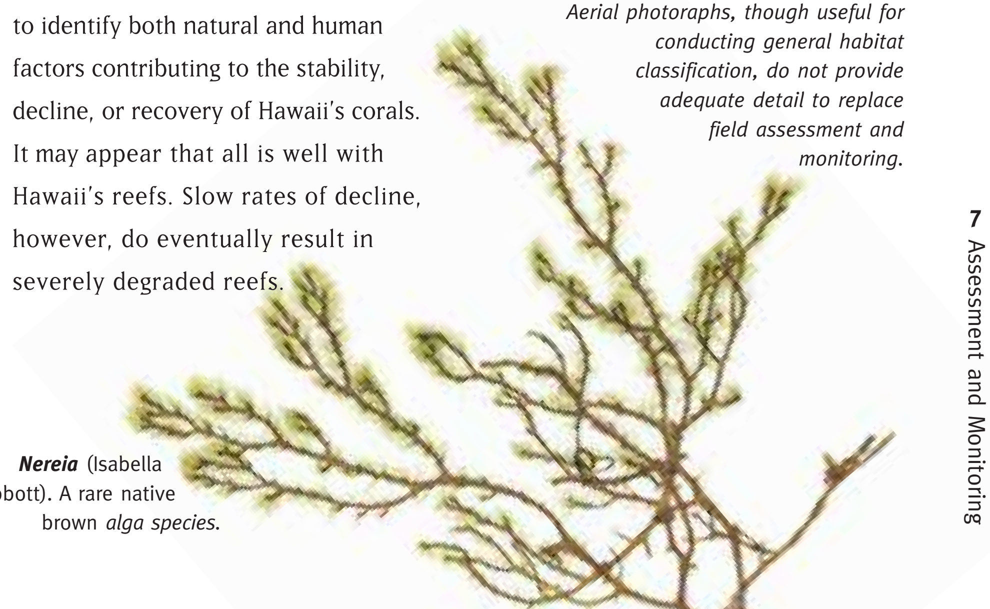
ARE HAWAII'S CORALS IN TROUBLE?

Hawaii is home to more than 410 thousand acres of beautiful, living coral reef in the main Hawaiian Islands. When combined with the northwestern islands, Hawaii hosts more than 80% of all such ecosystems under United States jurisdiction. There is no doubt these coral reefs are a precious resource deserving of our attention.

A bird's eye view (NOAA/NOS). *Aerial photographs, though useful for conducting general habitat classification, do not provide adequate detail to replace field assessment and monitoring.*

One of HCRI-RP's first steps was to support the establishment of a standardized, annual coral monitoring protocol allowing for comparison among sites. The program recognizes that the percentage of coral cover and the level of species diversity vary naturally. If the health of coral reef ecosystems is to be evaluated, effective and efficient long-term monitoring for corals, algae, fish, other invertebrates, and water quality is required.

The *Fine-Scale Processes on Hawaii's Reefs* project (1998-1999) attempted to develop a three-dimensional coral reef monitoring technique because two-dimensional photoquadrats typically underestimate the percent of algal cover. *Genetic Variation of Hawaii's Corals* (1998-1999) investigated using molecular protocols to determine genotypes of corals. The *Coral Reef Assessment and Monitoring Project*, supported from 1998-2002, is designed to identify both natural and human factors contributing to the stability, decline, or recovery of Hawaii's corals. It may appear that all is well with Hawaii's reefs. Slow rates of decline, however, do eventually result in severely degraded reefs.



Nereia (Isabella Abbott). A rare native brown *alga species.*

Pearl and Hermes, Northwestern Hawaiian Islands (© James Watt/NOAA, www.wattstock.com).
Lack of fishing pressure in the NWHI enables fish populations to thrive.

ARE HAWAII'S FISH DISAPPEARING?

Coastal areas around the world are facing severe depletion of fish populations. Hawaii is no exception. There has been a definite decline in fish abundance and size in the main Hawaiian Islands over the past several decades. Large predators have been fished out for many years. More recently fishing pressure (particularly in nearshore waters near heavily populated areas) appears to exceed the capacity of even the smaller fish species to reproduce.

HCRI-RP supported initial assessments and development of monitoring methods for fish populations through the *Coral Reef Assessment and Monitoring Project* (1998-2001). Researchers evaluated the relationship between fish assemblages and their associated habitat in marine protected areas (MPAs). Results demonstrate complex habitats often harbor larger fish assemblages and more species diversity. For management purposes, these results imply that habitats and fish assemblages are functionally connected and provide vital information for reef enhancement and restoration.

ARE ALGAE INCREASING?

HCRI-RP recognizes marine plants, one of the primary components of coral reef ecosystems are often ignored in resource assessment and monitoring projects. More than 500 species of marine algae are known from Hawaii's coral reefs. These plants are fundamental components of the food web and integral to any healthy reef.

Developing a strong identification database lays the groundwork for future efforts to use algal species as indicators of overall ecosystem health. Until recently, little was known about Hawaiian algae. The *Macroalgal Ecology and*

Taxonomic Assessment for HCRI-RP Sites (1999-2002) has filled this knowledge gap and begun developing an understanding of the dynamics of the relationships among invertebrates, fish, and algae in coral reef ecosystems.

Definitive information about algal responses to change would give resource managers and scientists a powerful tool to assess and manage coral reefs. *Fine-Scale Processes Affecting Health and Stability of Hawaiian Reefs* (1998-1999) examined techniques to rapidly and precisely monitor shifts in algal composition.

WHAT IS THE QUALITY OF NEARSHORE WATERS?

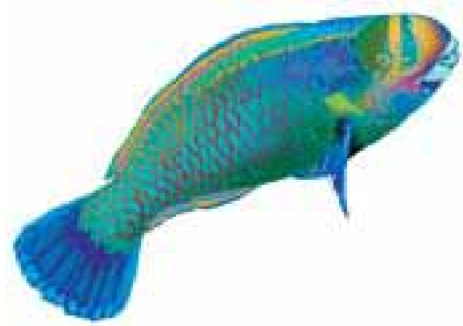
Coral reef researchers are currently surveying corals once per year as part of their monitoring projects. Fisheries researchers have been surveying twice per year. Water quality monitoring needs to be carried out continuously and new methods developed to assess the impact of nutrients and sediments on reef organisms. *Macroalgal Bioindicators of Nutrient-enriched Marine Waters,* funded in 2001-2002, developed methods for assessing nutrient levels in algae as a direct measure of nutrient loading and its impact on algal growth. *Continuous Water Quality Monitoring* (2001-2002) adapted a water quality monitoring instrument that, when used in conjunction with other methods, can establish a link between: variability in water quality; change in coral cover and diversity; and change in algal cover and diversity.

Cultural Importance (Jennifer Smith). *Sargassum (limu kala) is a common intertidal brown alga important for use in religious ceremonies and as spice for food, fish bait, and poultice for wounds.*

What is the impact? (Steven Dollar). *Domestic sewage and runoff from agricultural fields, urban lawns, and golf courses are sources of nutrients for nearshore waters – and probably influence coral and algal growth.*

THREATS TO HAWAIIAN REEFS

Coral Reef Ecocsystems in Peril (Greta Aeby). *These "zits" on Porites compressa, a dominant coral species in Hawaii, are caused by a parasite. Heavy infection can reduce coral growth by 50%.*



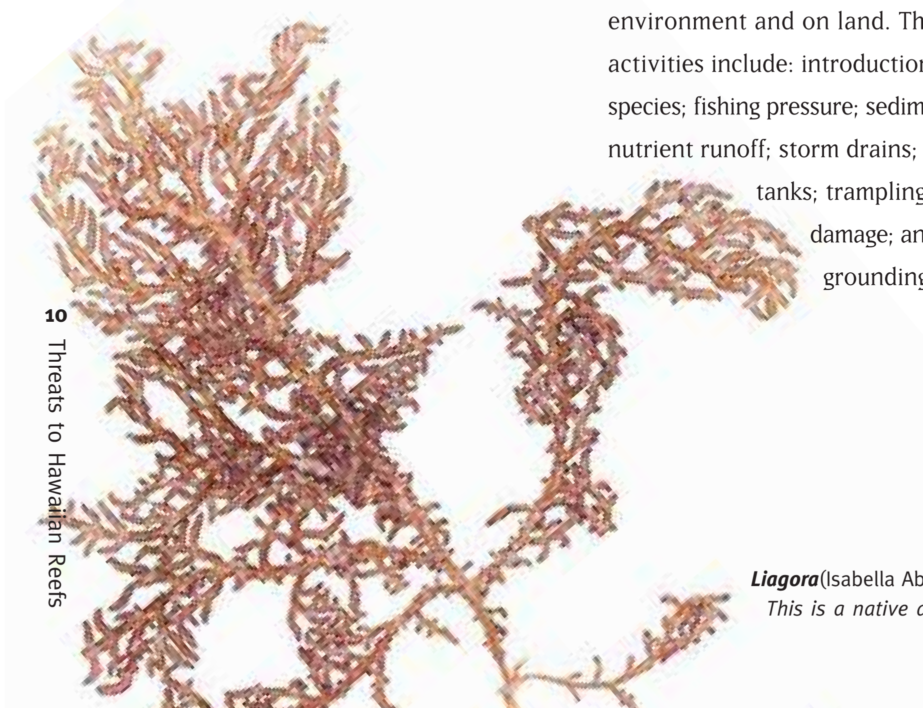
Human action can upset the balance of life on coastal reefs and amplify changes to natural cycles, resulting in the degradation of a coral reef ecosystem. All of the most significant problems threatening the reefs of the main Hawaiian Islands are the direct or indirect result of human activities, both in the marine environment and on land. These activities include: introduction of alien species; fishing pressure; sediment and nutrient runoff; storm drains; septic tanks; trampling; anchor damage; and vessel groundings.

While each poses a significant threat to coastal reef communities, the marine environment is subject to multiple threats at any one time, compounding the ecosystem's stress.

HCRI-RP has sponsored projects that provide resource managers with information allowing them to target their limited resources to areas needing greater management attention. This section introduces the threats investigated by HCRI-RP researchers: alien species; fishing pressure; water pollution; climatic impacts; and nearshore recreation.

Coral reef ecosystems are more susceptible to additional stressors once an initial imbalance is set in motion. As habitat degradation occurs, a shift in coral species may result, leading to decreased reef diversity. This, in turn, may lead to diminished genetic biodiversity and to increased disease susceptibility. HCRI-RP intends to sponsor research into this critical threat in FY2003-2004.

It is important that researchers and decision-makers address these types of issues in a proactive manner. Further research is needed to devise good management practices to conserve



Liagora(Isabella Abbott).
This is a native alga and an indicator of healthy reefs.

An Unwelcome Visitor (Jennifer Smith). *Kappaphycus rapidly overgrows corals and alters habitat complexity in Kaneohe Bay.*

Hawaii's coral reef ecosystem before irreversible degradation occurs.

ALIEN AND INVASIVE SPECIES

While terrestrial threats are well-known, marine alien species are less recognized and understood. But, they are no less dangerous.

The ability of modern ships to cover long distances in a short timespan provides a means for alien marine species, such as algae, invertebrates, and pathogens, to arrive in Hawaii through hull fouling and ballast water. Some alien species have been introduced for specific purposes, such as marine agronomy, sport fishing, or research. The expansion of the aquaculture industry, and even emptying out of private aquariums, could lead to the emergence of new, unwanted species in Hawaiian waters.

To understand the scope of the problem, HCRI-RP supported the first comprehensive surveys of alien algae through the *Ecological Success of Alien and Invasive Algae in Hawaii* project in 2000, which will be repeated in 2003. Researchers have identified four of the 19 known, introduced marine algal species as successful and threatening Hawaii's coral reefs: *Acanthophora spicifera*; *Gracilaria salicornia*; *Hypnea musciformis*; and *Kappaphycus* species.

Waikiki, one of Hawaii's most famous and profitable tourist attractions, is imperiled by the alien species *Gracilaria salicornia*. This alga dominates the inshore regions of Waikiki by the Natatorium, creating tangled, floating mats. Since its introduction some 30 years ago, it has grown unchecked and now is found from Diamond Head to Ala Moana. A similar problem exists on Oahu's windward side, with *Kappaphycus* spreading throughout Kaneohe Bay. In 2001-2002, HCRI-RP sponsored *Feasibility of Removing Alien and Invasive Species* to investigate practical management options to address this threat. Experiments examined what combination of physical removal and herbivore grazing will eradicate and control these species.

Macroalgal Bioindicators of Nutrient-enriched Marine Waters, (2000-2001) examined a localized area of nutrient enrichment in waters off western Maui that may fuel the formation and persistence of *Cladophora sericea* blooms.

FISHING PRESSURE

Hawaii's nearshore fish populations have been declining for several decades. There is some debate about whether this has resulted from degraded habitat or fishing pressure. Most scientists agree fishing pressure

6 REASONS ALIEN AND INVASIVE SPECIES ARE A THREAT

1. **Compete with native species for space and food.**
2. **Cause economic losses.**
3. **Reduce a reef's aesthetic value.**
4. **Kill some native species.**
5. **Cause irreversible damage.**
6. **Have unknown, long-term impacts.**

is contributing significantly to the problem.

Harvesting for the aquarium trade is one source of fishing pressure in Hawaii. The *West Hawaii Aquarium Project* (1999-2002) investigated the status of aquarium fish populations along the Kona Coast of the Big Island and the impact of nine fish replenishment areas (FRAs).

Several fish species found on Hawaiian reefs — including yellow tang, goldring surgeonfish, Achilles tang, clown tang, and longnose butterflyfish — are highly prized by the aquarium community. Results to date show that yellow tangs significantly increased (51%) in FRAs in 2002 relative to 1999 (baseline) levels. This population growth is higher than increases occurring in areas open to collecting (20%) and previously protected (19%).

A project funded in 2000-2001 entitled, *Assessment of Reef Fish Population Dynamics*, examined the impact of two approaches to fisheries management: permanently closed and pulse. Difficult shoreline access and prohibiting night-time spear fishing or gill netting are among the most important factors determining the success of a management regime. The results are critical to beginning to answer key questions in reserve design and administration.

Results from the *Coral Reef Assessment and Monitoring Project* (1998-2001) show "no take" protected areas with high habitat complexity, live coral cover, and optimal wave exposure provide maximum benefit to fish populations.

Reef Predators (© James Watt/NOAA, www.wattstock.com).
Bluefin trevally (omilu) are silvery fish that can quickly change their color.

WATER POLLUTION

Water pollution is one of the greatest threats to coral reefs around the world. Geographically, Hawaii is fortunate. Hawaii's steep mountains, narrow reef shelf, tidal action, ocean waves, and currents reduce the potential impact of polluted runoff, which is quickly mixed with ocean water. But, the impact of even brief exposure to nutrients and other pollutants in the water column, or repeated exposure to nutrients adhered to sediment, is unknown.

Fertilizer runoff from agricultural fields, urban lawns, and golf courses as well as domestic sewage, are major sources of nutrients that can find their way into nearshore waters. Nutrients from these sources can encourage rapid growth of algae that can crowd out corals and kill a reef. Sediments can smother coral and usually contain nutrients, encouraging algal growth. The impact of various nutrient inputs and the role of sediments on embayment water quality is an ongoing matter of concern to resource managers.

Fine-Scale Processes Affecting Health and Stability of Hawaiian Reefs, sponsored in 1998-1999, investigated the dynamics of ecological shifts from coral to algal dominances and the role of fishing pressure, eutrophication, and their combination. To prevent an overabundance of algae on coral reefs, resource managers should work to keep herbivore populations high and nutrient levels low.

As a result of hardening, streams in Hawaii deliver sediment, nutrients, and fresh water to the nearshore environment in an altered way. *Waimanalo Bay: A Case Study of the Linkage between Land-based Activities and Coral Reef Ecosystem Degradation* (2001-2002) looked at the impact of stream channelization on the nearshore marine environment and how to mitigate this degradation..

From 1999-2002, HCRI-RP sponsored *Providing Managers with Critical Tools for Assessing Reef Algae* to examine the potential of algal growth studies to assess impacts of low light intensities or changes in nutrient levels. Researchers then applied their results to make recommendations for resource managers.

Anthropogenic impacts on the nearshore water column are particularly important in areas protected from waves, generally embayments and lagoons. Based on research conducted through a project funded by HCRI-RP in 2001-2002, *Anthropogenic and Natural Stresses on Coral Reefs*, resource managers should concentrate on areas where circulation is confined, especially in areas where land uses result in increased input of materials to the nearshore.

CLIMATIC IMPACTS

If recent projections concerning climate change are correct, Hawaiian reefs will exist in a completely different global environment at the end of this century — and yet another in the next. What impacts can we expect from climate variability and change? How should we adapt our current management to address future threats?

The *Environmental Controls on Reef Development* project, funded in 2001-2002, shows climate variability clearly impacted coral reef ecosystems in the past. High wave action and tropical storms and hurricanes effected coral reef growth and accretion historically. Their frequency is strongly influenced by seasonal to interannual climate variability and El Niño events. If global warming results in either longer term or more frequent El Niño events, this will affect the status of coral reef ecosystems in Hawaii in the future.

NEARSHORE RECREATION

Coral reefs and the surrounding ocean support a wide range of recreational activities including: fishing, sailing, canoeing, kayaking, surfing, boating, jet-skiing, swimming, snorkeling, and scuba diving. Often, recreational users compete with each other for use of nearshore areas and embayments. Consumptive users (*e.g.*, fishermen) are often in conflict with nonconsumptive users (such as snorkelers and divers). The *Decision-Making Methodology to Resolve Multi-Use Conflicts,* funded in 1998-1999, was a first attempt to develop decision-support tools for allocating limited coral reef resources for competitive uses.

Without careful management, use of the coral reef environment by recreational users can destroy the very resource they enjoy. Anchor damage, physical damage from groundings, two-stroke motor discharge, trash, noise, and harassment are just a few examples of harm caused by human recreational activities. Perhaps the most common damage caused by recreational users is walking and trampling on the coral. In 1999-2000, *Coral Reef Assessment and Monitoring Project* conducted experiments to assess the impact of trampling on corals and to measure its impact on reef growth. In a controlled experiment, researchers found it takes up to nine steps to completely crush some species of coral. Recovery is possible, but only if the stress is discontinued.

Ship Groundings
(Christopher Becker, www.polihale.com).
Shipwrecks can cause considerable harm to reefs because they can dislodge, fracture, or destroy these fragile structures.

FINDINGS AND RECOMMENDATIONS

The next section of this report summarizes monitoring, assessment, and research projects sponsored by HCRI-RP. These contain results with implications for resource management. Some present recommendations to managers.

Scientists are often hesitant to make recommendations to government officials and resource managers. This is probably true because research findings are based on limited data and are rarely definitive. Nevertheless, HCRI-RP believes the findings of many of its sponsored research and monitoring projects are definitive enough to draw the following conclusions:

- Hawaii's coral reefs are subjected to substantial natural disturbances. Ocean waves greatly affect the state's coral reef ecosystems.
- Human impacts are clear. Some pose critical threats to coral reef ecosystems in Hawaii. Such effects are most conspicuous in bays and other areas protected from large-wave forces, as well as areas with urbanized land use
- Algae are an important component of coral reef ecosystems largely underemphasized. There are dynamic relationships among corals, algae, and fish that are not yet fully understood by scientists and resource managers.
- The relationships among land-based sources of pollution, water quality, overharvesting of fish, and the health of coral reef ecosystems are not well understood and more research is needed. Enough is known for managers to impose regulations minimizing polluted runoff and to try to prevent overfishing.
- Increasing phosphates and nitrates from cesspools, agricultural fertilizers, and other land-based sources may upset the balance between corals and algae in reef ecosystems, potentially causing algae to overgrow coral. Nutrient loading from land-based sources of pollution must be minimized to insure healthy coral reef ecosystems.
- Overharvesting of herbivorous fish can upset the balance of corals and algae and further tip the balance in favor of algae. Fisheries and aquarium collecting regulations must insure herbivorous fish are not overharvested.

Beachmaster 2000 (Jennifer Smith). *Physical removal of alien algae from the beach is possible, but may not be effective in solving the problem on the reef.*

- Alien and invasive algae are a major threat to coral reef ecosystems in Hawaii. Unless the growth of alien algae is mitigated, many reefs may be irreversibly altered.
- Resource managers should focus on rapid responses to newly observed alien introductions from hull fouling or other vectors.
- Physical removal of alien algae from coral reef ecosystems is possible, but may not be effective in preventing relatively rapid regrowth. Preliminary results suggest a combination of physical removal, native urchin grazing, and seeding areas with native algae may be effective. Further research is needed.
- Coral diseases plaguing reefs in other parts of the world are not seriously affecting Hawaii now. There is evidence, however, that some coral diseases are present on Hawaii's reefs. These diseases may cause serious problems in the future. Every effort should be made to prevent their spread and introduction. Resource managers and scientists should be trained to recognize symptoms.
- Physical damage to corals from trampling and small boat anchoring is considered a trivial concern compared to fishing pressure or alien species by some coral reef scientists. Trampling does damage and inhibit growth of corals, especially branching species like finger coral. Reef walking, snorkeling, diving, and anchoring must be prohibited in environmentally important coral reef ecosystems.
- The proportionate contribution of overfishing and habitat degradation on the marked declines in Hawaii's coastal fish populations has not been determined. The establishment of marine protected areas (MPAs) that prohibit taking fish has resulted in increased fish populations. MPAs that impose catch limits or gear restrictions (as opposed to no-take areas) afford some limitations on take, but are of little value for increasing or restoring fish populations.
- Regulations imposed to prohibit the collection of aquarium fish from designated fisheries replenishment areas (FRAs) along the Kona coast of Hawaii have been effective and should be continued.
- Various species of reef fish have different ranges of movement. Large predators roam over relatively large areas. MPAs intended to protect these predators must be large enough to include diurnal ranges. Areas intended to protect fish and other marine organisms with smaller ranges can obviously be smaller.
- Goals and objectives for MPAs are

Sea Urchin Power (Jennifer Smith). *A combination of physically removing alien algae, sea urchin grazing, and seeding areas with native algae may be an effective method of controlling alien algae.*

needed to develop criteria for choosing areas for protection and determining their size.

- Little is known about the lifecycles and population dynamics of many species that make up Hawaii's coral reef ecosystems. Further research is needed in order to determine what areas may require protection to insure adequate recruitment of keystone species.
- Monitoring protocols for coral reef ecosystems have been designed to detect changes in coral and algal cover and species composition, as well as fish and invertebrate diversity and densities. Developing systems that show the causes and effects of change appears to be much more difficult.
- Coral reef ecosystems contribute significantly to Hawaii's economy. Those contributions, and the economic costs and benefits of regulation and other management actions, have been estimated. Convincing decision-makers to increase state funding for resource management may prove more difficult, particularly given existing state budget priorities.
- Coral reef ecosystems have cultural, social, and environmental value. Methods need to be developed to assess these values and incorporate them into decisions about their protection.

Biodiversity (Jennifer Smith). *Corals provide habitat complexity that supports a highly diverse ecosystem.*

Ornate Butterflyfish (kikakapu) (Jennifer Smith). *They feed exclusively on live coral. They are not suitable for aquariums and should not be collected.*

HCRI-RP concentrated first on developing assessment and monitoring methods, establishing baseline information, and formulating responses to environmental threats. Other sponsored research focused on specific threats that currently endanger Hawaii's reefs. The results are already being used to develop programs to mitigate the negative impacts of human activities. Additional effort is needed to continue identify emerging threats. More research is needed to understand the impacts of specific threats on the dynamic relationships among coral, algae, fish, and other reef organisms.

How much research and monitoring is needed?

- At the very minimum, we need to assess the status of our coral reef ecosystems and monitor the emergence of threats, such as coral disease, bleaching, and alien species.
- We need to develop a basic understanding of reproduction and recruitment of important reef plants and animals and their movement and feeding habits. This understanding is needed to assess our current system of MPAs and set priorities for new sites.
- We need to identify all the alien and invasive species in our coastal waters and understand their impacts on native species and reef ecosystems and make recommendations for management action.
- We need to find ways to control or eradicate algal blooms, including determining their cause.
- We need to develop methods for preventing the introduction and spread of new alien species.
- We need to evaluate and improve fisheries management, polluted runoff control, and marine recreational regulations so that these activities will not degrade our marine ecosystems.
- We need to find new ways to finance and support resource management. Current financial support from the state is inadequate. Other parts of the world have developed innovative ways to finance resource management and protection that need to be evaluated for Hawaii.

Sea Star (Culcita novaeguineae) (Jennifer Smith). *The pin cushion sea star looks like a large sea urchin without spines. In actuality, it is a type of starfish.*

Where do we go from here?

The needs are numerous. Among the priorities listed above, we believe the next objective is to build sustainable programs that will carry on beyond the current-funding cycles.

Future HCRI-RP objectives include:

- Facilitate closer collaboration between scientists and resource managers. Develop enduring partnerships.
- Build capacity within the state's Division of Aquatic Resources (DAR) and Department of Health (DOH) to do resource monitoring.
- Facilitate the development of monitoring activites sustainable without federal funding.
- Collaborate with DOH-funded research and monitoring activities (e.g., Section 319 of the Clean Water Act) to assess the impact of human activity in watersheds on water quality and ecosystems in streams and into nearshore waters and coral reef ecosystems.
- Begin to understand reproduction and recruitment for important species of fish, algae, corals, and other invertebrates in coral reef ecosystems that can be used to develop an effective system of MPAs.
- Identify the physical, chemical, and biological mechanisms that result in algal blooms, coral bleaching, and disease.
- Evaluate systematically the costs and benefits of management measures used by DAR and DOH to protect the health of coral reef ecosystems, including management measures that are currently in place.
- Identify ways of financing resource management through user fees and other mechanisms, rather than increases in general fund revenues.
- Increase public, political, and financial support for resource management through a cooperative program of public education and awareness.

Hanauma Bay Education Center (Jeremiah Christiansen). *The education center is a long-term investment in environmental awareness across the state.*

The Research

What's the value?

(Herman Cesar)

One of the goals of the Hawaii Coral Reef Initiative Research Program (HCRI-RP) is to provide decision-makers with quantitative information on the value of Hawaii's coral reefs. Economic valuation offers a better understanding of their importance to the state's economy and their contribution to the nation.

It also assists in answering questions such as:

- How do we determine the amount of funding that should be devoted to coral reef ecosystem protection and enhancement?
- How do we assess damages and restoration costs? Cases involving coral reef damage in Florida show restoration costs alone can range from $550 to $10,000 per square meter.
- How much should local, state, and federal government spend on reef management?
- How do we assess the costs and benefits of management action and inaction?

ECONOMIC VALUE OF HAWAII

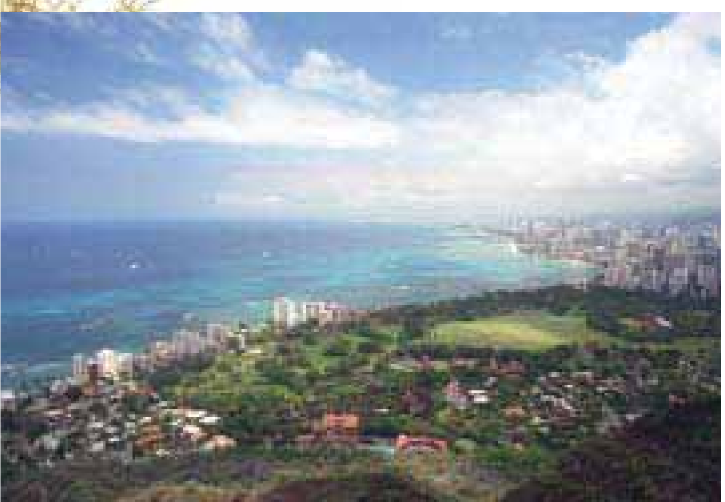
A Water Playground (© Ed Watamura). *Hawaii's coastal reefs generate about $364 million per year for Hawaii's economy.*

Economic Value of the Coral Reefs of Hawaii [2001-2002]

Principal Investigator
Dr. Herman Cesar

Project Collaborators
Dr. Pieter van Beukering
Mr. Sam Pintz
Mr. Jan Dierking

Hawaii's coastal reefs generate almost $364 million each year in added value. Hawaii's coastal reefs generate almost $364 million each year in added value. "Added value" is the net business revenues (income minus costs) that are directly and indirectly attributable to resident and tourist activities on Hawaii's reefs. About 84% of this added value ($304 million) is generated from snorkeling and diving and emerges from $700-$800 million in gross sales per year.



Added value from property generates another $40 million each year. This number reflects the higher prices for homes and higher occupancy and room rates for commercial properties adjacent to healthy coral reefs.

Approximately $10 million is spent each year on scientific research and monitoring of coral reef ecosystems in the main Hawaiian Islands. These monies generally come from sources outside of the state.

Waikiki, Oahu (Christopher Becker, www.polihale.com). *One of the world's most famous beaches.*

"Non-use value" ($7 million) estimates the amount of money residents, visitors, and non-visitors are willing to pay to ensure active management of a healthy reef. Hawaii residents are very aware of the state's reefs and their importance. From this, investigators estimated households would be willing to pay $10 per year to conserve the state's reefs. Based on a Florida study, only 1% of mainland households would be willing to pay around $3 a year to preserve Hawaii's reefs.

The annual added value for nearshore fisheries within the main Hawaiian Islands' coastal reefs is about $2.5 million. This amount reflects the revenues of fishermen minus their costs and modified with a multiplier.

Over two generations, reefs surrounding the main Hawaiian Islands will have contributed over $18 billion to the economy.

OVERALL VALUE OF CORAL REEFS IN HAWAII

	Hanauma Bay, Oahu millions/year	Kihei, Maui millions/year	Kona, Hawaii millions/year	Overall Value millions/year
recreational value	$36.23	$8.02	$8.06	$304
amenity value	—	$18.26	$4.47	$40
biodiversity value	$1.11	$1.71	$4.35	$17
fishery value	$0.01	$0.10	$0.70	$2.5
educational spill-over value	$0.22	—	—	—
total annual benefits	$37.57	$28.09	$17.68	$364
net present value (3%, 50 yr)	$1,053	$522	$389	$9,722

WHAT IS THE ADDED VALUE FOR HANAUMA BAY (OAHU)?

Hanauma Bay generates over $37 million each year. Over two generations, this translates to nearly $2 billion.

Of the $37 million, about 96% ($36 million) is added value derived from tourist and resident expenditures for snorkeling and diving at the bay. Non-use ($1 million) and adjacent recreational fisheries ($10,000) generate 3% of the bay's total added value. Educational spill-over, whereby residents and visitors adopt more reef-friendly practices after visiting the education center, contributes $220,000.

With more than 1 million visitors each year, Hanauma Bay is one of the most heavily used marine preserves in the world. These crowds have stirred up sediment, dropped rubbish, fed fish, and trampled coral. Typically, the rate of reef damage by snorkelers and divers is two square centimeters of reef per trip.

To mitigate this impact, a $13.5 million visitor center opened in 2002 that includes exhibits and an educational video shown to visitors before they enter the park. The cumulative annual effect of improved behavior by snorkelers at sites across the state results in an estimated four hectares of reef not being damaged. For divers, damage to about 0.2 hectares is prevented each year.

The Hanauma Bay Education Center is a long-term investment in environmental awareness for the state. Visitors generally go to two to three additional sites in Hawaii during their stay. Residents snorkel or dive at more than 10 sites a year. Over 50 years, the center will generate about $100 million in added value (using a 3% discount rate). This amount is the added value after subtracting $23 million in capital and operational costs from the total benefits generated by the center.

Researchers report visitors spend an average of $38 per visit, of which the entry fee is $3. Visitors indicated they would pay an $11 entry fee if a significant share of the monies were used for conservation at the bay. This would result in an additional $7,600,000 each year in added value, which Hanauma Bay would generate for management, education, and conservation.

What added value will be generated by the education center?
Over time, the center will generate about $100 million in added value (3% discount rate). Of that, $63 million will be due to the educational spill-over effect and $32 million because of greater recreational value.

WHAT IS THE ADDED VALUE OF MAUI'S KIHEI COAST?

Each year, reefs along Maui's Kihei coast contribute $28 million in added value to the economy. Over 50 years, these reefs will have generated over $1.4 billion.

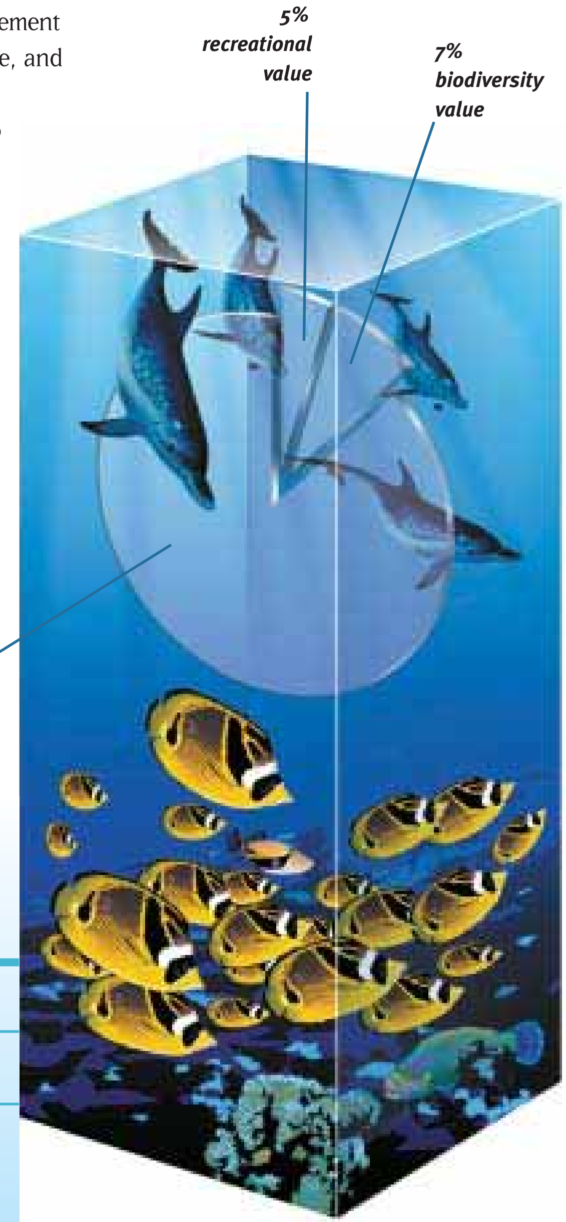
The principal generator of the reef's added value is property, which generates over $18 million annually. Tourist and resident diving and snorkeling contribute an additional $8 million. The added value for non-use is $1.7 million and for nearshore fisheries it is $100,000.

Unfortunately, over $20 million in potential revenue is lost each year due to algal blooms. Annually, these blooms decrease hotel and rental income by $10.8 million and depress property value by $9.4 million. In addition, Maui County and the condominium owners pay $250,000 to clean the algae off the beach each year.

The cause of the algal blooms is not known. Most scientists agree nutrient loading in the nearshore waters is probably involved.

- If the treated effluent from the Kihei sewage plant were the major contributor of nutrients and if upgrading the facility from secondary to tertiary treatment would solve the problem, then spending $13 million for the upgrade and $500,000 annually to operate is economically justifiable.
- If trace elements in slow-release fertilizer were the key, then monies spent for changes in turf management and education may be more cost effective.

In any case, because of the delay between the time of active management and the actual reduction of algae, and the initial costs involved, added value will inevitably continue to decline another 10 to 15 years.



What if algal blooms continue?
If the algal problem is not resolved, then in 50 years the added value would decline to less than $10 million. 88% of this decline is a decrease in real estate value.

RECREATIONAL SURVEY

	Hanauma Bay respondents cost per trip	Statewide respondents cost per trip	snorkelers cost per trip	divers cost per trip
money spent to dive or snorkel	**$38**	**$36**	**$27**	**$73**
additional money willing to pay	**$5**	**$5**	**$5**	**$5**
additional money willing to pay if earmarked for coral conservation	**$9**	**$10**	**$10**	**$9**

(Larry Basch, NPS).

WHAT IS THE ADDED VALUE OF REEFS ALONG HAWAII'S WEST COAST?

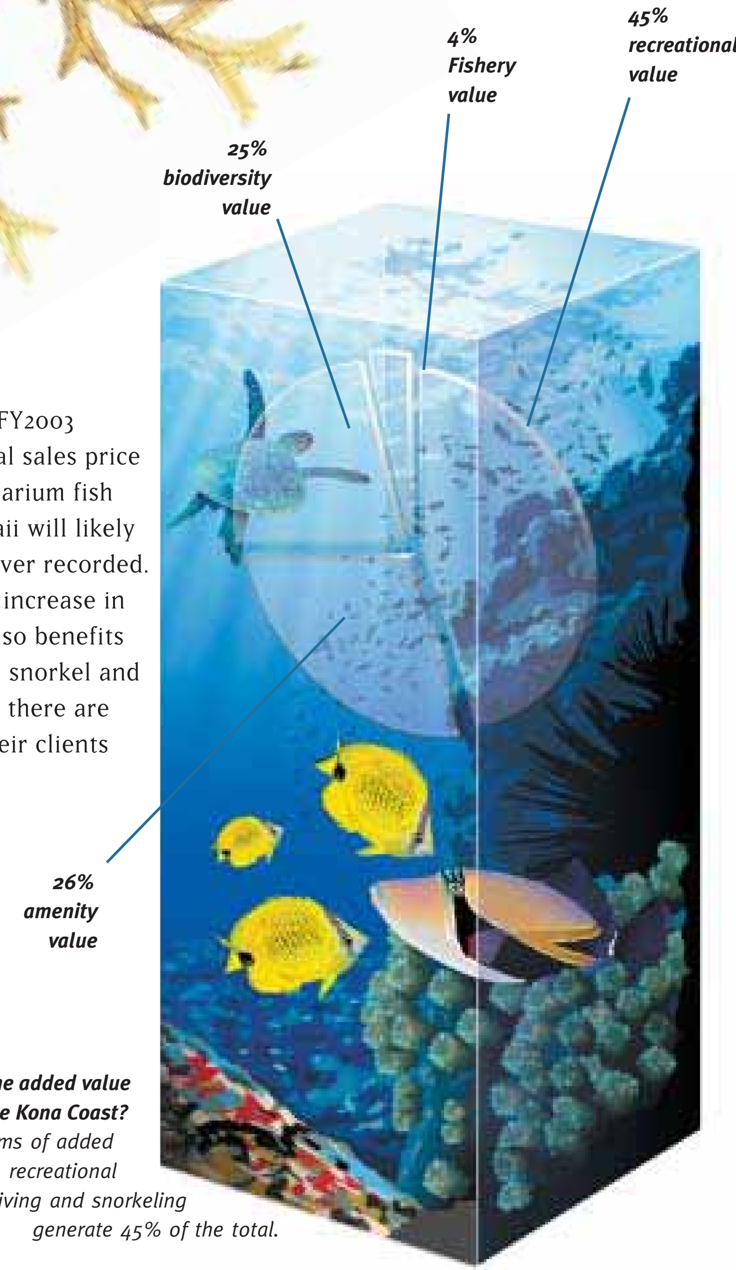
Each year, Kona coast reefs generate about $17.7 million in added value. Residential and tourist diving and snorkeling account for $8 million. Property values are enhanced by about $4.5 million. Non-use has an added value of $4 million. Nearshore fisheries, including the aquarium industry, generate another $700,000. Over time, these reefs will contribute over $880 million in added value.

The aquarium fish industry, although small in terms of added value, is one of the most economically valuable near-shore fisheries in the state. Statewide, aquarium fisheries have an added value of $1.8 million. Independent contractors gross $1.1 million in sales, with $700,000 in added value. The wholesale segment has gross sales of $2.1 million and an added value of $500,000. Therefore, the industry's gross sales are an estimated $3.2 million, with an added value of $1.2 million. Multipliers round out the total.

Fish replenishment areas (FRAs) along the Kona coast established by state government have decreased conflicts between aquarium collectors and other reef users over the past few years. Results of another HCRI-RP-sponsored project (*West Hawaii Aquarium Project* 1999-2002) show a recent increase in the abundance of aquarium fishes in both FRAs and unprotected sites.

Results show, since 2000 (when the FRAs were closed to aquarium fish collection), the overall price per fish collected has steadily grown.

Projections for FY2003 indicate the total sales price of collected aquarium fish from West Hawaii will likely be the highest ever recorded. In addition, the increase in aquarium fish also benefits the recreational snorkel and dive industry as there are more fish for their clients to see.



What is the added value of the Kona Coast?
In terms of added value, recreational diving and snorkeling generate 45% of the total.

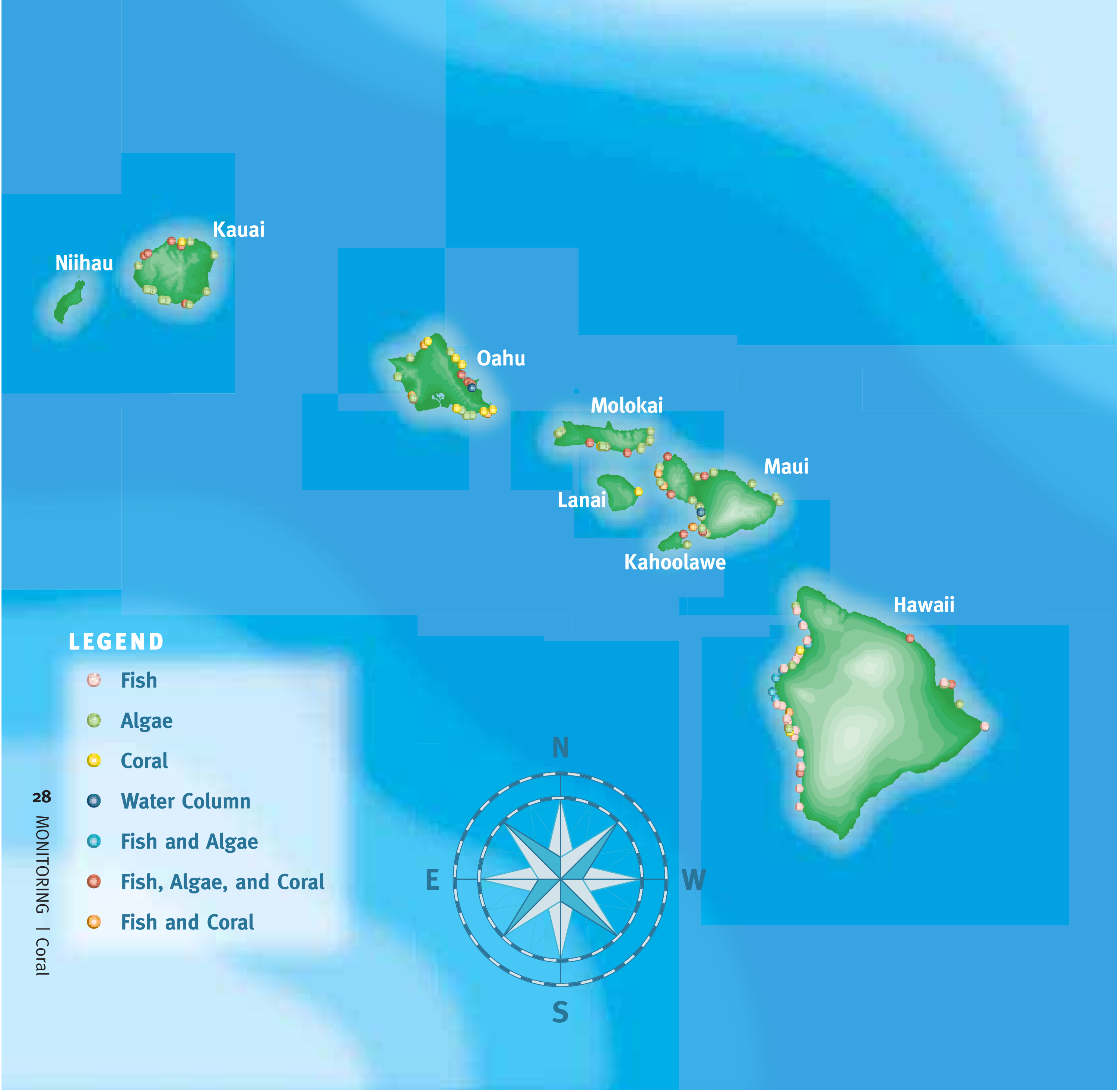
The monitoring projects

(Jennifer Smith)

Resource assessments and monitoring are crucial to understanding the health of coral reef ecosystems. Assessments gather information at one moment in time, giving a snapshot of the reef's health. Monitoring collects data over an extended time period, detecting fundamental ecological change. Both define key characteristics of reef ecosystems and can be used to identify resource management needs and to measure the effectiveness of specific resource management measures.

Monitoring methods that are effective for different components of an ecosystem may not be applicable to another. Methods to estimate coral cover are not easily applied to algae. Therefore, different monitoring and assessment methods need to be employed, with new ones continually under development.

CORAL MONITORING



HCRI-RP Project Sites.
HCRI-RP sponsors research and monitoring throughout the state. For detailed site information, go to: www.hawaii.edu/ssri/hcri

Transect and Photoquadrat Coral Monitoring

Coral Reef Assessment and Monitoring Project (1998-2002)

Principal Investigator
Dr. Paul Jokiel

Project Staff
Mr. Eric Brown
Ms. Kuulei Rodgers
Mr. William Smith

MANAGEMENT ISSUE

Designing a sampling protocol to detect change in coral cover depends on the variability of the existing habitat and the methods used, as well as time and monetary constraints. Taking this into consideration, HCRI-RP sponsored the establishment of a standardized, annual, coral monitoring protocol allowing for comparison between sites and through time with a high level of statistical power to detect change. This protocol uses digital video to capture data along a fixed line to determine coral cover by post-dive analysis. A second method employs permanent photoquadrats to establish coral abundance and, through time, can examine growth and mortality of individual corals.

RESULTS

Across the main Hawaiian Islands, the highest percentage of coral cover is found off southern Molokai, an area of low wave energy. The most common coral at 30-foot depths is the lobe coral *(Porites lobata).* Finger coral *(Porites compressa),* generally found in calm and shallow environments, seems to be the most common species in six-foot waters. Finger coral, among the most fragile of Hawaiian coral, also offers important habitat for fish, especially those prized by the aquarium industry. Other common corals include: cauliflower coral *(Pocillopora meandrina);* rice coral *(Montipora capitata);* and spreading coral *(Montipora patula).*

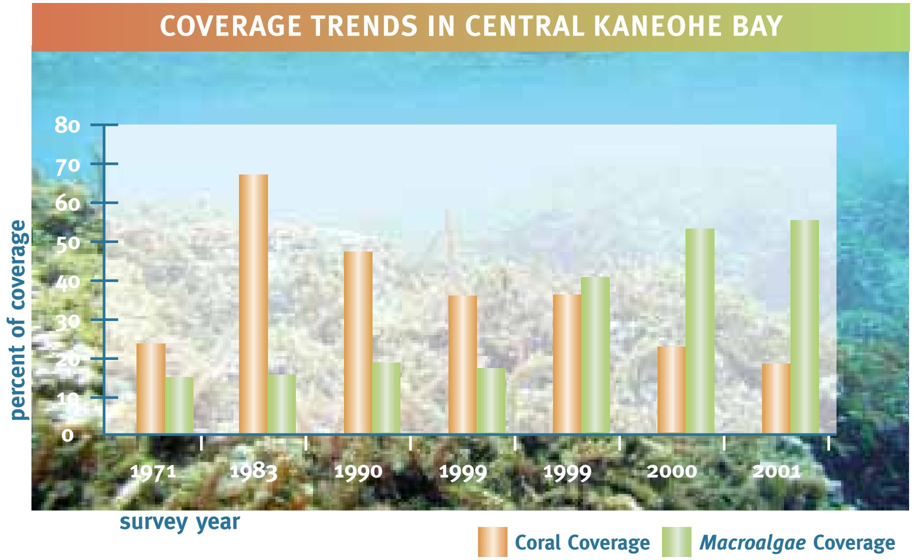
In general, coastal sites with high wave exposure (*e.g.*, Pupukea on Oahu, Hoai Bay on Kauai) have the lowest coral cover. Bays and wave-protected coastal areas (e.g., Palaau and Kamalo on Molokai) have the highest percentage of coral cover. Unfortunately, a large zone of damaged reef occurs in the middle portion of the south Molokai coastline as illustrated by Kamiloloa, which has the lowest coral coverage.

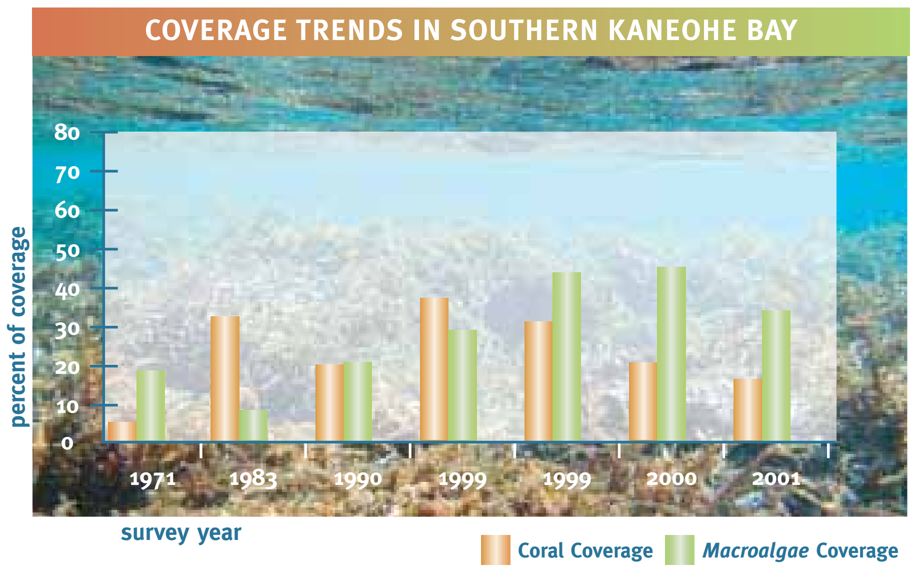
MANAGEMENT IMPLICATIONS

Initially, many considered the distribution of corals in Hawaii would change as one would move up the Hawaiian chain from the main to northwestern islands. The principal factor associated with coral distribution now appears to be water motion, with corals abundant in calm water regions. The evidence of the catastrophic, short-term declines found in other parts of the world could give the impression all is well with Hawaiian reefs.

Slow rates of decline will eventually result in severely degraded reefs. This decline could go undetected by researchers and managers without rigorous monitoring over a wide spatial array for many decades. The observed spatial patterns and temporal change of reef coral community struc-

Puako, Hawaii (Jennifer Smith).
Corals are the foundations of many reefs in Hawaii.





Coral and algae coverage trends in Kaneohe Bay.

ture in relation to human population suggests complex issues of algal-coral interactions continue to have significant effects on reefs.

Development of New Monitoring Tools for Coral Reefs

Fine-Scale Processes Affecting Health and Stability of Hawaiian Reefs (1998-1999)

Principal Investigator
Dr. Cindy Hunter

Project staff
Ms. Jennifer Smith

MANAGEMENT ISSUE

Coral reef biologists worldwide currently use a number of different monitoring techniques to assess the health and status of reef communities. Most techniques, however, take a complex three-dimensional community and flatten it into two dimensions. This process significantly biases the portion of the community the researcher is actually "monitoring" (usually the upper-most surface of the community).

For example, photographic quadrats are used to estimate the percent cover of specific organisms on a reef. With this method, the only part of the community that is seen is the very top, as if we were assessing a forest by simply studying the canopy. This is especially evident in areas where there is high rugosity. The downfall of such a method is that it fails to detect diverse populations of reef algae that grow on the vertical sides of corals or in cracks and crevices.

The lower left photo, next page, of *Porites compressa* (finger coral) shows a typical photographic quadrat. From this perspective, the percent cover of coral is estimated to be over 50%, with the rest of the area in the photo lost to dark crevices and unidentifiable. From the photograph on the lower right, next page (a side perspective), it is clear that the actual live coral is only the upper-most region. Filamentous turf algae actually dominate the overall three-dimensional substrate.

RESULTS

The project attempted to develop a monitoring technique that would address the three-dimensionality of coral reefs. To accomplish this, investigators worked to estimate the vertical height of a coral and then determine how much of the three-dimensional area was truly living coral.

MANAGEMENT IMPLICATIONS

Most monitoring methods are likely to significantly underestimate algal abundance on reefs. Coral cover may be changing vertically but, with current methodologies available to resource managers, changes in coverage or abundance of competing algae may remain undetected until substant shifts have occurred in the reef community. Further research is needed to add more sensitivity to detection of coral and algal competitors; the rapid ecological assessment protocol developed under the auspices of HCRI-RP for algal monitoring is a step closer.

Genetic Monitoring (Jennifer Smith). *It is possible to use genetic protocols to detrmine genotypes of important corals.*

Determining Genotypes of Coral via Molecular Methods

Genetic Variation and Status in Hawaiian Coral Species (1998-1999)

Principal Investigator
Dr. George Roderick

Project Collaborators
Dr. Amy Baco
Dr. Neil Davies
Dr. Sandra Romano
Ms. Amy Lack

MANAGEMENT ISSUE

Given the isolation of the state's reefs, limited understanding of dispersal distances among benthic reef species and concerns that populations remain poorly defined, this HCRI-RP project focused on examining the use of genetic markers for shallow water Hawaiian corals to add needed dimensions for future mitigation. With a historical genetic database, future genetic monitoring of reefs could be used to track human or natural disturbance. Genetic information also would provide the necessary data to evaluate the role of genetic diversity in the vulnerability of coral populations to disease and bleaching.

RESULTS

Gene regions for mitochondrial cytochrome oxidase I (COI) are likely to be sufficiently variable to resolve species, and some genotypes or clones within species. Mitochondrial DNA, however, is not variable enough for "genetic fingerprinting" of most coral genotypes. To address this problem, primers for a series of nuclear loci were designed and synthesized. Population sampling was initiated using samples collected by other HCRI-RP projects.

New Tools (Jennifer Smith). *Two-dimensional photoquadrants (left photo) fail to detect diverse populations of reef algae that grow on the vertical sides of coral or in the crack and crevices (right photo).*

MANAGEMENT IMPLICATIONS

In addition to the potential for genetic monitoring and species identification, future projects may require transplantation of corals into damaged regions as a form of mitigation. In such projects, genotype identity will be critical to select genotypes for the new outplants. Earlier work has demonstrated that coral genotypes can be numerous and co-occur on reefs. This work shows that it is possible to use genetic protocols to determine genotypes of important benthic species such as corals.

FISH ASSESSMENT AND MONITORING

Transect Fish Monitoring 33

Hawaiian Squirrelfish (ala`ihi)
(© James Watt/NOAA, www.wattstock.com).
Their red color makes these nocturnal fish difficult to see at night.

Transect Fish Monitoring

Coral Reef Assessment and Monitoring Project (1998-2001)

Principal Investigator
Dr. Paul Jokiel

Investigator
Dr. Alan Friedlander

Project staff
Mr. Eric Brown
Ms. Kuulei Rogers
Mr. William Smith

MANAGEMENT ISSUE

Current management strategies are directed at restricting fishing and often focus on particular species or small groups of species. These strategies do not address the habitat associated with these species and, therefore, may not be appropriate for the long-term sustainability of these resources.

This study evaluates the relationship between fish species and their associated habitat by examining these features at a range of locations that span sites with human impacts to remote locales, as well as varying wave exposures. The purpose is to determine the relative importance of particular reef characteristics to predict fish populations as an important new look at fisheries management.

RESULTS

Fish species' habitats varied depending on the degree of wave exposure associated with the sites. Out of 81 sites, species richness and diversity were highest in locations of moderate wave exposure. Kaneohe Bay had the lowest fish species richness and diversity compared to all other types of exposure. The total weight of all the fish present was lowest in areas exposed to north and south swells, regardless of human impact. Areas protected from direct swell activity had higher standing stock of reef fish, whether or not the site was remote.

A relationship between fish size and reef complexity suggests the importance of topographic rugosity providing shelter as a refuge for certain fish to avoid predation. Reef habitat roughness is provided by coral heads and fingers and explained almost 30% of the variability in the total weight of all the reef fish observed on transects.

Size Counts (Paul Jokiel). *Researchers assessing the size of the fish.*

In a few instances, high biomass occurred in locations with low habitat rugosity that was protected from fishing. This anomaly may be a result of migration from adjacent areas.

OTHER OBSERVATIONS

The most frequently seen fish found in nearshore coral reefs include: saddle wrasse *(Thalassoma duperrey)*; brown surgeonfish *(Acanthurus nigrofuscus)*; pacific gregory *(Stegastes fasciolatus)*; goldring surgeonfish *(Ctenochaetus strigosus)*; and blackfin chromis *(Chromis vanderbilti)*.

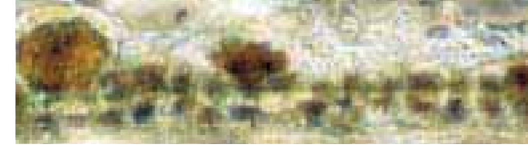
MANAGEMENT IMPLICATIONS

- Diversity, quality, and extent of habitat greatly influence the distribution, abundance, and diversity for coral reef fish.
- Identification and conservation of fisheries habitat is critical to sustain fisheries production.
- Habitat complexity provides refuges and barriers that result in more mixed species groupings.
- Habitats with limited shelter have low standing stocks for many fish species, while highly complex habitats are home to many and larger fish.

As a result of this study, managers have a better idea how to: assess overall health of reefs; identify which reefs are most valuable to protect as fish habitat; and approach selecting sites for possible active management. This new view identifies additional reasons why alien algal overgrowth (which fills in holes on reefs), leads to a decline in reef communities. Managers can now make informed decisions about sites for mitigation, development projects, and other human impacts that may affect reefs.

ALGAE ASSESSMENT AND MONITORING

Codium (Isabella Abbott).
This green alga's common name is "dead man's fingers."



Qualitative Macroalgae Monitoring

Macroalgal Ecology and Taxonomic Assessment for HCRI-RP Sites (1999-2002)

Principal Investigator
Dr. Isabella Abbott

Investigator
Dr. Celia Smith

Project staff
Mr. Ryan Okano

MANAGEMENT ISSUE

The major players on Hawaiian reefs, the reef algae, were poorly known for many of the islands prior to this series of studies. This plant group is 10 times more species rich than corals in the state and represents over 50% of the benthic cover in many regions of Oahu and the adjacent islands. Yet estimates of their abundance, or even lists of species, were missing from any quantative sampling approach. Given the more rapid growth rates for all algae when compared to coral, there is a need to know the constituent species in order to anticipate changes and practice informed management.

Under The Microscope (Isabella Abbott). *Enteromorpha is a green alga.*

The implementation of taxonomic research for Hawaiian marine algal communities permits greater understanding of species diversity. In turn, this leads to increased knowledge of algal interactions with other reef species. A solid taxonomic framework, in conjunction with quantitative monitoring, permits an understanding of any major changes in reef composition here or in many other places in the tropical Pacific. Most algal species respond to physical change in the environment more quickly than other marine organisms. Therefore, changes in algae cover and species composition may be an advance signal to resource managers of broader ecological changes that require management response.

RESULTS

The thirty-three sites sampled for algae yielded upwards of 1,200 specimens, of which 1,182 were processed and databased at Bishop Museum. 791 species were identified, although about 200 are tentative and require further study. An estimated 100 specimens remain unidentified and may be known elsewhere. These will be examined during FY2003. Twenty-eight new records of species previously not reported from the Hawaiian Islands, but known elsewhere, have been found. They are a mixture of green and brown algal species. In addition, seven species of red algae are new to science and are in the process of being described.

Red algae are the most commonly occurring algae in Hawaii. Of the five "most common" species of Hawaiian algae, four are red. Seventeen species of red algae are found in over 20 percent of all collections. Green and brown algae are widespread as well, with eight species of green algae and three species of brown algae found in over 20 percent of all collections.

MANAGEMENT IMPLICATIONS

Algae respond more quickly to changes in the ecosystem and the chances of seeing the changes are better. It is easier to ascertain these changes than changes in coral, fish, or invertebrate animal communities. Coupled with more definitive information about algal responses to environmental changes, resource managers and scientists will have another strong tool to assess health, monitor the status, and manage the coral reef ecosystem.

Workshops on algae identification, quantification, and the prevalence of weedy species, as well as invasiveness of a small number of introduced species, increased resource managers' awareness of the number of algal species and their role in the marine environment.

Rapid Ecological Assessment for Benthic Algae

Macroalgal Ecology and Taxonomic Assessment for HCRI-RP Sites (2000-2002)

Principal Investigator
Dr. Isabella Abbott

Investigator
Dr. Celia Smith

Project staff
Ms. Linda Preskitt

MANAGEMENT ISSUE

The goal of rapid ecological assessments (REA) is to quantitatively describe an ecosystem at a macrocommunity level as a baseline for future monitoring and management. In order to recommend a methodology to conduct rapid ecological assessments for benthic algae, researchers compared the efficiency and data consistency of photoquadrats and point grid quadrats.

RESULTS

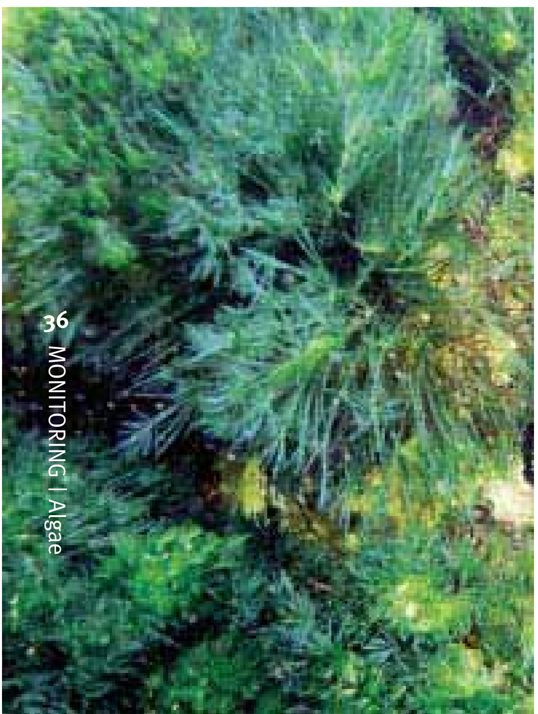
Photoquadrats are best used as a tool in transect-based reef assessments where one diver collects algae in conjunction with use of a photoquadrat. Practical advantages of photoquadrats as a tool for quantifying reef algae over point-intercept are numerous. In particular, photoquadrats:

- Generate significantly more data in post-dive analyses.
- Increase accessibility of vertical walls and pinnacles.
- Decrease training and experience requirements for some team members.
- Accommodate closer resolution and smaller organisms.
- Aid in laboratory identification and accuracy.
- Provide permanent records as photographs of areas.
- Lessen observational bias.
- Increase flexibility in statistical analysis.

No one method is without flaws. Digital photoquadrats are no exception. Each weakness, however, can be relatively easily overcome.

- Photoquadrats are more costly as equipment is susceptible to flooding and breakage. This necessitates having back-up cameras and housings available.
- Photoquadrats work best with flat surfaces for reefs with little rugosity. This can be overcome to some extent by using a light strobe.
- Misidentification can occur. Taking field notes and collections of the most abundant species and integrating this information in laboratory analyses can mitigate this problem.

Even with these added steps, rare, very small, and cryptic species are often overlooked in photoquadrats and necessitate a second diver whose collection activities provide tissues of cryptic species for identification. Photoquadrats will always prove costly in areas of algal canopy. Substantial canopies can completely conceal the understory in two-dimension photography, but removal of biomass and taking a series of pictures are not allowable within the time limits of REA. In addition, photoquadrats are more time-consuming than point-intercept quadrats during laboratory analysis.



***Bryopsis** (Jennifer Smith).*
A green alga that is common in areas near fresh water intrusion.

Tool For Quantifying Algae *(Linda Preskitt). Research divers using the photoquadrat method to survey reefs.*

MANAGEMENT IMPLICATIONS

The photoquadrat method provides adequate quantitative data when coupled with transects for study of benthic communities, flexibility for analysis, and permanent algal specimens to enable resource managers to see changes in remote, seasonally accessible regions.

Molecular Turf Algae Monitoring

Fine-Scale Processes Affecting Health and Stability of Hawaiian Reefs (1998-1999)

Principal Investigator
Dr. Cynthia Hunter

Investigator
Dr. Cliff Morden

Project staff
Ms. Rebecca Randall

MANAGEMENT ISSUE

Molecular characterization of species can be used to type corals as well as identify the tiny filamentous turf and crustose coralline algae that are too small to identify with the naked eye. These species require laborious effort to examine microscopically. Once processed, a "slurry" of genetic material reveals numerous species found in a one-inch by one-inch piece of algal turf.

The technique offers tremendous potential for rapid assessment of shifts in algal composition in reef communities. This new procedure allows for positive identification of a wide array of species in a relatively timely fashion, thereby making long-term monitoring of species composition more feasible.

RESULTS

Several variations on the original extraction protocol were employed to maximize the amount of DNA extracted. These included:

- altering incubation times and temperatures;
- modifying DNA extraction buffers; and
- altering amounts of algal tissue assayed

Species-specific molecular profiles have been developed that can be used to identify 16 species of red, green, and brown macroalgae and two species of microscopic blue-green algae.

While many challenges remain before this technique can be used to its full potential, the time savings and valuable information that can be collected from this process makes the technology promising for future use.

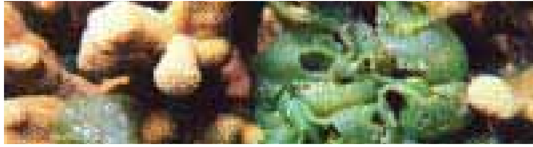
MANAGEMENT IMPLICATIONS

The techniques, once refined, have the potential to identify algae from as little as 0.2 grams of tissue in less than 48 hours, with a simple extraction process. This would give resource managers a tool to rapidly and precisely monitor shifts in algal composition in reef communities, enabling them to determine seasonal and year-to-year fluctuations. Eventually, this technique would be useful for early detection of the presence of a specific alga, such as an alien species. As with the molecular coral study, there is now a framework for interesting questions but much more research is needed before such a technique could be successfully applied.

Turf Wars (Jennifer Smith).
Turf algae and reef building coral are often in direct competition.

WATER COLUMN ASSESSMENT AND MONITORING

New Technology
(Jennifer Smith).
The pulse amplitude modulated (PAM) fluorometer is a relatively new device that can rapidly measure the photosynthetic rate of plants to assess the extent of pollution in the area.



Monitoring Nutrient Concentrations in Coastal Waters

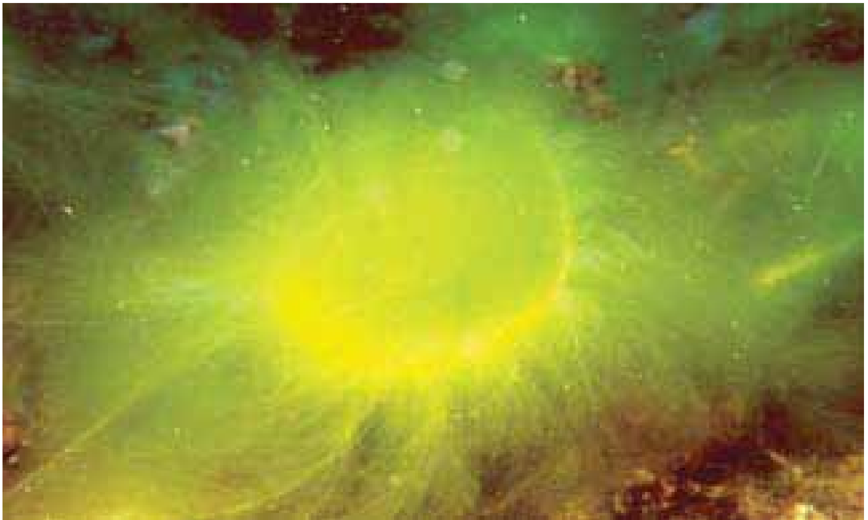
Macroalgal Bioindicators of Nutrient-enriched Marine Waters (2000-2002)

Principal Investigator
Dr. John Runcie

Investigator
Dr. Robert Kinzie

MANAGEMENT QUESTION

Addition of limiting inorganic nutrients stimulates growth of algae and can profoundly affect the balance between algae and coral dominance in reef ecosystems. To measure the responses of algae to ambient levels of inorganic nutrients found in coastal waters, this HCRI-RP project is using a relatively new device called a pulse amplitude modulated (PAM) fluorometer. The device, derived from plant physiology principles, is dive ready and allows for the rapid measurement of photosynthetic rates of plants (*e.g.*, seaweeds) and animals (*e.g.*, corals) in the field.



With these measurements, researchers or managers can assess the health of indicator algae and are thus able to estimate the flux of nutrients into a particular area. Elevated nutrient inputs are often related to major changes in coral reef ecosystem structure. Just as fisheries are intimately associated with reef habitat characteristics, algal productivity is similarly linked to the reef environment.

Chlodophora sericea (Isabella Abbott). *PAM technology can be used to measure the health of endemic alga such as this alga.*

RESULTS

Regular monitoring of *Dictyosphaeria cavernosa* developed a seasonal view of the physiology of this alga and the environmental conditions it experiences. During the wet season, nutrient concentrations at northern, central, and southern Kaneohe Bay sites were relatively high, as both tissue nutrient contents and photosynthetic rates of enriched algae were not greater than those of background algae. In contrast, both tissue nutrient content and photosynthetic rates of unenriched algae during the dry season were lower than for the enriched algae at southern and central Kaneohe Bay sites. Relatively high nitrogen levels were maintained at the northern Kaneohe Bay site. Thus, nutrients are generally more available at the north bay in times of low rainfall, and are available thorughout the bay when rain is more common.

MANAGEMENT IMPLICATIONS

Nutrients clearly drive the growth of algae, including the alien algae that have caused serious environmental problems in west Maui, Kihei, and Kaneohe Bay. Understanding the nature of nutrient runoff and the levels and types of nutrients that cause such problems is critical to controlling algal blooms. Regular monitoring will be required to pinpoint sources and understand better the dynamics of the relationship between land-based nutrients and negative impacts on coral reef ecosystems. This technique shows promise for both monitoring nutrient concentrations in surrounding waters via algal responses and understanding how nutrients affect marine algae and plants.

Continuous Monitoring of Water Quality (2000-2002)

Principal Investigator
Dr. Fred MacKenzie

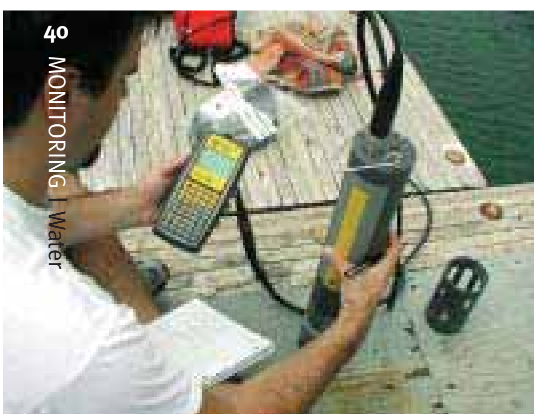
Investigator
Dr. Dan Hoover

Project staff
Ms. Stephanie Ringuet

MANAGEMENT QUESTION

The process of urban runoff and its impact on water quality in Hawaii, especially after rainfall, is highly dynamic. In the past, water quality was tested through water samples that were static one-time measures, merely snapshots in time of an ever-changing water column environment.

In contrast, continuous monitoring of water quality can capture data documenting effects of significant storm runoff events that may not be recorded using even biweekly manual sampling methods. These data include far more accurate assessments of peaks in inputs and volumes of runoff as a result of their repeated, rapid monitoring. Documenting the magnitude and persistence of storm runoff impacts on the quality of coastal waters will eventually lead to better management of coral reef ecosystems.



Continuous Monitoring (Dan Hoover). *Calibrating the instrument to measure temperature, pH, turbidity, salinity, chlorophyll, and dissolved oxygen.*

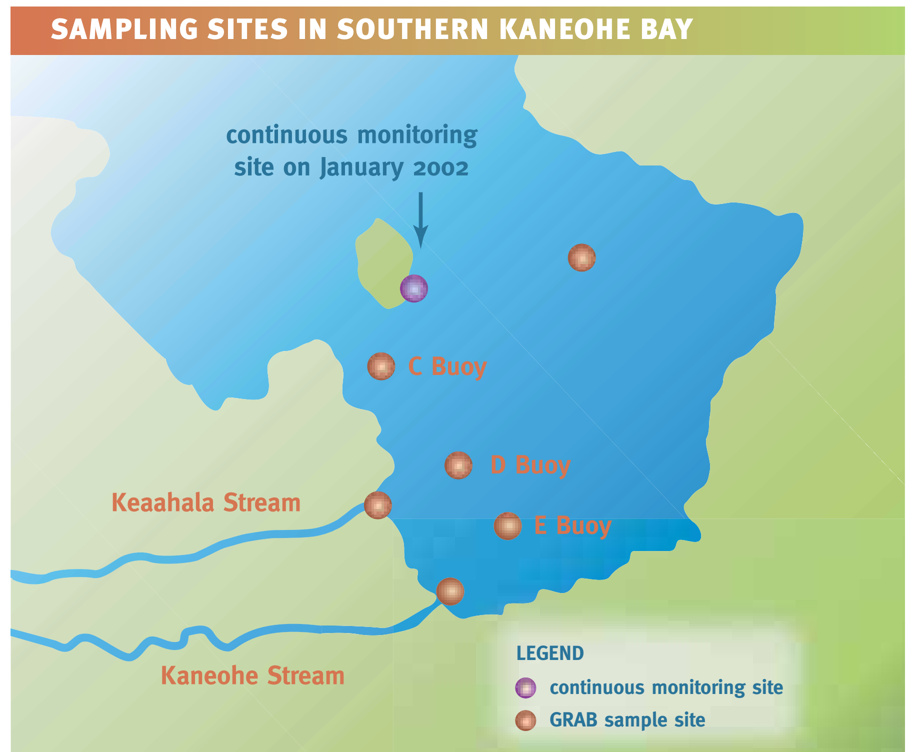
RESULTS

Taking advantage of technological developments in oceanographic instrumentation, the research project assembled a complete, continuous monitoring instrument package with both nutrient monitors (nitrate and phosphate) and a monitoring system for physical and biological parameters (temperature, salinity, pH, dissolved oxygen, turbidity, and chlorophyll-a). Researchers found that even though nutrient loading via storm runoff stimulates phytoplankton growth, the depletion in dissolved inorganic phosphorus can rapidly lead to a crash of the population. Therefore, an average storm runoff event in Kaneohe Bay cannot cause eutrophication without additional phosphorus inputs. In addition, while storm runoff plays an important role, variability in reef community production is strongly a function of meteorological parameters, such as solar radiation and wind.

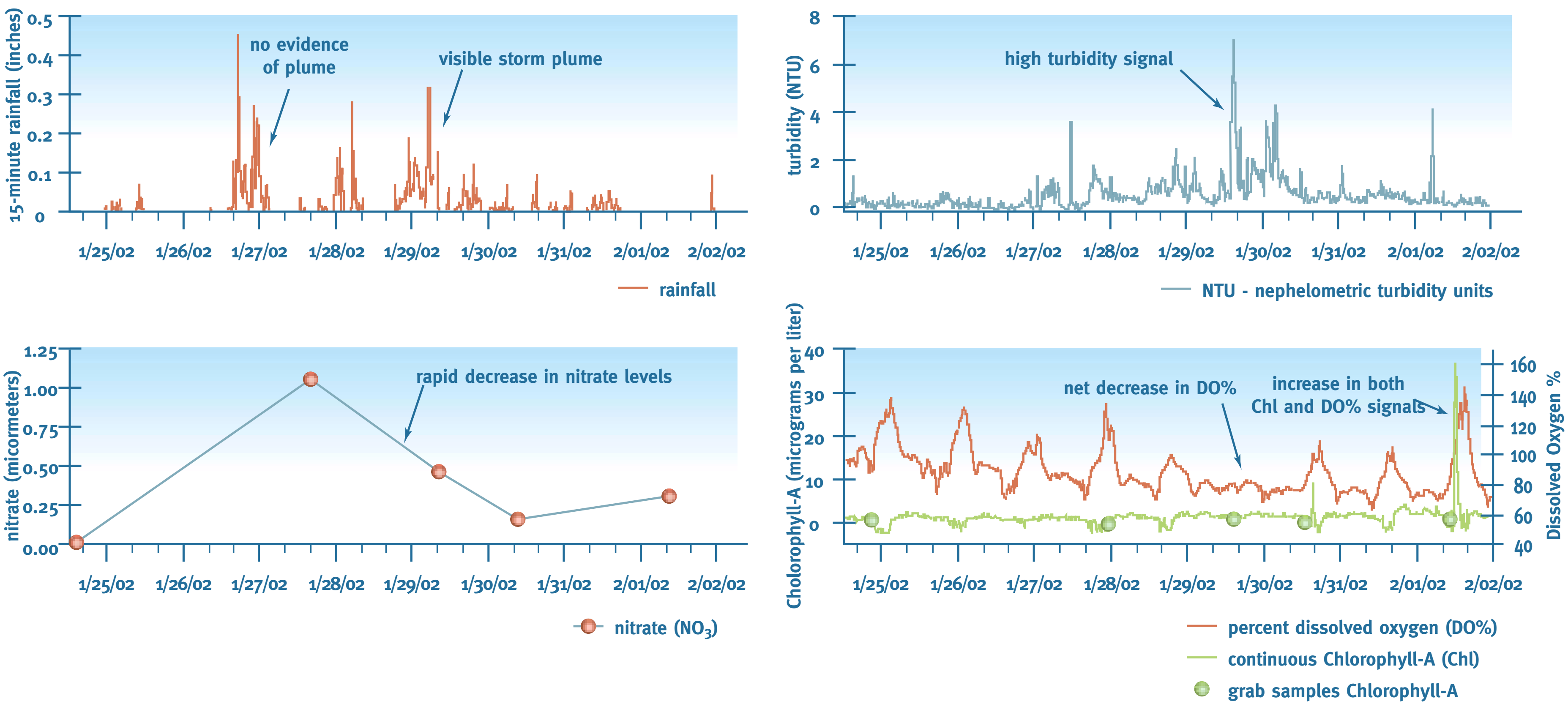
Capturing Data (Dan Hoover). *Retrieving data from the "in situ" nitrate analyzer after its deployment in Kaneohe Bay.*

MANAGEMENT IMPLICATIONS

Continuous monitoring of nutrients and other water quality parameters will enable resource managers to better assess the extents of input for the first time, as well as begin to monitor the potential for water pollution in coastal waters via remote instrumentation and to observe the range of natural variations in healthy waters. Ultimately, this innovation (which is not available commercially), makes it possible to have more informed and effective management of both land-based sources of pollution and the marine environment.



JANUARY 2002 STORM EVENT: AN ILLUSTRATION OF RUNOFF-INDUCED VARIABLES



Note that these graphs emphasize the impact of runoff over time at a particular point, but there is also a manifest lateral and vertical variability in southern Kaneohe Bay.

The threats

(Lisa Huynh)

Human action can upset the balance of life on coastal reefs and amplify changes to natural cycles, resulting in the degradation of the coral reef ecosystem.

All of the most significant problems threatening reefs of the main Hawaiian Islands are the direct or indirect result of human activities, both in the marine environment and on land. These activities include: the introduction of alien species; fishing pressure; sediment and nutrient runoff from agriculture, golf courses, and construction sites; storm drains and septic tanks; trampling; anchor damage; and vessel groundings.

While each poses a significant threat to coastal reef communities, the marine environment is subject to multiple threats at any one time, compounding the stress to the ecosystem.

ALIEN AND INVASIVE SPECIES

Washed up (Jennifer Smith). *An estimated two tons of Gracilaria salicorna washed up along a 200-foot section of Waikiki Beach after a large winter swell.*

Alien Algae Distribution

Ecological Success of Alien and Invasive Algae in Hawaii (1999-2000)

Principal Investigator

Dr. Cynthia Hunter

Project staff

Mr. Eric Conklin
Ms. Jennifer Smith
Dr. Randy Kosaki

MANAGEMENT ISSUE

Documentation of the distribution and abundance of alien algae in the first systematic, statewide assessment provides resource managers with the tools necessary to evaluate current threats from alien species in Hawaii, monitor their spread and impacts on other reef organisms, and evaluate the feasibility of removal and control options.

RESULTS

- Surveys were conducted at 81 sites, producing maps of the abundance of 19 alien algae introduced to Hawaii since 1950.
- Five alien algal species were found to be ecologically dominant in some shallow water Hawaiian reef habitats.
- *Acanthophora spicifera* is the most common alien alga in the state and can commonly be observed fouling boat hulls in many harbors suggesting a vector for interisland transport
- *Gracilaria salicornia* and *Kappaphycus* most often overgrow living coral.
- *Gracilaria salicornia* now covers over 50% of the bottom at the Pukoo lagoon and adjacent reef on Molokai.
- *Avrainvillea amadelpha* was recorded on Kauai, the first reported sighting of this species outside of Oahu.

MANAGEMENT IMPLICATIONS

The issues of alien and invasive algae in Hawaii are dynamic. Clearly each species is unique and each benefits from separate adaptations that lead to ecological success in a variety of habitats. If we are to manage each species and its impact, a diverse and multidisciplinary approach needs to be integrated into the development of a comprehensive management plan to span this diversity among alien algae.

Kappaphycus spp. | ***Gracilaria salicornia*** | ***Acanthophora spicifera*** | ***Hypnea musciformis*** | ***Avrainvillea amadelpha***

Macroscopic View of Alien Algae

Field Perspective of Alien Algae

MOLOKAI BEWARE — ALIENS NOW FOUND IN YOUR WATERS!

Within Molokai's Pukoo Harbor, huge mats of the alien alga *Gracilaria salicornia* were observed in surveys in 2000. This was the first (and, so far, only) record of this species for Maui County after its initial introduction for aquaculture in association with fishpond cultivation.

Why should Molokai residents be concerned about the emergence of this invasive alga? *Gracilaria* is a genus with many native species. *Gracilaria coronopifolia* and *Gracilaria parvispora* are our native limu manauea and ogo.

Although this species is not common throughout Hawaiian reefs, the alien *Gracilaria salicornia* typically becomes ecologically dominant where it occurs (*e.g.*, Waikiki and southern Kaneohe Bay on Oahu). This species has the potential to physically alter the environment by outcompeting native corals and algae and reducing species diversity.

Recent evidence suggests that *Gracilaria salicornia* is spreading along the fringing reefs of southern shorelines of Oahu and Molokai. In 2003, HCRI-RP is sponsoring a second assessment to quantify the spread of the alga since 2000.

Alien Algae Reproduction

Ecological Success of Alien and Invasive Algae in Hawaii (1999-2000)

Principal Investigator
Dr. Cynthia Hunter

Project staff
Ms. Jennifer Smith

MANAGEMENT ISSUE

Most algae can reproduce by fragmentation. From an ecological perspective, the ability to fragment readily, disperse widely prior to recruitment, and successfully attach in a short periods of time are important characteristics of invasive species. For species that reproduce by fragmentation, it is critical to determine the smallest size fragment necessary for regrowth. This is often unknown, but needed to set parameters for mitigation efforts aimed to remove plants or reduce population spread.

Morphological and physiological mechanisms that these plants exhibit must be identified and documented in order to more completely understand their biology and ecology. Management decisions based on a comprehensive understanding of algal biology have the best chance to achieve the goals of limiting alien dispersal and spread.

RESULTS

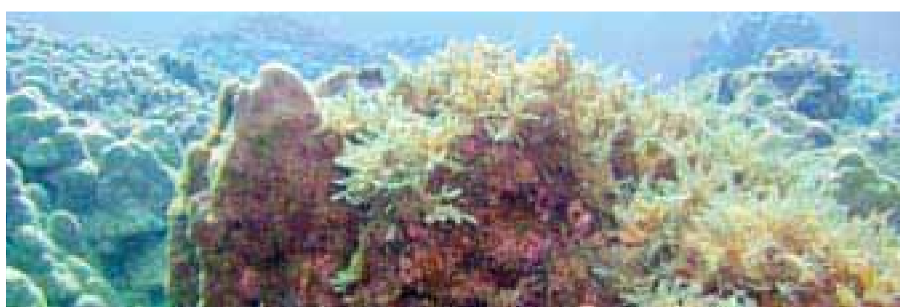
In recent experiments the alien red alga, *Hypnea musciformis*, showed great potential for fragmentation at all size classes with highest success in the smallest fragments. The morphology of this species is unusual in the Hawaiian flora by having apical hooks at the tips of its branches. These hooked tips are used by the plant to attach itself to other macroalgae or other available substrates. The smallest size fragments generated from these apical hooks increased up to a 200% in weight in one week of growth. When this species is ripped from the substrate, the hooks are left behind and can regrow rapidly.

All alien algae grew from small fragments. For *Hypnea musciformis* and *Gracilaria salicornia*, the smallest fragments (0.5 centimeters) grew fastest. For *Avrainvillea amadelpha*, the largest size fragments (3 centimeters or greater) were the most successful.

Prior to this study, sexual reproduction had not been observed in the field for any of the introduced species of algae in Hawaii. During field surveys, sexually reproductive individuals of *Acanthophora spicifera* were collected on all islands except for the Island of Hawaii. Individuals of this species were also observed on the hulls of ships on Oahu, Kauai and Molokai. No other alien algae were seen releasing spores or other sexual propagules in the field.

MANAGEMENT IMPLICATIONS

For the algal species in which fragmentation is a primary method of reproduction, any disturbance that



***Kappaphycus* in Kaneohe Bay, Oahu**
(Jennifer Smith).

results in detachment or breaking of these plants from the substrate – such as wave action, trampling, fish bites, or removal efforts – may lead to propagation and dispersal. The ability of these alien algae to reproduce by vegetative propagation may limit options for removal and enhances the need for proper training of volunteers and managers prior to conducting removal efforts.

Herbivorous Fish Grazing Preferences

Ecological Success of Alien and Invasive Algae in Hawaii (1999-2000)

Principal Investigator
Dr. Cynthia Hunter

Project staff
Mr. Eric Conklin
Ms. Jennifer Smith

MANAGEMENT ISSUE

Invasive and alien algal species in Hawaii may grow and spread more readily than native species because their natural predators may be absent or reduced in numbers by over fishing. A variety of tropical algae possess both physical and chemical defenses against herbivores. It is important to determine the level at which alien or invasive algae are palatable to Hawaiian grazers. Alien algal species that are preferred relative to their native counterparts may be kept in check under high grazing pressures.

In particular, resource mangers need to know if common reef grazers eat alien algae. If they do, is herbivore abundance in Hawaii sufficient to control the spread of invasive algal species?

RESULTS

Alien *Acanthophora spicifera* is highly preferred over an ecological native counterpart, *Laurencia nidifica*.

Gracilaria salicornia and *Kappaphycus* were the least preferred by herbivores, and are the most likely to overgrow corals, perhaps, in part, because of their low preference by herbivorous fish.

No significant differences were found between other alien-native pairs.

MANAGEMENT IMPLICATIONS

Highly preferred species are unlikely to displace native algae if sufficient herbivore populations are present. Species not preferred by herbivores may grow unchecked, posing a greater direct threat to native species. Alien algae that are not grazed by herbivores will require more effort in order to control their impacts on reefs.

Assessing Nitrate Use by Native and Alien Algae

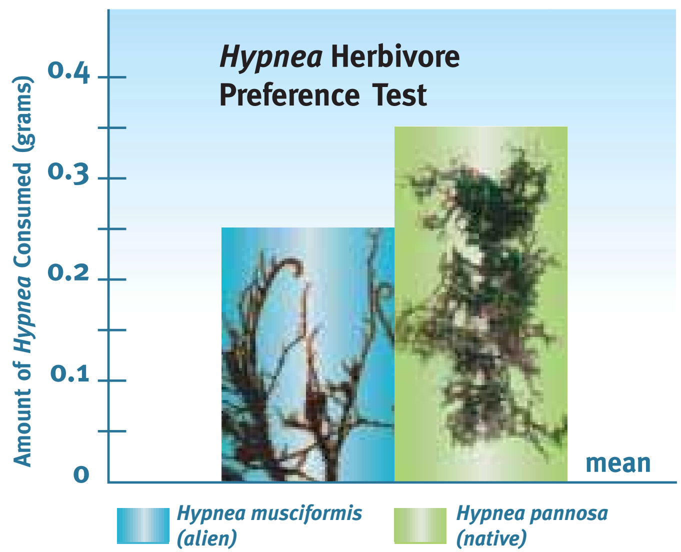
Ecological Success of Alien and Invasive Algae in Hawaii (1999-2000)

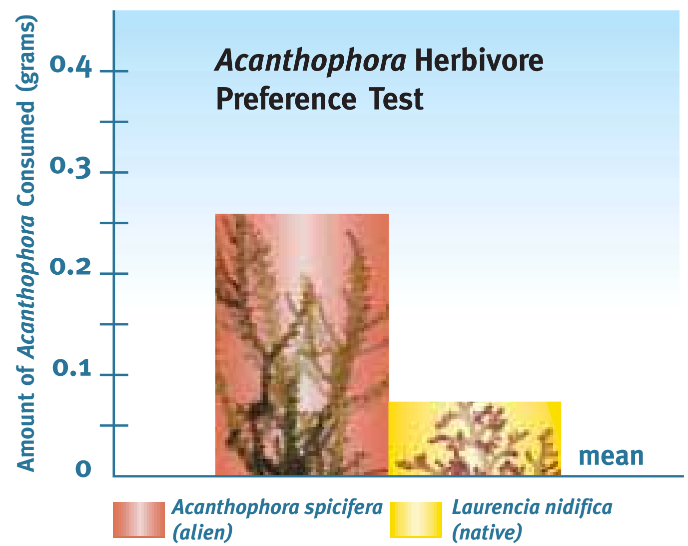
Principal Investigator
Dr. Cynthia Hunter

Project staff
Ms. Jennifer Smith

MANAGEMENT ISSUE

There are two primary forms of inorganic nitrogen that can be used by algae: nitrate and ammonium. Although nitrate is usually the more common form of nitrogen in nearshore waters, it is more metabolically costly for plants to use than ammonium.





SUMMARY OF ALIEN ALGAE CHARACTERISTICS INVESTIGATED

species	distribution	fragmentation	herbivory	nitrogen reductase activity
Acanthophora spicifera	All islands, naturalized, upper intertidal	No, but sexually reproductive individuals observed in field on three islands	Highly preferred	High
Hypnea musciformis	All islands, patchy, may be tied to land use activities	Yes, "apical hooks" appear to be unique propagules	Highly preferred	Very high
Gracilaria salicornia	Oahu, Molokai & Hawaii – very discontinuous	Yes, highly successful at all size classes	Not preferred	Moderate
Avrainvillea amadelpha	Oahu	Not successful for small size classes	Not eaten	Low to moderate

Algal species that are able to use ammonium or nitrate most efficiently may be able to sustain higher growth rates than other, less efficient, species. Nitrate reductase (NR) is an enzyme used by algae during the process of nitrate uptake. Experiments were conducted to determine if alien algae are able to use nitrate more readily than select native species, thereby giving these species a competitive advantage.

This information will help to determine if these invasive algal blooms are driven by altered nutrient conditions or other factors.

RESULTS

- *Ulva fasciata* (invasive) showed the highest rates of nitrate reductase activity. This species is able to take up nitrate even when ammonium concentrations are high.
- *Acanthophora spicifera* (alien) had NR levels similar to *Ulva fasciata*. These results suggest that where nitrogen concentrations are high, *Acanthophora spicifera* may respond by rapid growth.
- *Avrainvillea amadelpha* (alien) did not use nitrate more readily than its native counterpart. Many invertebrates, however, inhabit the interior spaces in *Avrainvillea*, and this infaunal contribution may provide high levels of ammonium directly to the plant.
- *Hypnea musciformis* (alien) showed high levels of NR activity, second only to *Ulva fasciata*. Because *Hypnea musciformis* is able to take up nitrate rapidly, it is also very likely to respond to high nitrogen inputs.
- Both *Gracilaria* species tested were competitively equivalent at taking up nitrate.

MANAGEMENT IMPLICATIONS

Results of this study showed that the capacity of alien and invasive algae to use nutrients differs markedly among species. *Ulva fasciata*, *Acanthophora spicifera*, and *Hypnea musciformis* had high rates of nitrate reductase activity, even in the presence of high ammonium concentrations. This suggests these species are able to take up both forms of nitrogen rapidly. Because these species are often seen "blooming" in nearshore environments, it is likely elevated nutrient levels may be influencing their proliferation.

Nutrient Uptake and Macroalgal Photosynthesis

Macroalgal Bioindicators of Nutrient-enriched Marine Waters (2000-2001)

Principal Investigator
Dr. John Runcie

Investigator
Dr. Bob Kinzie
Dr. Evelyn Cox, Investigator

MANAGEMENT ISSUE

Understanding the influence of nutrients on macroalgae and related macroalgal responses (i.e., photosynthesis) can assist in the identification of nutrient-related response of coral reef ecosystems to nutrient pollution. This helps resource managers understand the linkages between land-based activities and coral reef ecosystem health.

Nutrient sufficient macroalgae are those whose growth rates are not limited by a lack of essential nutrients, while nutrient deficient macroalgae require extra nutrients if they are to grow at maximum rates. Using modern techniques in fluorometry, researchers can distinguish between nutrient deficient and sufficient macroalgae. This approach offers a kind of early warning to the potential for plants in a region to bloom.

RESULTS

The photosynthetic rate of *Ulva fasciata*, an invasive alga, reflects the nutritional status of that macroalga. Specifically, photosynthesis was measured using a submersible fluorometer that allows rapid and sensitive parameters to be measured with the minimal amount of disruption to the alga. If macroalgae are treated to elevated nutrients and show responses to those nutrients, then we consider those responsive macroalgae as nutrient limited. For example, enrichment of the alga *Ulva fasciata* with nitrogen or phosphorus resulted in the highest rates of photosynthesis. Those macroalgae that were only enriched with nitrogen had the second highest photosynthetic rate, while rates of the control and phosphorus-enriched algae remained very low. *Gracilaria salicornia*, an alien alga to Oahu, responded to nitrate enrichment. *Dictyosphaeria cavernosa,* an invasive alga, provided consistent results and is recommended for use as a bioindicator when monitoring water quality in Kaneohe Bay on Oahu.

MANAGEMENT IMPLICATIONS

The *in situ* fluorescence technology shows much promise for conducting rapid assessment in the field. Selection of the most suitable alga is an important requirement for obtaining consistent results.

Investigating the Cause of an Algal Bloom (John Runcie). *To see if nutrient-laden groundwater significantly contributed to blooms of the Cladophora sericea, photosynthetic rates were measured with PAM directly offshore of a sewage treatment plant.*

Using Fluorometry to Assess Macroalgae Blooms

Macroalgal Bioindicators of Nutrient-enriched Marine Waters (2000-2001)

Principal Investigator
Dr. John Runcie

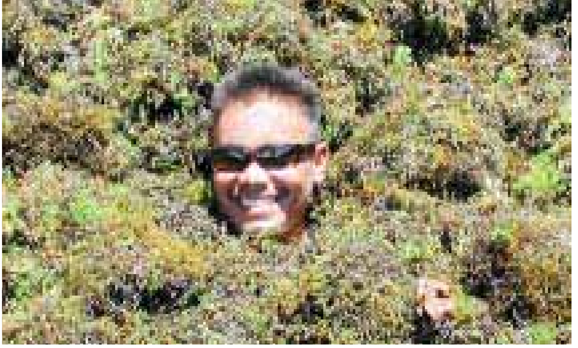
Investigator
Ms. Jennifer Smith

MANAGEMENT ISSUE

Seasonal blooms of the filamentous green alga *Cladophora sericea* have occurred frequently in west Maui. Large amounts of algal material are washed up on the shore where it becomes a nuisance for beachgoers. This project was designed to examine whether elevated nutrients may be influencing the formation and persistence of these blooms.

RESULTS

A pulse amplitude modulated (PAM) fluorometry device measures photosynthetic rates directly in the field, thereby allowing researchers and managers to use algae as a proxy for water quality. To determine if nutrient-laden groundwater was a significant contribution to blooms of the filamentous green alga *Cladophora sericea*, photosynthetic rates were measured with PAM directly offshore of a sewage treatment plant. Nutrient chemistry was assessed from porewater and water column samples. Porewater in some areas had a lower salinity than the surrounding seawater, and had much higher than ambient nutrient levels, suggesting that nutrient input at this location may be, at least in part, due to groundwater seepage.



***Gracilaria salicornia* Cleanup** *(Jennifer Smith). Over 32,000 pounds of alien algae were collected during four volunteer cleanup events.*

In areas where the bloom was most dense, *Cladophora sericea* plants did not respond to experimental nutrient enrichment. This suggests these plants were receiving sufficient nutrients to sustain maximal photosynthetic rates. Plants on the perimeter of the bloom, however, did respond to enrichment suggesting there may have been a localized source of nutrient enrichment in the bloom area. Water sample results further supported this observation. While water column nutrients were low for all sampling locations, porewater nutrients were highly correlated to bloom density, tissue nutrient levels, and overall algal physiology. These results suggest that a localized area of nutrient enrichment was fueling the algal bloom.

MANAGEMENT IMPLICATIONS

Resource managers need to understand the cause of algae blooms before definitive management action can be initiated. If nutrient enrichment is a primary factor in bloom formation, resource managers and environmental health officials must act cooperatively with land-based organizations to determine the source of nutrient loading, whether from wastewater treatment, agriculture runoff, or other sources.

Options for Eradication and Control of *Gracilaria salicornia*

Feasibility of Removing Alien and Invasive Algae (2001-2002)

Principal Investigator
Dr. Cynthia Hunter

Project staff
Ms. Jennifer Smith
Mr. Eric Conklin
Ms. Cheryl Squair
Ms. Rebecca Most
Mr. Thomas Sauvage

MANAGEMENT QUESTION

Very limited research has been conducted on the ecology of *Gracilaria salicornia*, an alien alga overgrowing reefs in Waikiki and Kaneohe Bay. This species forms coral-smothering mats, tolerates a wide-range of light environments, and monopolizes nutrients seeping out of the sediment.

Fragmentation is its primary mode of reproduction. Physical disturbance can generate fragments that disperse through currents. *Gracilaria salicornia* has become the single-most prominent species at the east end of Waikiki. The extensive accumulation of algae washed ashore can prevent beachgoers from using this area of Waikiki beachfront.

Prior to its introduction in the 1960s, well over 60 species of macroalgae could be found on this area of reef at Waikiki. At present, *Gracilaria salicornia* is the single most dominant species on this reef. Not only does *Gracilaria salicornia* appear to reduce species diversity, it may also outcompete and overgrow coral. Because of these potential impacts to Hawaii's reef ecosystems and economy, this study investigated strategies for its control.

RESULTS

Over two tons of *Gracilaria salicornia* were estimated to have washed up along a 200-foot section of Waikiki Beach after a large winter swell. At high tide, this material is washed back out onto the reef where it disperses and re-establishes. These fragments can remain viable after more than three hours desiccation on the beach and represent a large pool of potentially dispersive propagules.

Manual removal is effective, but time consuming. In four cleanup efforts, over 200 volunteers removed roughly 32,000 pounds of *Gracilaria salicornia* from the reef in Waikiki. The removed alga was recycled for use as compost and soil amendment. Several additional control strategies were examined, including use of chemical, temperature, and salinity manipulations. *Gracilaria salicornia* is very robust to changes in temperature and salinity, and extreme conditions are required to kill it.

MANAGEMENT IMPLICATIONS

Evidence from the recent surveys suggests that *Gracilaria salicornia* is still spreading and dispersal rates appear to be increasing. As new populations emerge, more biomass is available for fragmentation and subsequent dispersal. Without intervention, this species is highly likely to invade many new sites. A multifaceted approach is needed to develop a successful control program.

Manual removal is currently the most feasible control strategy available. This technique, however, is extremely time-consuming (6.9 person-hours to remove a square meter of alien algaefrom the reef). *Gracilaria salicornia* regrows rapidly from small pieces left behind. Most likely a combination of techniques will be needed for successful control. A promising combination is manual removal of the large biomass combined with enhancement of populations of native grazers to control the remaining fragments.

Options for Eradication and Control of *Kappaphycus*

Feasibility of Removing Alien and Invasive Algae (2001-2002)

Principal Investigator
Dr. Cynthia Hunter

Project staff
Ms. Jennifer Smith
Mr. Eric Conklin
Ms. Cheryl Squair

MANAGEMENT ISSUE

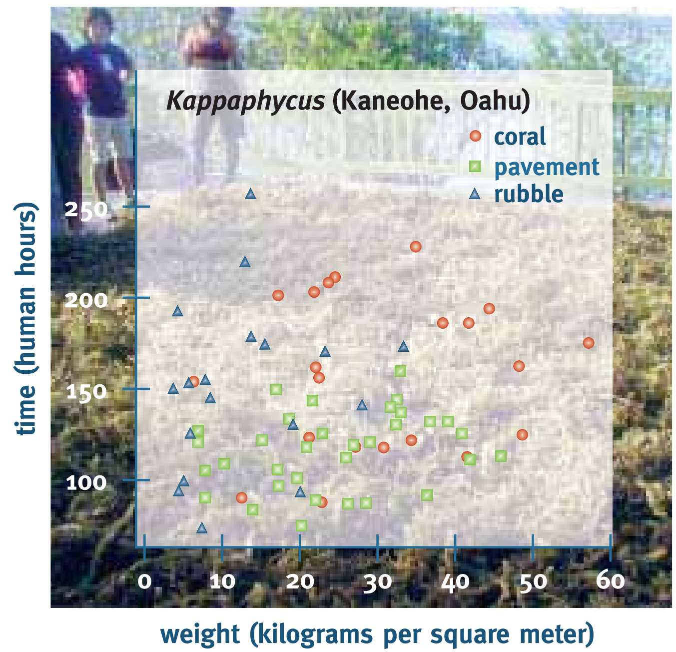
Kappaphycus is spreading rapidly through Kaneohe Bay, dramatically increasing in abundance on reefs over a short period of time, and overgrowing corals. It is one of the least preferred species by fish herbivores. There is a need to develop techniques to remove the alga in order to preserve the bay's coral reefs.

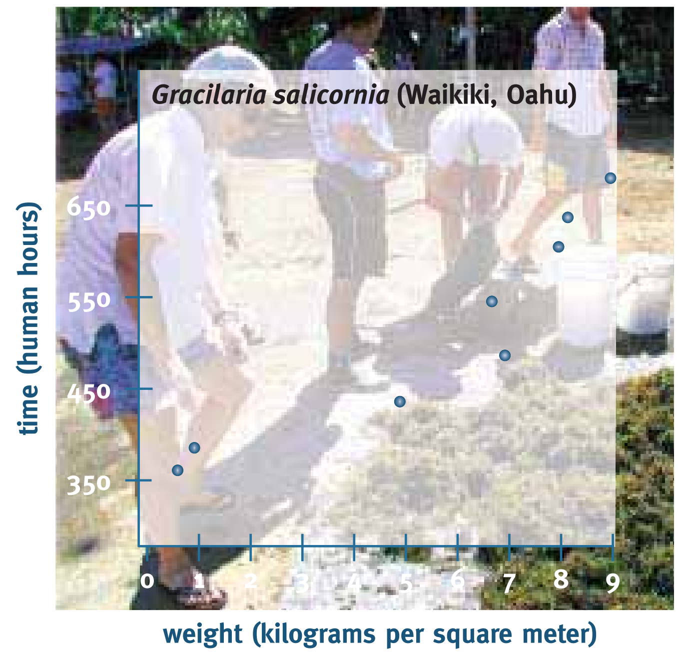
RESULTS

- *Kappaphycus* overgrows native algae and corals and its abundance is negatively correlated with species diversity.
- With up to 30 kilograms of algae per square meter, manual removal is extremely time-consuming.
- Chemical, temperature, and salinity treatments kill the alga, but may not be practical for use in the field.
- Volunteer clean-ups are very good at removing large amounts of *Kappaphycus* in a short period of time. Approximately 30 volunteers removed over 2000 pounds at two cleanup events.
- Increased nutrients enhance the ability of *Kappaphycus* to regrow.
- Native sea urchins (*Tripneustes gratilla*) consumed *Kappaphycus* in experimental plots and enhancement of this species may be a useful tool for *Kappaphycus* control.

MANAGEMENT IMPLICATIONS

Without a removal program, this alga will continue to spread and alter coral reefs in Kaneohe Bay. Manual removal is effective at removing *Kappaphycus*, but is time-consuming and the alga grows back. Developing a mechanized removal system to efficiently remove large mats, in conjunction with enhancing native urchin populations, is a promising strategy. HCRI-RP is sponsoring a project to investigate the potential of sea urchin control in 2003.





FISHING PRESSURE

Shore Fishing (© Ed Watamura). *40% of Hawaii residents fish for food or recreation.*

Viability of Transplanting Herbivorous Fish

Fine-Scale Processes Affecting Health and Stability of Hawaiian Reefs (1998-1999)

Principal Investigator
Dr. Cynthia Hunter

Investigator
Dr. John Stimson

Project staff
Mr. Eric Conklin

MANAGEMENT ISSUE

Other HCRI-RP projects have shown that nutrient loading and the depletion of herbivorous fish populations contribute to the growth of alien and invasive algae in Hawaii. Management strategies for addressing alien and invasive algae are limited and poorly developed. One option for controlling the growth of algae is to transplant herbivorous fish in order to increase grazing pressure on an alga overtaking an area.

RESULTS

Several hundred herbivorous fish were transplanted to two small reefs in Kaneohe Bay from larger reefs over one kilometer away. These transplants should have increased the fish population on each reef by over 50%. Two months later, there was no significant increase (relative to the control reef) in numbers of fish remaining in the transplant areas. Reefs selected for this effort had substantial algal overgrowth and were heavily degraded. The resulting lack of shelter or preferred foods may have limited the number of herbivorous fish the reef could support.

MANAGEMENT IMPLICATIONS

The reefs used in this experiment were heavily overgrown by algae with very little living coral or rugosity remaining. Algal removal and habitat restoration, in combination with fish transplantation, may be needed before herbivore populations can be increased.

Experimenting with fish (© Mark Mohlmann). *Herbivorous fish, such as these convict tangs, were transplanted to a small reef to help control the growth of algae.*

Monitoring Aquarium Fish Collection

West Hawaii Aquarium Project (1999-2002)

Principal Investigator
Dr. Brian Tissot

Investigators
Dr. Bill Walsh
Dr. Leon Hallacher

MANAGEMENT ISSUE

There is wide national and international interest in marine protected areas (MPAs) because they benefit fishery populations, protect marine ecosystems, and enhance human activities such as tourism. Few experimental studies, however, have focused on marine reserves because they require rigorous monitoring.

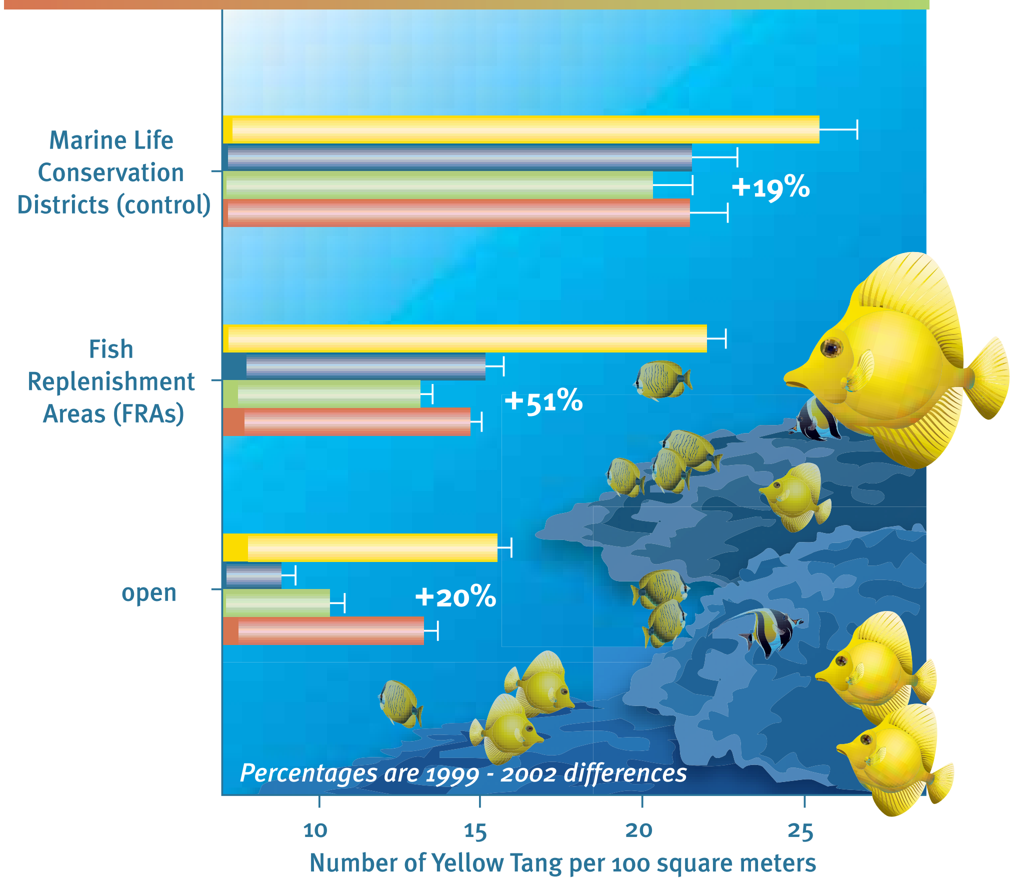
The Hawaii State Legislature enacted Act 306 in 1998 which established the West Hawaii Regional Fishery Management Area (WHRFMA). The major intent of the bill was to improve management of fish resources by declaring a minimum of 30% of the west Hawaii coastline as aquarium fish replenishment areas (FRAs), where fish collecting is prohibited. Additional components of the bill specify the designation of no gill netting and no fishing zones. In 1998, the West Hawaii Fisheries Council proposed the location and size of the nine FRAs in the WHRFMA.

A public hearing was held in April 1999 on the management plan developed by the Council. The public hearing was one of the largest ever held in Hawaii on a natural resource issue, and there was overwhelming public support for FRAs. FRAs were closed to aquarium collecting on Jan. 1, 2000. This project began in 1999 to monitor the impact of the management regime instituted in response to Act 306.

RESULTS

Yellow tangs, which account for the majority of collected aquarium fishes on the big island (76% in 2001-2002), significantly increased (51%) in FRAs in 2002 relative to baseline levels in 1999 (prior to reserve establishment). This population growth was higher than increases occurring in areas open to collecting (20%) and previously protected areas (19%). These results are due to high levels of juvenile fish recruitment in west Hawaii in 2001 and 2002. Moreover, analysis of the spatial distribution of juvenile yellow tangs suggest habitat may be an important factor influencing fish a bundance and reserve effectiveness. Clearly greater

COMPARISONS IN YELLOW TANG POPULATION OVER TIME



Yellow tangs significantly increased [51%] in FRAs relative to baseline levels in 1999. This population growth was higher than increases occurring in areas open to collecting (20%) and previously protected

Sunshine (© James Watt/NOAA, www.wattsstock.com). *Milletseed butterfly fish are common in Hawaii. These were photographed at Gardner Pinacle, Northwest Hawaiian Islands.*

complexity occurs in these systems than one might have previously considered.

Given the low frequency in which large recruitment events occur in Hawaii, it will probably be several more years until additional events of sufficient magnitude occur to allow rigorous testing of the effectiveness of the marine reserve network in west Hawaii for other aquarium fishes.

MANAGEMENT IMPLICATIONS

The State of Hawaii is evaluating the system of MPAs that currently exists in order to develop a process to establish an integrated system. One of the goals being discussed for the new system is to address the problem of fish stock depletion. The results of this project will help decision-makers evaluate the impact of FRAs and demonstrate monitoring techniques that could be used in the new system of MPAs.

Permanent versus Rotating Closure to Fishing

Assessment of Reef Fish Population Dynamics (2000-2001)

Principal Investigator
Dr. Kim Holland

Project Staff
Mr. Carl Meyer

MANAGEMENT ISSUE

Despite considerable theoretical benefits and the establishment of hundreds of marine reserves worldwide, hard data supporting reserve effectiveness is almost non-existent. Key questions in reserve design, such as optimum size, habitat features, proximity to adjacent reserves, and appropriate location remain largely unanswered. Historically, the establishment of reserves has occurred on an arbitrary basis and often based more on political considerations than biological data.

This project was designed to assess the impact of two approaches to fisheries management. Two adjacent marine protected areas MPAs were compared to determine the effectiveness of active management. One MPA is a region that is permanently closed to fishing, while the other area is "pulse-fished," that is, it is alternately open for fishing one year and closed the next. The main fishing activities observed during the open periods were pole-and-line fishing and spearfishing.

Visual census techniques were used to assess the characteristics of the reef fish assemblages in the two MPAs and during the "recovery" period when the pulse-fished area was closed to fishing. Acoustic tracking was used to monitor the movements of fishes living in the MPAs.

Fishing Zones in Waikiki (NOAA/NOS/MapFinder). *Banning night-time spear fishing proved to be a better reserve design than alternate yearly closure.*

What are the results of active management?

RESULTS

- Alternating yearly closure, or pulse fishing, of the fishery management area (FMA) was less important to the health of the fish assemblage (compared to permanently open sections of shoreline) than disallowing nighttime spear fishing at all times in the FMA (even during "open" years).
- The permanent MPA had more and larger fish than the pulse-fished FMA although the FMA had higher fish biomass than adjacent permanently fished areas. Thus, while the 12-

Tracking omilu (Kim Holland).

month closed period has some positive impact in protecting the resource, 12 months appears to be an insufficient recovery time to return the FMA to unexploited levels.

- Because there were no baseline data from before the MPAs were established, it is not possible to precisely quantify the protective impact of the MPAs because of the possibility that the habitat in this specific reef area may be naturally more conducive to high fish populations than adja areas that are not protected.
- The geographical distribution of all types of fishing activity was influenced by shoreline access. Distribution of fishing activity was greatly clustered around areas with beach access and parking.
- Acoustic tracking data indicate that the size of the Waikiki Marine Life Conservation District (MLCD) on Oahu should be tripled in order to more effectively protect weke and omilu. The de facto size of the Waikiki MLCD is larger than the official boundaries because of low fishing activity in the adjacent Waikiki Beach area.

MANAGEMENT IMPLICATIONS

Future implementation of MPAs should explicitly account for the types of habitat included within reserve boundaries and for the range of movement patterns (daily and seasonal) of key fish species that will be encompassed in the management area. The impact of MPAs can only be rigorously assessed if fish assemblage data are collected before the MPAs are established. In Hawaii, pulse-fishing at intervals longer than one year should be considered in order to replenish fish populations to maximum levels. These periods should be based on the life history characteristics (*e.g.*, growth rate, age at reproduction) of the main target species.

The effective size of MPAs can be enhanced by locating them adjacent to areas where shoreline access is difficult or where natural phenomena (high surf areas) limit the amount of fishing activity. Spearfishing (especially at night) and gillnetting have the greatest capacity for depleting reef fish assemblages.

Habitat Type and Reserve Effectiveness

Coral Reef Assessment and Monitoring Project (1998-2001)

Principal Investigator
Dr. Paul Jokiel

Investigator
Dr. Alan Friedlander

MANAGEMENT ISSUE

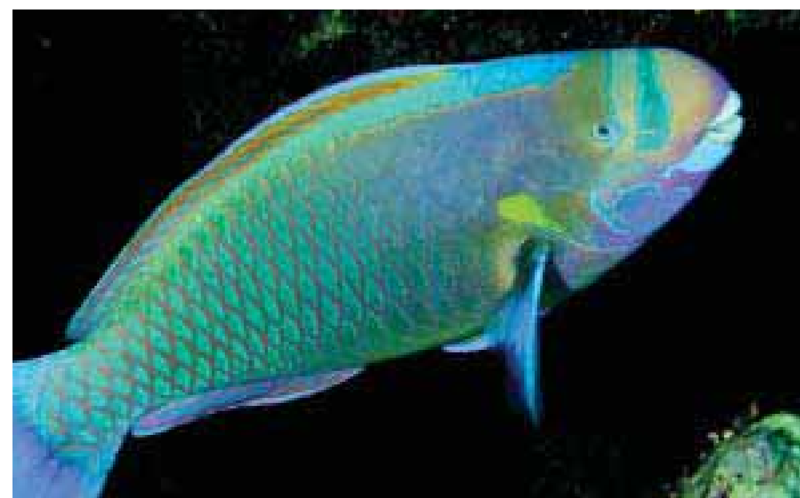
Current management strategies are directed at restrictions or control of fishing, and are often focused on particular species or small groups of species. These strategies do not address the habitat associated with these species and therefore may not be appropriate for the long-term sustainability of these resources.

The ecological unit of major interest in this study is the complete fish assemblage. To facilitate the understanding of the larger ecosystems in question, researchers examined components of these assemblages, as well as included various feeding guilds and their associated habitat interactions. These guilds seem appropriate ecological units of study in diverse reef fish communities. They reflect the characteristics of a "super-species," such that the unit responds to environmental variability in a more predictable and consistent manner than individual species.

If not a particular species, what should resource managers consider when designing a marine protected area?

RESULTS

Wave exposure, live coral cover, and habitat complexity all were all found



Making sand (© James Watt/NOAAm www.wattstock.com). *Parrotfish, such as this (uhu-uliuli), grind coral they have eaten into sand with special bones in their throat. It is said that most of the sand from Hawaii's beaches is the result of this "recycling."*

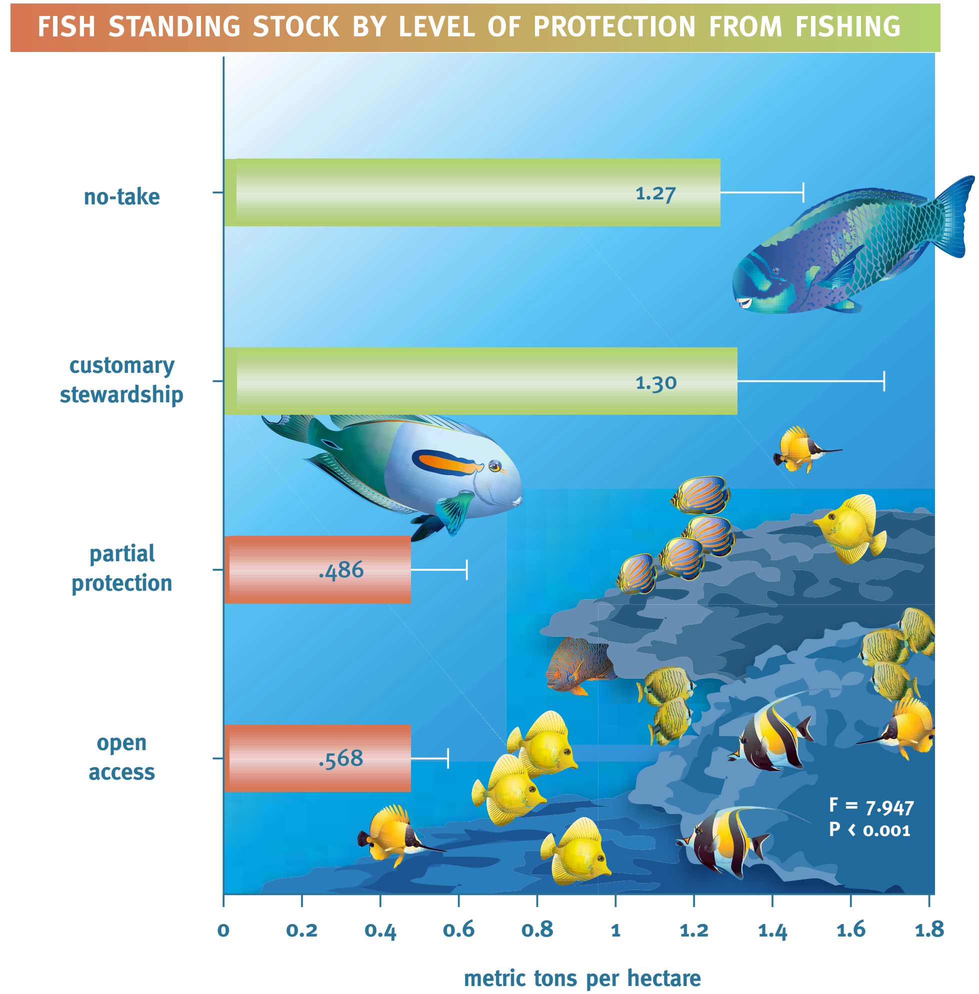
to be ecologically important environmental parameters to fish assemblages in Hawaii, and these parameters should be considered in future marine reserve design.

That is, resource managers should study:

- Diversity, quality, and extent of habitat are among the most important environmental determinants of distribution, abundance, and diversity for coral reef fish.
- Identification and conservation of fisheries habitat is an important consideration for sustaining fisheries production.
- Defining essential fish habitat has theoretical value in helping to explain the organization of fish assemblages and practical applications in designing reserve areas.
- Reef fish assemblages can be influenced by the physical structure of the associated reef.
- Habitat complexity provides refuges and barriers that fragment the area, resulting in more heterogeneous assemblages.
- The variety of microhabitats available on the coral reef provides shelter from predation. Habitats with low spatial relief and limited shelter are often associated with low standing stocks for many fish species while highly complex habitats harbor high fish biomass.
- A relationship between fish size and reef complexity may suggest the importance of shelter as a refuge for certain fish in avoiding predation. Many coral reef fish show considerable site fidelity and associate with particular habitats of rather limited size.

MANAGEMENT IMPLICATIONS

Marine reserve design must consider the habitat requirements and life histories of the species of interest, as well as the extent of fishing pressure in the area and the degree of enforcement. Making a functional match between habitats and the fish to be conserved is recommended for selection, evaluation, and management of reserves. The results provide managers with a better idea of how to select and manage reef habitat for maximum benefit to fish populations, with the attendant social benefits of improved fishery yield and improved results in preservation of fish populations and ecosystems quality.



MPAs are highly effective at conserving fish populations.
Results of studies suggest that coral reefs should be managed spatially, not by organisms.

Friedlander A. M., E. K. Brown, P. L. Jokiel, W. R. Smith, and K. S. Rogers. In press. Effects of habitat, wave exposure, and MPA status on coral reef fish assemblages in the Hawaiian archipelago. *Coral Reefs*.

WATER POLLUTION

Sediment Runoff *(NOAA/NOS/MapFinder). Adjacent land activities, such as agriculture and construction, are often the source of sediment runoff.*

Nutrients and Overfishing (Community Phase Shifts)

Fine-Scale Processes Affecting Health and Stability of Hawaiian Reefs (1998-1999)

Principal Investigator
Dr. Cynthia Hunter

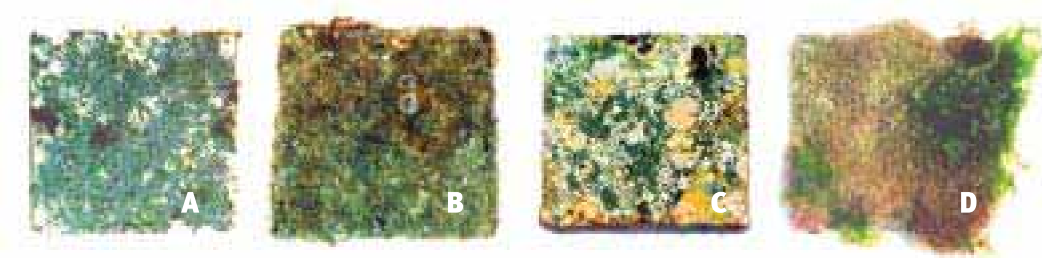
Project staff
Ms. Jennifer Smith
Dr. Randy Kosaki

MANAGEMENT ISSUE

Degraded or declining coral reefs are typically characterized by shifts to algal dominance, perhaps as the result of:

- Increased nutrient input leading to algal production that exceeds grazing pressures.
- Fishing pressure substantially reducing grazing pressure.
- Corals succumbing to disease, predation, bleaching, or other physical stress.

Because these processes alter the structure and productivity of coral reefs, such changes also impact the fish and invertebrate communities that depend on reefs for shelter and food.



Control No Manipulation — *Heribivores Excluded* — *Nutrients Added* — *Nutrients Added and Heribivores Excluded*

The dynamics of such ecological shifts are poorly understood for Hawaiian reef communities and require examination at a much finer scale than can be provided by monitoring efforts. What are the effects of fishing pressure, eutrophication, or their combination, on a coastal reef?

RESULTS

Total algal biomass was greatest on settlement surfaces exposed to both nutrient enrichment and herbivore exclusion simultaneously. Fleshy algae were most abundant on surfaces protected from grazing. Calcareous algae were most abundant on surfaces exposed to nutrient enrichment. Sediment accumulation was positively correlated with fleshy algal growth and was most abundant on surfaces within herbivore exclusion treatments.

This research demonstrates that on short time scales (less than six months), nutrient enrichment and herbivore exclusion can independently and interactively support shifts in benthic algal community structure on a Hawaiian reef.

MANAGEMENT IMPLICATIONS

This study shows the importance of both grazing and nutrient levels on coral reefs and how algal communities can respond rapidly to changes in either of these factors. Resource managers should work to keep herbivore abundance high and nutrient levels low on coral reefs in order to prevent an over-abundance of algae.

Stream Water Quality and Coral Reefs

Waimanalo Bay: A Case Study of the Linkage between Land-based Activities and Coral Reef Ecosystem Degradation (2001-2002)

Principal Investigator
Dr. Edward Laws

Project staff
Ms. Lauren Roth

MANAGEMENT ISSUE

Waimanalo and Kaneohe Streams are on the windward side of Oahu and have been hardened for purposes of flood control. The former is considered to be one of the most polluted streams in Hawaii. Both streams have been lined with concrete (*figure 1*), significantly reducing their ability to process nutrients and slow freshwater runoff. Several sections of Waimanalo Stream where the bottom is not lined with concrete and where there is inadequate shade to control plant growth are choked with dense stands of California grass and wild sugarcane (*figure 2*), which effectively block the normal transport of sediment by the stream. As a result of hardening, both streams deliver sediment, nutrients, and water to the nearshore environment in an aberrant way. In effect, the streams have been transformed into storm sewers by the hardening process. The management issue is to identify mechanisms of flood control that do not destroy stream functionality.

RESULTS

Results obtained to date clearly demon-strate the disruption of stream habitat and function caused by stream hardening. Natural streams contain sediments within which nitrate is converted to nitrogen gas (N_2). Streams that have been transformed into storm sewers for purposes of flood control no longer contain sediments. The result is greater delivery of nitrogen in the form of nitrate, which is effectively a fast-release fertilizer. If the hardening process extends to the mouth of the stream, the result is unnaturally high delivery of nitrogen to coastal waters.

If stream habitat is restored for a sufficient distance upstream of the mouth, some of the functionality lost by the hardening process can be restored. This fact is dramatically illustrated in the case of Waimanalo Stream, where concentrations of nitrate in the hardened section of the stream near Kalanianole Highway are more than ten times the state's Department of Health water quality criteria. Virtually all the nitrogen, however,

▲ ***Figure 1*** (Edward Laws).

▼ ***Figure 2*** (Edward Laws).

Kahekili, Maui (Jennifer Smith).

is stripped from the water downstream of the hardened section where a more natural habitat has been maintained as the stream flows through Bellows Air Force Station.

The stream hardening process, at least as practiced in Hawaii, involves creation of a wide, flat channel with little or no shade. During dry weather the stream becomes a thin veneer of water fully exposed to the sun, resulting in unnaturally high temperatures during the daylight hours — in excess of 30° Celsius (85-90° Fahrenheit).

The combination of an unnatural stream substrate (concrete), high temperatures, shallow water column, and absence of habitat variability results in a displacement of the stream's natural flora and fauna. As a result, materials washed into the stream are not processed in the usual way. They will be delivered to the coastal ocean in intense pulses in the absence of restoration efforts, particularly in the lower reaches of the stream.

MANAGEMENT IMPLICATIONS

Channelization of streams has been a flood control and erosion mitigation practice in Hawaii for many years. Habitats in channelized streams are obviously very different than natural streams. The impact on nearshore marine environments of changes in nutrient processing and other physical and ecological parameters of the stream can be dramatic. When considering channeling a stream, resource managers should consider, at a minimum, hardening only the sides of the stream and maintaining an adequate riparian buffer zone to provide shade to the stream channel and to intercept materials that would otherwise wash into the stream.

Using Growth of *Halimeda incrassata* as a Proxy for Habitat Health

Providing Managers with Critical Tools for Assessing Reef Algae (2000-2002)

Principal Investigator
Dr. Isabella Abbott

Investigator
Dr. Celia Smith

Project staff
Mr. Ryan Okano

MANAGEMENT ISSUE

Growth rates of macroalgae are a useful and important measure of the health of the environment in part because nearly every macroalga can grow more rapidly than corals. As rapid reporters of change on reefs, algal growth studies can be used as a tool to assess impacts of low light intensities or changes in nutrient levels. A simple staining technique, easily replicated, allows us to measure growth in a common green alga, *Halimeda incrassata*, of distinctive morphology and easily identified.

RESULTS

In the preliminary test study at Kualoa (impact) and Hunakai (control) on Oahu, there was significant difference in the growth of plants by location. The more comprehensive *Halimeda incrassata* study at Kahekili Park, Maui, showed significant differences in growth at depths and between treatments at the 50-foot depth but not at the 30-foot depth in two of the three quarterly studies. The fourth quarter's study did not show significant differences between depths. This suggests that, at times, plants in this meadow are equally productive across a depth gradient; while other seasons, plants in deeper water grow faster.

MANAGEMENT IMPLICATIONS

The meadows of *Halimeda incrassata* are unusually large monospecific stands

Halimeda incrassata *(Jennifer Smith). This green alga grows in large underwater meadows.*

where plants grow at high densities and support a number of other coral reef species, such as sessile invertebrates. In this way, the *Halimeda incrassata* meadow acts to increase diversity as well as stabilize sand movement. Growth of the species is probably an important part of reef productivity for the Maui site that is only now being realized. Even though other species of *Halimeda* (such as *Halimeda discoidea*) do not commonly form an extensive meadow, their growth is also important. These act as proxies for growth of many algae, contribute sand via their segment production, and are food items for reef herbivores.

Anthropogenic and Natural Stresses on Coral Reefs (2001-2002)

Principal Investigator
Dr. Steven Dollar

Investigator
Dr. Richard Grigg

MANAGEMENT ISSUE

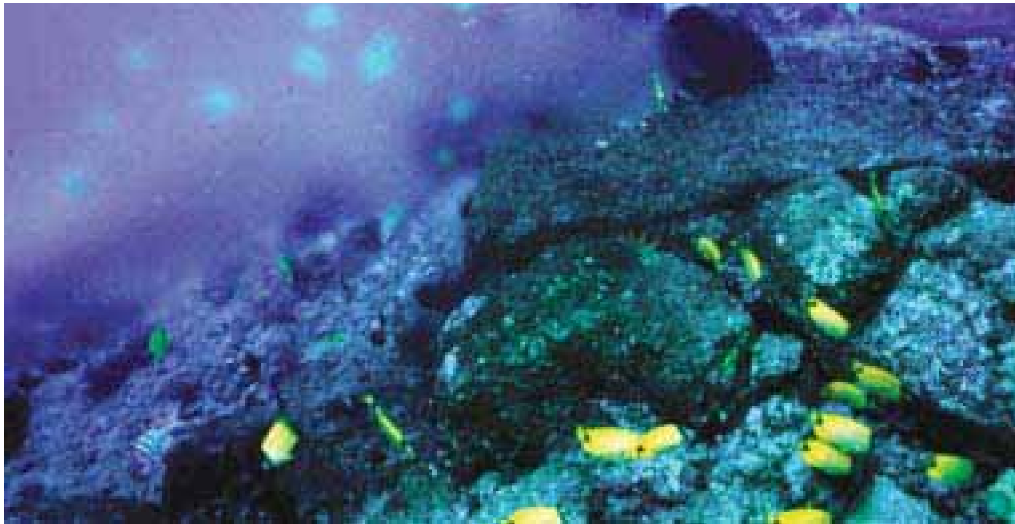
There is a strong and growing concensus that coral reefs are threatened on a global scale by the activities of man. While such alarm is well justified on many reefs of the world, is this view an accurate description of Hawaii's coral reefs? Long-term studies (10-30 years) of coral communities at six sites on the main Hawaiian Islands were undertaken to address this question. A main focus of these studies was to determine the relationship between human and natural stresses.

RESULTS

The sites included three adjacent to resort developments, two ocean sewage outfalls, and one relatively pristine site that has been affected only by the natural forces associated with storm waves. Of the three resort sites, two were located on open coastlines. The coral communities off the Mauna Lani resort can be considered thriving, with little or no apparent impact from anthropogenic activities related to land usage. As this open coastal site was protected from destructive surf over the study period (1983-2002), coral cover has increased at all survey stations. The lack of wave disturbance, as well as unrestricted circulation, has resulted in coral communities as near climax stages of succession.

The Princeville Resort on the north shore of Kauai is directly exposed to large surf generated by storms in the north Pacific every winter. Hence, coral community development is restricted to species assemblages that are able to withstand the concussive forces of waves and sediment scour. Time-series surveys at stations along eight kilometers of coastline bordering the resort between 1980 and 2002 revealed increases in coral cover at all stations. Results from the Mauna Lani and Princeville studies indicate that in open coastal areas, resorts are not affecting coral community structure.

Contrary to the open coastal sites, Honolua Bay on the west coast of Maui is a semi-enclosed embayment with restricted flushing. Poor flushing of inner Honolua Bay by restricted wave-induced currents resulted in prolonged trapping of sediment produced by erosion of pineapple fields that flowed into the bay following a period of heavy rainfall in January 2002. Time-series data suggest that sedimentation caused a reduction in coral cover of about 33% between 1992 and 2002. Records of rainfall from the last 50 years indicate the January 2002 storm was of relatively small magnitude in terms of total rainfall, and that there were no anomalies in wave climate that would have prevented flushing of sediment from the bay. Rainfall records do not indicate, however, the intensity of rainfall. The high sediment input in 2002 may have been a result of aanomalously intense rainfall over



Diffuser Port (Steven Dollar). *Treated sewage effluent discharging in 35-foot water off Sandy Beach, Oahu. Continuous monitoring since 1968 shows no effect on adjacent coral communities. Light areas are corals growing on the pipes and anchored rocks.*

a short period of time that overwhelmed sediment retention devices. Such periodic sedimentation in Honolua Bay results in a different assemblage of corals than found in other wave-sheltered Hawaiian embayments.

While sewage discharge is generally considered to be a major contributor to the degradation of reef coral communities, continuous monitoring of the East Honolulu Wastewater Treatment Facility off Sandy Beach, Oahu, from 1986 to 2002 shows the opposite result. Discharge of highly (secondary-tertiary) treated sewage effluent through a diffuser at a depth of 35 feet has resulted in no changes to the coral community adjacent to the outfall that are different from changes at control sites not affected by the discharge. Corals growing on the outfall and diffuser pipes, and the rocks anchoring the pipes, indicate that effluent does not prevent settlement or cause mortality of corals (see photo). Fish populations associated with the outfall are also higher than in control areas. These factors, along with the absence of algae, indicate that discharge of treated sewage effluent in open coastal areas does not constitute a negative impact to coral communities.

From 1955 to 1978, raw sewage was discharged from the old Sand Island Outfall, resulting in a zone of severe degradation with total elimination of reef corals. Diverting the sewage to a new deep-ocean outfall removed the stress from the reef, which showed initial signs of recovery within one year. A followup study in 2002 showed that in 25 years, the degraded reef had fully recovered, although the coral assemblages were altered along the entire reef tract by Hurricanes Iwa and Iniki, which impacted the south shore of Oahu in 1981 and 1991, respectively.

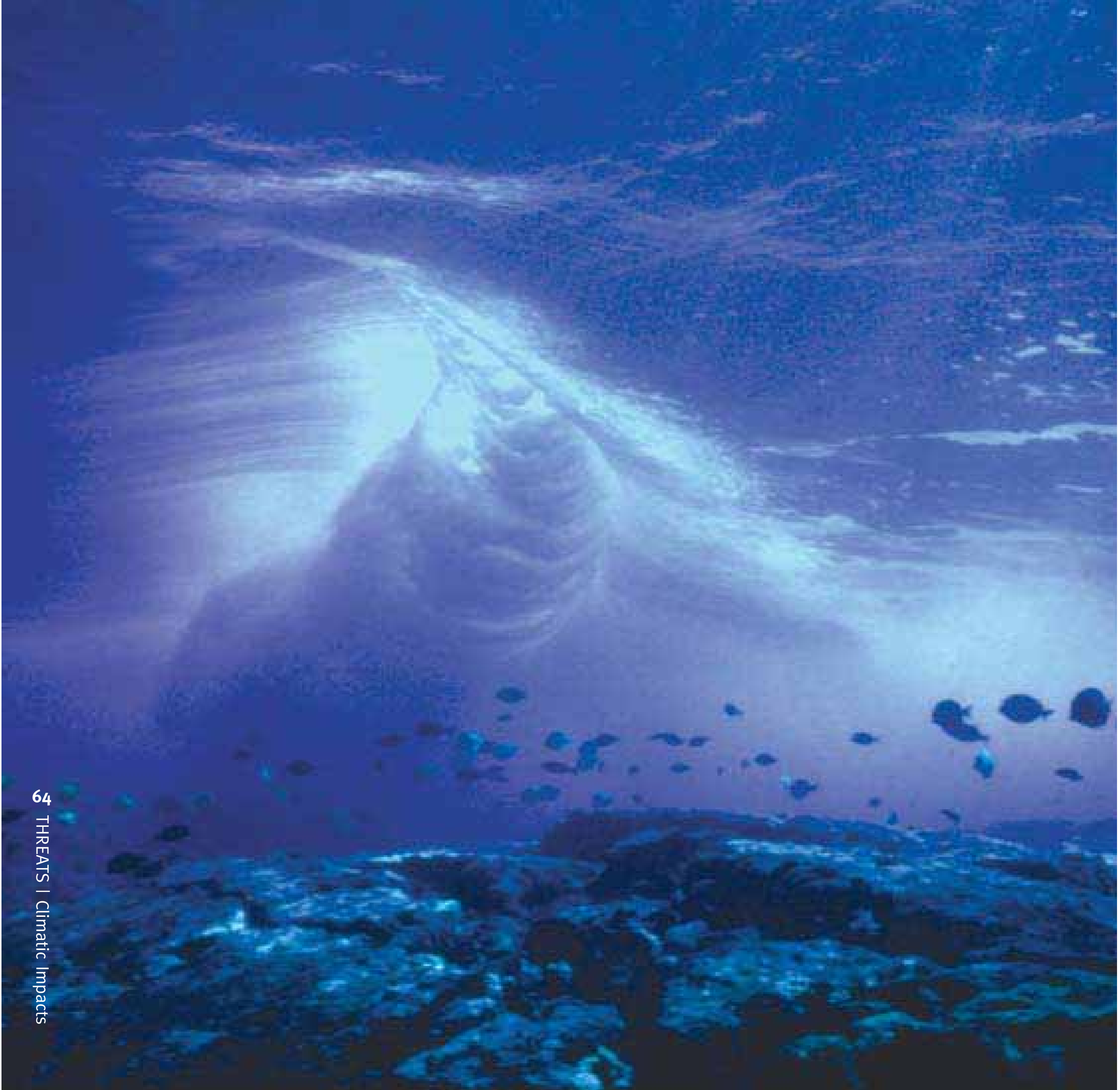
Time-series surveys of a reef off the Kona Coast of Hawaii from 1973 to 2002, which included impacts from a variety of storm wave events, reveal natural recovery patterns. Recovery degree was related to the depth and distance from the shore of each zone, with the areas closest to shore showing complete recovery after a severe storm in 20 years, while the deepest zone showed only initial levels of recovery.

MANAGEMENT IMPLICATIONS

Results show that, with exceptions, the activities of man are not resulting in widespread degradation of coral communities in enclosed embayments. Anthropogenic impacts to coral reefs are superimposed over natural controlling forces. The results of this work, as well as many other studies on community succession of coral reefs in Hawaii, indicate that anthropogenic impacts are only important in environments where wave forces are not the dominant factor controlling community structure. These environments are typically embayments and lagoons that are protected from wave stress, resulting in a relatively long residence time of the water column.

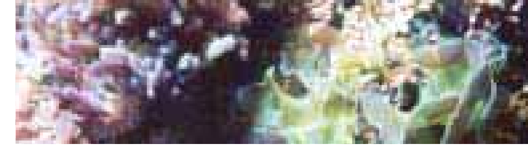
While management should not ignore or neglect open coastal areas, efforts should concentrate on the enclosed areas where both inputs of materials from land are occurring and where circulation is confined. By targeting these areas, effective mitigation can be maximized for the protection of the entire coastal region.

Sediment and Coral (Steven Dollar). *Sediment has buried the coral off Honolua Bay, Maui.*



CLIMATIC IMPACTS

The Underside of a Wave
(Steven Dollar).
Wave action plays a pivotal role in coral reef community structure. In general, sites with high wave exposure, such as Pupukea on Oahu and Hoai Bay on Kauai, have the lowest coral cover. Bays and wave-protected coastal areas, such as Palaau and Kamalo on Molokai have the highest percentage of coral cover.



Coral Growth and the Effect of Human Activities

Environmental Controls on Reef Development (2001-2002)

Principal Investigator
Dr. Charles Fletcher

Investigator
Dr. John Rooney

Project staff
Ms. Mary Engels

MANAGEMENT ISSUE

With improved knowledge of the factors governing reef growth over the past 1,000 to 10,000 years, resource managers can refine conservation policies to address future patterns of change. Without a longer-term perspective on reef evolution, managers may not grasp full impacts and significances of locally critical processes.

Details of modern reef accretion trends are lacking, and it is not yet possible to design management programs that take advantage of long-term growth patterns. From a management perspective, it is also important to assess how these patterns might enhance or suppress potential anthropogenic influences on reef growth in the future.

This study is designed to contribute to improved understanding of reef response to environmental controls, and the role of human impacts. The project also described likely future trends of Hawaiian reef response to shifts in environmental controls under business-as-usual global change scenarios.

RESULTS

Wave energy is the primary environmental control on reef development in Hawaii today. Although terrestrial sedimentation is known to have negative effects on coral growth, in areas of moderate wave energy, corals can thrive. Past reef accretion was able to occur in many areas where it is not possible today. Modern accretion is suppressed by large North Pacific swells. These wave events were more limited prior to 5,000 years ago.

Determining the Age of Coral *(Matt Barbee).*
Similar to tree rings, some coral species contain a physical mark showing their growth history.

Statistically significant correlations were found between maximum monthly wave heights and El Niño. This reflects a deepening of the Aleutian low pressure system and shifting of storm tracks closer to Hawaii about 5,000 years ago. This intensification of El Niño resulted in a reduction of substrate able to support net reef accretion in Hawaii.

According to model results, the frequency and intensity of El Niño events are likely to increase in the coming decades due to increasing concentrations of greenhouse gases. As a result, the Hawaiian archipelago will experience more hurricane and North Pacific Swell events capable of removing reef material. Prior to a climatic warming period 5,000 years ago, the altithermal was characterized by suppressed El Niño processes according to geologic records. The exact character of future warming vis-à-vis El Niño remains to be seen.

MANAGEMENT IMPLICATIONS

Given this additional natural stress on already limited reef systems, reduction of anthropogenic impacts becomes increasingly important. Management should concentrate on relatively sheltered areas where anthropogenic influence is of comparable (or greater) magnitude than natural forces. That is,

- Management efforts should be concentrated in areas where corals are protected from severe wave energy.
- Efforts to reduce delivery of terrestrial sediment to the coastal marine environment will have the most beneficial effect when sedimentation is occurring in protected embayments.

NEAR SHORE RECREATION

Hang 10 (Ed Watamura).
Along with winds and tides, coral reefs play a vital role in making a good surfing break.

Developing an Operational Methodology for Strategic, Multiobjective Coral Reef Management

Integrating Science and Policy for an Uncertain and Conflictive World (1998-1999)

Principal Investigator
Dr. Mark Ridgley

Project staff
Ms. Rikki Grober-Dunsmore

MANAGEMENT ISSUE

Having witnessed the demise of coral reefs using the current regulatory strategy, resource managers are eager to have new problem-solving approaches to meet contemporary challenges, particularly in the marine realm where uncertainty, limited data, and ever-scarcer resources make decision making particularly difficult. Solutions to many threats involve restricting or modifying the location, type, conduct, and timing of people's actions. Management interventions thus focus on human activities rather than on direct manipulation of the resource.

This project developed, and applied to illustrative examples, a range of methodologies to improve decision making and help respond to challenges regarding coral reef management. Some of the methodologies were also applied to support the Kaneohe Bay Regional Council's Long-Range Planning Committee (LRPC), stakeholders, resource users, and scientists in the design and evaluation of alternative marine protection areas for Kaneohe Bay. Researchers were fortunate to have played an integral role in the actual decision process, thus contributing to recommendations presented to the Kaneohe Bay Regional Council (KBRC).

Juggling Different Users (Terry Martin).
A methodology was developed to define multiparty objectives and performance indicators of coral reef management at Kaneohe Bay. This assisted in management actions and strategy development.

RESULTS

- Designed a general methodology to guide execution and integration of disparate tasks.
- Defined multiparty objectives and performance indicators of coral reef management in Kaneohe Bay, tasks crucial to problem definition, formulation of management actions, and strategy development.
- Developed a framework to integrate diverse scientific findings for communication to all stakeholders.
- Designed several modeling approaches to assist zoning of marine activities in coral reef-associated habitats, including those using: Geographic Information System (GIS)-based heuristic; optimization with multiobjective programming; and optimization with genetic algorithms that evolve or breed ever better solutions.
- Designed and applied user-friendly, template-based procedures to assist the LRPC develop and evaluate alternative marine protected areas (MPAs) for Kaneohe Bay.
- Formulated four very different scenarios of environmental, socioeconomic, institutional, and technological contexts within which coral reef management in Hawaii (including Kaneohe Bay) could find itself within the next 10-15 years.

- Conducted an environmental impact assessment (EIA) of alternative MPAs for Kaneohe Bay, including the one recommended by the LRPC to the KBRC.
- Identified and evaluated, employing the Analytic Hierarchy Process, possible interventions in consultation with participants of the LRPC.

Managing Coral Reefs fo the Future (Risa Minato). *We must promote stewardship and support coral reef management.*

MANAGEMENT IMPLICATIONS

Institutional Changes. Improve state-community co-management. There is need for an impartial, scientifically literate non-governmental organizations, with expertise in methodologies like those employed in this project, to coordinate community groups, government (policymaking and regulatory agencies), scientists, and the private sector to promote adaptive goal-directed management.

Data Acquisition. Data collection should correspond to explicitly articulated goals and objectives and distinctions between science-driven and management-responsive data need to be recognized. Classification and ground-truthing of GIS coverage is needed and improved soils data is required for estimating sediment delivery.

Decision Support. Model the linkage between land-derived sediment and nutrient fluxes and concentrations and fluxes on the reefs themselves. Integrate empirically-based versions of the prototype models designed in this research into a decision-support system (DSS) for management of Kaneohe Bay.

Education. To eradicate much misinformation and encourage better stewardship, improved education about human and environmental processes in Kaneohe Bay is needed. A scientifically rigorous volunteer monitoring program would promote stewardship and support of coral reef management.

Human Trampling of Coral Reefs

Coral Reef Assessment and Monitoring Project (1999-2000)

Principal Investigator
Dr. Paul Jokiel

Investigator
Ms. Kuulei Rogers

MANAGEMENT ISSUE

Many of Hawaii's coastal reefs are found at depths too deep for people to walk. A coral's polyp is essentially a fragile balloon. Short-term, but intense, pressures are likely to crush the polyp's hydrostatic "skeleton," leading to damage or death. More intensive impacts are likely to fracture and break the calcareous skeleton into pieces.

Natural disturbances via storm movement of large boulders could provide deep water populations with a range of impacts. Few studies, however, have documented the intuitive impacts of human trampling at shallow depths. The threat posed by people stepping and walking on coral likely occurs when polyps are fully extended (not retracted as in storms) is probably not widespread, but likely limited to a few discrete, high profile areas, such as the inner reef regions of Hanauma Bay and Kaneohe Bay.

What is the correlation between use and degradation of the reef? These data allow managers to articulate and reinforce appropriate behavior, as well as decisions on uses within MPAs.

RESULTS

The quantification of use patterns allowed evaluation of the relationship between various impacts on reef communities and how people use the marine environment. This study enabled determination of the physical and biological impact to corals *(e.g.,* waves) directly related to specific anthropogenic factors (*e.g.*, overuse, trampling, divers). Such information can show a quantified relationship between human use and coral contact.

These community-level experiments were an attempt to replicate realistically the impacts of trampling in an affected environment. Although direct cause and effect cannot be established through observational surveys alone, this is a first step in the assessment of links between impact and mortality. There was 100% coral mortality at the high-use site. Trampling is a plausible explanation for coral mortality, as flood event, damaging storm surf or boat groundings did not occur at this site during the period of study. Higher levels of impact were associated with high levels of coral mortality; the cause (trampling) occurred simultaneously with the response of mortality. By itself, even the strong association demonstrated between trampling and mortality is not sufficient evidence to affirm a cause and effect relationship but in conjunction with the colony level manipulative experiments, a direct causal link between coral damage and trampling was established.

Researchers determined that the most fragile corals are most commonly found in protected, low-wave energy regions, areas also preferred for snorkeling and recreational swimming. Experiments showed these corals (*i.e.*, rice and finger corals) would easily break under the stress exerted by the weight of an average person standing on corals.

Coral mortality in this study was low, resulting in 93% survivorship of impacted colonies compared to 95% survivorship in control colonies. All four species in this experiment were highly tolerant of inflicted damage, suggesting that corals can withstand limited episodic events if time is allowed for recovery.

MANAGEMENT IMPLICATIONS

Coral death can be prevented if the amount of direct human contact is minimized. For example, snorkelers should be taught "to not touch corals." When snorkelers used flotation devices, snorkeling was less harmful to coral, despite moderate to high use of an area.

Don't step on the reef!
(University of Hawaii, Sea Grant). *Research found that reef corals in shallow areas with high visitor use (over 300,000 visitors annually) are quickly pulverized by human contact and fail to survive. It only takes up to nine trampling incidents to damage coral.*

Glossary of terms...

accretion: A gradual growth through accumulation.

analytic hierarchy process: A quantitative decision-making method based upon performing pairwise comparisons, assessing consistency of pairwise judgments, and computing their relative weights.

apical: Situated at the tip

assay: A test for a particular substance

assemblage: an integrated group of species inhabiting a specific location; also called a community

benthic: Aquatic organisms living on the bottom.

biomass: Total weight of all the organisms present

calcareous: Containing calcium or calcium carbonate (lime)

cytochrome oxidase I (COI): Electron transport enzyme of a mitochondrial gene.

diffuser: A device that causes a gas or a liquid to spread through or into a surrounding substance by mixing with it

effluent: Something that flows out, like the outflow of a stream

El Niño: A disruption of the ocean-atmosphere system in the tropical Pacific having important consequences for weather around the globe.

eutrophication: The gradual increase in nutrients in a body of water. Natural eutrophication is a gradual process, but human activities may greatly accelerate the process.

filamentous: Thin in diameter; resembling thread

fluorescence: A term that describes any substance that emits light at a certain wavelength (emission wavelength) when it is illuminated by light of a different wavelength (excitation wavelength)

fluorometer: A device used to measure the amount of fluorescence released by a sample that is exposed to a single wavelength of light or other electromagnetic radiation.

genotype: The particular type and arrangement of genes for each organism.

heuristic: A method of teaching that allows students to learn by discovering things for themselves

hydrostatic: A type of skeleton that is comprised of a water-filled body cavity controlled by muscles.

in situ: In the original place

mitochondrial: Genetic material and enzymes important for cell metabolism.

Morphology: Study of the structure and form of plants or animals

nitrate reductase: An enzyme utilized by plants as they use nitrate.

Photoquadrat: Sampling technique using a stardard-sized frame (e.g., one square meter) and a camera to determine the species present.

physiology: Processes and functions of an organism

phytoplankton: Planktonic plant life.

porewater: Water sampled from within the sediments

point-intercept quadrat: A variation of the photoquadrat sampling technique.

predation: Mode of feeding where food is obtained by killing and consuming animals.

propagation: To produce new plants

quadrat: Plot of substrate, often a square meter, used by ecologists to quantify type and amount of plant and animal life

rugosity: "Bumpiness" (or, topography) of the coral.

substant: Substantial, firm

substrate: Ocean bottom

transect: A sample area usually in the form of a long, continuous strip

CREDITS

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Hawaii Coral Reef Initiative Research Program
2424 Maile Way, Saunders Hall #718
Honolulu, HI 96822
Ph: (808) 956.7479
Fax: (808) 956-2884
hcri rp@hawaii.edu
www.hawaii.edu/ssri/hcri

HCRI-RP Management Committee

Mr. William Devick, Division of Aquatic Resources/Department of Land and Natural Resources

Dr. Lucius Eldredge, Bishop Museum/Pacific Science Association

Mr. Kevin Foster, US Fish and Wildlife Service

Dr. Jo-Ann Leong, Hawaii Institute of Marine Biology/University of Hawaii

Dr. Robert Nishimoto, Division of Aquatic Resources/Department of Land and Natural Resources

Mr. Francis Oishi, Division of Aquatic Resources/Department of Land and Natural Resources

Dr. Celia Smith, Department of Botany/University of Hawaii

Emeritus Management Committee

Dr. Edward Laws, Department of Oceanography/University of Hawaii

Dr. Fred Mackenzie, School of Ocean & Earth Science & Technology, University of Hawaii

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Hawaii Coral Reef Initiative Research Program
2424 Maile Way, Saunders Hall #718
Honolulu, HI 96822
Ph: (808) 956.7479
Fax: (808) 956.2884
hcri_rp@hawaii.edu
www.hawaii.edu/ssri/hcri

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HCRI-RP Program Staff

Director: *Michael Hamnett*

Manager: *Kristine Davidson*

Specialist: *Risa Minato*

Assistants: *Jeremiah Christiansen, Terry Martin, Stephen Cheng, Lisa Huynh*

HCRI-RP Management Committee

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Dr. Edward Laws, Department of Oceanography/University of Hawaii

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DAR

University of Hawai'i Mānoa