CHAPTER 1

INTRODUCTION TO THE PLAN

1.1 Prologue

Long before Western contact and association with the U.S., what are now the U.S. Pacific Islands were settled by seafaring peoples whose continued survival depended on fishing wisely. This is the basis for indigenous islanders' cultural and spiritual relationship with marine resources, especially coral reef resources. It is not surprising, therefore, that the indigenous cultures of the U.S. Pacific Islands abound in proverbs, myths, and legends about coral reef resources. A few of these follow.

Hawaiian

Translated from the Hawaiian chant of creation, *Kumulipo* (Beckwith 1951):

> The night gave birth
> Born was *Kumulipo* in the night, male
> Born was *Po`ele* in the night, female
> Born was the coral polyp, born was the coral, came forth
> .....(over 2,000 more lines of the creation chant follow)

Hawaiians of old used products of the coral reef for nearly every purpose. Some organisms were collected to extract medicine. Some organisms had a darker purpose. *Limu make*, a soft coral *(Palythoa toxica)*, contained a deadly poison. Scientists from the Hawaii Institute of Marine Biology traveled to Kanewai, Hana, island of Maui in December 1961 to collect specimens for research. They were warned by native residents of the area that *limu make* was *kapu* (forbidden). That same day, a fire of undetermined origin occurred at their Coconut Island marine laboratory, completely destroying the main building (Titcomb 1978).

Samoan

The *tulavae* is a portion of the fish net made by one person. All of the *tulavae* made by a section of the village are joined into a *fata*. The totality of the *fata* forms the complete net. A person who has supplied a *tulavae* for the *fata* is entitled to take part in the fishing and to share in the catch.

Ua `ou seuseu ma le fata. "I am fishing because I have helped to make a *fata*."

The saying means: I have the right to take part in the discussion.

Chamorro

Long ago, Guam was inhabited by a race of superhuman people (known as the taotaomona) who were capable of magic. One day, fishermen noticed that Hagatna Bay and Pago Bay were growing. They saw that a giant parrotfish was nibbling at the shoreline and eating away the island. "If this keeps up, our island will be cut into two pieces," they said. Their search could not find the fish, however.

Every day, maidens would gather at Hagatna Springs to wash their beautiful long hair and rinse it with the juice of lemons. The maidens noticed that the discarded lemon peels they had thrown into Hagatna Bay later appeared in Pago Bay. Thinking that the giant fish was tunneling between bays, they were determined to trap it. The maidens cut off their long hair and wove it into a magic net. They sang into the tunnel to lure the fish into Hagatna Bay where it became tangled in the net made from their hair. This is how their island was saved from destruction.

Pacific Remote Island Areas

In Marshallese tradition, Eneen-Kio (Wake Island) was associated with a large bird whose bones were used to fashion tattooing chisels. Legend recounts that when a chief required a tattoo the only suitable chisels were made from human bones or the bones of this large bird, most likely the albatross. The albatross nested on Eneen-Kio but only flew over the other Marshall Islands. When a human sacrifice was selected, he could be spared if he was able to procure the proper bird bones for the tattooing chisel. This required a voyage to Eneen-Kio. Archeological surveys of other Pacific remote island areas provide little evidence of human habitation or use prior to Western contact.

1.2 History of Coral Reef Resource Use and Management

The seafaring people who settled Samoa, Hawaii, and the Mariana Islands depended on marine fisheries–and especially coral reef resources–for protein in their diet. Through much trial and error, the indigenous peoples devised social and cultural controls to foster, in modern terminology, "sustainable" use of these resources several thousand years before Western forms of marine resource management were introduced. After European contact, Westernization eroded island cultures and subsistence economies; but islanders have perpetuated some ancestral fishing techniques, sophisticated knowledge of marine resources, and a code of fishing conduct.

Fisheries for coral reef resources in the U.S. Pacific Islands are multi-species and multi-gear. Harvesting methods include hand gathering, hook-and-line, spear, and various types of nets and traps. The existing fisheries target several hundred different species of inshore fishes, invertebrates, and in Hawaii, seaweeds, with most of the harvest from reef areas near the main populated islands. Many of the fisheries that currently harvest coral reef resources in the U.S. Pacific Islands can be traced back to fishing methods that were practiced by indigenous populations hundreds to thousands of years ago. Population growth, cash economies, Western laws designating the oceans as a commons, breakdown of traditional knowledge, and the introduction of modern, manufactured gear have magnified the impact of these fisheries in modern times. They are managed under island government laws and regulations. (These governments are the Territories of American Samoa and Guam, the State of Hawaii, and the Commonwealth of the Northern Mariana Islands.) More recently, established fisheries that target coral reef resources for the marine ornamental products market are also controlled, to varying degrees, by island governments.

Fishing controls vary among the different island governments, but they include commercial fishing licenses, gear restrictions, bag limits, seasonal closures, and minimum size restrictions for possession and sale of fish. In addition to specific limitations on fishing effort and catch, some island governments have closed particular reefs indefinitely to most types of fishing, and have zoned other areas to separate competing uses. Destructive fishing methods, such as explosives and poisons, are prohibited by the island governments.

A few fisheries reef-related resources are harvested farther offshore in the U.S. Exclusive Economic Zone (EEZ) surrounding U.S. Pacific Islands. These commercial and semi-commercial activities require boats. Bottomfish are taken by hook-and-line on deep slopes in the EEZ around American Samoa, Guam, Hawaii, and CNMI. Spiny and slipper lobster are trapped in some areas of the Northwest Hawaiian Islands (NWHI).

These and other fisheries in the EEZ around the U.S. Pacific Islands are managed by the Western Pacific Regional Fishery Management Council (hereafter, the Council). The Council is composed of government officials and members of the public who reflect various interests. Its primary function is to prepare, evaluate, and revise FMPs, which must balance long-term conservation of fish stocks and fish habitats with optimal use of these resources. These plans must be approved by the Secretary of Commerce before implementation.

1.3 Purpose and Need for Action

Coral reefs are relatively robust and have survived millions of years of natural disturbance. Despite such long-term resiliency, however, reefs undergo episodes of high natural stress. Human uses of, and impacts on, reefs have never been higher, and there is growing concern that human stressors could add to cumulative natural impacts on reefs in the Western Pacific Region. A Fishery Management Plan (FMP) for Coral Reef Ecosystems of the Western Pacific region is needed:

- To establish a management regime for the protection and sustainable use of coral reef ecosystems and their associated marine resources.

- To anticipate and avoid potential damage to essential and non-renewable coral reef habitat.

- To address the secondary effects of all reef-related fisheries on non-target coral reef resources, thereby encouraging ecosystem-scale management.

- To ensure that newly emerging coral reef fisheries are managed using precautionary principals and the best available information.

- To manage new underwater harvesting technologies that are extending the depth and time limits at which coral reef resources can be harvested.

- To encourage coherent and coordinated coral reef management, monitoring, and enforcement across jurisdictional boundaries.

- To facilitate consensual management that considers all types of stakeholders, and adaptive management that considers new data and unforeseen impacts.

- To allow sustained use of the coral reef resources, which are important for the continuity of indigenous cultures in the U.S. Pacific Islands.

Stony corals are among the principal reef-framework-building organisms in the U.S. Pacific Islands. In 1998, global coral bleaching and die-off was unprecedented in geographic extent, depth, and severity. Several studies have related bleaching to the combination of increased ultraviolet radiation and ocean warming, phenomena that may be exacerbated by human activities. Projected long-term climatic changes are likely to expose stony corals to an increasingly hostile environment and could possibly lead to mass extinctions.

The degradation and destruction of essential habitats for many coral reef species' reproduction and recruitment is of foremost concern. To date, non-fishing activities—such as coastal and harbor development, watershed land use practices and runoff, industrial discharges, and military use—have caused much of the damage to coral reef habitats in the U.S. Pacific Islands, but fishing and non-fishing vessels also have the potential to degrade habitat through vessel grounding, anchoring, introduction of invasive exotic marine species, and substrate scouring and ghost fishing by derelict gear and other marine debris. Removing live rock and using destructive fishing techniques, such as explosives and poisons, can also directly affect coral reef habitats. Because many resources that contribute to coral reef habitat are essentially non-renewable, when gauged by our life span, preventing damage, rather than mitigating its effects, is a far more effective strategy.

1.3.1 Ecosystem Effects of Established Fisheries

Fisheries for coral reef resources are well established around the inhabited U.S. Pacific Islands. Currently, most coral reef fishing occurs on nearshore reefs, which are regulated by U.S. Pacific Island governments, while the Council, through its FMPs, manages fisheries in the federal EEZ. Fishermen use a wide variety of gear and some of these gear types, or the ways in which they are used, can cause habitat degradation. For example, a new method of reef fishing with gill nets was recently introduced to Hawaii. When retrieved by hydraulically-powered reels from depths of 10 to 100 m, the nets snag and damage the bottom. Lobster tangle nets used in nearshore areas around the main Hawaiian Islands have the same impact. The State of Hawaii has taken action to control destructive gill-netting in state waters around the main Hawaiian Islands, but no equivalent regulations apply in federal EEZ waters surrounding other U.S. Pacific Islands.

Although the Council has already developed and implemented four FMPs—to manage pelagic, bottomfish, lobster, and precious coral fisheries in federal waters—they do not comprehensively address fisheries targeting coral reef resources. In addition, they have been crafted around conventional fishery management objectives: to prevent overfishing; minimize bycatch; and produce optimum yield of target resources. There are, however, no procedures or requirements for monitoring or managing ecosystem effects of reef-related fishing activities. As a result, their management regimes may overlook the potential for secondary effects on non-targeted resources resulting from effects on habitat and other interactions. Such effects, if severe enough, can bring about undesirable structural or functional changes to complex coral reef ecosystems. Fortunately, hook-and-line, longline, lobster traps, and hand harvest—the predominant gear types used in Council-managed fisheries—are not known to cause significant adverse impacts to coral reef habitat (URS Corp., in prep). Several other measures also limit the ecosystem effects of these fisheries. First, these FMPs prohibit fishing with potentially destructive fishing gear such as bottom trawls, bottom-set nets, explosives, and poisons. Second, the Precious Corals FMP prohibits using non-selective gear to harvest precious corals in the MHI. A regulatory adjustment to this FMP—developed by the Council and awaiting secretarial approval—will extend this prohibition to the entire Western Pacific Region EEZ.

There are two ways that the four implemented Council FMPs, along with this FMP, can more effectively address ecosystem effects. First, recently implemented essential fish habitat (EFH) provisions are designed to prevent, mitigate, or minimize any adverse habitat effects, when it can be documented that these impacts result from fishing. (See Chapter 6 in this volume and Volume III for a discussion of EFH.) These effects can include physical, chemical, or biological alterations of the substrate and loss of, or injury to, benthic organisms and prey species, their habitats, and other components of the ecosystem. Second, this Coral Reef Ecosystem FMP (CRE-FMP) outlines a formal process to coordinate the plan teams established under each of the Council's FMPs. This process will allow plan team members to identify and control the secondary effects that may result from fisheries managed by the Council's four implemented FMPs. Similarly, this CRE-FMP also describes a mechanism to enhance coordination and cooperation with State, territorial, and other agencies managing coral reef resources in the Western Pacific Region.

1.3.2 Ecosystem Effects of Developing Fisheries

Coral reefs represent one of the Earth's most genetically and biologically diverse and undocumented environments (Birkeland 1997a). Because a coral reef ecosystem is composed of many species with a long co-evolutionary history, removing certain species may result in undesirable changes in ecosystem structure or function, such as a predominance of less valuable generalist species. Most species of reef organisms have small body size, restricted dispersal, and small geographic ranges. They often have low population densities and low turnover rates that limit the potential harvest of any single species.

Bioprospecting for emerging biomedical and natural products industries, and the expanding trade in marine ornamental products, coupled with new harvest technologies, could result in the harvest of organisms whose characteristics—particular life cycle, place in the food web, or their abundance and distribution—are poorly understood or completely unknown. Like the tropical rainforest, their terrestrial equivalent, coral reefs harbor hundreds of thousands of mostly cryptic and unnamed species.

Bioprospecting

The search for promising new medicines provides strong incentives to explore coral reef ecosystems for potentially useful resources. This activity is known as "bioprospecting." This search for novel natural products for medicine, industry, and agriculture has become an established field over the past quarter-century. About half of the potential pharmaceuticals being explored are from the ocean, many from coral reef ecosystems.

The companies involved in the business are often billion-dollar corporations. Due to the high profiles of bioprospectors and some initial harmful bioprospecting, advocate groups have been active in impeding wholesale harvest and protecting the rights of local indigenous groups throughout the world. In addition, the Convention on Biological Diversity, drafted at the Rio Earth Summit, recommends strong measures to protect against harmful bioprospecting. These companies now write detailed contracts with local and indigenous groups, strictly regulate harvest, negotiate up-front cash and royalties for successful products, train local people in the field, and offer means for environmental protection.

Pharmaceutical companies are only interested in collecting enough material from the wild to screen for active ingredients that could be useful for biomedical applications. Virtually any coral reef resource could become a target for bioprospecting, including species presently unknown to science and for which there is no understanding of sustainable yield. Million-dollar grants have been given for medical bioprospecting in coral reef ecosystems in the Pacific basin, although not yet in the U.S. Pacific Islands. Coral reef resources that have already attracted research interest include bryozoans, sponges, tunicates, coral, and seaweeds. The most interesting chemicals are usually species-specific; these species may be rare or patchily distributed, and the natural production of the active chemical may vary in time and space (Birkeland 1997a).

Initial screening of the organisms, generally algae, sponges, and lower invertebrates, requires less than 1 kg of sample material. If a potentially useful bioproduct is discovered, the laboratory will make every attempt to synthesize the product in the lab without collection of additional samples. The reason for this is two-fold. Most important, this research requires multiple replications under strict protocols to verify the nature and intensity of bioactivity, and natural variation between samples of the same species can confound these protocols. Therefore, laboratory-grown samples or synthesized products are necessary for large-scale development and production. Second, field sampling is expensive and samples often arrive at the laboratory in poor condition for screening.

Several organizations are bioprospecting on reefs near several U.S. Pacific Islands. The U.S. National Cancer Institute has contracted the Coral Reef Research Foundation, a non-profit organization based in the Republic of Belau, to collect and identify coral reef and other marine organisms for anti-cancer and anti-AIDS screening tests (CRRF 2000). In addition, the University of Guam Marine Laboratory is seeking new examples of the chemical deterrents that coral reef organisms possess to deter predators. They are collaborating with researchers at the University of Hawaii, who are also examining the properties of these chemical deterrents. Some of these substances could have biomedical uses: they might kill cancer cells; halt inflammatory responses; or deter microbes and viruses. Other substances may be effective insecticides for use in agriculture.

Since its founding in 1999, the Marine Biotechnology Engineering Center in the Department of Oceanography at the University of Hawaii has been actively screening organisms from the marine environment. This multi-disciplinary group connects researchers from many University departments with industry sponsors. In addition, the Governor of Hawaii has made biotechnology industry development a priority for State economic development; and the most prestigious biotechnology conference in the world is scheduled to take place in Hawaii in 2004. Bioprospecting in the EEZ around U.S. Pacific Islands can be socially beneficial, with minimal adverse effects, if it is carefully monitored and managed. The take of potentially-harvested coral reef resources can be maintained at safe levels while new resource information is gathered to estimate biological reference points, assess sustainable yields, and learn how to improve management of new fisheries.

Marine Ornamentals Collection

With dramatic improvements in husbandry techniques and distribution abilities, the private sector marine aquarium trade has expanded considerably in the past decade. This trade, encompassing both public and private aquaria and including pet shop retailing, imports hundreds of species of reef-dwelling fish, corals, and other invertebrates.

Coral reef organisms for the marine aquarium trade are predominantly collected in the Indo-Pacific region. This trade involves numerous species of reef fish (especially angelfish, butterflyfish, and damselfish), and a widening spectrum of invertebrates, including corals, anemones, crustaceans, molluscs, polychaetes, echinoderms, and sponges. Endemic coral reef resources could become locally extinct if heavily collected in their limited range of distribution. In order to address some of their impacts, the aquarium trade is developing education and conservation projects meant to improve fish survivability. These projects include captive breeding of fishes, propagation of corals, and education about advanced husbandry techniques. The goal of these efforts is to significantly decrease the number of species harvested from the wild. So far, few marine ornamental products are collected from reef areas in the EEZ around U.S. Pacific Islands. Nevertheless, the rapidly expanding reef ornamentals industry could soon begin harvesting coral reef resources in some areas of the U.S. Pacific Islands' EEZs.

Live Rock Harvest

Harvesting coral reef habitat itself, in the form of "live rock," is rapidly increasing in the marine ornamentals trade. These rocks consist of stony corals, soft corals, and other attractive reef substrates. Their removal is harmful because many extracted coral species grow so slowly that, in human terms at least, they can be considered non-renewable resources. In addition to a direct loss of valuable habitat, the harvest of live rock substratum unavoidably includes an incidental harvest of commensal and infaunal organisms, which are removed with the rock.

The harvest and possession of live rock and certain coral species are prohibited, with limited exceptions, by island governments in the U.S. Pacific Islands. Collection of live rock and hard coral in the EEZ is completely unregulated, however. Both Hawaii and Guam have recently faced cases in which live rock or coral was being exported, but prosecution was impeded by claims that the collection took place outside territorial waters in the EEZ. This demonstrates that management and enforcement is currently inadequate and cannot effectively control this threat in the EEZ around the U.S. Pacific Islands.

Improvements in Underwater Harvesting Technology

Long established reef-related fisheries in the U.S. Pacific Islands employ conventional types of gear, subject to regulation by the island governments and through FMPs. Advances in scuba technology (e.g., mixed gas, rebreather) and manned and unmanned submersibles are providing greater access to deep-water coral reef resources. As this technology becomes more affordable, fishing pressure will increase on high-value species that are already heavily exploited at shallower depths. Unless new harvesting technologies are monitored and controlled, they could harm the reproductive capacity of species that have slow population turnover or those with few reproductive-size adults because of heavy fishing in shallow habitats.

Recently, the demand for small, immature black coral colonies has increased because of the growing popularity of household marine aquaria. To date, black coral in Hawaii has been hand harvested by a small group of divers using conventional compressed air scuba gear. Divers using this gear can safely descend to a maximum depth of less than 75 m. However, it is likely that in the near future black coral divers will start using mixed-gas diving methods or re-breathers that enable divers to increase both their safe diving depth and their bottom time. Already, some harvesters are experimenting with towed underwater camera systems and other devices that may increase the output from old harvest areas and lead to the discovery of new beds (URS Corp. in prep).

Manned submersibles and remotely-operated vehicles are still very expensive, but during the past two decades innovations in submersible technology in the petroleum and defense industries have significantly reduced their capital and operating costs (URS Corp. in prep).

1.3.3 Need for Comprehensive Ecosystem-Based Management, Monitoring, and Enforcement

Reefs extend across jurisdictional boundaries, and mechanisms for coordinated management among different government agencies are largely *ad hoc*. Reefs in nearshore areas are under the jurisdiction of the island governments. Coral reef resources in the EEZ are managed by the Departments of Commerce and Interior. Fisheries throughout the U.S. EEZ—including coral reef fisheries—are managed under the authority of the Magnuson Fishery and Conservation Act of 1997, as amended (MSFCMA). This legislation delegates much of the responsibility to regional councils. The reef-related bottomfish and lobster fisheries conducted in the EEZ around the NWHI have been actively managed by the Council for more than a decade.

The management objectives of the various agencies are not consistent. Even when effective regulations are in place enforcement is difficult, labor intensive, and often inadequate. Fragmented jurisdiction and management authority complicate prosecution of violators. Coral reefs represent an extreme in biological diversity, habitat complexity, and competing demands for resource use. Only holistic management is likely to be effective.

1.3.4 Need for Consensual and Adaptive Management

A wide range of consumptive and non-consumptive activities, commercial and non-commercial uses, and resident and non-resident populations compete for coral reef resources. Residents of the U.S. Pacific Islands include significant numbers of indigenous people whose cultures are dependent on fishing and seafood. Increased tourism-related ocean recreation in Hawaii, CNMI, and Guam means more island visitors who place a premium on non-consumptive uses of nearshore coral reef resources (Pooley 1993b).

There is almost universal agreement about the need for sustainable resource use, but users are divided by fundamentally different views on marine resources: how to study them, analyze them, and manage them. It is difficult, therefore, to define management objectives and "preferred" ecosystem outcomes that are clearly desirable and recognizable by all interests.

The council system, created by the MSFCMA, is more decentralized than other forms of living resource management by U.S. government agencies (e.g., national parks, forests and wildlife refuges, endangered species). Under the council process management policies for EEZ fisheries evolve during the preparation and amendment of FMPs. Participants in plan development are diverse—they include regulators, scientists, and resource users. The process is also very open: public participation—through advisory panels and at meetings—is early, systematic, and meaningful. The process encourages participation by stakeholders representing different views and cultures, facilitating dialogue even in an adversarial environment. Decision-making relies heavily on consensual agreement. Typically, the technical data available for management decisions are uncertain and incomplete. The Council, therefore, follows an adaptive management strategy that allows for improvement of FMPs as new information becomes available. An adaptive management process is well suited to coral reef fisheries management because of the diverse stakeholders and poor biological and ecological understanding of the resource base.

1.3.5 Consideration Given to Indigenous People in Plan Development

The indigenous people of the U.S. Pacific Islands have centuries-old connections to coral reefs that pre-date European contact and Western concepts of coral reef management. Beginning when the islands were first settled, indigenous cultures evolved a physical, economic, and spiritual life defined by dependence on marine fisheries for food security. Indigenous cultures believe that the ocean and land environments are inextricably connected. Because of this holistic perspective, Pacific Islanders see themselves as an integral part of the ecosystem. And because of their intimacy with local inshore marine environments, indigenous communities developed a far more detailed understanding of coral reefs than that of modern-day resource users and managers. This fostered the development of relatively sophisticated social controls over fishing, in order to ensure sustainable harvests. For example, islanders recognized that fishing should not disrupt crucial life history bottlenecks like spawning aggregations, and they often imposed corresponding restrictions on fishing times and places. Because of the precision of these controls, traditional conservation measures can be likened to a "rifle" as opposed to a "shotgun."

In developing this FMP, the Council has been ever appreciative of these accomplishments. As important, when preparing FMPs the Council is required to take into account the various traditional fishing practices of indigenous island residents. For example, marine protected areas, one of the management measures outlined in this FMP, could be construed as a limited access system. In this case the MSFCMA dictates that the Council must take into account "historical fishing practices in, and dependence on the fishery" and "the cultural and social framework relevant to the fishery" (§303 (b)(6)).

Apart from considerations of historical participation and cultural dependence on coral reef fisheries, the Council is concerned that communities consisting of descendants of indigenous Pacific Islanders have not sufficiently benefitted from the region's fisheries. The MSFCMA provides for the establishment of a community development program for Western Pacific fisheries. This provision is intended to increase opportunities for indigenous communities to participate in and benefit from fisheries in the Council's jurisdiction.

It is also important to note that in numerous statutes the U.S. Congress has specially considered aboriginal Hawaiians because they are socio-economically disadvantaged and there is a federal trust obligation stemming from Section 5 of the Admissions Act. In addition, the way that the U.S. gained control of Hawaii should be taken into account. As a result, in 1993 Congress passed the Apology Bill, which states that "...the indigenous Hawaiian people never directly relinquished their claims to their inherent sovereignty as a people or over their national lands to the United States, either through their monarchy or through a plebiscite or referendum." In the absence of any treaty or voluntary relinquishment, the lingering sovereignty claim by Hawaiians may dictate caution in establishing regulations that restrict the right of Hawaiians to harvest coral reef marine resources, particularly in areas held by the State of Hawaii as part of the Ceded Lands Trust for the benefit of Native Hawaiians. Many of the submerged lands surrounding the NWHI are part of the Ceded Lands Trust.

1.4 Management Plan Objectives

The MSFCMA mandates fishery management measures that achieve optimum yield from fisheries resources of the U.S., while preventing overfishing. However, in 1999 the Ecosystems Principles Advisory Panel (EPAP) submitted a report to Congress arguing for management that—while not abandoning optimum yield and overfishing principles—takes an ecosystem-based approach (EPAP 1999). Heeding the basic principles, goals, and policies for ecosystem-based management outlined by EPAP, the Council plans to develop "Fisheries Ecosystem Plans" for each major ecosystem under its jurisdiction. This Coral Reef Ecosystem FMP represents the first of these plans. While outlining several new and important coral-reef-specific management measures, it also serves as a framework for incorporating ecosystem approaches into the regulatory structure created by the already-implemented Bottomfish, Crustaceans, Precious Corals, and Pelagics FMPs.

The overall goal of this management program is to establish a management regime for the entire Western Pacific Region that will maintain sustainable coral reef fisheries while preventing any adverse impacts to stocks, habitat, protected species, or the ecosystem. To further this goal the Council established eight objectives for the CRE-FMP. The objectives promote: (1) sustainable use of coral reef resources, especially by fishing communities and indigenous fishermen in the region; (2) an adaptive management approach based on fishery-dependent and fishery-independent research; (3) marine protected areas and habitat conservation; (4) cooperative and coordinated management by the various agencies concerned with the conservation of coral reef resources; and (5) education to foster public support for management.

Objective 1: To foster sustainable use of multi-species resources in an ecologically and culturally sensitive manner, through the use of the precautionary approach and ecosystem-based resource management.

Objective 2: To provide a flexible and responsive management system for coral reef resources that can rapidly adapt to changes in resource abundance, new scientific information, and changes in fishing patterns among user groups or by area.

Objective 3: To establish integrated resource data collection and permitting systems, establish a research and monitoring program to collect fishery and other ecological information, and to collect scientific data necessary to make informed management decisions about coral reef ecosystems in the EEZ.

Objective 4: To minimize adverse human impacts on coral reef resources by establishing new—and improving existing—marine protected areas, managing fishing pressure, controlling wasteful harvest practices, reducing other anthropogenic stressors directly affecting coral reef resources, and allowing the recovery of naturally-balanced reef systems. This objective includes the conservation and protection of essential fish habitats.

Objective 5: To improve public and government awareness and understanding of coral reef ecosystems and their vulnerability and resource potential in order to reduce adverse human impacts and foster support for management.

Objective 6: To collaborate with other agencies and organizations concerned with the conservation of coral reefs, in order to share in decision-making and to obtain and share data and resources needed to effectively monitor this vast and complex ecosystem.

Objective 7: To encourage and promote improved surveillance and enforcement to support the plan's management measures.

Objective 8: Provide for sustainable participation by fishing communities in coral reef fisheries and, to the extent practicable, minimize the adverse economic impacts on such communities.

1.5 Management Plan Approach

Coral reefs are complex, multi-resource marine ecosystems comprising thousands of species, few of which are targeted by existing fisheries. They represent an extreme in biological diversity, ecological complexity and competing demands for resource use. Therefore, only holistic management is likely to be effective. However, the basics, much less the intricacies, of coral reef ecosystems are poorly understood. Furthermore, it is doubtful that there will ever be enough data available to calculate total removals, including incidental mortality, and show how they relate to standing biomass, production, optimum yields, natural mortality, and trophic structure. Ecosystem-based management of coral reefs, therefore, is a long-term goal that can only be achieved as new information allows for improved understanding and decision-making. EPAP (1999) made recommendations to guide the further development of ecosystem management for fisheries, built around the following policies:

- Change the burden of proof.
- Apply the precautionary approach.
- Purchase "insurance" against unforseen, adverse ecosystem impacts.
- Learn from management experience.
- Make local incentives compatible with global goals.
- Promote participation, fairness, and equity in policy and management.

To the extent possible, the CRE-FMP attempts to incorporate these concepts. According to EPAP, a fishery ecosystem plan should incorporate eight actions (EPAP 1999, pp. 27-32). The way in which this FMP incorporates each of these action items is outlined below.

1. *Delineate the geographic extent of the ecosystem(s) that occur(s) within Council authority, including characterization of the biological, chemical, and physical dynamics of those ecosystems.*

   The geographic extent and ecological characterization of coral reef ecosystems around the U.S. Pacific Islands are described in Chapter 2 of this FMP. High biological and environmental variability is a natural characteristic of these ecosystems, with or without fishing. Irregular pulses of new recruits cause cycles in the abundance and harvest potential of individual reef species. Environmental variability is both spatial—related to differences in the quality of habitat—and temporal—related to monthly moon phase, and seasonal and longer-term environmental changes. Coral reef resources are also affected by large-scale climatic shifts. Natural disturbance cycles in areas exposed to large storm waves can dramatically alter coral cover and resulting habitat quality.

2. *Develop a conceptual model of the food web.*

   The ECOPATH model, as applied to coral reef ecosystems, is described in Section 2.4 of this FMP. ECOPATH is a simple mathematical model that estimates mean annual biomass, production, and food consumption for major components (species groups) of an ecosystem. Application of ECOPATH to French Frigate Shoals found that the coral reef ecosystem is controlled mainly by predation from the top down and primary production is controlled mainly by nutrients, photosynthetic rate limits, and habitat space.

3. *Describe the habitat needs of different life history stages for all plants and animals that represent the "significant food web."*

In addition to Chapter 2, Chapter 6 and Volume III of this FMP, which describe and discuss essential fish habitat, detail the habitat needs of different life history stages for all species managed under this FMP, based on available scientific information.

4. *Calculate total removals—including incidental mortality—and show how they relate to standing biomass, production, optimum yield, natural mortality and trophic structure.*

Because available biological and fishery data are poor for all species and areas covered by the CRE-FMP, it is not possible to address this action item.

5. *Assess how uncertainty is characterized and what kind of buffers against uncertainty are included in conservation and management actions.*

The FMP acknowledges that there is uncertainty regarding the impacts of fishing and other human activities on coral reef ecosystems. As a buffer against uncertainty, the FMP establishes marine protected areas as insurance against this risk, and reporting requirements to monitor changes in the fisheries, as described in Chapter 5.

6. *Describe available long-term monitoring data and how they are used.*

Section 3.3 includes an overview of available long-term monitoring data while Chapter 7 describes research needs. Fishery monitoring and fishery-independent research activities will generate information that may be used for future adjustments to the CRE-FMP under a framework procedure that allows for timely action.

7. *Develop indices of ecosystem health as targets for management.*

What constitutes a "healthy" reef in the U.S. Pacific Islands is difficult to define, but should be considered within a specific geographic and temporal context, considering the quality of natural habitat, environmental variability, natural disturbance cycles, and also the history of human impacts. Measuring changes and differentiating natural rhythms from fisheries' effects, even in specific localities, present major challenges because of the highly dynamic ecosystem. Because of these factors, no indices of ecosystem health have yet been established under this FMP beyond the MSY, OY and overfishing reference points, as discussed in Chapter 4.

8. *Assess the ecological, human, and institutional elements of the ecosystem which most significantly affect fisheries, and are outside Council/Department of Commerce authority. Included should be a strategy to address those influences in order to achieve both FMP and FEP objectives.*

Much of the previous damage to coral reefs around U.S. Pacific Islands has occurred as a result of non-fishing activities such as coastal and harbor development, watershed land use practices and runoff, industrial discharges, non-fishing vessel operation, and military and tourist use. The most severe impacts have occurred on nearshore reefs under island government jurisdiction. Few reefs in the EEZ are close enough to inhabited land areas to be significantly affected by tourism, coastal development, upland runoff, beach erosion, and other terrestrial impacts. Some impacts occur at a scale too large to be mitigated by unilateral management actions for the Western Pacific Region. These include: overpopulation, ocean warming and increased ultraviolet radiation, introduction of invasive exotic marine species, and accumulation of marine debris.

Reefs extend across jurisdictional boundaries, and mechanisms for coordinated management among different government agencies are largely *ad hoc*. Inter-regional and international management will be necessary to find solutions to this problem. Reef areas in near-shore areas are under the jurisdiction of the island governments. Other reefs are in areas managed by various federal agencies (e.g., national parks, marine sanctuaries, national wildlife refuges). The management objectives of the various agencies are not consistent. Even when effective regulations are in place, enforcement is difficult, labor intensive and often inadequate. Fragmented jurisdiction and management authority complicate prosecution of violators.

To address these problems, several steps could be taken. The Council could negotiate a memorandum of understanding with states to increase the extent of marine protected areas. Reliance on island government permit and reporting for the EEZ adjacent to populated islands, as described in this FMP could be enhanced. Through an amendment to the MSFCMA, the Council's and NMFS's authority could be expanded to address non-fishing vessel impacts on habitat. Finally, the essential fish habitat consultation process, mandated by the 1996 Sustainable Fisheries Act amendment to the MSFCMA, could be actively pursued and enhanced. These possible measures are described in more detail in Chapters 5 and 6 of the FMP.

1.6 Management Unit

1.6.1 Management Area

The Coral Reef Ecosystems Management Area (CRE management area, or management area) includes the EEZ surrounding Hawaii, Guam, Samoa, CNMI and Pacific Remote Island Areas.[1] (The Pacific Remote Island Areas, hereafter PRIAs, consist of Palmyra Atoll,

[1] Generally, EEZ waters are outside of territorial waters, which extend from the shore to 3 miles, and within 200 miles from shore. However, jurisdictional issues in the CNMI are complicated because the federal government claims jurisdiction to the shoreline while the CNMI claims jurisdicition over the whole EEZ. For purposes of the CRE-FMP, waters from shore to 3 miles offshore are the management responsibility of CNMI. Management of inshore waters around CNMI remains with the regional authorities because (1) cooperation between the

Kingman Reef, and Howland and Baker Islands in the central south Pacific; Midway Island at the northwest end of the Hawaiian archipelago; Johnston Atoll southwest of the main Hawaiian Islands; and Wake Island in the Marshall Islands Archipelago.) The management area for this FMP includes at least 11,382 km^2 of reef area, summarized in Table 1.1. Approximately 80% of the coral reef area that would be managed under the CRE-FMP is in the NWHI. The nature and extent of coral reefs in EEZ waters around each Western Pacific Region jurisdiction[2] are briefly described below.

During the development of the Bottomfish, Crustacean and Precious Corals FMPs, the EEZs surrounding the CNMI and the PRIA were not initially included under the management regime. This omission was due to the fact that these fisheries were not active in the EEZ when the FMPs were being developed. Since that time, bottomfisheries in the CNMI and the PRIA have developed. While data has been collected through voluntary compliance, these areas have yet to be included in the management areas of the bottomfish FMP. An amendment to include these areas in existing FMPs is near completion with submission to NMFS expected at same time as submission of this FMP. The amendment will include the CNMI and PRIA under the crustacean and bottomfish FMPs and the CNMI under the Precious Corals FMP.

American Samoa

American Samoa is composed of seven islands in the eastern part of the Samoan Archipelago (14° S, 168-173° W). The islands are small, ranging in size from the densely populated high island of Tutuila (145 km^2) to the remote and uninhabited Rose Atoll (4 km^2). Mean air and sea surface temperatures (27.0° C and 28.3° C, respectively) vary little seasonally, although average air temperatures rose sharply, by 2° C, in the 1990s. The high islands receive heavy annual rainfall (300-500 cm on Tutuila) (Craig *et al.* in press).

As shown in Table 1.1, coral reefs are limited in area and only 8.4% of them are located within the EEZ, mostly on offshore banks (Green 1997). The main islands are volcanic mountains that descend steeply below sea level. They are fringed by narrow reef flats (50-500 m wide) that drop steeply to a depth of 3-6 m and descend gradually to 40 m. From this depth, the ocean bottom drops rapidly, reaching depths of 1,000 m within 1-3 km from shore (Craig *et al.* in press). Almost 300 coral species occur in American Samoa (Green 1997). The reefs also support a diverse assemblage of nearly 900 fish species. Dominant families are damselfish, surgeonfish, wrasse, and parrotfish. Spawning for some, and perhaps most, species occurs year-round, although peak spawning may be seasonal (Craig *et al.* in press).

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regional government and the Council relies on recognition of local management authority of the state waters, (2) the CNMI-based small vessel fishermen are best managed by local hands-on interaction and knowledge of the issues, and (3) this regime retains consistency with the other areas under Council jurisdiction.

[2]Recognizing that the region comprises several different political entities—a state, a commonwealth, two territories, and unincorporated federal territory—hereafter, as shorthand, these constituent parts (excluding federal territory) will be generically referred to as states.

Table 1.1: Coral reef area (in km^2 <100m deep) in nearshore waters (0-3 nmi from shore) and offshore waters (3-200 nmi from shore) in each location in the Western Pacific Region (Hunter 1995).

Location	0-3 mni	3-200 nmi	Total Coral Reef Area
American Samoa	271	25	296
Guam	69	110	179
Hawaii			
Main Hawaiian Islands	1,655	880	2,535
Northwestern Hawaiian Islands	2,227	9,104	11,331
CNMI	45	534	579
PRIAs	620	89	709
Midway*	203	20	223
TOTAL	5,090	10,762	15,852

*Midway is a PRIA located in the Hawaiian Archipelago.

Little is known about the biological assemblages on offshore banks in the EEZ around American Samoa. Species composition on the offshore reefs may be similar to that on the outer reef slopes, although species diversity may be less because of the absence of estuarine, reef flat and shallow lagoon habitats (Green 1997).

Guam

Situated at 13° N latitude and 144° E longitude, Guam is the southernmost and largest island (550 km^2) in the Mariana Islands Archipelago. Guam's climate is warm and humid year round. Annual rainfall ranges from approximately 200 cm along the coast to 220 cm at higher elevations. The rainy season is generally from July through November. Sea surface temperatures range from a monthly mean of 27-28° C in February to 30° C in August. Guam regularly experiences typhoons, with winds greater than 65 knots. Typhoons are possible throughout the year, but their likelihood is greatest from July through December.

Guam is largely a raised limestone island on a volcanic base. Approximately half of the shoreline is bordered by well-developed coral reefs with reef flats as wide as 600 m. A broad barrier reef encloses Cocos Lagoon at the southwest tip of the island. A raised barrier reef, a greatly disturbed barrier reef, and a coral bank enclose the deep lagoon of Apra Harbor. The 110 km^2 of coral reefs on offshore banks in the EEZ account for about 60% of the total reef area in Guam (Green 1997).

Over 250 stony coral species have been recorded in the southern Mariana Islands (Birkeland 1997c). Guam's reefs also support a diverse assemblage of about 800 fish species. The fish families most important to coral reef fisheries—based on the number of fished species they contain—are the wrasses, groupers, surgeonfish, jacks, squirrelfish, snappers, parrotfish, emperors, and goatfish (Green 1997).

Little is known about the biological assemblages on offshore banks in the EEZ around Guam. The tops of these banks are relatively deep (20-40 m) (Green 1997). Myers (1997) has suggested species composition on these banks may be similar to that on the outer reef slope around the island of Guam, although the relative abundance of species would probably be different because of the isolation of the banks from continuous reef tracts and from heavy fishing pressure.

Hawaii

The Hawaiian Islands are the exposed parts of an elongated submarine ridge that extends for a length of nearly 2,400 km, between 19°-28° N latitude and longitudes 155°-178° W. Based on geologic age, the Hawaiian chain is divisible into three sections: eight major volcanic islands, most of which are inhabited, make up the southeastern part; several small islets and pinnacles constitute the middle section; finally, low atolls, sand islets, and shoals compose the most northwesterly part of the chain. The islands have a combined land area of over 16,600 km^2.

The northernmost atolls of Midway and Kure are exposed to cool temperatures during the winter months, but the rest of the chain is subtropical. The climate is determined by prevailing northeast trade winds.

With 89% of the total, Hawaii's coral reefs constitute the vast majority of coral reef area in the U.S. Pacific Islands. By the same token, this 10,004 km^2 of coral reefs is by far the largest area in the Council Region, and 90%, or 9,124 $km^2$of these reefs, is in the NWHI. Almost all sizeable coral reef area (880 km^2) in the EEZ surrounding the main Hawaiian Islands (MHI) is located on Penguin Bank between the islands of Molokai and Oahu.

The islets and atolls between Nihoa Island and Kure Atoll (excluding Midway Atoll), are known as the Northwestern Hawaiian Islands. Except for Kure, these islands are national wildlife refuges, providing habitat for several protected species, including the green sea turtle and the Hawaiian monk seal.

The main Hawaiian Islands represent the young part of the Hawaiian Archipelago; consequently, they have less well-developed fringing reefs, which have not subsided as far below sea level as those in the NWHI (Green 1997). The coral reefs of the MHI were mapped extensively in the 1970s and 1980s, and have since been surveyed only intermittently. Grigg (1997) summarized the condition of MHI reefs in 1996-97, based on a statewide survey of knowledgeable individuals and agencies. He reports, based on that survey, that 90% of the reefs in Hawaii are healthy. The best reef development and highest live coral cover in the MHI are found in areas sheltered, or partially sheltered from, open ocean swell.

Coral reef resources in Hawaii are characterized by relatively low biological diversity, but a high degree of endemism. Hawaii's isolation has produced a large proportion of endemic coral reef species. It is estimated that 20-30% of the fish, 18% of the algae, and 20% of the molluscs are endemic to Hawaii. Hawaii's coral reefs are also unique because some species that are relatively uncommon in other areas of the Pacific are quite abundant in Hawaii (Fielding and Robinson 1987). Only 47 species of reef-building corals have been recorded. Coral species richness tends to be higher in the NWHI, where the genus *Acropora*, not found in the MHI, is present. Many reefs in the NWHI are comprised of calcareous algae (Green 1997). Black corals are found off promontories at depths of 30-100 m in both state and federal waters around the MHI (URS Corp. in prep).

A total of 557 marine reef fish species have been identified from the Hawaiian Islands, and about 24% of these are considered endemic. Reef and coastal pelagic fish families with species valued for food include surgeonfish, goatfish, parrotfish, jacks, bigeye scad, mackerel scad, and soldier fish. Coral reefs in Hawaii also provide habitat for over 1,000 mollusks, 1,350 other macroinvertebrates, and 400 seaweeds.

In general, fish species diversity appears to be lower in the NWHI than in the MHI. Although the inshore fish assemblages of the two regions are similar, fish size, density, and biomass are higher in the NWHI. Fish communities in the NWHI are dominated by apex predators, such as sharks and jacks, while communities in the MHI are not. Some fish species are common in parts of the NWHI that are rare elsewhere in the archipelago (Green 1997).

Perhaps the most important factor in the population dynamics of many coral reef species in the NWHI, and the ecosystem as a whole, are cyclical oceanographic events, which affect productivity over large areas and may account for large fluctuations in population abundance. In a comprehensive study of recent climatic and oceanographic events and their effect on productivity in the NWHI, Polovina *et al.* (1994) found that declines of 30-50% in a number of species from various trophic levels, from the early 1980s to present, could be explained by a shift in oceanographic conditions. Before this, oceanographic conditions lasting from the late 1970s until the early 1980s moved nutrient-rich deep ocean water into the euphotic zone, resulting in higher survival of reef fish, crustaceans, monk seals, and sea birds. The researchers caution that "resource managers need to be aware that target levels of productivity (in the NWHI), for protected species, or sustainable yield for fishery resources, may vary with interdecadal climate events."

The new NWHI Coral Reef Ecosystem Reserve is a related management issue. Executive Orders (EO) 13178 (December 4, 2000) and 13196 (January 18, 2001), issued by President Clinton, established the Reserve which spans the 1,200 mile length of the NWHI by a 100 mile corridor. Conservation measures listed in these EOs include:

- A cap on commercial and recreational fishing at the "previous year's" (from December 4, 2000) level of effort and take. (The bottomfish level would be based on an individual's average over the previous five years.)

- Establishing Reserve Preservation Areas that prohibit almost all activities to 100 fm around most islands. (But bottomfishing and recreational trolling would be allowed in waters deeper than 25 or 50 fm around some islands.)
- Prohibiting anchoring on live or dead coral, where the bottom can be seen.
- Prohibiting anchoring where buoys are available or outside a yet-to-be-determined designated area.
- Prohibiting removal of living/non-living resources.
- Prohibiting taking or touching of living or dead coral.
- Prohibiting discharging or depositing any material, except cooling water or engine exhaust.
- Additional restrictions on non-fishing activities.
- Certain Native Hawaiian uses are allowed in yet-to-be-identified sub-areas. Activities allowed in both the Reserve and Preservation Area would be restricted to subsistence, cultural, and religious purposes.

The Reserve is intended to serve as a temporary management regime until completion of the process to designate the NWHI as a National Marine Sanctuary. On January 19, 2001, the NOAA/NOS Office of National Marine Sanctuaries announced its intent to initiate the Sanctuary designation process for the Reserve pursuant to sections 303 and 304 of the National Marine Sanctuaries Act (16 U.S.C.1433, 1434). During this process, NOAA will prepare an environmental impact statement and management plan, which will examine the management, boundary, and regulatory alternatives associated with sanctuary designation. As required, NOAA must also initiate public scoping meetings to solicit information and comments on the range and significance of issues related to sanctuary designation and management.

In designating the sanctuary, the EOs direct the Secretary of Commerce to supplement or complement the existing Reserve, and in consultation with the Governor of the State of Hawaii, determine whether State submerged lands and waters should be included as part of the Sanctuary. The effect of the reserve on the CRE-FMP, and existing FMPs, cannot be fully assessed until an ongoing review of the EOs by the new Administration is completed. Still ambiguous conservation measures also need to be clarified before the relation between measures in this FMP and Reserve regulations can be resolved.

Commonwealth of the Northern Mariana Islands

The Commonwealth of the Northern Mariana Islands is a subset of the Mariana Archipelago. It encompasses 14 islands (15-21° N latitude, 144-146° E longitude) oriented along a north-south axis stretching over a distance of 740 km. The islands can be divided into two sections based on age and geology. Saipan, Tinian, Rota, Aguijan, and Farallon de Medinilla, in the southern part of the chain, are old, raised limestone islands. In contrast, the northern islands—Anatahan, Sarigan, Guguan, Alamagan, Pagan, Agrihan, Asuncion, Maug, and Uracas—are geologically young volcanic islands with steep seaward slopes.

The CNMI's 579 km^2 of coral reefs represent the second largest reef area in the U.S. Pacific Islands. The 534 km^2 of reefs in the 3-200 nm offshore zone (see footnote 1) account for the majority of this area. The largest single tract is off Farallon de Medinilla (311 km^2). Saipan's best developed reefs occur in the 0-3 nm nearshore zone. These include fringing reefs, inshore and offshore patch reefs, and a well-developed barrier reef-lagoon system along most of the western leeward coast. In the northern islands in general, reef development is poor to non-existent. In addition, there are numerous shoals along the island chain (Green 1997). A chain of small, shallow banks topped with coral reefs lie in a parallel arc 240 to 320 km to the west of the Mariana Islands (Myers 1997).

The number of stony coral and reef fish in the southern part of the CNMI is similar to that of Guam. Diversity drops markedly off the northern volcanic islands, where only 159 species of stony coral and only about 360 species of reef fish have been recorded (Birkeland 1997c). Dominant fish families are the same as in Guam.

Pacific Remote Island Areas

Howland, Jarvis, and Baker are arid coral islands located close to the equator in the southern Line Island group. Kingman Reef is a coral reef shoal in the central Pacific in the northern Line Islands. Palmyra Atoll is a wet atoll located. It is composed of three sub-lagoons and over 50 separate islets that have been modified by construction activity. Johnston Atoll is an open atoll in the north Central Pacific. Until the 1940s, there were only two islands, but by 1964 massive dredge-and-fill operations significantly expanded the original area of Johnston Island. Wake Island is an isolated island north of the Marshall Islands, and consists of three islets and a reef enclosing a sheltered lagoon.

The total reef area around remote U.S. Pacific Islands (not including Midway) is 709 km^2, of which 89 km^2 is offshore (3-200 nmi). The remote U.S. Pacific Island possessions range in location from less than 1° S latitude to 20° N latitude and from 162° W to 167° E longitude. The climate regimes range from arid to wet and equatorial to sub-tropical. Marine resources are similarly varied. Several of these islands are of extreme scientific interest because of their age, with origins in the Mesozoic era, and the majority are designated or proposed as national wildlife refuges. The biological diversity of coral reef ecosystems in these areas varies considerably from island to island. Fish densities and biomass are higher than around the populated islands in the region. Rare species occur in some areas. For example, giant clams are prolific throughout the lagoon at Wake Atoll (Green 1997).

Johnston Atoll has a unique mix of coral reef species not duplicated elsewhere in the Pacific. Invertebrates from both the Western and Central Pacific are present, suggesting that the atoll serves as a bridge connecting distributions of Polynesian and Micronesian invertebrate fauna. The coral fauna has a strong affinity with that of Hawaii, but the appearance of the reef is quite different. This is due to the dominance of *Acropora*, not found in the main Hawaiian Islands, and the lack of the common Hawaiian species *Porites compressa*. Endangered

Hawaiian monk seals occasionally visit the atoll, but are not known to pup there. NMFS has released bachelor male monk seals there to reduce harassment of females in the NWHI. The extremely rare Cuvier's beaked whale is regularly seen offshore and may actually calve in the lagoon (Green 1997).

1.6.2 Management Unit Taxa

As already noted, many different organisms inhabit the coral reef ecosystem. Numerous species are caught in different reef-related fisheries. The biology and population dynamics of many coral reef organisms are poorly understood and it is possible that they may be targeted by commercial fishermen in the future. In developing an FMP, councils must identify management unit species (MUS), which are those species that come under the purview of the management plan. For all the reasons just outlined, this is difficult for coral reef species. The approach taken here is to rely on taxonomically more general designations and to divide these taxa into two groups:

1. Currently Harvested Coral Reef Taxa (CHCRT). Because these organisms are commercially harvested, fishery information for them is available, allowing more effective management. The species in this group have been reported on commercial fishery catch report records for federal EEZ waters but are not MUS under any of the Council's already-implemented FMPs. Membership in this group is based on two criteria: (1) More than 1,000 lbs. annual harvest for all members of a taxon, based on commercial fishery catch reports. These taxa are families or subfamilies. (2) Within these taxa particular genera or species are identified, based on their appearance on catch reports. CHCRT are listed in Table 1.2, grouped by family or subfamily. Table 1.2 also lists Aquarium taxa (discussed below.)

2. Potentially Harvested Coral Reef Taxa (PHCRT). These are coral reef organisms that are not known to be currently caught, or for which very little fishery information is available. However, emerging coral reef fisheries—such as the rapidly expanding marine ornamental products trade and the emerging industries for pharmaceutical and natural products—may target them at some future date. Several family/subfamily taxa in the CHCRT list are also PHCRT. As noted in Table 1.3, which lists PHCRT, all genera or species in these taxa that are not listed as CHCRT are by default PHCRT.

Because fishing for coral reef resources is light to non-existent in the EEZ, the CHCRT list was developed as a functional means to facilitate data collection and monitoring of coral reef ecosystem species that are currently being harvested, both directly and incidentally in commercial fisheries in state/territorial and federal waters. It will also help fishery managers to develop harvest strategies and proxies so that they can begin managing the coral reef ecosystem as a whole. The Currently Harvested Coral Reef Taxa also includes a subgroup of species that aquarium fish collectors presently harvest. With the exception of the nearshore waters of West Hawaii (Big Island), the commercial collection of Aquarium Taxa is minimal throughout the management area. However, the taxa listed in this category represent individual species that have been harvested in the EEZ and will likely continue to be harvested in the EEZ. For this reason they are listed separately at the end of Table 1.2. Their inclusion in the CHCRT list will allow continuing data collection by existing local management programs. As a result, the impacts on resources and habitats by aquarium fish collectors in the EEZ can be better assessed. As discussed in Section 5.3.1, local fishery management agencies will oversee permitting and reporting requirements for harvest of these species.

Subdividing the MUS and limiting the number of species on the CHCRT list makes it easier to establish baseline reference points. These reference points will be used to assess changes in species composition and abundance and will help to manage both currently harvested coral-reef-associated species and those likely to be targeted, should a coral reef fishery in the EEZ develop in the future. This subdivision also encourages cooperation of fishermen by reducing unreasonable permitting requirements, which also reduces unnecessary administrative and regulatory burdens.

The Potentially Harvested Coral Reef Taxa list consists of literally thousands of taxa for which little to no catch or effort data exist. For a great majority of these species scientific knowledge about their life histories, habitat requirements, and other biological information is completely lacking. Therefore, to begin data collection for management purposes, special permits will be required to target the PHCRT listed in Table 1.3 and for any species that is not explicitly listed on the CHCRT list. (Permitting is detailed in Section 5.3.)

The ecosystem concept considers the organisms themselves, grouped by taxa, their interactions, and their relationship to habitats. Taken together, these are the characteristics that structure the ecological relationships. Cooperation by fishermen, coupled with continued data collection and analyses, are all necessary in order to further our understanding of the intricacies of these relationships. Ecosystem-based management of coral reef resources will continually improve as a result. Management Unit Species designation is an important initial step in this effort

In 1999, the bottomfish plan team noted that a large number of species were currently being harvested in Guam, American Samoa and the CNMI using bottomfish gear and techniques. There regularity in catch has been documented since the onset of the WPacFIN creel surveys. They recommended that the Council include these species under the bottomfish FMP to allow for future management measures as needed. The list of species is found in Table 1.4 and will be part of the Bottomfish MUS upon approval of an amendment to be submitted to the NMFS at the same time as this FMP.

Table 1.2: Currently Harvested Coral Reef Taxa.

Acanthuridae (Surgeonfishes)	Orange-spot surgeonfish (*Acanthurus olivaceus*) Yellowfin surgeonfish (*Acanthurus xanthopterus*) Convict tang (*Acanthurus triostegus*) Eye-striped surgeonfish (*Acanthurus dussumieri*) Blue-lined surgeon (*Acanthurus nigroris*) Whitebar surgeonfish (*Acanthurus leucopareius*) Blue-banded surgeonfish (*Acanthurus lineatus*) Blackstreak surgeonfish (*Acanthurus nigricauda*) Whitecheek surgeonfish (*Acanthurus nigricans*) White-spotted surgeonfish (*Acanthurus guttatus*) Ringtail surgeonfish (*Acanthurus blochii*) Brown surgeonfish (*Acanthurus nigrofuscus*) Elongate surgeonfish (*Acanthurus mata*) Mimic surgeonfish (*Acanthurus pyroferus*) Yellow-eyed surgeonfish (*Ctenochaetus strigousus*) Striped bristletooth (*Ctenochaetus striatus*) Twospot bristletooth (*Ctenochaetus binotatus*)
	Bluespine unicornfish (*Naso unicornus*) Orangespine unicornfish (*Naso lituratus*) Humpnose unicornfish (*Naso tuberosus*) Black tongue unicornfish (*Naso hexacanthus*) Bignose unicornfish (*Naso vlamingii*) Whitemargin unicornfish (*Naso annulatus*) Spotted unicornfish (*Naso brevirostris*) Humpback unicornfish (*Naso brachycentron*) Barred unincornfish (*Naso thynnoides*) Gray unicornfish (*Naso caesius*)
Balistidae (Triggerfishes)	Titan triggerfish (*Balistoides viridescens*) Clown triggerfish (*B. conspicillum*) Orangstriped trigger*fish* (*Balistapus undulatus*) Pinktail triggerfish (*Melichthys vidua*) Black triggerfish (*M. niger*) Blue Triggerfish (*Pseudobalistesfucus*) Picassofish (*Rhinecanthus aculeatus*) Wedged Picassofish (*B. rectangulus*) Bridled triggerfish (*Sufflamen fraenatus*)
Carangidae (Jacks)	Bigeye scad (*Selar crumenophthalmus*) Mackerel scad (*Decapterus macarellus*)
Carcharhinidae (Sharks)	Grey reef shark (*Carcharhinus amblyrhynchos*) Silvertip shark (Carcharhinus albimarginatus) Galapagos shark (*Carcharhinus galapagenis*) Blacktip reef shark (*Carcharhinus melanopterus*) Whitetip reef shark (*Triaenodon obesus*)

Holocentridae (Soldierfish/Squirrelfish)	Bigscale soldierfish (*Myripristis berndti*) Bronze soldierfish (*Myripristis adusta*) Blotcheye soldierfish (*Myripristis murdjan*) Bricksoldierfish (*Myripristis amaena*) Scarlet soldierfish (*Myripristis pralinia*) Violet soldierfish (*Myripristis violacea*) Whitetip soldierfish (*Myripristis vittata*) Yellowfin soldierfish (*Myripristis chryseres*) Pearly soldierfish (*Myripristis kuntee*) (*Myripristis hexagona*) Tailspot squirrelfish (*Sargocentron caudimaculatum*) Blackspot squirrelfish (*Sargocentron melanospilos*) File-lined squirrelfish (*Sargocentron microstoma*) Pink squirrelfish (*Sargocentron tieroides*) Crown squirrelfish (*Sargocentron diadema*) Peppered squirrelfish (*Sargocentron punctatissimum*) Blue-lined squirrelfish (*Sargocentron tiere*) Ala'ihi (*Sargocentron xantherythrum*) (*Sargocentron furcatum*) (*Sargocentron spiniferum*) Spotfin squirrelfish(*Neoniphon spp.*)
Kuhliidae (Flag-tails)	Hawaiian flag-tail (*Kuhlia sandvicensis*) Barred flag-tail (*Kuhlia mugil*)
Kyphosidae (Rudderfish)	Rudderfish (*Kyphosus biggibus*) (*Kyphosus cinerascens*) (*Kyphosus vaigienses*)
Labridae (Wrasses)	Saddleback hogfish (*Bodianus bilunulatus*) Napoleon wrasse (*Cheilinus undulatus*) Triple-tail wrasse (*Cheilinus trilobatus*) Floral wrasse (*Cheilinus chlorourus*) Harlequin tuskfish (*Cheilinus fasciatus*) Ring-tailed wrasse (*Oxycheilinus unifasciatus*) Bandcheek wrasse (*Oxycheilinus diagrammus*) Arenatus wrasse (*Oxycheilinus arenatus*) Razor wrasse (*Xyricthys pavo*) Whitepatch wrasse (*Xyrichtes aneitensis*) Cigar wrass (*Cheilio inermis*) Blackeye thicklip (*Hemigymnus melapterus*) Barred thicklip (*Hemigymnus fasciatus*) Threespot wrasse (*Halichoeres trimaculatus*) Checkerboard wrasse (*Halichoeres hortulanus*) Weedy surge wrasse (*Halichoeres margaritacous*) (*Halichoeres zeylonicus*) Surge wrasse (*Thalassoma purpureum*) Redribbon wrasse (*Thalassoma quinquevittatum*) Sunset wrasse (*Thalassoma lutescens*) Longface wrasse (*Hologynmosus doliatus*) Rockmover wrasse (*Novaculichthys taeniourus*)

Mullidae (Goatfishes)	Yellow goatfish (*Mulloidichthys spp.*) (*Mulloidichthys Pfleugeri*) (*Mulloidichthys vanicolensis*) (*Mulloidichthys flaviolineatus*) Banded goatfish (*Parupeneus spp.*) (*Parupeneus barberinus*) (*Parupeneus bifasciatus*) (*Parupeneus heptacanthus*) (*Parupeneus ciliatus*) (*Parupeneus ciliatus*) (*Parupeneus cyclostomas*) (*Parupeneus pleurostigma*) (*Parupeneus indicus*) (*Parupeneus multifaciatus*) Bantail goatfish (*Upeneus arge)*
Mugilidae (Mullets)	Stripped mullet (*Mulgil cephalus)* Engel's mullet (*Moolgarda engeli*) False mullet (*Neomyxus leuciscus*) Fringelip mullet (*Crenimugil crenilabis*)
Muraenidae (Moray eels)	Yellowmargin moray (*Gymnothorax flavimarginatus*) Giant moray (*Gymnothorax javanicus*) Undulated moray (*Gymnothorax undulatus*)
Ocotpodidae	Octopus (*Octupus cyanea; O. ornatus*)
Polynemidae	Threadfin (*Polydactylus sexfilis*) -Moi
Pricanthidae (Bigeye)	Glasseye (*Heteropriacanthus cruentatus*) Bigeye (*Priacanthus hamrur*)
Scaridae (Parrotfishes)	Humphead parrotfish (*Bulbometapon muracatum*) Parrotfishes (*Scarus spp.*) Pacific longnose parrotfish (*Hipposcarus longiceps*) Stareye parrotfish (*Catolomus carolinus*)
Scombirdae	Dogtooth tuna (*Gymnosarda unicolor*)*
Siganidae (Rabbitfish)	Forktail rabbitfish (*Siganus aregentus*) Golden rabbitfish (*Siganus guttatus*) Gold-spot rabbitfish (*Siganus punctatissimus*) Randall's rabbitfish (*Siganus randalli*) Scribbled rabbitfish (*Siganus spinus*) Vermiculate rabbitfish (*Signaus vermiculatus*)
Sphyraenidae (Barracuda)	Heller's barracuda (*Sphyraena helleri*) Great Barracuda (*Sphyraena barracuda)*
Turbinidae (turban shells/green snails)	Green snails (*Turbo spp.*)

*Moved from Pelagic MUS list as part of this FMP.

Aquarium Taxa/Species	**Acanthuridae** Yellow tang (*Zebrasoma flavescens*) Yellow-eyed surgeon fish (*Ctenochaetus strigosus*) Achilles tang (*Acanthurus achilles*) **Muraenidae** Dragon eel (*Enchelycore pardalis*) **Zanclidae** Morrish idol (*Zanclus cornutus*) **Pomacanthidae** Angelfish (*Centropyge shepardi* and *C. flavissimus*) **Cirrhitidae** Flame hawkfish (*Neocirrhitus armatus*) **Chaetodontidae** Butterflyfish (*Chaetodon auriga, C. lunula, C. melannotus* and *C. ephippium*) **Pomacentridae** Damselfish (*Chromis viridis, Dascyllus aruanus* and *D. trimaculatus*) **Sabellidae** Featherduster worm (*Sabellidae*)

Table 1.3: Potentially Harvested Coral Reef Taxa (PHCRT). Several taxa in the CHCRT list appear below. As noted in the table, all species in these taxa that are not listed as CHCRT are by default PHCRT.

Other Labridae spp. (wrasses) *(Those species not listed on CHCRT list)*	Ephippidae (batfish)
Other Carcharhinidae, Sphyrnidae (*Those species not listed on CHCRT list*)	Monodactylidae (mono)
Dasyatididae, Myliobatidae, Mobulidae (rays)	Haemulidae (sweetlips)
Other Serranidae spp. (groupers) *(Those species not managed under the Bottomfish FMP or listed in table 1.4)*	Echineididae (remoras)
Carangidae (jacks/trevallies) *(Those species not listed on CHCRT list or managed under the Bottomfish FMP or listed in table 1.4)*	Malacanthidae (tilefish)
	Acanthoclinidae (spiny basslets)
Other Holocentridae spp. (soldierfish/squirrelfish) (*Those species not listed on CHCRT list*)	Pseudochromidae (dottybacks)

Other Mullidae spp. (goatfish) (*Those species not listed on CHCRT list*)	Plesiopidae (prettyfins)
Other Acanthuridae spp. (surgeonfish/unicornfish) (*Those species not listed on CHCRT list*)	Tetrarogidae (waspfish)
Other Lethrinidae spp. (emperors) *(Those species not managed under the Bottomfish FMP or listed in table 1.4)*	Caracanthidae (coral crouchers)
Chlopsidae, Congridae, Moringuidae, Ophichthidae (eels) Other Muraenidae (morays eels) (*Those species not listed on CHCRT list*)	Grammistidae (soapfish)
Apogonidae (cardinalfish)	*Aulostomus chinensis* (trumpetfish)
Other Zanclidae spp. (moorish idols)	*Fistularia commersoni* (coronetfish)
Other Chaetodontidae spp. (butterflyfish)	Anomalopidae (flashlightfish)
Other Pomacanthidae spp. (angelfish)	Clupeidae (herrings)
Other Pomacentridae spp. (damselfish)	Engraulidae (anchovies)
Scorpaenidae (scorpionfish)	Gobiidae (gobies)
Blenniidae (blennies)	Lutjanidae *(Those species not managed under the Bottomfish FMP or listed in table 1.4)*
Other Sphyraenidae spp. (barracudas)	Other Ballistidae/Monocanthidae spp. (*Those species not listed on CHCRT list*)
Pinguipedidae (sandperches)	Other Siganidae spp. (*Those species not listed on CHCRT list*)
Gymnosarda unicolor	Other Kyphosidae spp.
Bothidae/Soleidae/Pleurnectidae (flounder/sole)	Caesionidae
Ostraciidae (trunkfish)	Cirrhitidae
Tetradontidae/Diodontidae (puffer/porcupinefish)	Antennariidae (frogfishes)
	Syngnathidae (pipefishes/seahorses)
Stony corals	Echinoderms (e.g., sea cucumbers, sea urchins)

Heliopora (blue)	Mollusca
Tubipora (organpipe)	Sea Snails (gastropods)
Azooxanthellates (non-reefbuilders)	Trochus spp.
Fungiidae (mushroom corals)	Opistobranchs (sea slugs)
Sm/Lg Polyped Corals (endemic spp.)	*Pinctada margaritifera* (black lipped pearl oyster)
Millepora (firecorals)	Tridacnidae
Soft corals and Gorgonians	Other Bivalves
Anemones (non-epifaunal)	Cephalopods
Zooanthids	Crustaceans (Lobsters, Shrimps/Mantis, True Crabs and hermit crabs) (*Those species not managed under the Crustacean FMP*)
Sponges (non-epifaunal)	Stylasteridae (lace corals)
Hydrozoans	Solanderidae (hydroid fans)
Bryozoans	Annelids
	Algae
Tunicates (solitary/colonial)	Live rock
All other coral reef ecosystem marine plants, invertebrates and fishes not listed under existing FMPs.	

Table 1.4 Proposed Bottomfish Species for Bottomfish Management Unit Species List

Carangidae	
Carangoides orthogrammus	yellow-spotted trevally
Carangoides caeruleopinnatus	coastal trevally
Caranx melampygus	bluefin trevally
Caranx papuensis	brassy trevally
Caranx sexfasciatus	bigeye trevally
Caranx lugubris	black jack
Seriola rivoliana	almaco jack/amberjack

Lethrinidae	
Gnathodentex aurolineatus	yellowspot emperor, striped large eye bream
Gymnocranius microdon	blue-spotted large-eye bream
Gymnocranius rivulatus	blue-line, large-eye bream
Lethrinus atkinsoni	Pacific yellowtail emperor
Lethrinus erythacanthus	orange-spotted emperor
Lethrinus harak	thumbprint emperor, blackspot emperor
Lethrinus kalliopterus	orange-spotted emperor
Lethrinus obsoletus	orange-striped emperor
Lethrinus olivaceus	longnose emperor
Lethrinus xanthochilus	yellowlip emperor
Monotaxis grandoculus	humphose bigeye bream, bigeye emperor
Lutjanidae	
Aphareus furca	blue smalltooth jobfish
Lutjanus bohar	twinspot snapper, red snapper
Lutjanus fulvus	flametail snapper
Lutjanus gibbus	humpback snapper
Lutjanus monostigmus	onespot snapper
Lutjanus rufolineatus	rufous snapper
Lutjanus sanguineus	blood snapper
Paracaesio kusakarii	kusakar snapper
Paracaesio stonei	stone's snapper
Paracaesio xanthurus	deepwater bream
Pristipomoides argyrogrammicus	blue gindai
Pristipomoides multidens	multidens snapper
Serranidae	
Cephalopholis argus	peacock grouper
Cephalopholis igarashiensis	yellow-banded grouper
Cephalopholis sonnerati	tomato grouper
Cephalopholis urodeta	flagtail grouper
Epinephelus hexagonatus	hexagon grouper
Epinephelus howlandi	blacksaddle grouper
Epinephelus lanceolatus	giant grouper
Epinephelus macrospilos	snubnose grouper
Epinephelus maculatus	highfin grouper
Epinephelus merra	honeycomb grouper
Epinephelus microdon	smalltooth grouper
Epinephelus morrhua	striped grouper
Epinephelus octofasciatus	eightbar grouper
Epinephelus polyphekadion	camouflaged grouper
Epinephelus timorensis	yellowspotted grouper
Plectropomus laevis	giant coral grouper
Saloptia powelli	pink grouper
Variola albimarginata	white-margined lyretail grouper
Scorpaenidae	
Pontinus macrocephala	hogo

1.7 Definitions and Acronyms Applicable to the Coral Reef Ecosystem FMP

1.7.1 Definitions

Adaptive Management: A program that adjusts regulations based on changing conditions of the fisheries and stocks.

Bycatch: Any species caught in a fishery, but which are not sold or kept for personal use, and includes economic discards and regulatory discards.

Barrier Net: A small-mesh net used to capture coral reef or coastal pelagic fishes.

Bioprospecting: The search for commercially valuable biochemical and genetic resources in plants, animals and microorganisms for use in food production, the development of new drugs and other biotechnology applications.

Bottomfish Fishery Management Plan: Council's FMP for bottomfish and seamount groundfish of the Western Pacific Region.

Charter Fishing: Fishing from a vessel carrying a passenger for hire (as defined in section 2101(21a) of Title 46, United States Code) who is engaged in recreational fishing.

Commercial Fishing: Fishing in which the fish harvested, either in whole or in part, are intended to enter commerce or enter commerce through sale, barter or trade. For the purposes of this Fishery Management Plan, commercial fishing includes the commercial extraction of biocompounds.

Consensual Management: Decision making process where stakeholders meet and reach consensus on management options to implement.

Coral Reef: All benthic substrata from 0 to 50 fathoms deep.

Coral Reef Ecosystem (CRE): Those species, interactions, processes, habitats and resources of the water column and substrate located within any waters less than or equal to 50 fathoms in total depth.

Coral Reef Ecosystem Management Area *(CRE management area, or management area)*: all Hawaii, PRIA, American Samoa, CNMI and Guam EEZ waters (from surface to ocean floor) that are outside of state or territorial waters and within 200 miles from shore. Because the EEZ of the CNMI currently extends to the shoreline, it is separated into two zones: the inshore zone (0-3 miles from shore) and the offshore zone (3-200 miles from shore), with federal management of the coral reef ecosystem proposed for the offshore zone only. The inshore zone would continue to be managed by local authorities. The CNMI government should manage the inshore zones because (1) cooperation between the local governments and the Council relies on recognition of local management authority of nearshore waters, (2) the CNMI-based small vessel fishermen are best managed by a local regime with hands-on interaction and knowledge of the issues, and (3) this regime retains consistency with the other areas under Council jurisdiction.

Coral Reef Ecosystem Management Unit Species (*CRE MUS or MUS*): an extensive list of coral reef organisms, many included by family. Includes some management unit species from existing FMPs (bottomfish, crustaceans, precious corals) for which primary management would remain under their current FMPs but ecosystem effects would be addressed via the CRE-FMP. CRE MUS are listed in two categories: Currently Harvested Coral Reef Taxa (CHCRT) and Potentially Harvested Coral Reef Taxa (PHCRT).

Coral Reef Ecosystem General Permit (CRE general permit, or general permit): a permit which would be required under some alternatives if deemed necessary by the Council to harvest Currently Harvested Coral Reef Taxa from all non-MPA coral reef management areas. This permit would involve simple application procedures and reporting requirements.

Coral Reef Ecosystem Special Permit (CRE special permit, or special permit): a permit which would be required under some alternatives to (1) fish for any coral reef MUS (both Currently Harvested and Potentially Harvested Taxa) within low-use MPAs (with some exceptions), and (2) fish for any Potentially Harvested Coral Reef Taxa outside of MPAs. This permit would be approved and issued on a case-by-case basis and would have more complex application procedures and reporting requirements.

Coral Reef Resources: The currently or potentially exploitable resources in coral reef ecosystems.

Council: The Western Pacific Regional Fishery Management Council (WPRFMC).

Critical Habitat: Those geographical areas that are essential for bringing an endangered or threatened species to the point where it no longer needs the legal protections of the Endangered Species Act (ESA), and which may require special management considerations or protection. (That is, the critical habitat consists of those areas that must be managed to permit an endangered or threatened species to recover to a level where it is safe, for the foreseeable future, from the danger of extinction.)

Currently Harvested Coral Reef Taxa (CHCRT): A sub-category of management unit species (MUS) including species that have been reported on commercial fishery catch report records for federal EEZ waters but are not MUS under any of the Council's already-implemented FMPs. Membership in this group is based on two criteria: (1)

More than 1,000 lbs. annual harvest for all members of a taxon, based on commercial fishery catch reports. These taxa are families or subfamilies. (2) Within these taxa particular genera or species are identified, based on their appearance on catch reports.

Dealer: One who buys and sells species in the fisheries management unit without altering their condition.

Depleted Coral Reef Taxon: Species or taxon that is locally in low abundance but not overfished (by definition).

Dip Net: A hand-held net consisting of a mesh bag suspended from a circular, oval, square or rectangular frame attached to a handle. A portion of the bag may be constructed of material, such as clear plastic, other than mesh.

Ecology: The study of interactions between an organism (or organisms) and its (their) environment (biotic and abiotic).

Ecological Integrity: Maintenance of the standing stock of resources at a level that allows the ecosystem processes to continue. Ecosystem processes include replenishment of resources, maintenance of interactions essential for self-perpetuation and, in the case of coral reefs, rates of accretion that are equal to or exceed rates of erosion. Ecological integrity cannot be directly measured but can be inferred from observed changes in coral reef ecology.

Economic Discards: Coral reef resources that are the target of a fishery but which are not retained because they are of an undesirable size, sex or quality or for other economic reasons.

Ecosystem: The interdependence of species and communities with each other and with their non-living environment.

Ecosystem-Based Fishery Management: Fishery management actions aimed at conserving the structure and function of marine ecosystems, in addition to conserving the fishery resource.

Ecotourism: Observing and experiencing, first hand, natural environments and ecosystems in a manner intended to be sensitive to their conservation.

Environmental Impact Statement (EIS): A document required under the National Environmental Policy Act (NEPA), that assesses alternatives and addresses the impact on the environment of a proposed major federal action.

Essential Fish Habitat (EFH): Those waters and substrate necessary to coral reef resources for spawning, breeding, feeding or growth to maturity.

Exclusive Economic Zone (EEZ): The zone established by Proclamation numbered 5030, dated March 10, 1983. For purposes of application, the inner boundary of that zone is a line coterminous with the seaward boundary of each of the coastal states, commonwealths, territories or possessions of the United States.

Existing CRE Fishery: A fishery targeting organisms that are currently harvested from coral reef areas, but not covered by existing FMPs

Exporter: One who sends species in the fishery management unit to other countries for sale, barter or any other form of exchange (also applies to shipment to other states, territories or islands).

Fish: Finfish, mollusks, crustaceans and all other forms of marine animal and plant life other than marine reptiles, marine mammals and birds.

Fishery: One or more stocks of fish that can be treated as a unit for purposes of conservation and management and that are identified on the basis of geographical, scientific, technical, recreational and economic characteristics; and any fishing for such stocks.

Fishery Management Plan (FMP): A plan prepared by a Regional Fishery Management Council or by NMFS (if a Secretarial plan) to manage fisheries.

Fishery Management Unit Species (MUS): The coral reef resources in the FMP, including fish, corals, certain species associated with live rock, reef-associated invertebrates and plants.

Fishing: The catching, taking or harvesting of fish; the attempted catching, taking or harvesting of fish; any other activity that can reasonably be expected to result in the catching, taking or harvesting of fish; or any operations at sea in support of, or in preparation for, any activity described in this definition. Such term does not include any scientific research activity that is conducted by a scientific research vessel.

Fishing Community: A community that is substantially dependent on or substantially engaged in the harvest or processing of fishery resources to meet social and economic needs and includes fishing vessel owners, operators and crews and United States fish processors that are based in such community. The FMP defines fishing communities as: American Samoa, the Northern Mariana Islands and Guam, and each of the inhabited main Hawaiian Islands.

Food Web: Inter-relationships among species that depend on each other for food (predator-prey pathways).

Framework Measure: Management measure listed in an FMP for future consideration. Implementation can occur through an administratively simpler process than a full FMP amendment.

General Permit: Permit, for possible future implementation under the framework process, to harvest and report take of coral reef taxa in non-MPA areas, issued upon meeting basic minimum requirements.

Ghost Fishing: The chronic and/or inadvertent capture and/or loss of fish by lost or discarded fishing gear.

Habitat: Living place of an organism or community, characterized by its physical or biotic properties.

Habitat Area of Particular Concern (HAPC): Those areas of EFH identified pursuant to Section 600.815(a)(9). In determining whether a type or area of EFH should be designated as a HAPC, one or more of the following criteria must be met: (1) ecological function provided by the habitat is important; (2) habitat is sensitive to human-induced environmental degradation; (3) development activities are, or will be, stressing the habitat type; or (4) the habitat type is rare.

Hand Harvest: Harvesting by handline.

Harvest: The catching or taking of a marine organism or fishery MUS by any means. Marine organisms or MUS that are caught but immediately returned to the water free, alive and undamaged are bycatch.

Hook-and-line: Fishing gear that consists of one or more hooks attached to one or more lines.

Incidental Catch: Any non-targeted species harvested while fishing for the primary purpose of catching a different species.

Large Fishing Vessels: a vessel equal to or greater than 50 ft length overall. (These vessels are prohibited from anchoring on Guam's southern banks.)

Live Rock: Any natural, hard substrate (including dead coral or rock) to which is attached, or which supports, any living marine life-form associated with coral reefs.

Longline: A type of fishing gear consisting of a main line which is deployed horizontally from which branched or dropper lines with hooks are attached.

Low-Use MPA: Marine Protected Area zoned to allow limited fishing activity controlled under special permit.

Main Hawaiian Islands (MHI): The high islands of the State of Hawaii consisting of Niihau, Kauai, Oahu, Molokai, Lanai, Maui, Kahoolawe, Hawaii and all of the smaller associated islets (from 154° W longitude to 161°20' W longitude).

Marine Protected Area (MPA): Designated area within the federal EEZ, which is used as a management measure to allow or prohibit certain fishing activities.

Maximum Sustainable Yield: A management goal specifying the largest long-term average catch or yield (in terms of weight of fish) that can be taken, continuously (sustained) from a stock or stock complex under prevailing ecological and environmental conditions, without reducing the size of the population.

National Marine Fisheries Service (NMFS): The component of the National Oceanic and Atmospheric Administration (NOAA), Department of Commerce, responsible for conservation and management of living marine resources.

No-Take MPA: Marine Protected Area where no fishing or removal of living marine resources is authorized.

Northwestern Hawaiian Islands (NWHI): The EEZ of the Hawaiian islands archipelago lying to the west of 161°20'W longitude.

Optimal Economic Productivity: The greatest long-term net economic benefit from the resources. Economic benefits are defined as both market price-based benefits and non-market benefits.

Optimum Yield (OY): With respect to the yield from a fishery "optimum" means the amount of fish that (a) will provide the greatest overall benefit to the nation, particularly with respect to food production and recreational opportunities and taking into account the protection of marine ecosystems; (b) is prescribed as such on the basis of the MSY from the fishery, as reduced by any relevant economic, social or ecological factor; and (c) in the case of an overfished fishery, provides for rebuilding to a level consistent with producing the MSY in such fishery.

Overfishing: Fishing at a rate or level that jeopardizes the capacity of a stock or stock complex to produce maximum sustainable yield on a continuing basis.

Pacific Island Area: American Samoa, Guam, Hawaii, the Commonwealth of the Northern Mariana Islands, Baker Island, Howland Island, Jarvis Island, Johnston Atoll, Kingman Reef, Midway Island, Wake Island or Palmyra Atoll, as applicable, and includes all islands and reefs appurtenant to such island, reef or atoll.

Pacific Remote Islands (PRIAs): Baker Island, Howland Island, Jarvis Island, Johnston Atoll, Kingman Reef, Midway Island, Wake Island and Palmyra Atoll and includes all islands and reefs appurtenant to such islands, reefs and atolls.

Passive Fishing Gear: Gear left unattended for a period of time prior to retrieval (e.g., traps, gill nets).

Plan Team (PT): A team appointed by the Council to help prepare an FMP under the direction of the Council. The PT utilizes input from all committees and panels as well as outside sources in developing the FMP and amendments.

Potentially Harvested Coral Reef Taxa (PHCRT): A sub-category of MUS. These are coral reef organisms that are not known to be currently caught, or for which very little fishery information is available. Several Currently Harvested Coral Reef Taxa (listed by family/subfamily) are also PHCRT. All genera or species in these taxa that are not listed as CHCRT are by default PHCRT.

Precautionary Approach: The implementation of conservation measures even in the absence of scientific certainty that fish stocks are being overexploited.

RA: Regional Administrator, NMFS Southwest Region

Recreational Fishing: Fishing primarily for sport or pleasure.

Recruitment: A measure of the weight or number of fish which enter a defined portion of the stock such as fishable stock (those fish above the minimum legal size) or spawning stock (those fish which are sexually mature).

Reef: A ridgelike or moundlike structure built by sedentary calcareous organisms and consisting mostly of their remains. It is wave-resistant and stands above the surrounding sediment. It is characteristically colonized by communities of encrusting and colonial invertebrates and calcareous algae.

Reef-obligate Species: An organism dependent on coral reefs for survival.

Regulatory Discards: Any species caught that fishermen are required by regulation to discard or to retain but not sell.

Regulatory Impact Review (RIR): Assessment of all costs and benefits of available regulatory measures, including the alternative of not regulating (per Executive Order 12866). The emphasis of the analysis is on the changes in the stream of net benefits that will occur as a result of each of the alternative management measures. NOAA requires that this analysis, through a Regulatory Impact Review, be done for all regulatory actions that are of public interest, such as those associated with new fishery management plans.

Resilience: The ability of a population or ecosystem to withstand change and to recover from stress (natural or anthropogenic).

Restoration: The transplanting of live organisms from their natural habitat in one area to another area where losses of, or damage to, those organisms has occurred with the purpose of restoring the damaged or otherwise compromised area to its original, or a substantially improved, condition; additionally, the altering of the physical characteristics (e.g., substrate, water quality) of an area that has been changed through human activities to return it as close as possible to its natural state in order to restore habitat for organisms.

Rock: Any consolidated or coherent and relatively hard, naturally formed, mass of mineral matter.

Rod-and-Reel: A hand-held fishing rod with a manually or electrically operated reel attached.

Scuba-assisted Fishing: Fishing, typically by spear or by hand collection, using assisted breathing apparatus.

Secretary: The Secretary of Commerce or a designee.

Sessile: Attached to a substrate; non-motile for all or part of the life cycle.

Slurp Gun: A self-contained, typically hand-held, tube–shaped suction device that captures organisms by rapidly drawing seawater containing the organisms into a closed chamber.

Small Fishing Vessel: a vessel less than 50 ft length overall. (These vessels are exempt from alternatives prohibiting anchoring on Guam's southern banks.)

Social Acceptability: The acceptance of the suitability of the FMP by stakeholders, taking cultural, traditional, political and individual benefits into account.

Spear: A sharp, pointed, or barbed instrument on a shaft, operated manually or shot from a gun or sling.

Special Permit: Permit with stringent criteria for issuance and operation. Required for fishing for coral reef taxa in low-use MPAs or for potentially harvested coral reef taxa in non-MPA areas. Also required for harvesting live hard coral for aquaculture seed stock, traditional indigenous use, scientific collecting and bioprospecting.

State: Recognizing that the Council Region comprises several different political entities—a state, a commonwealth, two territories, and unincorporated federal territory—hereafter, as shorthand, these constituent parts (excluding federal territory) will be generically referred to as states.

Stock Assessment: An evaluation of a stock in terms of abundance and fishing mortality levels and trends, and relative to fishery management objectives and constraints if they have been specified.

Stock of Fish: A species, subspecies, geographical grouping or other category of fish capable of management as a unit.

Submersible: A manned or unmanned device that functions or operates primarily underwater and is used to harvest fish.

Subsistence Fishing: Fishing primarily to obtain food for personal use rather than for sale or recreation.

Sustainable Use: The use of components of an ecosystem in a way and at a rate that does not lead to the long-term decline of biological diversity, size structure or abundance of any of its components, thereby maintaining their potential to meet the needs and aspirations of present and future generations.

Target Resources: Species or taxa sought after in a directed fishery.

Total Allowable Level of Foreign Fishing (TALFF): The portion of the OY on an annual basis that will not be harvested by U.S. vessels.

Trophic Web: The network that represents the predator/prey interactions of an ecosystem.

Trap: A portable, enclosed, box-like device with one or more entrances used for catching and holding fish or marine organism.

Unincorporated U.S. Island Possessions: Johnston Island, Wake Island, Midway Island, Palmyra Atoll, Kingman Reef, Jarvis Island, and Howland and Baker Islands.

Western Pacific Regional Fishery Management Council (WPRFMC or Council):
Representatives from the State of Hawaii, the Territories of American Samoa and Guam and the Commonwealth of the Northern Mariana Islands with authority over the fisheries in the Pacific Island Area EEZ.

1.7.2 List of Acronyms

B:	Stock biomass
B_{FLAG}:	Minimum Biomass Flag
B_{MSY}:	Biomass Maximum Sustainable Yield
B_{OY}:	Biomass Optimum Yield
^0C:	Degrees Celsius
CITES:	Council on International Trade and Endangered Species
cm:	centimeters
CNMI:	Commonwealth of the Northern Mariana Islands
CPUE:	Catch per unit effort
$CPUE_{MSY}$:	Catch per unit effort Maximum Sustainable Yield
$CPUE_{REF}$:	Catch per unit effort
CRAMP:	Coral Reef Assessment and Monitoring Program
CRE:	Coral Reef Ecosystem
CRE-FMP:	Coral Reef Ecosystem Fishery Management Plan
CRTF:	Coral Reef Task Force
CDP:	Community Development Plan
DAR:	Division of Aquatic Resources, Department of Land and Natural Resources, Hawaii
DAWR:	Division of Aquatic and Wildlife Resources, Department of Agriculture, Guam
DBOR:	Division of Boating and Ocean Resources, Department of Land and Natural Resources, Hawaii
DEIS:	Draft Environmental Impact Statement
DFW:	Division of Fish and Wildlife, Department of Land and Natural Resources, CNMI
DLNR:	Department of Land and Natural Resources, Hawaii
DMWR:	Department of Marine and Wildlife Resources, American Samoa
DOC:	Department of Commerce
DOI:	Department of the Interior
E:	Effort
E_{AVG}:	Effort average
EEZ:	Exclusive Economic Zone
EFH:	Essential Fish Habitat
EIS:	Environmental Impact Statement
E_{MSY}:	Effort Maximum Sustainable Yield
ENSO:	El Niño Southern Oscillation
EO:	Executive Order

EPAP:	Ecosystem Principals Advisory Panel
ESA:	Endangered Species Act
F:	Fishing mortality
F_{MSY}:	Fishing mortality Maximum Sustainable Yield
F_{OY}:	Fishing mortality Optimum Yield
FEP:	Fishery Ecosystem Plan
FDM:	Farallon de Medinilla, CNMI
FFS:	French Frigate Shoals, NWHI
FLPMA:	Federal Land Policy Management Act
fm:	fathoms
FMP:	Fisheries Management Plan
g:	grams
GIS:	Geographic information systems
HAPC:	Habitat Areas of Particular Concern
HCRI:	Hawaii Coral Reef Initiative Research Program
HINWR:	Hawaiian Islands National Wildlife Refuge
HIR:	Hawaiian Islands Reservation
ICRI:	International Coral Reef Initiative
IRFA:	Initial Regulatory Flexibility Analysis
km:	kilometers
lbs.	pounds
m:	meters
maxFMT:	maximum fishing mortality threshold
MHI:	Main Hawaiian Islands
min SST:	minimum spawning stock threshold
mm:	millimeters
MMPA:	Marine Mammal Protection Act
MPA:	Marine Protected Area
MSFCMA:	Magnuson-Stevens Fisheries Conservation and Management Act
MSY:	Maximum Sustainable Yield
mt:	metric ton
MUS:	Management Unit Species
NDSA	Naval Defensive Sea Area
NEPA:	National Environmental Policy Act
nm or nmi:	nautical miles
NMFS:	National Marine Fisheries Service
NMFS-HL:	National Marine Fisheries Service - Honolulu Laboratory
NOAA:	National Oceanic and Atmospheric Administration
NWHI:	Northwestern Hawaiian Islands
NWR:	National Wildlife Refuge
NWRAA:	National Wildlife Refuge Administration Act
OY:	Optimum Yield
PIAO:	Pacific Islands Area Office
PRA:	Paperwork Reduction Act

PRIA:	Pacific Remote Island Areas
PT:	Plan Team (for FMP development)
RA:	Regional Administrator, NMFS
RFA:	Regulatory Flexibility Act
RIR:	Regulatory Impact Review
SFA:	Sustainable Fisheries Act
SLA:	Submerged Lands Act
SPR:	Spawning Potential Ratio
SSC:	Scientific and Statistical Committee
TALFF:	Total Allowable Level of Foreign Fishing
TSLA:	Territorial Submerged Lands Act
USFWS:	United States Fish and Wildlife Service
USCG:	United States Coast Guard
VMS:	Vessel Monitoring System
WpacFin:	Western Pacific Fisheries Information Network
WPRFMC:	Western Pacific Regional Fishery Management Council

CHAPTER 2

DESCRIPTION OF THE CORAL REEF ECOSYSTEM

2.1 Coral Reef Ecosystems

Coral reefs are carbonate rock structures at or near sea level that support viable populations of scleractinian or reef-building corals. Apart from a few exceptions, coral reefs are confined to the warm tropical and sub-tropical waters lying between 30° N and 30° S. Coral reef ecosystems are arguably the oldest and certainly the most diverse and complex ecosystems on earth. Their complexity is manifest on all conceptual dimensions, including geological history, growth and structure, biological adaptation, evolution and biogeography, community structure, organism and ecosystem metabolism, physical regimes, and anthropogenic interactions (see sources cited by Hatcher *et al.* 1989). There is a voluminous and expanding literature on coral reefs and coral reef ecosystems (Birkeland 1997a), beginning with Charles Darwin's 1842 volume, *The Structure and Distribution of Coral Reefs*, which remains the seminal volume on reef formation and structure, including reefs in the Western Pacific Region. The symbiotic relationship between the animal coral polyps and algal cells known as zooxanthellae is a key feature of reef building corals. Incorporated into the coral tissue, these photosynthesizing zooxanthellae provide much of the polyp's nutritional needs, primarily in the form of carbohydrates. Most corals supplement this food source by actively feeding on zooplankton or dissolved organic nitrogen, due to the low nitrogen content of the carbohydrates derived from photosynthesis.

The corals and coral reefs of the Pacific are described in Wells and Jenkins (1988) and Veron (1995). The number of coral species declines in an easterly direction across the Western and Central Pacific in common with the distribution of fish and invertebrate species. Over 330 species are contained in 70 genera on the Australian Barrier Reef, compared with only 30 coral genera present in the Society Islands of French Polynesia, and 10 genera in the Marquesa and Pitcairn Islands. Hawaii, by virtue of its isolated position in the Pacific, also has relatively few species of coral (about 50 species in 17 genera) and, more importantly, lacks most of the branching or "tabletop" *Acropora* species that form the majority of reefs elsewhere in the Pacific. The *Acropora* species provide a large amount of complex three-dimensional structure and protected habitat for a wide variety of fishes and invertebrates.

Most forms of coral reef development can be found in the Western Pacific Region, including barrier reefs in Guam and Saipan, fringing reefs in the Samoas and Hawaii, and patch and submerged reefs, banks and shoals throughout the region, but particularly abundant in the NWHI and within the EEZ of the Northern Mariana Islands. Other habitats commonly associated with coral reefs include mangrove forests, particularly in estuarine areas. The natural eastern limit of mangroves in the Pacific is American Samoa, although the red mangrove *Rhizophora mangle*, was introduced into Hawaii in 1902 and has become the dominant plant within a number of large protected bays and coastlines on both Oahu and Molokai (Gulko 1998). Apart from the usefulness of the wood for building, charcoal, and tannin, mangrove forests stabilize areas where sedimentation is occurring and, from a fisheries perspective, are important as nursery grounds for peneaeid shrimps and some inshore fish species, and form the habitat for some commercially valuable crustaceans.

Sea grasses are common in all marine ecosystems and are a regular feature of most of the inshore areas adjacent to coral reefs in the Pacific Islands. According to Hatcher *et al.* (1989), sea grasses stabilize sediments because leaves slow current flow, thus increasing sedimentation of particles. The roots and rhizomes form a complex matrix that binds sediments and stops erosion. Sea grass beds are the habitat of certain commercially valuable shrimps, and provide food for reef-associated species such as surgeonfishes (Acanthuridae) and rabbitfishes (Siganidae). Sea grasses are also important sources of nutrition for higher vertebrates such as dugongs and green turtles. A concise summary of the seagrass species found in the western tropical South Pacific is given by Coles and Kuo (1995). From the fisheries perspective, the fishes and other organisms harvested from the reef coral and associated habitats such as mangroves, seagrass beds, shallow lagoons, bays, inlets, and harbors, and the reef slope beyond the limit of coral reef growth, contribute to the total yield from coral reef-associated fisheries. Unlike other Council FMPs, which are broadly species-based, this FMP is ecosystem-based. It is concerned not only with the health of target stocks, but also with the preservation of the coral reef ecosystems within the Western Pacific Region. To do this requires an understanding of the ecosystem components and how these various components interact.

2.1.1 Reef Productivity

Coral reefs are among the most biologically productive ecosystems in the world. The global potential for coral reef fisheries has been estimated at 9 million mt per year, which is impressive given the small area of reefs compared to the extent of other marine ecosystems, which collectively produce between 70 - 100 million mt per year (Munro 1984; Smith 1978). An apparent paradox of coral reefs, however, are their location in the nutrient deserts of the tropical oceans. In these areas the water is very clear because gross primary productivity is low, generally ranging between 20 to 50 $gCm^{-2}yr^{-1}$. Coral reefs themselves are characterized by the highest gross primary production in the sea, with reef flats and margins sustaining primary production rates of between 1,800-3,700 $gCm^{-2}yr^{-1}$, and sand and rubble zones about 370 $gCm^{-2}yr^{-1}$. The main primary producers on reefs are the benthic microalgae, macroalgae, symbiotic microalgae of corals, and other symbiont-bearing invertebrates. Zooxanthellae living in the tissues of hard corals make a substantial contribution to primary productivity in zones rich in corals due to their density—greater than 10^6 cells cm^{-2} of live coral surface—and the high rugosity of the surfaces on which they live, as well as their own photosynthetic potential. However, zones of high coral cover make up only a small part of entire coral reef ecosystems, and so their contribution to total reef gross primary productivity is small.

Although the ocean's surface waters in the tropics generally have low productivity, these unproductive waters, which bathe coral reefs, are continually moving. Reefs therefore have access to substantial open-water productivity. Thus, particularly in inshore continental waters, shallow benthic habitats such as reefs must not always be considered the dominant sources of carbon for fisheries. Outside sources may be important for reefs, and while this significance is rarely estimated, its input may be in living (plankton) or dead (detrital) forms. In coastal waters detrital matter from land, plankton, and fringing marine plant communities are particularly abundant. There may be passive advection of particulate and dissolved detrital carbon onto reefs, and active transport onto reefs via fishes that shelter on reefs but feed in adjacent habitats. There is, therefore, greater potential for nourishment of inshore reefs than offshore reefs by external carbon sources, and this inshore nourishment will be enhanced by large land masses.

For most of the Pacific Islands, rainfall typically ranges from 2,000 to 3,500 mm per year. Low islands, such as *makateas* and atolls, tend to have less rainfall and may suffer prolonged droughts. Further, when rain does fall on coral islands and *makateas* that have no major catchment area, there is little allochthonous nutrient input into surrounding coastal waters and lagoons. Lagoons and embayments around high islands are therefore likely to be more productive than atoll lagoons. There are however, some exceptions. Both Palmyra Atoll and Rose Atoll are unique in that they may receive up to 4,300 mm of rain per year. These atolls are among the few wet atolls in the world. The productivity of high island coastal waters, particularly where there are lagoons and sheltered waters, is possibly reflected in the greater abundance of small pelagic fishes such as anchovies, sprats, sardines, scads, mackerels, and fusiliers. Furthermore, the range of different environments that can be found in the immediate vicinity of the coasts of high islands also contributes to the greater range of bio-diversity found in such locations.

Studies on coral reef fisheries are relatively recent, commencing with the major study by Munro and his co-workers during the late 1960s in the Caribbean (Munro 1983). Even today, only a relatively few examples are available of in-depth studies on reef fisheries. It was initially thought that the maximum sustainable yields for coral reef fisheries were in the range of 0.5-5 $t/km^{-2}yr^{-1}$, based on limited data (Marten and Polovina 1982; Stevenson and Marshall 1974). Much higher yields of around 20 $t/km^{-2}yr^{-1}$, for reefs in the Philippines (Alcala 1981; Alcala and Luchavez 1981) and American Samoa (Wass 1982), were thought to be unrepresentative (Marshall 1980), but high yields of this order have now been independently estimated for a number of sites in the South Pacific and Southeast Asia (Dalzell and Adams 1997; Dalzell *et al.* 1996). These higher estimates are closer to the maximum levels of fish production predicted by trophic and other models of ecosystems (Polunin and Roberts 1996). Dalzell & Adams (1997) suggest that the average MSY for Pacific reefs is in the region of 16 $t/km^{-2}yr^{-1}$ based on 43 yield estimates where the proxy for fishing effort was population density.

However, Birkeland (1997a) has expressed some scepticism about the sustainability of the high yields reported for Pacific and south east Asian reefs. Among other examples, he notes that the high values for American Samoa reported by Wass (1982) during the early 1970s were followed by a 70% drop in coral reef fishery catch rates between 1979 and 1994. Saucerman (1995) ascribed much of this decline to a series of catastrophic events over the same period. This began with a crown of thorns infestation in 1978, followed by hurricanes in 1990 and 1991, which reduced the reefs to rubble, and a coral bleaching event in 1994, probably associated with the El Niño phenomenon. These various factors reduced live coral cover in American Samoa from a mean of 60% in 1979, to between 3-13% in 1993.

Further, problems still remain in rigorously quantifying the effects on yield estimates of factors, such as primary productivity, depth, sampling area, or coral cover. Polunin *et al.* (1996) noted that there was an inverse correlation between estimated reef fishery yield and the size of the reef area surveyed, based on a number of studies reported by Dalzell (1996). Arias-Gonzales *et al.* (1994) have also examined this feature of reef fisheries yield estimates and noted that this was a problem when comparing reef fishery yields. The study noted that estimated yields are based on the investigator's perception of the maximum depth at which true reef fishes occur. Small pelagic fishes, such as scads and fusiliers, may make up large fractions of the inshore catch from a particular reef and lagoon system, and if included in the total catch can greatly inflate the yield estimate. The great variation in reef yields summarized by authors such as Arias-Gonzales et al (1994), Dalzell (1996) and Dalzell and Adams (1997) may also be due in part to the different size and trophic levels included in catches.

Another important aspect of the yield question is the resilience of reefs to fishing and recovery potential when overfishing or high levels of fishing effort have been conducted on coral reefs. Evidence from a Pacific atoll where reefs are regularly fished by community fishing methods, such as leaf sweeps and spearfishing, indicated that depleted biomass levels may recover to pre-exploitation levels within one to two years. In the Philippines, abundances of several reef fishes have increased in small reserves within a few years of their establishment (Russ and Alcala 1994; White 1988), although recovery in numbers of fish is much faster than recovery of biomass, especially in larger species such as groupers. Other studies in the Caribbean and South East Asia (Polunin *et al.* 1996) indicate that reef fish populations in relatively small areas have the potential to recover rapidly from depletion in the absence of further fishing. Conversely, Birkeland (1997a) cites the example of a pinnacle reef off Guam fished down over a period of six months in 1967 that has still not recovered thirty years later.

Estimating the recovery from, and reversibility of fishing effects over large reef areas appears more difficult. Where growth overfishing predominates, recovery following effort reduction may be rapid if the fish in question are fast growing, as in the case of goatfish (Garcia and Demetropolous 1986). However, recovery may be slower if biomass reduction was due to recruitment overfishing because it takes time to rebuild adult spawning biomasses and high fecundities (Polunin and Morton 1992). Further, many coral reef species have limited distributions; they may be confined to a single island or a cluster of proximate islands.

Widespread heavy fishing could cause regional extinctions of some such species, particularly if there is also associated habitat damage. Unfortunately, the majority of species with a limited range are also valuable to the aquarium trade, and in the future restrictions on capture, possibly through CITES listing, may be appropriate to prevent overfishing.

2.1.2 Extent and Distribution of Coral Reefs

Roughly 70% of the world's coral reefs, or 420,000 km^2 are located in the Pacific Ocean (Bryant *et al.* 1998). Of all reefs under U.S. jurisdiction, 94%, or an estimated 15,852 km^2 of reef area, are associated with U.S. Pacific Islands (Clark and Gulko 1999; Hunter 1995). Table 1.1 shows their geographical distribution. Note that many of these coral reefs are located in areas where there is no human population, like the NWHI and the PRIAs, or in island archipelagos, like American Samoa and the CNMI, where population is concentrated on one or two islands.

2.2 Coral Reef Ecological Characteristics and Resource Dynamics

Coral reefs and reef-building organisms are confined to the shallow upper photic zone. Maximum reef growth and productivity occurs between 5-15 m (Hopley and Kinsey 1988) and maximum diversity of reef species occurs at 10-30 m (Huston 1985). Thirty meters has been described as a critical depth below which rates of growth (accretion) of coral reefs are often too slow to keep up with changes in sea level. This was true during the Holocene transgression over the last 10,000 years, and many reefs below this depth drowned during this period. Coral reef habitat does extend deeper than 30 m, but few well developed reefs are found below 50 m. Many reefs in the world are bordered by broad areas of shelf habitat between 50-100 m. Many of these shelf habitats were formed by wave erosion during periods of lower sea level during the Pleistocene period. Today, extensive areas of shelf habitat exist in the NWHI. These habitats consist primarily of carbonate rubble, algae and micro-invertebrate communities, some of which may be important nursery grounds for some coral reef fish, as well as habitat for several species of lobster. However, the ecology of this habitat is poorly known and much more research is needed in this zone. This will help in defining the lower depth limits of the coral reef ecosystem, which by inclusion of shelf habitat, could be viewed as extending to 100 m.

Available biological and fishery data are poor for all species and areas covered by the CRE-FMP; therefore, it is not possible to implement the Fishery Ecosystem Plan action item 4, elaborated by EPAP.[2] Furthermore, high biological and environmental variability is a natural characteristic of coral reef ecosystems around the U.S. Pacific Islands, with or without fishing. Irregular pulses of new recruits (Walsh 1987) cause cycles in the abundance and

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[2]As discussed on page 14 in this FMP, FEP action item four states "Calculate total removals—including incidental mortality—and show how they relate to standing biomass, production, optimum yields, natural mortality, and trophic structure."

harvest potential of individual reef species. Environmental variability is both spatial, related to differences in the quality of habitat (Friedlander and Parrish 1998a), and temporal, related to monthly moon phase, seasonal and longer-term environmental changes (Friedlander and Parrish 1998b).

Polovina *et al.* (1994) examined a large-scale climatic shift that affected coral reef resources in the NWHI from the mid-1970s to the late 1980s. During this period, the central North Pacific experienced increased vertical mixing, with a deepening of the wind-stirred surface layer into nutrient-rich lower waters and probable increased injection of nutrients into the upper ocean. Resulting increased primary productivity likely provided a larger food base for fish and animals at higher tropic levels. In the NWHI, changes of 60-100% over baseline levels in productivity for lobsters, sea birds, reef fish, and monk seals were observed and attributed to deeper mixing during 1977-1988.

The highest quality habitat on a coral reef is often where abundant living coral has created high bottom relief. Natural disturbance cycles in areas exposed to large storm waves can dramatically alter habitat quality. For example, periodic storms in the NWHI reduce live coral cover to 10% in some areas. Coral cover eventually returns to 50% or more, depending on how protected the area is (R. Grigg, 104th Council meeting, June 2000).

Unlike pelagic ecosystems, which are driven primarily by oceanographic forces operating on a large scale, coral reef ecosystems are strongly influenced by biological processes, habitat utilization, and environmental conditions at a relatively small scale. Innumerable animals and plants shelter, attach, or burrow into the reef structure, creating some of the most biologically diverse and complex ecosystems on earth.

2.2.1 Ecological Relationships

Coral reef ecosystems have existed in geological terms for nearly twice as long as flowering plants, and some of the coral genera are more ancient than any grasslands. Therefore, the ecological relationships have had more time to develop complexity in coral reefs. A major portion of the primary production of the coral reef ecosystem comes from complex inter-kingdom relationships of animal/plant photo-symbioses hosted by animals of many taxa, most notably stony corals. Most of the geological structure of reefs and habitat is produced by these complex symbiotic relationships.

Complex symbiotic relationships for defense from predation, removal of parasites, building of domiciles, and other functions are also prevalent. About 32 of the 33 animal phyla are represented on coral reefs (only 17 are represented in terrestrial environments) and this diversity produces complex patterns of competition. The diversity also produces a disproportionate representation of predators, which have strong influences on lower levels of the food web in the coral reef ecosystem (Birkeland 1997c). Figure 2.1 shows, in a schematic fashion, inter-relationships between reef fishes and with the surrounding environment, and how these relationships can affect population dynamics during different life phases.

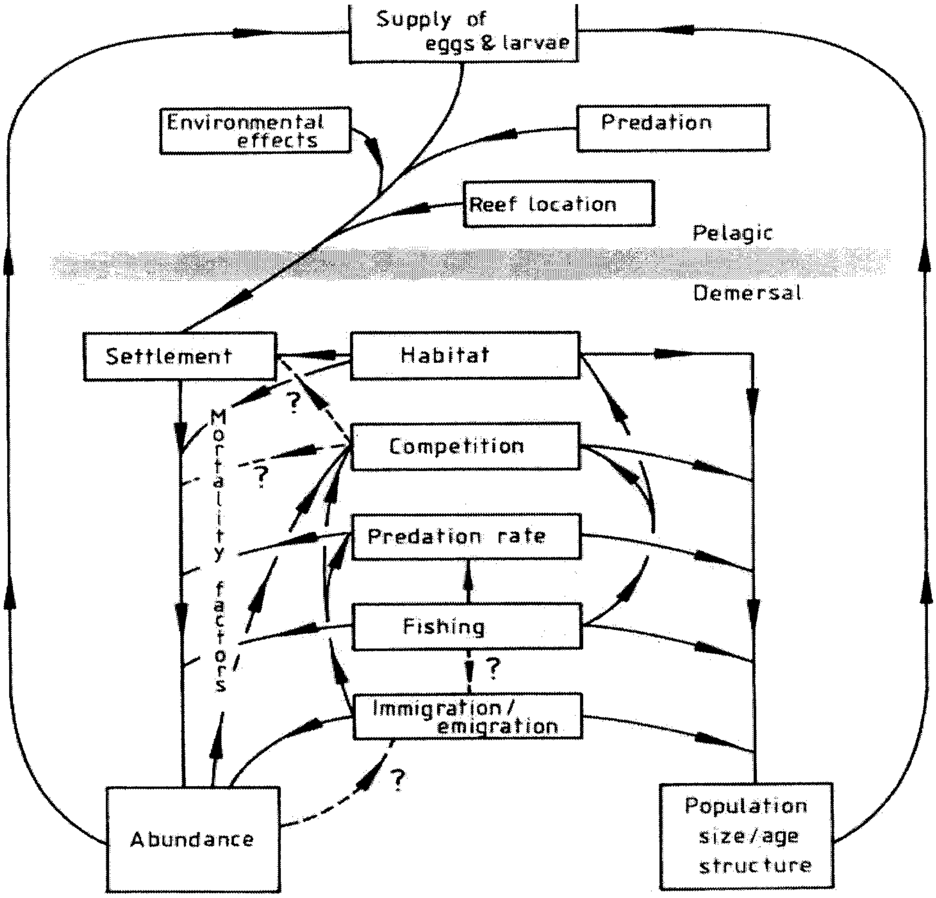

Figure 2.1: Interrelationships within the coral reef ecosystem. Flow diagram illustrating factors determining the abundance and size/age structure of populations. Arrows show direction of effects. Dashed lines with ? indicated expected relationships but without supporting evidence. (Source: Polunin and Roberts 1991.)

In areas with high gross primary production but low net primary production or yield—such as rain forests and coral reefs—animals and plants tend to have a higher variety and concentration of natural chemicals as defenses against herbivores, carnivores, competitors, and microbes. Because of this tendency, and the greater number of phyla in the system, coral reefs are now a major focus for bioprospecting, especially in the southwest tropical Pacific (Birkeland 1997c).

2.2.2 Coral Reef Habitat

Even within a thriving coral reef habitat, not all space is occupied by corals or coralline algae. Reefs are typically patchworks of hard and sediment bottoms. A reef provides a variety of environmental niches, or combination of resources. The wide variety of survival strategies employed by coral reef organisms allows different species to exploit some combination of resources better than their competitors. The ecosystem is dynamic, however. If conditions change, a very specialized species may not be able to survive the rigors of the new environment or may be forced out by another species more adept at using the available resources, including space, food, light, water motion, and temperature.

2.2.3 Long-term Ecosystem Variability

Climate and ecosystem shifts may occur over decadal scale cycles or longer, meaning that resources management decisions need to consider changes in target level productivity over the long-term as well as short-term inter-annual variation. For example, the climatic shift that occurred in the central North Pacific in the late 1980s (see Section 2.20 produced an ecosystem shift in the NWHI to a lower carrying capacity, with a 30-50% decline in productivity (Polovina *et al.* 1994). This in turn reduced recruitment and survival of monk seals, reef fish, albatross, and lobsters. Under lower carrying capacity regime, fishing alters the age-structure of the population and may also lead to stock depletion.

At Laysan Island, where lobster fishing is prohibited, spawning biomass of lobsters was also depleted by natural mortality. This suggests that marine reserves may not guarantee the protection that is typically assumed (Polovina and Haight 1999). In response to this natural variability, the Council adjusted its management measures (e.g., limited entry, annual quota) to reduce catch and effort to about 25% of its 1980's level.

The destruction of coral reefs around Tutuila, the principal island in American Samoa, forced fishermen to move into predominantly pelagic fishing, initially trolling, and later, small-scale longline fishing. As a result, much of the reef fish consumed in American Samoa now comes from Western Samoa. The reduction of fishing on coral reefs may also aid in the recovery of live coral cover, but the long-term recovery of the reefs around Tutuila will principally depend on a benign climate and marine environment over the next decade. Furthermore, these destructive events occurred during a long-term shift in the physical environment of the equatorial Pacific Ocean, which began in 1977 (Miller *et al.* 1994). Conditions included more clouds, more rainfall, warmer sea surface temperatures, and weaker trade winds, similar to a weak decadal El-Niño state. They were most pronounced in the central equatorial Pacific, so American Samoa was close to the center of this shift, which persisted until 1999, when conditions began to change. Whether 1999 marks another regime shift will not be known for several years (Polovina pers. comm.).

The destruction of American Samoan coral reefs included, in 1994, a coral bleaching episode. This phenomenon also affected reefs in the Cook Islands and French Polynesia, and was due to unseasonably high sea water temperatures. Coral bleaching occurs when corals lose or expel their zooxanthellae in large numbers, usually due to some trauma such as high or low temperatures or lower than usual salinities (Brown 1997). The corals that lose zooxanthellae also lose their color, becoming white and hence the term 'bleaching.' Although first described in the 1900s, interest in this phenomenon was heightened in the 1980s and 1990s after a series of major bleaching events in the Atlantic and Pacific Oceans. Some of these episodes were linked to the El-Niño Southern Oscillation or ENSO events (Gulko 1998).

When bleaching occurs, some corals are able to regain zooxanthellae by slowly re-infecting themselves with the algae, or through the reproduction of remaining zooxanthellae within the colony. Frequently, the loss of large amounts of symbiotic algae results in the colony becoming energy deficient; it expends more energy than it is consuming. If this occurs over the long term the colony dies (Brown 1997; Gulko 1998). Coral bleaching events require only a 1-2° C increase in water temperature. Thus, due to global warming, bleaching may become more common. According to Goreau *et al.* (1997), similar events in the Atlantic and the Indian Oceans suggest that worldwide corals are acclimated close to their upper temperature limits. As a result, they are unable to adapt rapidly to an anomalous warming (Goreau *et al.* 1997). Consequently, global warming represents a very serious threat to the survival of coral reefs.

Other physical phenomena that may bring long-term change to coral reef systems include the impact of hurricanes and tectonic uplift. Bayliss-Smith (1988) describes the changes in reef islands at Ontong-Java Atoll over a 20-year period following a severe hurricane. Most atoll islands are on reef flats in what are frequently high wave-energy locations near to seaward reef margins. Unless composed of coarse shingle and rubble, these islands are unstable. Hurricanes will destroy such small cays and scour *motu* beaches, and strip small or narrow islands of fine sediment during over-wash periods. Bayliss Smith (1988) notes that while hurricanes tend to erode islands, they also produce the material for their reconstruction. More frequent, lower magnitude storms contribute to the process by transporting the rubble ramparts thrown up by hurricanes. This reconstructs scoured beaches and eroded shorelines. Clearly, such destruction and reconstruction activity on reef flats will have an effect on reef organisms, including fish and invertebrates, particularly where large areas of reef are smothered by sand and silt following a hurricane.

The process of tectonic uplift can profoundly influence coral reef systems. It is a much slower process, however, taking several centuries or even millennia to significantly change coral reefs. Tectonic uplift can push a productive reef flat above the water's surface, producing an exposed limestone terrace. This reduces the amount of reef area available for fishing, as occurred at Niuatoputapu and in the Tonga archipelago (Kirch and Dye 1979). Tectonic uplift was also partially responsible for changing Tongatapu Island's central lagoon from a marine to a brackish water environment. This resulted in the loss of an important reef mollusc resource, *Anadara antiquata,* which could not survive the reduced salinity. A similar event occurred at Tikopia in the Solomon Islands. There, a circular bay with a narrow entrance became a brackish coastal lake as the bay entrance was sealed through a combination of tectonic uplift and increased sedimentation caused by agricultural runoff from neighboring slopes. Again, this major habitat change wiped out reef- and lagoon-associated molluscs, a major food source for the indigenous people (see sources cited in Dalzell 1998).

2.3 Coral Reef Communities

Coral reef communities are among the most diverse and ecologically complex systems known. The structure of reef communities is usually defined in terms of the diversity and relative abundances of species characteristic of a habitat type. Commonly, only a few species compose over half the abundance, while hundreds of others are present in low numbers.

2.3.1 Life History

The literature on coral reef fish life histories is voluminous, but convenient entries into the literature are provided by Sale (1991), Polunin and Roberts (1996), and Birkeland (1997b). The life of a coral reef fish includes several stages. Typically, spawning occurs in the vicinity of the reef and is characterized by frequent repetition throughout a protracted time of the year, a diverse array of behavioral patterns, and extremely high fecundity. The eggs of many species are fertilized externally and dispersed directly into the pelagic environment as plankton. Other species have demersal eggs, which upon hatching disperse larvae into the pelagic realm. Planktonic mortality is very high and unpredictable. Recruitment is the transition stage from the planktonic larval life to demersal existence on a coral reef. Recruitment is both spatially and temporally highly variable. This is when post-larval juveniles begin their residence on reefs where many remain for life. Highest predation mortality occurs in the first few days or weeks, thus rapid growth out of the juvenile stage is a common strategy.

Terrestrial animal populations are usually dispersed by adults, who deposit eggs or build nests in selected locations. In contrast, the most frequent pattern for coral reef organisms is dispersion of eggs and larvae in water currents, which determines the final locations of adults. The adults are often sedentary or territorial. The differences in factors that bring about success in these two life history phases complicate fisheries management (Birkeland 1997c).

2.3.2 Species Distribution and Abundance

Species diversity declines eastwards across the Pacific from the locus of maximum species richness in Southeast Asia (especially in the Philippines and Indonesia), and is related in part to the position of land masses in relation to the Pacific Plate, the earth's largest lithospheric plate (Springer 1982). In general, species richness is greatest along the plate margin and declines markedly on the plate itself. As a result, islands in the Central Pacific generally have a lower reef organism diversity, but also a high degree of endemism. For example, Guam has about 269 species of zooxanthellate Scleractinian corals, about 40 Alcyonacea and just under a thousand species of fishes; Hawaii has far fewer in comparison. The proportion of endemic species increases in the opposite direction. For example, the Hawaiian Islands have about 18% endemic zooxanthellate corals, 60% endemic Alcyonacea and 25% endemic reef fishes. The proportion of alien species in Hawaiian waters is also greater, and it is increasing (Birkeland 1997c).

As noted above, among the diverse array of species in each taxa on coral reefs, there are usually only a few that are consistently abundant, with the relative abundance of species within a taxa possibly approximating a log-normal distribution. The majority of species are relatively uncommon or only episodically abundant, following unusually successful recruitment (Birkeland 1997c).

Individual sub-populations of larger stocks of reef species may increase, decrease, or cease to exist locally without adversely affecting the overall population. The condition of the overall populations of particular species is linked to the variability among sub-populations: the ratio of sources and sinks, their degrees of recruitment connection, and the proportion of the sub-populations with high variability in reproductive capacity. Recruitment to populations of coral reef organisms depends largely on the pathways of larval dispersal and "downstream" links. In considering recruitment mechanisms one must ask: Are the connections sufficient to actually restock distant sub-populations or only enough to maintain a homogenous genetic stock?

2.3.3 Reproduction and Recruitment

The majority of coral reef animals are very fecund, but temporal variations in recruitment success have been recorded for some species and locations. Many of the large, commercially-targeted coral reef animals are long-lived and reproduce for a number of years. This is in contrast to the majority of commercially-targeted species in the tropical pelagic ecosystem. Long-lived species adapted to coral reef systems are often characterized by complex reproductive patterns like sequential hermaphroditism, sexual maturity delayed by social hierarchy, multi-species mass spawnings, and spawning aggregations in predictable locations (Birkeland 1997c).

2.3.4 Growth and Mortality Rates

Recruitment of coral reef species is limited by high mortality of eggs and larvae, and also by competition for space to settle out on coral reefs. Predation intensity is due to a disproportionate number of predators, which limits juvenile survival (Birkeland 1997c). In response some fishes—such as scarids (parrotfish) and labrids (wrasses)—grow rapidly compared with most coral reef fishes. But they still grow relatively slowly compared to pelagic species. In addition, scarids and labrids may have complex haremic territorial social structures that contribute to the overall effect of harvesting these resources. It appears that many tropical reef fishes grow rapidly to near-adult size, and then often grow relatively little over a protracted adult life span; they are thus relatively long-lived. In some groups of fishes, such as damselfish, individuals of the species are capable of rapid growth to adult size, but sexual maturity is still delayed by social pressure. This complex relationship between size and maturity makes resource management more difficult (Birkeland 1997c).

2.3.5 Community Variability

High temporal and spatial variability is characteristic of reef communities. At large spatial scales, variation in species assemblages may be due to major differences in habitat types or biotopes. Seagrass beds, reef flats, lagoonal patch reefs, reef crests, and seaward reef slopes may occur in relatively close proximity, for example, but represent notably different habitats.

As suggested in Section 2.2.3, reef fish communities from the geographically isolated Hawaiian Islands are characterized by low species richness, high endemism, and exposure to large semiannual current gyres, which may help retain planktonic larvae. The NWHI is further characterized by: (1) high latitude coral atolls; (2) a mild temperate to subtropical climate, where inshore water temperatures can drop below 18° C in late winter; (3) species that are common on shallow reefs and attain large sizes, which to the southeast occur only rarely or in deep water; and 4) inshore shallow reefs that are largely free of fishing pressure.

2.4 Ecosystem Models

Several approaches to model multi-species fisheries have been used by coral reef fishery scientists with varying levels of success. The simplest approach has been to treat a community as the sum of its species. These general multi-species models have been applied by several researchers to estimate yields in coral reef fisheries. They are based on simultaneous Lotka-Voltera equations, which incorporate the impact of each species' population size on every other species through use of shared resources. Researchers have also incorporated predation and harvesting effects into these models. Unfortunately, with highly diverse systems such as coral reefs, this leads to an extremely complex model with potentially hundreds of parameters. Nonetheless, these approaches are mentioned as possible avenues for future assessment methodologies, although at present the lack of data limits confidence in their results.

An alternative is to divide the assemblage into separate trophic levels and model the energy flow through the system to estimate potential yields. The two linked models described in more detail below take this approach.

2.4.1 ECOPATH

ECOPATH is a simple mathematical model that estimates mean annual biomass, production, and food consumption for major components—defined in terms of species groups—of a coral reef ecosystem (Polovina 1984). Polovina used the following species groups to model the ecosystem at French Frigate Shoals in the NWHI: tiger sharks, monk seals, seabirds, reef sharks, sea turtles, small pelagics, jacks, reef fish (and octopus), lobsters and crabs, deepwater bottomfish, nearshore scombrids, zooplankton, phytoplankton, heterotrophic benthos, and benthic algae. A box model illustrates a biomass budget schematic for major predator-prey pathways and lists annual production and annual biomass for each group. The model shows a high percent of internal predation, which partially explains why fishery yields from coral reefs are generally low despite high primary productivity. The allocation of species to trophic compartments constrains the ECOPATH approach because it imposes an artificial structure that may not coincide with actual community structure. This approach is also data intensive and requires information on each species' diet, mortality, and growth rates.

Extensive field work from French Frigate Shoals provided estimates of parameters used to validate the model. Application of ECOPATH to French Frigate Shoals found that the coral reef ecosystem is controlled mainly by predation from the top down and primary production is controlled mainly by nutrients, photosynthetic rate limits, and habitat space (Grigg *et al.* 1984). Fishery yields can be maximized by targeting lower trophic levels and cropping top predators to release pressure on prey. Thus, a fishery targeting tiger sharks at French Frigate Shoals should help ease predation pressure on endangered Hawaiian monk seals and threatened green turtles. Coral reef ecosystems are susceptible to overfishing due to high levels of natural mortality and low net annual production. A study of coral reef fish communities on patch reefs at Midway Atoll found that they were relatively resilient to several years of fishing pressure on top predators, while some control by predation was detected (Schroeder 1989).

2.4.2 ECOSIM

ECOSIM is a computer model that uses the output of the ECOPATH model. Input parameters by species (or species group) include natural and fishing mortality, diet composition, and production to biomass ratio. The vulnerability level of prey to predators can be adjusted and gear selectivity levels can also be set. Predation levels are then determined. In order to determine qualitative changes in the structure of the resource community, the model can be run for several decades. Applying various levels of fishing pressure can reveal which target and non-target species increase and which decrease in abundance, considering predator-prey interactions (Kitchell *et al.* 1999).

2.5 Ecosystem Overfishing

The special vulnerability of targeted coral-reef resources comes from life-history traits of these economically valuable species, which live in diverse communities with strong predatory and competitive forces. Coral reef species are adapted to reproduce often because so few of their progeny are likely to survive. Therefore, they grow slowly, delay first reproduction, and are more territorial than pelagic species. These life history traits make recovery from overfishing very uncertain. Some coral reef ecosystems, driven by biological interactions, have not recovered for decades following intensive harvest, and there are no indications that they will recover. In contrast, pelagic fisheries, driven by oceanographic processes, usually do recover. For example, black-lipped pearl oysters at Pearl and Hermes Atoll in the NWHI were over-harvested to commercial extinction in the late 1920s; according to recent surveys, stocks have still not recovered after 70 years. Holothuroids (sea cucumbers) were over-harvested in the late 1930s in Chuuk, Eastern Caroline Islands, and recent surveys there also show no recovery after 60 years. Dalzell *et al.* (1996) cite several other examples from the Pacific Islands where pearl oyster and sea cucumber populations have failed to recover from over-harvesting, even after several decades of no fishing.

Some fishing activities, such as overfishing, may degrade coral reef ecosystems and ultimately affect ecosystem processes. For example, the removal of herbivorous fishes can lead to the overgrowth of coral by algae, eventually destroying some coral reef resources. Munro (1983; 1999) has suggested that overfishing of predatory reef species may lead to a decline in the natural mortality of herbivores; in response, their biomass increases. When the herbivores are in turn overfished, algal production is uncontrolled. Most of the resulting increase in algae and sea-grass biomass then turns to detritus. However, there are few well documented examples of such effects cascading through ecosystems.

Munro (1999), cites the north coast of Jamaica as an example of reefs almost entirely overgrown by macro-algae and where the cover of live coral is extremely low. Although scientists do not fully agree, it appears that this can be attributed to the long-term effects of overfishing. The very narrow island shelf (less than one kilometer wide) was covered by flourishing coral reefs until 1984. Then several events combined to change the situation. First, the herbivorous long-spined sea urchin, *Diadema antillarum,* spread rapidly throughout the Caribbean. Then the north coast of Jamaica took a direct hit from a major hurricane. The reefs were pulverized by heavy seas and large corals were stripped of tissue. Macro-algae colonized all these newly exposed surfaces. In the absence of sea urchins and herbivorous fish, the macro-algae have remained dominant (Hughes 1994). Other parts of the Caribbean with less heavily exploited fish stocks also lost their urchin populations and suffered hurricanes, but these reefs were not massively overgrown with algae. While it cannot be proven that overfishing was the cause of this catastrophe, the evidence points in that direction.

The MSFCMA requires managers to identify the individual species composing a fishery management unit and calculate Maximum Sustainable Yield (MSY) for each. But on coral reefs, although there are thought to be thousands of economically valuable species, many of them have not been named or described by scientists. However, bio-prospectors—the major near-term users of reef resources—will try to find as many pharmaceutically useful species as possible, whether or not they have been officially described by scientists. If managers have to name each species, and estimate their MSY, it will be many decades before an FMP can be completed and these kinds of economic uses can begin. Thus, the sort of ecosystem-level approach espoused by EPAP is well suited to the complex multi-species coral reef ecosystem.

In concert with the ecosystem approach, an alternative overfishing definition seems most appropriate for the CRE-FMP. In contrast to the single-species approach, the ecosystem overfishing concept considers how fishing pressure can cause changes to species composition in a multi-species setting, often resulting in changes in ecosystem function (DeMartini *et al.* 1999). This can be detected by shifts in species composition or trophic web dynamics. Using this concept can also guard against single-stock recruitment overfishing, where applicable.

There are other reasons for adopting this approach. First, the loss of some species in the multi-species coral reef ecosystem—due to overfishing or other human impacts—could allow often less valuable generalist species to predominate. As in the example cited above, these types of changes to heavily fished reefs have been reported for a number of tropical stocks from various areas around the world. Second, multi-species systems become more vulnerable to environmental fluctuations as exploitation increases.