An Evaluation of the Likelihood of Successful Implementation of the Long Term Coral Reef Monitoring Program on the Commonwealth of the Northern Mariana Islands

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Research Report

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I. INTRODUCTION

Coral reef ecosystems are the oceanic equivalent of tropical rainforests, in terms of biodiversity. The estimated 1,037,000 square kilometers worldwide of reef provide habitat for over one million species of plants and animals (Hinrichsen, 1997). Coral reefs are important to the economy of coastal nations because of the fisheries and tourism industries they support. Reef ecosystems provide a host of important natural services such as storm buffering, a protein source for islanders, breeding and nursery grounds for marine organisms, water filtration and a source of biomedically important products. Coral reef areas also have aesthetic and intrinsic value that is reason enough to protect them.

Coral reefs are also among the most endangered ecosystems on Earth. Naturally occurring disturbances are compounded by the impacts of anthropogenic disturbance. Factors that threaten the health of coral reef ecosystems on a global scale include global warming, the continuing increase in coastal populations and associated impacts such as nutrient pollution, sedimentation and runoff, coral mining, ship groundings, overfishing, and recreational overuse. Globally, coastal areas accommodate about 60% of Earth's human population. A significant portion of the population lies within tropical regions. This population pressure subjects coral reef environments to effects of increased competition for coastal resources, increased coastal pollution and problems related to coastal construction. The synergistic effect of stressors has been the irreversible degradation worldwide of 10% of reefs and another 60% in critical condition leaving, only 30% as stable (Wilkinson, 1993).

The coral reefs of the Commonwealth of the Northern Mariana Islands (CNMI) are a good example of how the combination of increasing human population and the associated environmental pressure has resulted in degradation of the reef ecosystem. The CNMI has undergone significant change in economic and population growth within the past decade. To accommodate the rapid and continuing development of the tourism industry, numerous golf courses and resort hotels have been constructed on Saipan. The population of Saipan has increased over 30% in the last ten years.

Currently, the local/resident population is 60,000 while the visitor population is 750,000 per year. This rapid growth has had serious ecological consequences. Coral roads have been converted to four lane highways and infrastructure such as septic tank systems has not been improved to meet higher demand. More and more development projects have been proposed without adequate consideration of environmental impacts. Conflicts over the use and conservation of marine and watershed resources continue to arise.

The continuing decline of reef systems globally and in specific areas like the CNMI, highlights the need for effective methods of assessing change in nearshore ecosystems. This paper explores the ways that coral reef monitoring can provide information about reef health that serves to affect positive changes in management strategies for marine systems. Using a criteria drawn from case study comparisons of on-going, well established coral monitoring programs and evaluation framework proposed by policy analysts Using criteria drawn from case, the Long Term Marine Monitoring Program (LTMMP) on Saipan, CNMI is evaluated. The evaluation provides insight about coral monitoring plan components that are essential to the effectiveness of coral reef monitoring programs.

This report is an outgrowth of an internship the author performed with the CNMI Division of Environmental Quality on the island of Saipan from June to October of 1997. The University of Oregon Micronesia and South Pacific Program and the government of the Commonwealth of the Northern Mariana Islands (CMNI) sponsored the internship project. The objectives of the internship were to

- Assist in field data collection and continuing development of the ongoing Long Term Marine Monitoring Plan (LTMMP)
- Assist and instruct Marine Monitoring Team (MMT) members in basic computer skills, understanding of data applicability, management, interpretation and analysis, basic biology and resource management techniques as it relates to marine monitoring work
- Facilitate inter-governmental agency coordination of marine monitoring activities
- Assess likelihood of success and explore challenges facing Saipan in implementation of the monitoring program

This report first describes functions and services provided by coral reefs and an introduction to the stresses and disturbances that compromise the health of reef systems globally. Using examples from case studies of established marine monitoring programs, this report considers how effective monitoring can reveal changes in the reef system over time, enabling conservation measures to be taken. It then turns to the island of Saipan and briefly describes the environmental and socio-economic framework within which the coral reef related provisions of the CNMI coastal management program are considered. This background information is used to evaluate the Long Term Marine Monitoring Plan currently in place on the CNMI. This evaluation provides insight into the challenges to implementation of coral reef monitoring plans and recommendations for improvements in the LTMMP on Saipan.

II. BACKGROUND

Coral Reef Ecology

Coral reefs occur in oligotrophic tropical waters between 30° N and 30° S and are the largest biological constructions on earth (Viles and Spencer, 1995). About half of the world's coastlines are in the tropics and about a third of these are comprised of limestone of coral origin (Birkeland, 1997). It is estimated that shallow living coral reefs currently cover over 600,000 km^2 (Smith, 1978) (Figure 1). Reef building coral tolerate a narrow range of environmental conditions. Hermatypic or reef building corals are most successful within a temperature range of 26°-28° C with a tolerance limited to between 18°C and 36°C. Because the majority of corals live at temperatures that approach the upper thermal limits of viability, even a slight increase in sea surface temperature may have a drastic impact on coral vitality and distribution (Hubbard, 1997). It is thought that increased water temperature is associated with episodes when the symbiotic algae living within the coral polyp, zooxanthellae, are expelled or leave the coral polyp. The coral reefs of Florida exist at the opposite end of the temperature scale. In the northern Florida Keys, coral is restricted to areas shielded from the cold front cooled water flowing in from Florida bay (Walker et al. 1982).

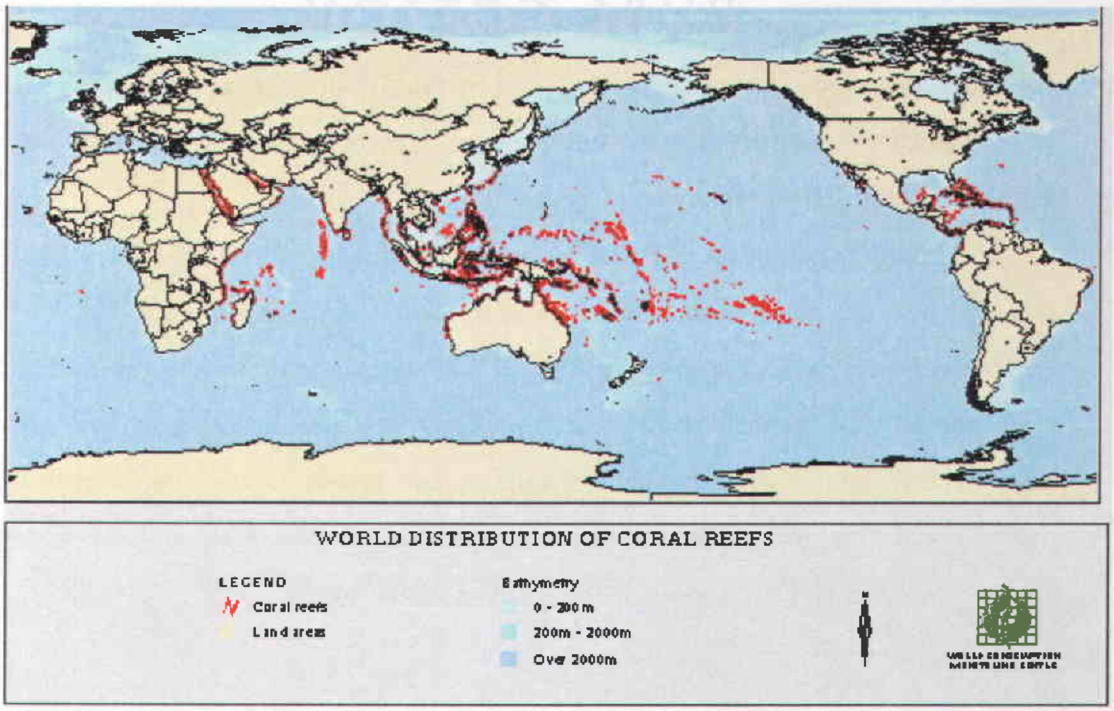

Figure 1. Global Coral Distribution SOURCE: Reefbase

Another process affecting coral at a reef level scale is salinity. Reefs are restricted to regions that have salinity ranging from 33 parts per thousand (ppt) to 36 ppt. Oysters, marine worms and algae generally dominate limestone aggregates in areas that are lower in salinity. In addition to increased turbidity, lower salinity is the reason that reefs do not exist near major river mouths (Birkeland, 1997; Sorokin, 1993).

Wave energy also limits the distribution and character of reef building coral. Adey and Burke (1977) and Geister (1977) have shown that reef zonation patterns result from the interaction of currents and wave intensity. The high wave energy zones are characterized by encrusting coralline algal ridges such as *Porolithon* in the Indo-Pacific while the more finely branching corals like *Porites* occur at the other end of the scale in low wave energy zones

A fourth factor that determines hermatypic coral distribution is light availability. As mentioned above, coral reefs occur in nutrient-poor water, yet are among the most productive ecosystems on earth. The key to this is the highly efficient internal nutrient cycling and recycling that occurs within the coral polyp's tissues. Zooxanthellae is a photosynthetic, symbiotic, single-celled algae that translocates carbon to the host polyp in exchange for protection and a source of essential limiting nutrients, nitrogen and phosphorus, excreted by the host. The translocated carbon is used by the coral host in light-enhanced calcification of reef structure (Muller-Parker and D'Elia, 1997). Because of this light dependent process, hermatypic coral is restricted to clear, shallow waters with depths of no more than 100 meters (Viles and Spencer, 1995).

These limitations on distribution of reef building coral restrict them to shallow, sunlit tropical and subtropical waters. Most of these tropical regions are less economically and technologically developed than temperate regions to the north and south. As a result, these ecosystems are important to coastal human populations for the many natural services they provide. Ultimately, this factor, in combination with rapid coastal population growth, has led to the degradation of reef areas due to the synergistic effects of natural and anthropogenic threats and disturbances.

Coral Reef Ecosystem Services

Reefs provide the primary source of dietary protein and a livelihood for tens of millions of people in tropical coastal areas (Salvat, 1992). Additionally, coral reefs supply food for commercially, recreationally and locally significant species of pelagic fish. For example, the combined consumption of benthic fauna by two species of jacks can be up to 30,600 metric tons per year off French Frigate Shoals in the northwestern Hawaiian Islands (Sudekum et al. 1991). It has been estimated that the standing stocks of reef fish are as high as 160 metric tons km^{-2} in the Atlantic (Randall, 1963) and up to 239 metric tons km^{-2} in the Pacific (Williams and Hatcher, 1983). However, according to Richmond (1993), estimations by McAllister (1988) of fisheries losses due to reef degradation is over $80 million yearly, affecting 127,000 jobs and 637,000 family members.

In addition to providing coastal and island communities with a protein source, coral reefs serve many other functions for human populations. During storm events and typhoons, reefs dissipate wave energy acting as natural, self-repairing breakwaters protecting against substantial coastal erosion. Coastal communities that are adjacent to extensive reef areas sustain much less damage from typhoon-generated waves than those with a narrow reef margin. The reef structure also provides protection for mangroves and seagrass beds that serve as nursery habitat for locally and commercially important fish and invertebrate species (Birkleland, 1997; Richmond, 1993). Reef dwellers that are bioeroders serve an invaluable function of sand replenishment. Coral also has biomedical applications. For instance, the skeleton of *Porites astreoides* has been successfully used since 1985 in orthopedic human surgery as bone replacement material (Bouchon *et al.*, 1995). Sarcophytolide 1, a compound isolated from the soft coral *Sarcophyton* sp. that occurs in the Red Sea, exhibits effective antimicrobial activity towards organisms including *Staphylococcus aureus* (Badria et al., 1997).

Stressors and Disturbances to Coral Reef Ecosystems

Stressors to coral reefs that threaten health, condition, and integrity of reef systems fall into two general types: natural and anthropogenic. These classifications can be further subdivided into impacts resulting from chemical, physical and biological sources (Table

1). It is important to distinguish between stress and disturbance. In the literature, these terms have several different interpretations with regards to ecosystems. The definitions used in this paper are derived from ideas suggested by Rosen (1982) and Brown and Howard (1985) as stated by Richmond (1993), in addition to those from Sebens (1994). *Stress* is a physiological condition that results from adverse, chronic, or excessive environmental factors and can be measured in corals by decreased growth rates, metabolic differences, and biochemical changes. Stress compromises the health and disease fighting ability of the coral. *Disturbance* is a generally localized ecological phenomenon that includes acute departures from a routine set of conditions that may result in clearing of primary substratum. It is also important to recognize that disturbances occurring at some intermediate level open up space allowing for greater diversity; a balance of several coral species at many successional levels rather than domination by one. This describes the ideal state of an equilibrium community which is a landscape of all successional stages for a given pattern and rate of disturbance over time instead of the conventional climax or undisturbed community state (Paine and Levin, 1981).

Table 1. Typology of Disturbances and Stresses to Coral Reef Ecosystems

	Natural	Anthropogenic
Chemical	None	• Pollution • Sewage • Increasing atmospheric CO_2 levels/global warming • Destructive fishing practices (cyanide, bleach)
Physical	• Typhoons and storm events and resultant wave action • Temperature stress • Sea Level Rise	• Boat anchoring • Destructive fishing practices (blast fishing) • Sedimentation/siltation • Dredging/Coral mining • Temperature stress • Careless divers/snorkelers • Fish collecting
Biological	• Crown of thorns seastar outbreaks	• Destructive fishing practices (overfishing) • Crown of thorns seastar outbreaks

SOURCE: Richmond, 1993; Sebens, 1994; De Vantier, 1986; Birkeland, 1997

Natural physical disturbances

Storm events such as typhoons and hurricanes generate high wave action that can cause coral breakage and deposition of large amounts of sediment. If cyclonic events occur concurrently with a high tide, then the effects on the reef can be more severe (De Vantier, 1986). In contrast to the reef system response to anthropogenic physical impacts, coral communities tend to recover much more quickly from natural episodic disturbances like storms.

Coral tolerate a narrow window of variability in temperature. Temperature increases in marine waters, for example, those associated with global warming or El Niño events, are thought to be the primary mechanism triggering large-scale bleaching events (Figure 2). Under temperature stress, coral polyps expel or lose their algal symbionts, zooxanthellae, resulting in bleaching. Reef researchers became aware of this process about fifteen years ago and attributed it to warmer ocean temperatures, adding fuel to the growing concern about global climate change. Additionally, the photosynthetic activity of the zooxanthellae accelerates with increasing temperatures resulting in high

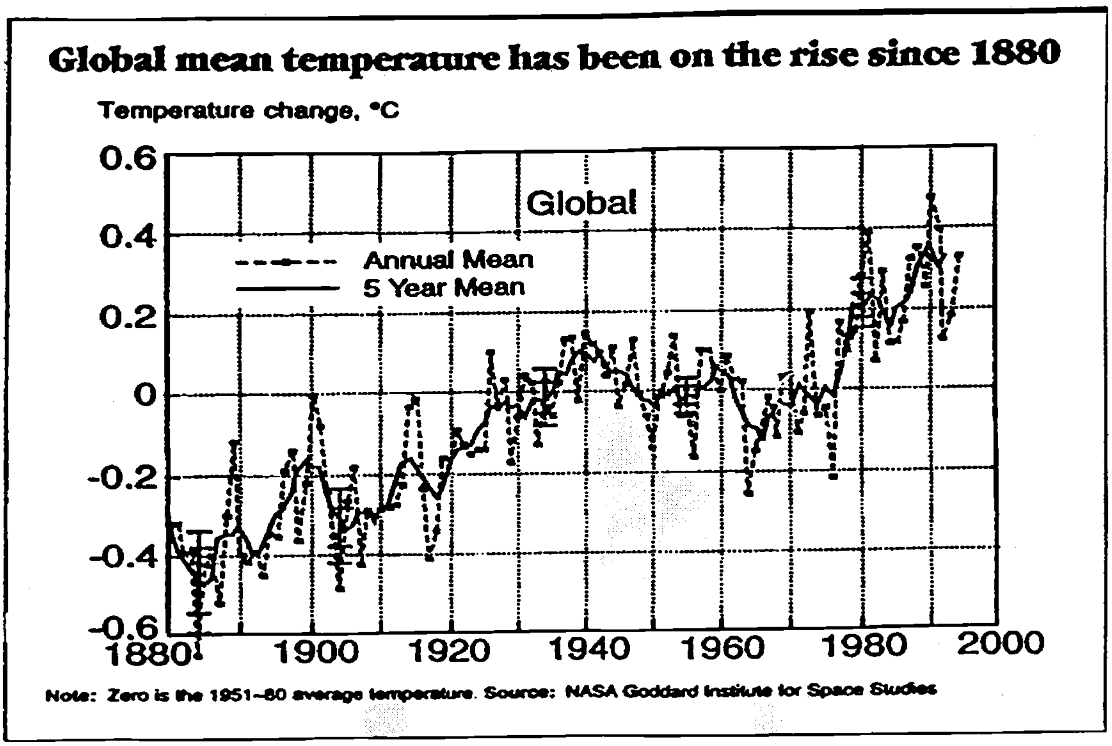

Figure 2. Global temperature increase

concentrations of oxygen inside the host cells. This affects the metabolic rate of the coral polyps and results in an increase in toxic forms of oxygen which can damage host cell nucleic acids and interfere with biochemical pathways (Sebens, 1994; Lesser *et al.*, 1990).

An additional global warming-related concern is sea level rise. It is undetermined to what degree sea level rise will impact coral. It is thought that coral growth rates will keep up with the rate of sea level rise for the next fifty years or so. There may be regional variations due to differences in local rates of sea level rise and coral growth.

Natural biological threats

There has been a long, on-going debate about the trigger of the outbreaks of crown-of-thorns starfish, *Acanthaster planci.* These corallivorous animals can devastate hundreds of square kilometers of reef. The debate centers on whether these population explosions are natural disturbances or directly attributable to the activities of humans. Sediment core records from the Great Barrier Reef reveal evidence of outbreaks occurring up to 8,000 years ago (Walbran *et al.*, 1989). *A. planci* predation has likely been a part of Holocene reef ecology from its beginning given that Holocene reef growth first started in the Great Barrier Reef about 9,000 years ago (Davies and Hopley, 1983).

Other studies have revealed a correlation between major tropical storm events and runoff from high islands and outbreaks of *Acanthaster planci* (Birkeland, 1982). The nutrient rich freshwater in substantial runoff lowers the salinity of nearshore water triggering *A. planci* spawning and enhances phytoplankton growth, providing food for the growing crown-of-thorns seastar larvae. After a growth period of about three years, the seastars emerge and begin their destructive feeding patterns. It seems that although *A. planci* populations have historically been a natural part of disturbance regimes in reef ecosystems, anthropogenic sources of nutrients due to land use practices play a role in the frequency and magnitude of crown-of-thorns outbreaks.

Anthropogenic chemical threats

Pollution includes inputs from many different sources. The pollutants that pose a problem for reef systems include oil spills, heavy metal concentrations from industrial and mining sources, pesticides and herbicides, and increased nutrient loading from sewage and agriculture (Loya and Rinkevich, 1980; LaPointe and Clark, 1992; LaPointe *et al.*, 1993). Generally speaking, anything that is applied to the land in coastal areas will eventually end up in coastal waters. Runoff from agriculture, golf course maintenance, and sewage overflow from poorly maintained wastewater treatment facilities are the primary contributors to eutrophication of tropical coastal waters. These pollutants increase the biomass of phytoplankton, affecting light transmission and increasing the biochemical oxygen demand (BOD). Nitrogen and phosphorus compounds encourage the faster growing algae which overgrow and suffocate coral colonies, potentially shifting the community structure of the reef from a coral-dominated autotrophic community to an algae-dominated suspension feeding community. The ultimate impacts include coral mortality, coral damage, and a reduction of surface area available for coral recruitment (Richmond, 1993; Sebens, 1994).

Although discussion of runoff is usually associated with impacts from sedimentation, the chemistry of runoff water requires attention as well. Freshwater runoff from the land carries pesticides, herbicides and fertilizers with it and alters the salinity of nearshore ecosystems. Studies have demonstrated that alterations in salinity due to contamination of coastal marine surface waters with fresh water is linked to reduction in coral fertilization rates and numbers of embryos developing to the planula larval stage compromising recruitment ability and ultimately leading to reproductive failure (Richmond, unpublished).

Water quality analyses find chemicals occurring "below detectable limits". Other, more specific analyses need to be performed to assess the affect on reef communities of chemicals in land runoff. It does not follow that because pollutants are below detectable limits of standard lab equipment that they would not be at levels high enough to interfere with critical processes in marine invertebrates.

In addition to the possibility of warmer sea temperatures and sea level rise resulting from global warming, another climate change issue thought to affect coral populations is an increase in atmospheric carbon dioxide (CO_2). Although the predicted increase in mean air temperature has been harder to confirm, the increase in CO_2 has been well documented (Figure 3) (Dickenson and Cicerone, 1986; Gates *et al.*, 1992). Corals have been considered resilient to disturbances, able to recover afterwards and adaptable to

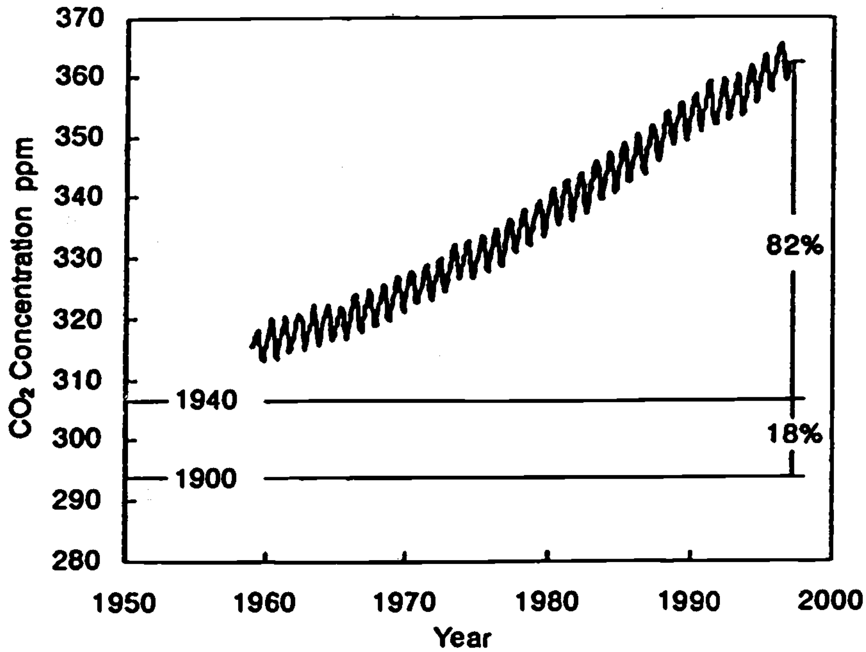

Figure 3. Average global CO_2 increase over the last several decades.

global change. This current upward trend in atmospheric CO_2 is occurring at a higher rate that is previously unprecedented. The concern is that coral adaptability will not be able to keep up with such a rate of change. Rising atmospheric CO_2 levels lower the carbonate ion activity of the sea surface which increases the acidity of the sea water and may lower calcium carbonate deposition rates in coralline algae and reef building corals. Additionally, CO_2 fertilizes algae, enhancing its ability to compete with corals, compounding the effects of overfishing and nutrient pollution (Wilkinson and Buddemeier, 1994). Results from recent experiments indicate that the predicted doubling of atmospheric CO_2 by the year 2100 will result in a 10-20% reduction in coral and reef calcification (Kleypas et. al., 1999; Pennisi, 1997). The synergistic effects of this and the already existing impacts of anthropogenic stressors and natural disturbances have a direct effect on the coral community's resistance to storm damage and disease.

Destructive fishing practices inflict chemical, physical, and biological disturbance and stress on reef ecosystems. The practice of using chemicals such as cyanide and bleach has been on the rise worldwide due to increased demand by the aquarium trade and restaurants in Southeast Asia and China. This type of chemical fishing not only decreases fish populations, but causes mortality in non-target reef species in the process. Additionally, the use of cyanide to fish is potentially harmful to divers.

Anthropogenic physical threats

Tourism contributes over 50% of the gross national product of several tropical countries where coral grows, providing an economic incentive for reef protection (Bischof, 1997). However, a rise in numbers of visitors to these regions means an increase in damage caused by direct physical impact from boat anchoring, coral collecting, and breakage by careless divers and snorkelers. Other physical impacts that are of concern are ship groundings, fish collecting, and dynamite blast fishing. Building and maintenance of infrastructure associated with continually increasing demands placed on marine resources by a declining fishing industry and a growing tourism industry present several reef health-related concerns. For example, dredging of channels and harbors to allow boat access to port areas often results in breakage and destruction of coral communities. Additionally, coral reefs are excavated for use in cement production, roads, and sometimes airport runways.

Sedimentation seems to have a three-fold impact on corals: photosynthetic, physical, and chemical as addressed in the chemical threats section. Chronic, low amounts of sedimentation associated with deforestation, dredging, and runoff from road building and maintenance and construction of hotels and golf courses, all lead to reduced coral growth, recruitment, and resilience to stress (Table 2). Sediment coats the feeding surfaces that enable coral to catch prey needed to supplement the fuel provided by the zooxanthellae. Although coral do have cleaning mechanisms that combine secretion of mucous and ciliary action, chronic sedimentation requires coral to expend more energy which compromises the health of the colony (Richmond, 1993). Photosynthetically, sedimentation reduces the amount of light, thus affecting the ability of the zooxanthellae to provide the nutrients and metabolites required by the coral hosts. Studies have demonstrated that this affects coral nutrition, growth, reproduction, and range of depth distribution (Bak 1978; Rinkevich 1989; Brown and Howard 1985; Rogers, 1990). The synergistic effects of photosynthetic, chemical, and physical impacts of sedimentation on coral can alter species composition and community structure of the reef.

Table 2. Degree of impact on coral communities by various levels of sedimentation

	Sedimentation rate (mg cm^{-2} day^{-1})		
	1-10	**10-50**	**>50**
Degree of Impact	**Slight to moderate** • decreased abundance • altered growth forms • possible reductions in recruitment • possible reductions in numbers of species	**Moderate to severe** • greatly reduced abundance • greatly decreased growth rates • predominance of altered growth forms • reduced recruitment • decreased numbers of species • possible invasions of opportunistic species	**Severe to catastrophic** • severely decreased abundance • severe degradation of communities • most species excluded • many colonies die • recruitment severely reduced • regeneration slowed or stopped • invasion by opportunistic species

SOURCE: Pastorak, R.A. and G.R. Bilyard, 1985.

Thermal discharge originating, for instance, from power plant cooling systems is also associated with coral mortality. As explained in the natural physical threats section, the symbiotic relationship between the coral host and the zooxanthellae is disrupted by increases in water temperature. It is unclear whether the algal symbionts are expelled by the host or if they leave, resulting in coral beaching. Studies have shown that when the heat stress is acute in duration and is removed, coral rebounds. Coral communities require considerably more time to recover from chronic heat stress (Gustav Paulay, University of Guam Marine Laboratory, personal communication, 1997)

Anthropogenic biological threats

In addition to fishing method-related problems in many tropical regions, overfishing is contributing to the global degradation of reef communities. Key concerns are that the larger fish are targeted for harvest and are being removed at critical points in their reproductive cycle (Nash, 1996). This pressure is no longer simply from relatively benign levels of subsistence fishing. The immediate economic incentive of supplying restaurants and the aquarium trade with large, tropical fish has compounded the problem. This results in an imbalance in the coral ecosystem. For example, in 1983, the combination of a rapid decline in sea urchin populations and low remaining numbers of herbivorous fish on Jamaican reefs led to an overgrowth of benthic algae that caused wide spread coral mortality in that area (Lessios, 1988; Hughes *et al.*, 1987).

As discussed in the natural biological threats section, *Acanthaster planci* seastar outbreaks may not be a completely natural phenomena. It is thought that the natural cycle of population increases of this species is more frequent with anthropogenic sources of nutrients present in runoff waters. Additionally, reef systems that are compromised by anthropogenic sources of stress are less resistant to predation and may recover more slowly from *A. planci* attacks than reefs that are removed from anthropogenic stress.

Coral Reef Protection Strategies

It is important to recognize that what is sustainable reef activity such as fishing or recreational diving involving just a few people may become unsustainable when hundreds or thousands of people are involved, unless management measures are introduced to minimize and control impacts (Kenchington, 1990). Increasing awareness of the need to mitigate and minimize human impact on reef systems has resulted in an effort to determine effective protection strategies. Two of the strongest tools available are community education and the establishment of Marine Protected Areas (MPAs) within the broader context of coastal management planning (Kenchington and Bleakley, 1994). Marine monitoring can play an important role in both measures.

Public involvement and education play an important role in successful reef protection strategies because they instill a sense of stewardship and ownership. This involves changing certain public attitudes and reinforcing others, necessitating that education programs allow the time needed for this process to take hold. Education is most effective when implemented in a step-wise manner. For instance, rather than one public forum, a better approach may be to have a public forum that serves to foster interest in and as an introduction to the rest of the public involvement plan. An experiential learning approach helps to reinforce intended messages. One way to incorporate this idea into a monitoring program is to have a volunteer monitoring component.

There are several volunteer monitoring programs globally that involve both community members and area visitors. For example, one global monitoring effort is the Reef Check coral reef survey program. The purpose of this program is to focus attention on and raise awareness about coral reefs and to obtain sufficient data on coral reef status to allow them to be managed locally, nationally, and regionally. This concept was developed during 1996 and grew from the initiative to declare 1997 the International Year of the Reef. Reef Check was initially designed as a one-time, global scale assessment of coral health using teams of recreational divers trained and led by marine scientists. The Global Coral Reef Monitoring Network (GCRMN) has chosen the Reef Check methods for its community-based monitoring work. The program was successfully adopted by users including government and non-government monitoring and management programs in both developing and developed countries (Hodgson, in press). Based on examples from well-developed monitoring programs such as in Australia and the Florida Keys, it is thought that a volunteer monitoring program is best suited to be a component of a higher resolution program that is carried out by scientific teams. These types of community/volunteer-based monitoring efforts help to foster stewardship as well as provide additional information to researchers and managers about changes in the reef environment.

Within the last two decades, the idea of setting aside certain marine areas as a protection strategy has become well accepted; over 1000 MPAs have been established in 100 countries. Marine protected areas have the potential to play a significant role in preserving biodiversity and special marine areas, increasing public awareness and support for marine conservation, and providing sites for research and monitoring (Sobel, 1993).

In coastal and coral reef environments, marine monitoring may be used as a tool to help researchers and coastal managers determine the appropriate site, extent, and purpose of a marine protected area. MPAs are critical locations where natural processes, least affected by episodic anthropogenic disturbance, can be studied and monitored for environmental change. They often serve as reference sites to help differentiate between changes associated with natural variability and those caused by humans. By establishing reference sites in areas with minimal human impact, MPAs can help marine resource managers understand how human activities affect natural systems.

The extent of MPAs is dependent on the purpose and uses intended. The range of purpose and size is evidenced by the classification system followed by the International Union for the Conservation of Nature (see box). Large geographical scale, multi-use MPAs allow management of mobile populations, planktonic larval recruitment, and pollution issues. Smaller but ecologically significant areas that are set aside as highly protected or 'no take' areas allow maintenance or restoration of pristine conditions and are thereby effective in preserving marine biodiversity. Although each kind of MPA is individually sufficient on its own, the two approaches are also complementary. The example used in this discussion to illustrate the effectiveness of the MPA concept is that of the Great Barrier Reef Marine Park (GBRMP) in Australia.

Kenchington asserts that management strategies of MPAs include three general techniques: prohibition, limitation, and permitting. The first is complete prohibition of access to the protected area. Total prohibition is unusual, however, as research and monitoring activities are generally allowed upon approval from the managing authority.

Limitations are used to restrict activities to environmentally sustainable levels by regulating the area and time in which activities may be conducted, the gear type that is allowed, or the number and skill of people that may participate. There are six types of strategies that fall within this category: spatial controls, temporal controls, gear-type restrictions, quotas, skill licenses and resource allocation licenses (Kenchington, 1990). The categories that will be discussed in further detail, due to their pertinence to small island areas like the CNMI, are spatial controls, temporal controls, and gear and method restrictions.

As mentioned earlier, one of the most noted examples of MPA as a method of coastal protection is the Great Barrier Reef Marine Park. This marine park was created by an Act of Parliament in 1975. It is administered by the Marine Park Authority which divided the 350,000 square kilometer area into four large management zones (Hinrichsen, 1997). Each of these zones was then further subdivided based on resource user categories that include fishing and harvesting, recreation and tourism, and conservation and science.

Management Objectives for IUCN-Classified Protected Areas

I. Scientific Reserve/Strict Nature Reserve
To protect nature and maintain natural processes in an undisturbed state in order to keep available representative examples of the natural environment in a dynamic and evolutionary condition.

II. National Park
To protect natural and scenic areas of national or international significance for scientific, educational and recreational use and to provide ecosystem stability and diversity.

III. Natural Monument/ Natural Landmark
To protect and preserve nationally significant natural features and to provide opportunities for interpretation, education, research and public appreciation.

IV. Nature Conservation Reserve/Managed Nature Reserve/Wildlife Sanctuary
To assure the natural conditions necessary to protect nationally significant communities or physical features of the environment where these require specific human manipulation for their perpetuation.

V. Protected Landscape or Seascape
To maintain nationally significant natural landscapes and seascapes which are characteristic of the harmonious interaction of man and land while providing opportunities for tourism and recreation.

VI. Resource Reserve (Interim Conservation Unit)
To restrict the use of these areas until adequate studies have been completed on how best to use the remaining resources.

VII. Natural Biotic Area/Anthropological Reserve
To allow the way of life of societies living in harmony with their environment to continue undisturbed by modern technology.

VIII. Multiple Use Management Area/Managed Resource Area
To provide for the sustained production of water, timber, wildlife (including fish), pasture or marine products and outdoor recreation.

IX. Biosphere Reserves
To provide a network of reserves representative of the world's ecosystems and develop effective models for conservation, research and monitoring, training and education and sustainable development.

X. World Heritage Sites (natural)
To foster international cooperation in safe guarding areas of "outstanding universal value" with respect to conservation, natural beauty or science.

The GBRMP zoning plans are based on spatial and temporal controls which establish purposes and times for or during which each area of the Marine Park may be used or entered. Spatial control defines the area of application of a management scheme (Kenchington, 1990). For instance, in the GBRMP, general use zones are areas where activities other than, mining, trawling, and oil drilling are allowed freely or by permit. Areas zoned as Marine National Parks are most frequently visited by divers and restrict activities to those that are non-extractive and non-destructive. The third type of management area the Preservation zone. These zones only allow those activities associated with scientific research.

Temporal control is employed in order to allow for variations either in the reef environment or in the life cycles of the organisms with in the management area. There may be a need to prohibit access to an area during a time of particular vulnerability to disturbance. This usually relates to the reproductive cycle or migratory periods. Fish are vulnerable in spawning aggregates while certain, predictable sites are needed for undisturbed feeding or resting during the migratory cycles of some species. It is in these instances when access by humans may need to be restricted or prohibited. Another reason to use temporal control is to allow an overused area time to recover. In a reef system, this is applicable to vegetation and coral as well as allowing the replenishment of fish stocks or other target species. Monitoring activity can determine the need for different types of management control, the extent of the area and permitted uses of MPAs.

Gear and fishing technique limitations are primarily targeted at protecting reef fish populations. Some of the methods and equipment used that are common, particularly in developing areas, raise concern about specific reef fisheries or causing physical damage to the reef. For example, in Saipan, the prevalence of the use of dynamite and Clorox (sodium hypochlorite) was identified as a major concern. The blast from the explosive results in structural damage to the coral, while poisoning with Clorox or cyanide causes widespread mortality of reef species in addition to the target fish. This technique has since been outlawed in the CNMI, but is still practiced on occasion. Some fishing gear that is highly effective for its purpose may ultimately allow its users to cause a severe decline in a particular target fish population. This can range from the use of spear guns to SCUBA and snorkeling gear. For instance, in Cabo Blanco, Costa Rica snorkeling gear is prohibited even for tourists. The local fishermen became so proficient at hunting spiny lobsters that the populations declined to an alarmingly low level. Since the restriction on equipment use, the populations have recovered to a self-sustaining level.

In 1985, the CNMI Coastal Resources Management Office drafted a Marine Park Management Plan. This was motivated by the recognition that the marine environment contains resources of significant natural, cultural and recreational value. The purpose of the plan was to ensure that representative examples of those resources were preserved and that their historical, cultural and recreational potential was realized. A zoning scheme was proposed that included three zones: outstanding natural feature zone allowing no taking of artifacts or marine life, a natural environment zone allowing environmentally compatible recreational activities and conservation zone permitting only subsistence fishing (CRMO, 1985). This plan was never officially adopted by the Commonwealth (Muna, 1999).

Monitoring as a tool for Coral Reef Management

Marine monitoring is an essential component of any natural resource management or protection strategy because it provides a method to assess whether management goals are being met. Monitoring is generally intended to furnish information about three areas: compliance with regulations, model validation and verification, and trend monitoring for long term changes. The encompassing goal of all types of environmental monitoring is protection of the environment, living resources and human health. Coral reef monitoring programs are most concerned with the detection of long term change and trends and documentation of current conditions within the reef system. Marine monitoring information can also be used to:

- establish a starting point for future comparisons
- provide coastal managers with a basis for setting standards
- make effective management decisions and identify strategies
- give an early warning of future problems, allowing them to be addressed more easily and economically than if left unattended
- enhance knowledge of marine ecosystems (NRC, 1990)

Although marine monitoring can provide useful, meaningful, statistically significant data that provides information about change in the system, it is not without limitations. As mentioned in the previous section, because of its multiple sources and scales, natural variability creates a background of change that may make it difficult to quantify environmental responses to human activity (Nichols, 1985). Natural variation affects monitoring sample design in two ways. One, natural changes may be on such a large scale that anthropogenic change is obscured or covered up. Second, false signals or "noise" due to episodic or random variation make the ecosystem response difficult to discern (Christie, 1985; Coull, 1985). To add to the complexity, human activity also occurs at multiple spatial and temporal scales that interact with natural processes. Recognition and understanding of variability does help to identify key natural processes and linkages that affect the resources being monitored and it helps partition variability by ensuring that data is collected on appropriate spatial and temporal scales (Livingston, 1987).

Another limitation to marine monitoring is time. Management decisions need to be made based on good science. In order to be able to detect change in an ecosystem and then to tease out an anthropogenic source, a monitoring program has to be long-term. Decision-makers who are under pressure due to public concern or political pressure want to be able to take management action quickly. The time necessary for research and information acquisition is not available. Often researchers and coastal managers are asked to make predictions based on limited knowledge. Monitoring programs can serve to narrow uncertainty, but cannot eliminate it. This reinforces the importance of careful experimental design and periodic evaluation (NRC, 1990).

Changes in a reef system may be difficult to detect over the short term or highly variable from one season or year to the next, therefore, assessing long term trends is essential. It is recommended that several indicators of reef health be considered rather than depending on a single set of observations. For instance, a reef with 50% live coral cover and 41 species may appear to be healthy, however, if there are no juvenile corals, then some factor is negatively impacting coral larval recruitment. This is cause for further investigation.

This having been said, there are efforts to develop and employ rapid assessment of coral reefs. The goal is to provide a regional perspective of coral condition. It is most successful when it is used to address specific question about specific areas such as the incidence of disease, premature mortality and geographical extent of decline in health (Ginsberg *et al.*, 1998). The limitations of this technique include: findings cannot be extrapolated to larger areas of that region nor to similar ecosystems in different regions and trends cannot be established.

There is no one data collection technique that can provide all the information necessary to assess changes in the coral reef environment. There are a host of methods that are commonly used in marine monitoring programs, in fact, there are no less than 20 handbooks and numerous other references that detail monitoring methods (Richmond, 1995). In island areas like Saipan, it is important that the methods chosen are not only going to provide statistically significant data, but are inexpensive, easy to learn and non-technologically dependent. The methods employed by the CNMI LTMMP are discussed in greater detail in the LTMMP section.

III. Coral Reef Management in the CNMI

Environmental Setting

Located at 15° north and 145° east, the Northern Mariana Islands are comprised of fourteen islands in the West Pacific Ocean approximately three quarters of the way between Hawaii and the Philippines (Figure 4). With a land area of almost 125 square kilometers and a coastline stretching for 330 kilometers across low lying sandy beaches, volcanic rock outcroppings, dramatic limestone cliffs and expansive reefs, Saipan is the largest of the three principal islands. Saipan was created by volcanic activity and uplift when the Philippine plate collided with and subducted under the Pacific plate

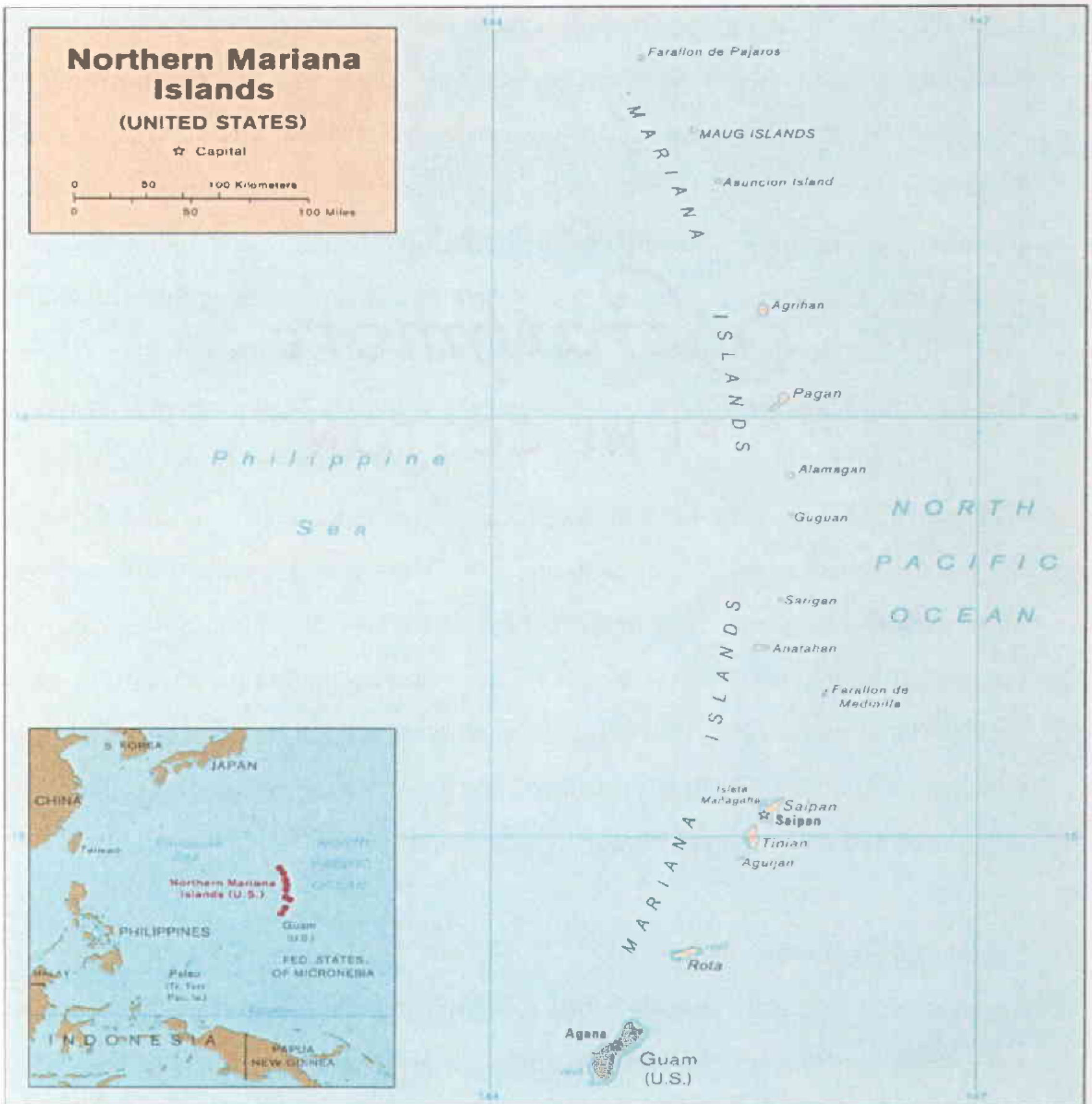

Figure 4. Northern Mariana Islands.

(Birkeland,1997). Limestone associated with reef building corals was deposited on the volcanic base forming the high platform like islands characteristic of the Northern Marianas. Saipan has well developed coral reefs with 100m wide reef flats and barrier reefs across lagoons as broad as 3.5 kilometers. Partially due to this range of diverse nearshore habitats, the Northern Mariana Islands and Guam, support about 253 species of reef-building coral (Randall, 1995).

The Northern Marianas are situated in the West Pacific along the eastern fringe of the Asiatic monsoons and within the trade wind latitudes. The CNMI has abundant rainfall occurring primarily in the wet season from about June through November ranging from 208 centimeters on Saipan to 307 cm on Rota. Warm air and sea temperatures averaging 27° Celsius and persistent northeasterly tradewinds predominate from January through May. Tropical storms and typhoons occur near the CNMI between July and December on an average of 2.3 times per year (Hamnett, 1990). Saipan is protected from potentially damaging wave energy by the buffering effects of the fringing reefs along the western side of the island. Moderate to steep cliffs, interrupted occasionally with pocket coral sand beaches, dominate the northern, eastern, and southern shoreline. (Office of the Coastal Zone Management, NOAA and Coastal Resource Management Division, 1980).

In contrast to the eastern Pacific, the islands of Micronesia and Melanesia, of which the CNMI is a part, have high tropical marine biodiversity. Within the region, there are hundreds of species of coral and fish. The western tropical Pacific supports the largest stocks of commercially important fish in the world, including skipjack, yellow fin tuna and albacore. In 1984, catches of these species accounted for 35% of the global tuna harvest (Doulman, 1986). However, the endemic terrestrial biodiversity of many of these islands including the CNMI has declined significantly over the last few centuries as population and development have increased (Dahl, 1995).

Social and Economic setting

To adequately assess the success of the LTMMP on Saipan, it is important to understand the historical influences, the traditional lifestyle and social structure, and the current economic situation in the CNMI. It is thought that the earliest settlers of the Mariana

Islands were the Chamorros, most likely to have come from present day Indonesia about 3000 BCE. These people were subsistence farmers and fishers. In 1521, Magellan arrived on Guam and claimed the islands for Spain. Jesuits arrived in 1668 and named the islands Las Marianas in honor of Mariana of Austria, widow of Philip IV of Spain. Through an act of genocide committed in 1698 by the Spanish against the Chamorros, the local race was nearly wiped out. In 1899, the islands were sold to Germany and remained under the German flag until the Japanese seized the Northern Marianas at the beginning of World War I in 1914. Japan was awarded a mandate for the islands from the League of Nations. By 1936, the Japanese developed a thriving fishing industry as well as an intensive agricultural industry centered around sugar production which brought more than 50,000 Japanese, Koreans and Philippines to work in the sugarcane industry. The United States' invasion of Saipan marked 1944 with huge losses in military and civilian lives. The construction of bases and airfields began by American troops whose numbers were around 250,000. In 1947, the United Nations recognized the Northern Marianas as a Trust Territory, later giving the administrative authority to the United States in 1952. In 1978, the islands became self governing as a commonwealth in political union with the U.S. and in 1986 the people of the CNMI were recognized as U.S. citizens (Stewart, 1997).

"It has been said that the Spanish brought Christianity to the islands; the Germans copra commerce; the Japanese agricultural and industrial development; and the Americans the concept of self government" (Kakzu, 1994). The CNMI has a long history of western influences, which have discouraged the traditional, pre-colonial, family-based social structure. Currently the native Chamorros hold the majority of the government positions and through homesteading laws own significant portions of the valuable land on the islands. The rest of the land is owned by the Carolinians who arrived more recently than the Chamorros. As in many family-based cultures, on Saipan, political decisions result more from family influences and allegiances than on the logic of the decision. Currently, this emerging combination of traditional decision-making structure and the western governmental structure is the source of some of the resistance to interagency cooperation in resource management in the CNMI.

The CNMI has been experiencing a steady increase in population that began with the inflow of alien workers in the 1980s and has continued since then, as the economy has become more dependent on tourism. In 1988, tourism accounted for 55% of CNMI's gross island income. This influx has created socioeconomic imbalances and tensions and has encouraged locals to seek well paying government jobs rather than leading a traditional natural resource based subsistence lifestyle. It is thought that this loss of connection with the natural resources has advanced the trend towards land development for tourism uses. Additionally, the 1978 Covenant that established the CNMI prohibits anyone but those residents of indigenous descent to own land (Stewart, 1997). Although only local residents are permitted to own land, they have created a system of long-term leases to foreign investors that allows them to increase the short-term value of their land. As a part of this arrangement, landowners own any buildings or other additions the lessors construct on the property. This system contributes to the continuing increase of tourism-related development by foreign investment interests on Saipan.

IV. Managing Development: The CNMI Coastal Program

The CNMI established its coastal management program in 1980. This occurred just after creating its new government structure as a protectorate of the United States in 1978. Because of the interconnected nature of the people and the sea, coastal management was extended to include resource management generally. The CNMI Coastal Resource Management program states, "In recognition of the delicate balance between man and the island environment, the Commonwealth considers all of its land, and to the extent provided by law, its water areas to be subject to its coastal management program." With the combined area of the land and the Exclusive Economic Zone, the CMNI's coastal management program encompasses nearly 1,825,000 square kilometers of land and water.

Within the Coastal Resource Management Plan, the coastal zone is divided into two distinct tiers, each with its own management framework. The first tier incorporates geographically defined areas that are subdivided into four Areas of Particular Concern (APCs) as required by the Federal CZMA. By definition, activities that occur within an APC could have direct and significant impacts on coastal waters and are therefore subject to coastal zone regulations. These designated areas are 1) shorelines, 2) lagoons and reefs, 3) wetland and mangrove areas and 4) port and industrial sites. Activities in each APC are overseen by a different natural resource agency that is given the initial proposal processing responsibility. The Coastal Resource Management Office (CRMO) is responsible for a final evaluation of proposed activities within APCs. Although this type of multi-agency responsibility strategy necessitates clear and effective communication between the agencies, occasionally the coordination system breaks down lacking the needed communication. For example, in 1997, the one employee of the CRMO who is trained in wetland delineation stopped land clearing and filling operations, approved and permitted by other agencies, because the activities were inconsistent with US federal and island (Personal communication, 1997).

Although the CNMI CZMP of 1980 expresses the general need to protect the reefs, it does not include policies specific to coral reef protection (NOAA, Office of Coastal Zone Management and CNMI Coastal Resources Management Office, 1980). The management policies for the reef and lagoon APC state that the Commonwealth shall, where appropriate, designate underwater preservation areas for non-extractive recreational purposes in areas representing the richness and diversity of the reef community; balance economic development with the conservation and management of living and non-living resources of the lagoon and reef APC; and prevent significant adverse impacts to reefs and corals.

In addition to the Federal CZMA requirement to designate APCs, it provides for the establishment of guidelines for assigning priorities (highest, moderate, lowest and unacceptable) to proposed projects with in those APCs. The use priority categories for the coral reefs of Saipan, Tinian and Rota from highest priority to lowest, include:

1) maintenance of highest levels of primary productivity
2) creation of underwater preserves in pristine areas
3) dredging of moderately productive corals and reefs associated with permitted uses and activities
4) taking of corals for commercial fisheries below sustainable limits
5) the destruction of reef and corals not associated with permitted projects.

The second tier of the CNMI coastal zone is defined by activity instead of geography and encompasses all remaining land and water areas. These include activities such as dredging, filling or discharge into marine or fresh waters, wastewater facilities, major recreational or urban development and aquaculture operations that occur outside the APC yet potentially may have direct and significant impacts on coastal water and are subject to CRMP review. These areas are identified as "major sitings". Some of the activities covered in the second tier require permits from federal agencies as well. For example, under section 404 of the Clean Water Act, dredge and fill activities require a permit from the Army Corps of Engineers. By including activities such as this in the approved CRM plan, the CNMI has review and approval authority for all federal permits and activities under the section 307 in those areas as allowed by the federal consistency provisions of the CZMA. Again, this requires information sharing between the responsible natural resources agencies, state and federal. However, the reluctance to share information potentially presents obstacles to interagency coordination.

The Division of Environmental Quality (DEQ) is charged with the responsibility of evaluating proposal applications for major sitings described previously. After review approval from other agencies, the CRMO then has final permit granting authority. Because the non-point source section of the DEQ has historically been responsible for water quality monitoring, they have also been designated as the lead agency for coordination of marine monitoring activity within the Long Term Marine Monitoring Program.

V. Monitoring Coral Reef Health in the CNMI

The Commonwealth of the Northern Marianas has developed and begun implementing a Long Term Marine Monitoring Program. Guided by the existing federal and Commonwealth mandates outlined in Table 3, the program focuses on coral reef monitoring as a means to track the impacts of non-point source pollution and other human disturbances to nearshore waters. This program began with the Lau Lau Bay Watershed Nonpoint Source Pollution Project in 1996. The Lau Lau Bay project became the model for a Commonwealth-wide marine monitoring plan. Cooperators in continuing development and implementation of the CNMI Long Term Marine Monitoring Plan (LTMMP) include the CNMI Division of Environmental quality (DEQ), CNMI Coastal Resource Management Office (CRMO), Northern Marianas College (NMC), and the CNMI Division of Fish and Wildlife (DFW).

Table 3. Federal and Commonwealth Mandates Influencing the Marine Monitoring Program on the CNMI

Date	Title	Number
1899	Rivers and Harbors Act	
1969	National Environmental Policy Act (NEPA)	PL 91-190
1972	Federal Water Pollution Control Act (FWPCA or "Clean Water Act")	PL 80-845
1972	Coastal Zone Management Act (CZMA)	PL 92-585
1972	Marine Mammal Protection Act (MMPA)	
1973	Endangered Species Act (ESA)	PL 92-205
1977	Marine Protection, Research, and Sanctuaries Act (MPRSA)	PL 95-153
1978	National Ocean Pollution Research, Development and Monitoring Planning Act of 1978	PL 95-273
1978	Migratory Bird Treaty Act	
	Manguson Fishery Conservation and Management Act	
1982	CNMI Environmental Protection Act	PL 3-23
1988	CNMI Ground Water Management and Protection Act	PL 6-12
1989	CNMI Solid Waste Management Act	PL 6-30
	CNMI Water Quality Standards	
	CNMI Drinking Water Regulations	
	CNMI Pesticide Regulations	
	CNMI Earthmoving and Erosion Control Regulations	
	CNMI Individual Wastewater Disposal Regulations	
1990	CNMI Coastal Resources Rules and Regulations	
	CNMI Submerged Lands Act	
1990	Water Quality Act (Clean Water Act as amended)	PL 100-4
	All Federal Implementing Regulations applicable to above listed acts	

Source: Adapted from EPA as described by NRC, 1990 and CNMI LTMMP, 1996

The primary goal of the LTMMP is to determine how and to what degree human activities in the uplands are affecting the nearshore environment, with particular focus on sources of non-point source pollution. As stated in the draft of the Long Term Marine Monitoring Plan, the following objectives are designed to move towards attaining the goal of the plan.

1) To establish a baseline database of nearshore conditions in order to qualify and quantify changes that occur in the coral community over time.
2) To establish an early warning system which will allow the appropriate agencies and organizations to respond to problems in a timely manner.
3) To enable resource managers, decision makers and the general public to make informed decisions leading to appropriate action about coastal resources.

Marine Monitoring Team

One of the first steps in implementing the CNMI LTMMP was to form the marine monitoring team. Interested and qualified staff members from the DEQ, CRM, DFW and NMC attended training courses that were completed in August 1997. The marine monitoring team is responsible for regular field collection of sedimentation rate, biotic and abiotic community structure, and water quality data from established sites on Saipan, Tinian and Rota. With advice and assistance from the Australian Institute of Marine Science (AIMS), University of Guam, University of Hawaii and the Environmental Protection Agency, the Marine Monitoring Team decided which methods and protocols are appropriate for the marine monitoring program. The survey and data collection techniques are modeled after the AIMS methods described in the *Survey Manual for Tropical Environments* (English *et al*, 1994).

Monitoring Sites and Protocol

Assessments of the coral communities are conducted at four sites on Saipan (Figure 5). Sites 1 and 2 are adjacent to a stretch of coast on Lau Lau Bay. Site 3 is adjacent to Obyan Beach and site 4 is adjacent to Boy Scout Beach. As this plan continues to develop, monitoring activity will include both Tinian and Rota with the addition of two permanent monitoring sites on each island as well as broadscale surveys of some of the reefs of the Northern islands.

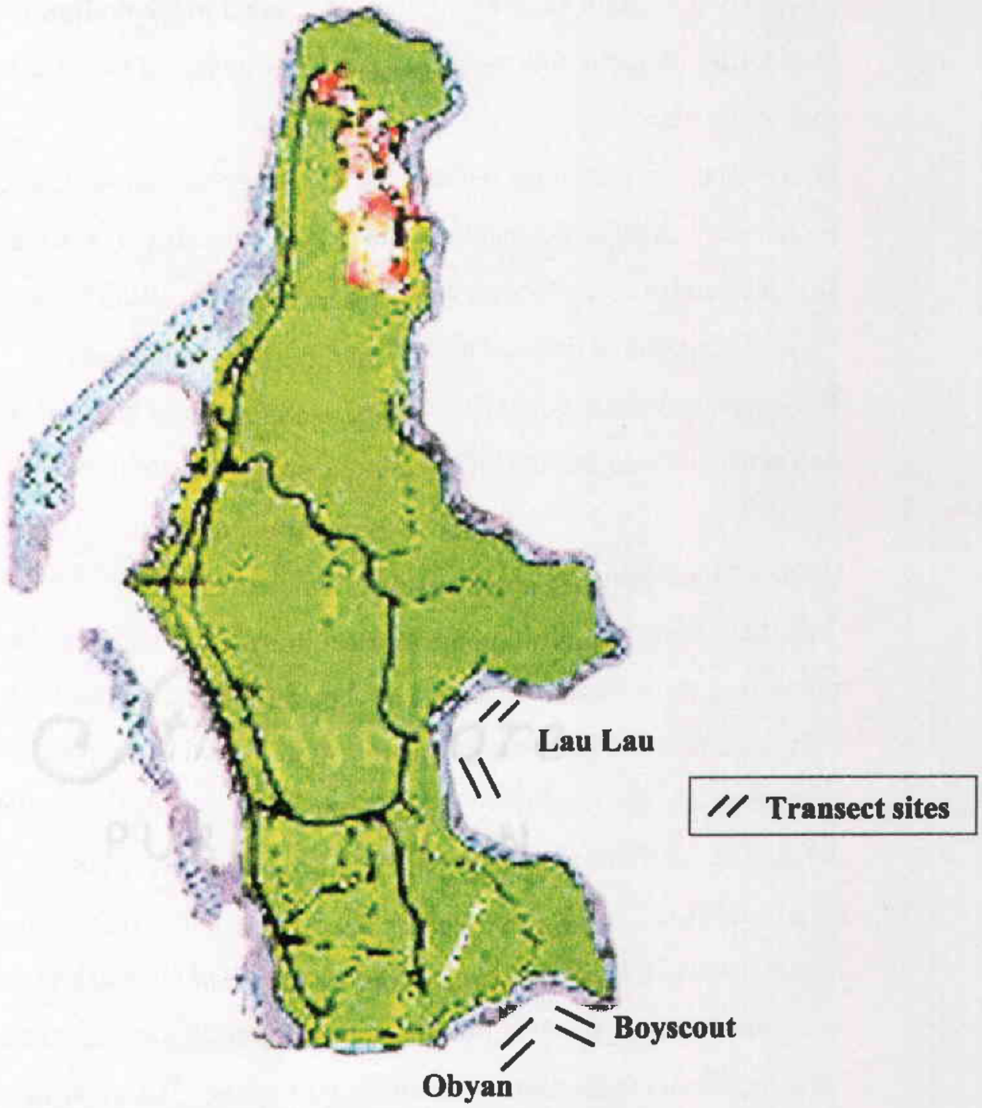

Figure 5. Coral reef monitoring tramect sites on Saipan.

At each site, a series of five 50 meter transects are set on the mid-reef slope parallel to the shoreline at depths of 5 and 10 meters. Forty individual 50 meter transects have been established within the three study areas. These sites were informally selected as representative of coastal areas and habitats typical of the nearshore ecosystem of Saipan. Two meter long rebars are permanently installed in rocky or dead spots on the reef to mark the endpoints of the transects to allow time series comparisons at the same locations. Sets of four sediment traps are placed at one end of the third transect at both 5 and 10 meter depths at each site.

At each of the four sites, the marine monitoring team collects reef composition and percent coral coverage information by employing the line intersect transect (LIT) and point intercept quadrant (PIQ) methods. To comply with the safe diving standards described by the scientific diving safety guidelines and to be able to complete the necessary tasks required by some of the monitoring methods used, marine monitoring team members always dive in buddy teams. For the LIT, the buddy team stretches out a 20 meter fiberglass tape along the permanent transects marked by the rebar stakes. One member of the team measures and records the length of tape overlying various types of organisms or non-living substrate. Organisms are identified by the lifeform categories described by English *et al* (Table 4). The PIQ uses a quadrant constructed from PVC pipe that is double strung with a total of eight lines arranged in two parallel sets of four and oriented at right angles to each other. This creates sixteen points of intersection. The quadrant is placed at ten randomly selected points along a 50 meter transect line. The organism or nonliving substrate that occurs under the intersection of the lines is recorded. Currently, during the early stages of implementation which involve training of the marine monitoring team members, these techniques are employed monthly at each site. It is the intent of the LTMMP that the LIT and the PIQ will be conducted on a biannual basis.

Table 4. Benthic Life Form Categories

Life Form Categories			
ACE	Acropora Encrusting	OT	Other
ACB	Acropora Branching	AA	Algae Assemblage
ACT	Acropora Tabulate	TA	Turf Algae
ACD	Acropora Digitate	MA	Macro-algae
ACS	Acropora Sub-massive	HA	Halimeda
CF	Coral Foliose	WA	Water
CE	Coral Encrusting	DCA	Dead Coral with Algae
CB	Coral Branching	R	Rubble
CM	Coral Massive	SC	Soft Coral
CS	Coral Sub-massive	RCK	Rock
CMR	Coral Mushroom	S	Sand
ZO	Zoanthid	SI	Silt
CME	Coral Meliopora	SP	Sponge
CHL	Coral Heliopora	DC	Dead Coral
CA	Coralline Algae	DDD	No Data

SOURCE: English *et al*, 1994

Fish census and indicator species surveys provide the marine monitoring team with information that will enable evaluation of reef composition and health. A 50-meter tape is placed randomly in the area of the permanently established monitoring sites. For the fish census survey, after deployment of the line, the divers wait for the fish disturbed by the deployment process to resume normal activity patterns. The buddy team members proceed down the transect line, one on each side, recording all fish seen in the water column and on the sea bed on their respective side of the transect line.

The indicator species survey described by Crosby and Reese, (1996) is a method used to assess stress in the coral community. This method requires a set of two or three dives to accomplish the tasks necessary to complete this survey. During the first dive, the observer records the numbers of each species of butterflyfish occurring within five meters of either side of the transect line. It is important that effort is made not to count individuals twice. Then a modified LIT, known as the line and point intercept transect is done. The diver swims along the transect line identifying the organism or nonliving substrate that occurs under the line at .5 meter intervals. This modified LIT provides percent coral cover data.

During the second and possibly third dive, the observer locates a pair of focal obligate corallivorous butterflyfish, marks the territory boundaries, measures the territory, area and records chasing and feeding behavior. In the Saipan sites, the Ornate Butterflyfish (*Chaetadon ornatissimus*) or the Oval Butterflyfish (*C. trifasciatus*) were observed because of their occurrence in the monitoring sites. These fish are territorial, strongly site attached, and have long life spans. These characteristics mean that even if changes occur leading to the eventual decline of the coral reef, these fish will be present throughout the process. Observing their distribution, abundance and social behavior allows inferences to be made regarding the condition of the reef. For example, if the territory size becomes gradually larger over time and the fish display more agonistic behavior in an effort to gain more territory from their neighbors, this indicates that the level of coral food value of the area is decreasing. These types of behaviors that precede the point at which the fish actually leave the reef occur at a sub-lethal level when the corals are just beginning to become unhealthy, not yet unrecoverable, providing a warning signal early enough for remedial action to be taken. This is with the one caveat that the changes detected are in fact due to anthropogenic disturbances.

The final method used by the CNMI marine monitoring team to detect change in the biotic community is the manta tow survey. This method may be used in the initial stages of a monitoring program to determine where transect sites should be established. As an annual survey, the manta tow provides broadscale data that can reveal changes in the percent coral cover, percent lifeforms cover, and fish abundance. Teams of observers are towed behind a boat on a tow sled. The tows are for two minute periods over the selected reef crest. A category value representing percent coral cover of live, dead and soft corals is assigned. Abundance of the crown-of-thorns (*Acanthaster planci*) starfish and presence of their feeding scars is also recorded.

The marine monitoring team collects and replaces sediment traps at the end of transect three at both depths of each monitoring site monthly. The samples are dried and weighed at the DEQ lab to assess sedimentation rate (mg cm^{-2} day^{-1}) and type of sediment at each site. In areas that yield unusually high rates of terrigenous sedimentation, the marine monitoring team will attempt to identify upland sources. Sediment traps yield time-integrated samples of material settling from the water column (English, et. al. 1994).

An additional component of the Long Term Marine Monitoring Program is water quality. The DEQ has been measuring water quality parameters including salinity, temperature, dissolved oxygen, turbidity (Figure 6), pH, and fecal coliform since 1984. These can be used to characterize a specific site and reflect changes over time in the nearshore environment. Another water quality parameter that is a valuable measurement to make is that of nutrient levels, specifically, nitrogen and phosphorus. The LTMMP discusses the intent to incorporate this assessment into the established water quality testing regime after the first year of the monitoring program implementation, yet has not done so at this point. Seventy-seven water quality monitoring sites are established on Saipan, Rota and Tinian. The sites on Saipan are sampled most frequently, while the sites on Rota and Tinian are sampled on a quarterly basis.

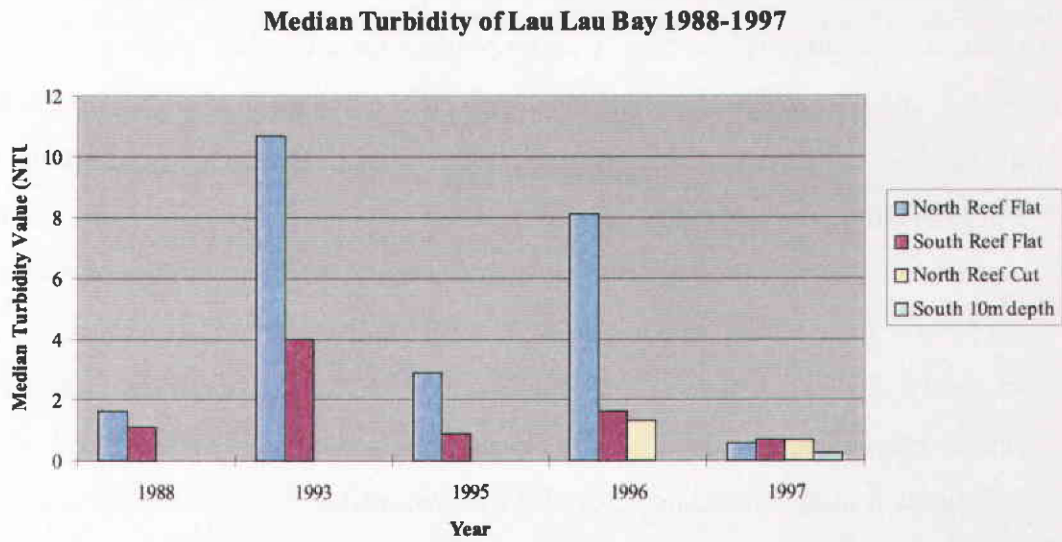

Figure 6 . Median Turbidity Values of Lau Lau Bay

Critique of the monitoring plan

The monitoring methods employed by the LTMMP were chosen because they are reliable, inexpensive, non-technologically dependent and easy to learn. This is essential in small island areas where funding and personnel are uncertain. These methods are summarized in Table 5.

The draft of the LTMMP also includes description of video monitoring and aerial photography monitoring. However, to date, neither one has been effectively implemented as a part of this current plan.

Additionally, the draft discusses data management, reporting and action. The monitoring program draft recognizes that data management is an integral part of any long-term monitoring program. It states, “collected data are useless if they cannot be analyzed and used to make sound resource management decisions.” The LTMMP is clear in the intent to develop a database to store the data, and asserts that an essential component of the data management section of the program is that the data are analyzed on a regular basis. The DEQ Marine Monitoring Quality Assurance (QA) Plan describes the proposed data collection and management procedures of the marine monitoring program. The QA plan provides detailed descriptions of how all data should be collected, stored, and analyzed. However, as with many natural resource management and monitoring programs, the intent is there, but the implementation is not. At this point, although the data are regularly being entered into databases, they have not yet been analyzed to the degree that they may be used to make "sound resource management decisions".

The coral reef monitoring program also addresses reporting and distribution of monitoring results. It proposes that comprehensive data analysis is reported on a quarterly basis to the program directors of agencies concerned with monitoring findings. Four times per year, a report will be developed that is targeted at the public. This report will describe the studies that were conducted during the previous time period and will briefly outline the major findings from the surveys. The intent is written into the monitoring program draft, however this portion has not been enacted. The data is being collected and entered into the databases. No further analysis or reporting as designed is being completed.

The action section of the monitoring program is intended to describe agency responses to problems revealed by monitoring activity as well as notification and involvement of the public. Although some action measures are currently being conducted, i.e. a road demonstration project and the continuing non-point source program, there is no comprehensive action plan that includes factors such as responsible agencies, personnel required, necessary equipment or public role. Once again, the recognition of a need is present, yet implementation is lacking.

The DEQ laboratory has data sheets to record water quality parameters and a database will be developed to store and regularly analyze this data. The Australian Institute of Marine Science has developed a database called ARMDES (AIMS Reef Monitoring Data Entry System), which will be used to record and analyze data collected from manta tows and LIT surveys. Additional databases will be developed to record the data collected from point quarter, permanent quadrat, and butterflyfish surveys; the coral reef fish censuses; and the underwater videos.

Table 5. Comparison of Monitoring Techniques Currently Employed on Saipan

Monitoring Technique	Measurement Parameters	Impacts Assessed	Equipment Required	Advantages	Disadvantages
Indicator Species[2] (Obligate Corallivores)	• Number and size of fish territories • Rates of agonistic and feeding behavior • Percent coral cover	• Anthropogenic effects on reefs • Chronic reef disturbances • "Early warning"	• SCUBA gear • Two 50 meter fiberglass measuring tapes for transect lines • Matte acetate data sheets • Nails • Surveyors tape	• Ecologically low impact or non-destructive • Does not require knowledge of the scientific names of corals and fishes • Employs a stepwise approach, with each step providing more information	• Data is not always usable quantitatively • Does not identify cause of changing conditions
Fish Censusing Survey[1] visual assessment	• Abundance • Species composition • Diversity • Density • Frequency of occurrence	• Habitat and fish association • Fishing effects	• SCUBA gear • 50 meter fiberglass measuring tape for transect line • Writing slate or matte acetate data sheet	• Non-destructive • Reasonably accurate estimation of fish present • Simple and inexpensive	• Under or over estimation of fishes present due to visibility and observer error • Misses cryptic and nocturnal species • Diver presence may affect fish behavior
Line Intercept Transect[4,5]	• Percent coral cover • Percent lifeforms cover • Species diversity	• Pollutant effects • Fishing • Natural disturbances • Sewage • Sedimentation • Diver impact	• SCUBA gear • 50 meter measuring tape for transect line • Writing slate or matte acetate data sheet • Rebar rods (1x only)	• Non-destructive • Rapid technique for estimating substrate cover	• Rare or uncommon species may not fall under transect line
Point Intersect Quadrant[6]	• Percent coral cover • Percent lifeforms cover • Species diversity	• Pollutant effects • Fishing • Natural disturbances • Sewage • Sedimentation • Diver impact	• SCUBA gear • Quadrant: PVC pipe • Writing slate or matte acetate data sheet • Rebar rods (1x only)	• Non-destructive • Because it is fast, it allows many replicate quadrants to be searched during one dive	• Rare or uncommon species may not be recorded because they rarely fall under intersecting points
Manta Tow[3]	• Percent coral cover • Percent lifeforms cover • fish abundance	• Change in coral cover	• Boat • Tow sled • Data slate	• Large areas of reef can be surveyed in a short period of time	• Possibility of missing or misidentifying species because of rapid movement over survey area • Cost of boat and sled • Possible danger to towed diver
Sedimentation Monitoring	• Sedimentation rate • Sediment composition/source	• Effects of upland construction and road maintenance projects on reefs	• Rebar rods (1x only) • SCUBA gear • Fiberglass measuring tape • Sledge hammer	• Simple and inexpensive	

Source: [1]Brock, 1954, [2]Crosby and Reese, 1996; [3]English, Wilkinson and Baker, 1994; [4]Jokiel and Tyler, 1992; [5]Loya, 1978; [6]Manton and Stephenson, 1935

VI. Evaluation Methods

As discussed in the monitoring section, a successful ecological monitoring program is important to the management of threatened resources like coral reef ecosystems. An effective, well implemented and carried out monitoring program can document the impacts of single disturbances like typhoons, oil spills, or ship groundings as well as provide an understanding of the cumulative impacts and trends of natural or anthropogenic changes over time, such as increased recreational use, fish harvesting, or sedimentation.

Implementation refers to the act of transferring policy decisions or program concepts into practice (Miles, 1989). The difference or inconsistency between a policy idea conceived at one level or branch of government, and the translation of that idea into specific actions at another level or branch is termed an "implementation gap" (Lowry, 1985). The occurrence of implementation gaps can result in ineffective or failed programs. Evaluation provides a feedback mechanism in the analysis of implementation activities, impacts, outcomes, and processes of policies and programs (Putt and Springer, 1989). Implementation evaluation serves to update concerned agencies and individuals about post-initiation program standing, to gauge consistency between the actual program implementation and the planned program goals and objectives, and to guide further management action. The ultimate goal of implementation assessment is to foster improvement.

In the process of attempting to understand, classify, and describe factors that contribute to successful policy and program implementation, analysts have also provided a structure within which to evaluate implementation activity. There are several conceptual models from which to draw an evaluation framework for implementation. For example, some analysts hold that implementation is shaped by administrative and political currents; programs are designed to accommodate the implementer's agenda. Sabatier and Mazmanian's (1981) conceptual model asserts that successful implementation is governed to a significant extent by the statutory requirements. According to this model, a policy or program will achieve its goals and objectives if it meets six conditions that include consideration of factors such as the role of the courts, the support of constituency groups, the political and administrative environment and the clarity and consistency of goals and objectives. Because of the focus on objectives and the types of actions that should result in achievement of goals and objectives, this approach lends itself to an evaluation framework within which the outcomes are discernable through geographic, site-specific analysis (Good, 1992).

Specific to the CNMI is an added need to consider this implementation evaluation within the context of coastal management of an island environment. Agenda 21, the global environmental agenda that resulted from the United Nations Conference in Rio de Janeiro (Brazil) in 1996, states that any plan for coastal management of a small island must include the following principles: adequate financial resources, government support, community support and involvement, free exchange of information, data collection and quality standards, and appropriate technology transfer (Griffith and Ashe, 1993). The evaluation framework ideas offered by policy analysts such as Sabatier and Mazmanian and by Agenda 21 can be readily adapted to address the particular issues of coral reef ecosystem management.

Implicit in most program evaluation is the assumption that effective implementation is synonymous with meeting goals and objectives (Lowry, 1985). Are the goals of the CNMI LTMMP sufficient to provide linkages to coral reef management? How likely is it that the LTMMP will be effectively implemented? These questions suggest a number of specific, tailored evaluation questions that can be used to assess the likelihood of effective long-term implementation of the coral reef monitoring program for Saipan.

Evaluation Question 1.

Are the goals and objectives of the monitoring program clear, consistent, and comprehensive with respect to the broader goals of the CNMI Coastal Management Program?

Evaluation Question 2.

Do the coral reef monitoring parameters and the frequency, duration, and extent of monitoring activities provide adequate measures for tracking coral reef health?

Evaluation Question 3.

Are the coral reef monitoring parameters, individually and/or collectively, linked to potential causes of reef decline or improvement?

Evaluation Question 4.

Does the principal implementing agency have the necessary funding, staffing, training, and interagency coordination authority and skills needed to carry out the program?

Evaluation Question 5.

Is there a feedback mechanism that links monitoring program output to coastal managers and policy-making bodies to affect needed changes in the CNMI coastal management program?

Evaluation Question 6.

Is there a local constituency that supports the monitoring effort, or if not, is there an effective public participation program designed to foster such a constituency?

Evaluation Question 7.

Is there political support for the monitoring program and associated management regulations?

Each of these questions is examined here, followed by an overall assessment of the likelihood of successful implementation of the CNMI coral reef monitoring program. Several coastal management and monitoring plans, the CNMI monitoring program draft and the author's internship experiences and observations were reviewed for this report and form the basis for the assessment below.

VII. Results and Discussion

Evaluation Question 1.

Are the goals and objectives of the CNMI LTMMP clear, consistent, and comprehensive with respect to the broader goals of the CNMI Coastal Management Program?

Clear and consistent goals and objectives provide a starting point for future evaluation of the management program and serve to keep the program on target and focused (English *et al*, 1994; NRC, 1990; Rogers, 1994). Sabatier and Mazmanian (1983) assert that clear and consistent goals and objectives serve as unambiguous directives to implementing officials. The principal goals and objectives of the CNMI monitoring program are:

1. To minimize the adverse effects of development and use of the CNMI's resources on the marine environment.

2. To establish a baseline database of nearshore conditions in order to qualify and quantify changes that occur in the coral community overtime.

3. To establish an early warning system which will allow the appropriate agencies and organizations to respond to problems in a timely manner.

4. To enable resource managers, decision-makers and the general public to make informed decisions leading to appropriate action about coastal resources.

The goals of the monitoring program are clear and consistent. What is less clear is the larger coastal zone management (CZM) framework for coral reef management within which the monitoring goals and objectives are to be carried out. The CNMI CZMP gives little specific policy guidance in terms of policies related directly to management of coral reefs. They are limited to the management policies for the reef and lagoon APC. Those policies state that the Commonwealth shall, where appropriate, (1) designate underwater preservation areas for non-extractive recreational purposes in areas representing the richness and diversity of the reef community; (2) balance economic development with the conservation and management of living and non-living resources of lagoon and reef APC; and (3) prevent significant adverse impacts to reefs and corals

(NOAA, Office of Coastal Zone Management and CNMI Coastal Resources Management Office, 1980).

In the CNMI CZMP, the majority of the discussion about reef protection falls within the policies about the lagoon and reef APCs that indirectly include issues addressed by monitoring goals 2 and 3. The tone of the language of the policies makes it clear that the primary interest is in insuring the maintenance and growth of the development and tourism industries. Because the success of these industries depends on an appealing, healthy reef system, preservation of the ecological integrity of the reef is favored. However, in the coastal plan, there is no indication, other than the general policies stated above, of a broader framework within which to apply monitoring results in an effort to improve reef management. No explicit links have been made between the coral reef monitoring program and the policies of the CZMP.

The coastal permit program is intended to provide a means for managing land and water uses that may directly affect the coastal resources of the Commonwealth. Activities that require a permit include those that occur partially, completely or intermittently within an APC or if the project constitutes as a major siting; an activity that occurs outside a reef or lagoon APC, but will have direct and significant impacts on coastal waters. The permit application is first reviewed by the project lead agency, other participating agencies, and the CRMO. The CRMO is also responsible for determining whether the proposed project is consistent with the policies of the CRMP and for making the Section 307 federal consistency determinations, if a federal permit is also required. The lead agency and any participating agencies will either approve, conditionally approve, or deny the application. The decision will be communicated in writing to the CRMO which has the issuing authority for coastal permitting decisions. If the permit is denied, the CRMO must provide supportive conclusions that the proposed activity would be inconsistent with the policies of the CRMP and the standards and priorities applicable to the areas subject to the management program. If the CRMO fails to issue a decision within 90 days of receiving the application, or 180 days if a federal consistency certification is required, without a mutual extension agreement, the application is automatically approved. According to CRMO records, it seems that the majority of applications are at least conditionally approved and enforcement of compliance is minimal. (NOAA, Office of Coastal Zone Management and CNMI Coastal Resources Management Office, 1980).

As in most areas that have multiple agencies with overlapping management authority, interagency cooperation and communication could be improved. The CNMI is no exception. Currently, Marine Monitoring Team (MMT) members are only informed about those development projects over which their agency has principal responsibility. For instance, the majority of the MMT members are from the DEQ; they are aware of the projects which are reviewed by the DEQ such as well digging. It would be beneficial for the MMT members to be informed about projects occurring on the island that may affect reef monitoring sites. This would allow them to insure that the project is conducted in a way that can mitigate or reduce negative impacts to the area. Additionally, it would create an opportunity to gauge the effectiveness of those mitigation measures by conducting monitoring of the area before and after the project. This could encourage evaluation, and if deemed necessary, adaptation of management strategies. The combination of these approaches allows working within the intent of the marine monitoring program goals as well as connecting them to the broader goals of the CNMI CZMP.

In addition to fostering communication and coordination at a government level, it is also essential to involve the public and encourage their participation in the program. Another goal to consider adding to those already included in the LTMMP is that of promoting stewardship. It is widely acknowledged that if people are given sense of ownership and involvement, then the likelihood of their becoming advocates of program goals is greater.

It is important for program goals and objectives to be clear and fit into the policies and intent of the broader plan, in this case the CNMI CZMP. The goals of the LTMMP do in a general sense, but more direct linkages need to be made in order for the monitoring results to make any difference in island management strategies.

Evaluation Question 2.

Do the coral reef monitoring parameters and the frequency, duration and extent of monitoring activities provide an adequate measure for tracking coral reef health?

The coral reef monitoring program for Saipan is modeled after the program of the Australian Institute of Marine Science, which has proven useful and successful in the Great Barrier Reef (GBR) area. Under the AIMS system used by the CNMI, health of coral reefs is evaluated through parameters or indicators that assess live coral cover, coral diversity and species abundance, coral recruitment, algae cover, fish abundance and species diversity, butterfly fish behavior (Crosby and Reese 1997), sedimentation rate, and water quality (Rogers, 1985; Porter and Meier 1992; English et al 1994). See Table 5.

As evidenced by their successful use in the GBR and other monitoring programs, these indicators should be adequate to track reef health on Saipan. The AIMS program has produced three status reports since the inception of their program that demonstrate its utility. Because of the interdependent nature of reef organisms and habitat, individual parameters provide only a part of the necessary picture of reef condition. Collectively, however, these survey techniques, if conducted by well-trained personnel, do render usable, replicable data that can be interrelated to track system health. They can serve to establish a baseline that reflects current reef condition against which to measure future changes. Additionally, assuming proper data management, analysis and reporting to appropriate audiences and authorities, these data can be used to influence management decision and policy.

A decrease in live coral cover may be attributed to sedimentation, algal cover, a change in water quality, a decline in fish populations, or physical damage; all of which are indicators in the CNMI monitoring program. By using observable and measurable reef processes as parameters and indicators of representative ecosystem health, researchers and managers can detect trends. For example, changes in percent of live coral cover may indicate several different anthropogenic or natural perturbations. Figure 7 schematically illustrates these relationships between indicators of change and the sources to which those changes may be attributed. To discern which disturbances are causing a change in an indicator, further experiments or investigations may need to be conducted.

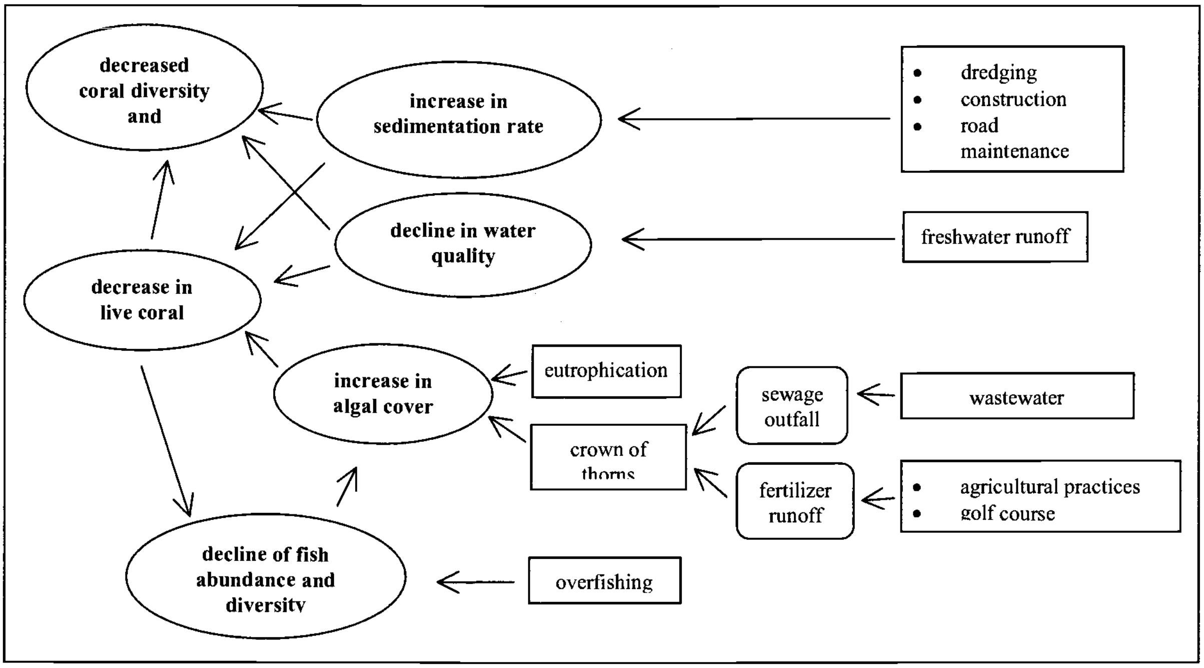

Figure 7. Management areas to monitoring indicator flow
The bulleted information enclosed by the rectangles describes source areas where management and regulatory action may be targeted in order to minimize the impact on reef systems. The rectangles are the outcomes that are responsible for causing a change in the monitoring indicators or parameters. The parameters/indicators are in bold print and enclosed in the ovals.

Evaluation Question 3.

Are the coral reef monitoring parameters, individually and/or collectively, linked to potential causes of reef decline or improvement?

The indicators used by the CNMI coral reef monitoring program can be linked to causes of reef decline and improvement, at least in theory. Monitoring of the indicators in the CNMI program provides a basis for the LTMMP to meet program goals 2 and 3; to establish a baseline and to establish an early warning system, respectively. However, a mechanism or process to achieve this linkage between the Saipan reef health indicators and possible causes of change or trends is lacking. Even if data is being collected, analyzed, and summarized, there is no identified way to make the link back to causal conditions or activities. Without this, the program has no means to influence management decisions, either generally or for specific projects.

Because of the interconnected nature of the reef environment, the monitoring parameters themselves are interrelated. For example, live coral cover may decrease due to excessive sedimentation which may be caused by land clearing or dredging activity. For example, Maragos (1993) describes the effect of upland construction activity on adjacent reef systems. Excessive or chronic sedimentation can smother existing coral colonies and also prevent recruitment and settlement of planular coral larvae. Based on studies in Pala Lagoon (Helfrich, 1975) and Kaneohe Bay, Hawaii (Evans and Hunter, 1992; Evans et al, 1986; Hunter and Evans, 1993; Maragos, 1972; Maragos et al, 1985), the potential synergistic effects of sedimentation and water pollution such as sewage discharges can also inhibit coral recolonization on dredged surfaces. Algal cover may increase due to overfishing of herbivorous species or introduction of excess nutrients from sewage or fertilizer runoff. Fish populations may decline because of overfishing or a decrease in live coral cover. Extending the linkages further, excessive sewage discharge may indicate poor wastewater management methods, high fertilizer runoff may be due to poor agricultural practices. One intent of marine monitoring is to measure those indicators that can reveal an existing problem and perhaps suggest the probable mechanism. Often, additional studies are needed to determine the actual cause and effect relationship which may direct changes in management strategies or actions.

A common challenge of program implementation that makes application of monitoring data problematic is poor interagency coordination. Information-hoarding is a common problem, especially in small bureaucratic governments where information is perceived as power. These factors combined with agency overlaps in management responsibility and authority often results in either redundancy of action or implementation gaps. One way to approach these issues is to develop a process or model that makes the roles of key agencies in natural resource management processes clear and consistent. An example of such a tool that is specific to marine monitoring activity is presented in Table 6. It serves as an incomplete prototype of a process that should be further developed and put into use on Saipan to allow linkages to be made between monitoring results and management activities, or action.

With the implementation of the LTMMP, the present focus is on establishing a baseline. No further attempts to determine correlation between trends on the reef and causes have been made to date.

Table 6. Links between Monitoring Parameters, Impacts, and Agencies Responsible

Measurement Parameters	*Monitoring Technique (monitoring frequency)*	*Direct Impact Type*	*Activity Potentially Causing Impact*	*CNMI Agency Responsible*
Percent Coral Cover	• point intercept quadrat • indicator species (obligate corallivores) • line intercept transect • manta tow	a) sedimentation b) decline in water quality c) increase in algal cover d) physical/structural damage e) fishery decline f) storm damage	a) dredging filling earthmoving activities deforestation b) poor agricultural practices poor wastewater management earthmoving activities c) poor agricultural practices poor wastewater management golf course maintenance overfishing crown of thorns seastar outbreak d) fishing practices diver impact boat anchoring ship grounding e) overfishing/practices	a) CRMO DLM DEQ b) DEQ DoA DLM c) DEQ DoA CRMO d) DFW CRMO Coast Guard e) CRMO DFW
Fish species abundance Fish species composition Fish species diversity	• fish censusing survey • manta tow (abundance only)	g) decrease in live coral cover h) overfishing and d) above	g) see a) – d) above h) gear type overexploitation	e) CRMO DEQ f) CRMO DEQ DFW

Measurement Parameters	*Monitoring Technique (monitoring frequency)*	*Direct Impact Type*	*Activity Potentially Causing Impact*	*CNMI Agency Responsible*
Coral species diversity	• point intercept quadrat • line intercept transect	i) sedimentation j) decline in water quality k) decrease in live coral cover l) increased algal cover see e) and f) above	i) see a) above j) see b) above k) see a) – e) above l) see c) above	g) DEQ DLM CRMO h) DEQ DoA DLM i) CRMO DEQ j) DEQ CRMO DoA
Number and size of fish territories Rates of agonistic and feeding behavior	• indicator species survey (obligate corallivores)	m) decline of coral food value n) sedimentation o) decrease in live coral cover p) increased algal cover q) decline in water quality	m) cumulative affects of several impacts n) see a) above o) see a) – d) above p) see c) above q) see b) above	l) DEQ DLM CRMO m) CRMO DEQ n) DEQ CRMO DoA o) DEQ DoA DLM
Water quality parameters temperature fecal coliform salinity pH turbidity	• water quality	r) coral bleaching s) t) freshwater runoff u) v) sedimentation/siltification	r) thermal input climate change s) poor wastewater practices sewage outfall near shore t) deforestation earthmoving activities u) v) dredging filling earthmoving activities deforestation	1) OM 2) DEQ DoA DLM 3) DEQ DFW DLM CRMO 5) DEQ DFW DLM CRMO

Source: Brock, 1954; Crosby and Reese, 1996; English, Wilkinson and Baker, 1994; Jokiel and Tyler, 1992; Loya, 1978; Manton and Stephenson, 1935; CNMI CRMO, 1980.

Evaluation Question 4.

Does the principal implementing agency have the necessary funding, staffing, training, and interagency coordination authority and skills needed to carry out the program?

The effectiveness of monitoring is limited by the adequacy of financial and human resources available (NRC, 1990). Funding cycles generally fall within the time frame of a fiscal year while the temporal scale of a monitoring program tends toward a minimum of 5 years needed to define ecosystem variability and trends. Consequently, monitoring programs may experience inconsistency in and discontinuity of financial support. Although the coordinator of the CNMI LTMMP currently does not anticipate a lack of financial resources for the duration of the monitoring program (Susan Burr, CNMI DEQ, personal communication, Sept. 1998), given the typical pattern, it may be short-sighted not to incorporate consideration of the occurrence of program funding gaps. Funding of the LTMMP currently originates from several sources; the Clean Water Act Sections (106) and (319), NOAA 6217 (Coastal Nonpoint Pollution and Control), the International Coral Reef Initiative and limited financial support from the involved agencies.

Although the availability and allocation of funding limit the adequacy and usefulness of monitoring, insufficient experience and skill of the monitoring staff may also be limiting. Not only do monitoring specialists need to have the capability to collect quality biological, chemical, and physical data, but effective monitoring requires individuals with broad skills and experience in experimental design; data analysis, synthesis, and interpretation; communication of results; and environmental management (NRC, 1990).

It is noted that the success of a monitoring program is dependent upon direction by at least one broadly experienced and trained person (NRC, 1990). The LTMMP does have a well-qualified individual coordinating the monitoring efforts. However, while the supporting staff is well-trained in data collection techniques, they are lacking in the experimental design, data management, and interpretation and reporting components. As a result, responsibility for all parts of the program falls on one, over-extended individual. This may mean that although at least one individual has all of the necessary skills, because of time and energy constraints the less immediate but essential details, like data management and reporting, are delayed or neglected. Thus far, no reports on the monitoring results have been prepared since the initiation of the program. Consequently, the monitoring results and findings do not reach decision-makers, therefore, the likelihood of positive changes occurring in reef management lessens. A concerted effort to follow through with all parts of the program – from data collection to formal reporting – is needed.

The South Pacific Regional Environment Program (SPREP) sponsored an initial two week monitoring technique training program in 1996. Unfortunately, little monitoring activity occurred after this training. The MMT members did not have a chance to regularly practice their newly acquired skills. A follow-up training occurred in June of 1997. Topics included coral reef ecology, monitoring survey methods, coral identification, fish identification, natural resource management and data management, analysis and reporting. This level of training provided basic information upon which to build. The LTMMP states "The marine monitoring team will implement and continually develop this marine monitoring program. Training opportunities will continuously be afforded to the team so the members can keep their skills current and upgrade their certifications". Because the team members have since been utilizing their monitoring method skills on a regular basis, they are able to collect good data. The deficiency occurs after the data entry stage. There is a lack of training and skill in data analysis and synthesis. Follow-up training workshops in these skills need to continue in order to maintain and improve the quality of the data collected and analyzed.

As discussed in the monitoring and protocol section, the DEQ Marine Monitoring Quality Assurance (QA) Plan describes procedures for data collection and management to be used for the marine monitoring program. The QA plan provides detailed descriptions of how all data should be collected, stored, and analyzed. If it is implemented and followed, the QA plan will be sufficient for data analysis needs of the CNMI coral reef monitoring program. One reason that it currently is not being followed may be due to the absence of specifically assigned tasks and responsibilities of the staff. If the expectation is that someone else will complete analysis tasks, then it is likely that no one will do them. Summarizing the data management steps, step components, skills required to accomplish the steps and personnel responsible for completing each step, can clarify what needs to be accomplished and staff members responsible for task completion. A preliminary design for a data management tool is illustrated by Figure 8.

There are several distinct steps in the data management process as shown by Figure 7. Most of them require no more knowledge than familiarity with the collected data and basic computer skills. This is not to trivialize the importance of performing each step regularly and accurately. The data analysis step does demand the ability to determine the most appropriate types of tests and analyses given the monitoring objectives An effective strategy may be to train a DEQ staff member as the data analysis specialist. This relieves the time demands of the NPS Coordinator and ensures that the collected data are regularly converted to a usable format for the reporting and dissemination step.

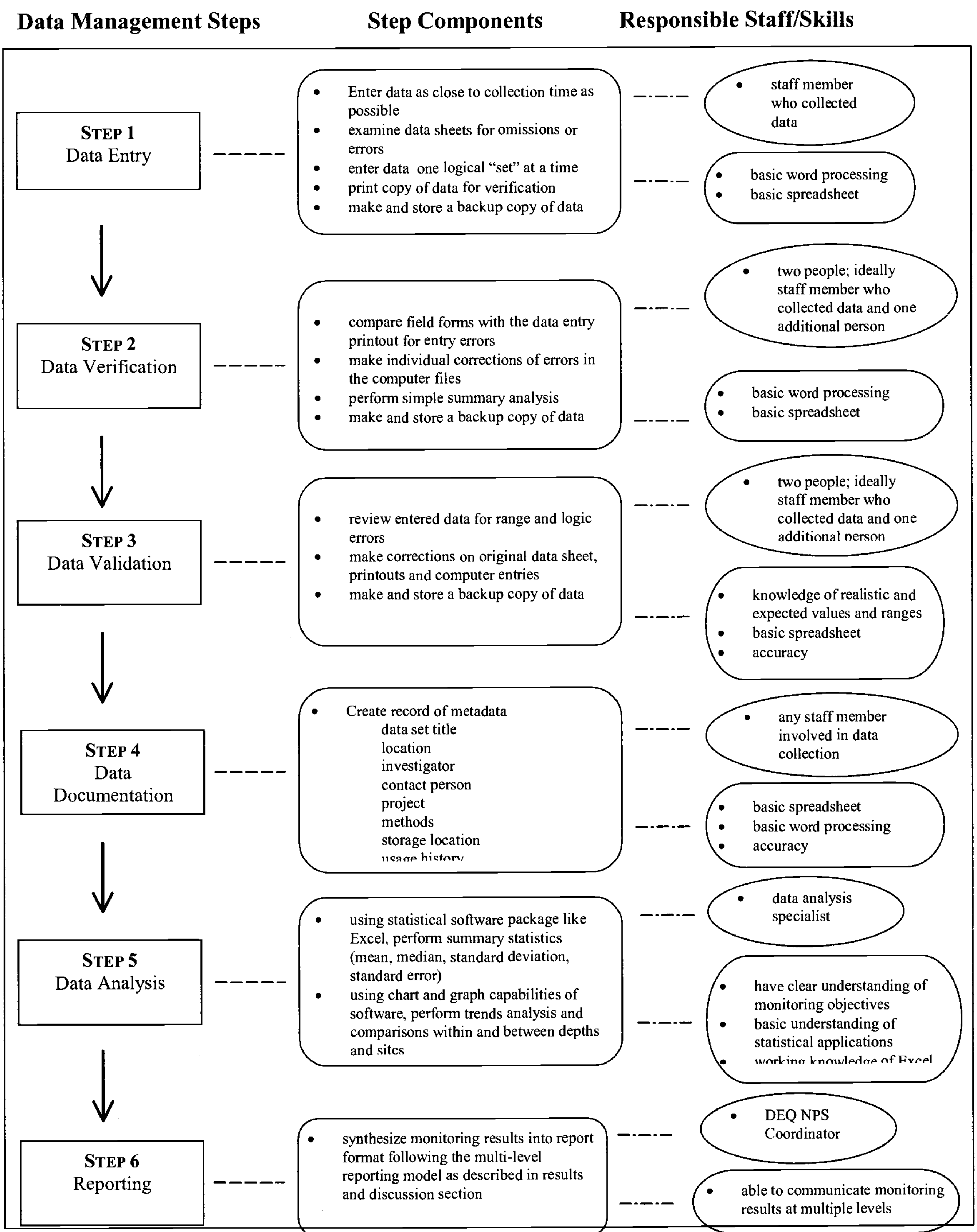

Figure 8. Data Management

Evaluation Question 5.

Is there a feedback mechanism that links monitoring program output to coastal managers and policy-making bodies to affect needed changes in the CNMI coastal management program?

Too often monitoring and research efforts stop after the data collection and tabulation phase of the project. Data reports are prepared and distributed, but not really applied to real world issues. Central to a successful ecological monitoring effort is dissemination of information to those who have the ability to use it to make positive changes in the management system. The weak link in this process is most commonly in converting the data to information useful to the end users. Drucker (1988) described the difference between data and information: "Information is data endowed with relevance and purpose. Converting data into information thus requires knowledge." The final determination of program effectiveness then is whether a monitoring program provides mechanisms to ensure that knowledge is used to convert data collected into information and then to disseminate that information so it may be applied in the decision-making process.

An example from a coral reef monitoring program illustrates this process. Measurements of percent live coral cover in and of themselves do not provide useful information. These measurements must be tracked, analyzed and compared to describe ecosystem patterns and trends. Other measurements like water quality, sedimentation rate, and fish surveys need to be incorporated and analyzed to determine possible explanations for changes in coral cover. Additional data and information about runoff patterns, currents and land-based projects should be combined with monitoring data to link sources of nutrients and sediment with effects on the reef. Conversion of monitoring data into information, therefore, involves a range of activities, including data management, statistical analysis and causal investigation (NRC, 1990). Then, in order to make this information applicable to management, it must be distributed to resource managers, decision-makers and the public in a useable, accessible form. In fact, resource managers and others need to be directly involved in this process of discovery because they are the ones with the authority to apply it.

The Long Term Marine Monitoring Plan has a brief discussion of reporting and information dissemination. It states: "Comprehensive data analysis will be reported to the respective program directors on a quarterly basis. In addition, a public report will be developed on a quarterly basis. This report will describe the studies that were conducted during the previous time period and will briefly outline the major findings from the surveys." The intent is written into the monitoring plan, but no such reports have been produced to date. The data is being collected and entered into databases, with no further analysis or reporting.

An example that offers a realistic model of information dissemination for the CNMI is the Chesapeake Bay Water Quality Monitoring Program, albeit at a different scale. This program follows a multi-level approach in reporting its results to the public, decision-makers and scientists. At *level one*, semiannual reports summarize the status of data collection activities. These include displays of spatial, seasonal, and long-term trends, analyses of results, and tabular data summaries. They are distributed to all appropriate agencies and organizations. The *level two* reports, prepared every two years, are more interpretive than the level one reports, yet they are distributed to the same agencies and organizations. They evaluate relationships among study elements, place the data in an ecological and regional perspective, and quantify the effects of major processes affecting water quality in the Chesapeake. *Level three* reports are targeted at politicians, high-level decision-makers, and the public. They provide a broader scope of the status of the bay and changes that have occurred over defined periods. The purpose of this level of reporting is to identify the factors influencing environmental conditions, evaluate restoration actions, and identify management actions and policies that would improve conditions. In addition to these more detailed levels of reporting, the Chesapeake program prepares annual *executive summaries* for each major program element. Listed in these summaries is the data being collected; descriptions of how, when, and where data are collected; the name, telephone number, organization, an address of the principal investigator. The program summaries also include information about how to obtain data summaries and raw data; highlight major findings, conclusions, and recommendations;

and discuss future plans (NRC, 1990). This model of multi-level reporting and distribution could be adapted at an appropriate scale for use by the LTMMP.

It is unrealistic to expect the standard report format to be an effective method to communicate information to all target groups; other types of information distribution should also be used on the CNMI. These include press releases, quarterly newsletters and workshops. Press releases can be used to bring attention to a unique finding or simply periodic updates of activity. Quarterly newsletters that include MMT activity, findings, and volunteer opportunities could be distributed to the Northern Marianas College and dive operators. An annual workshop that is interactive and experientially oriented is an effective method of sharing information as well as receiving input about progress and direction of monitoring activities. Attendees would be those agencies involved in monitoring efforts or affected by monitoring results, like those who make permit decisions, do CZM Section 307 federal consistency determinations, and conduct land-based natural resource research and survey activity.

Evaluation Question 6.

Is there a local constituency that supports the monitoring effort, or if not, is there an effective public participation program designed to foster such a constituency?

In low-income tropical areas like the CNMI, environmental plans and programs that have been adopted too often have little or no discernible impact on the trends in ecosystem misuse and overuse that they were designed to modify (Olsen, 1993). The plans, policies and regulations imposed may be potentially useful and good quality; however, a key factor that is often overlooked is the "constituency problem". An example of this is the development of shrimp aquaculture in Ecuador. The methods used to develop this industry have resulted in the destruction of mangrove wetlands. This is recognized as a major problem because the mangroves play a key role in the life cycle of the shrimp that are cultured in the ponds in addition to providing a host of natural ecosystem services. The government's approach to the problem was to adopt a suite of laws and regulations to protect the mangroves from alteration. Clearly, the problem was not the lack of protective policies, but the absence of effective implementation. It was not in the short-term interest to those whom the regulations affected to implement the regulations that had been passed. A significant challenge to program implementation is often the building of a supportive, effective constituency. Linking back to question 1 that describes the need for clear and consistent goals, an initial step in constituency organizing is to choose program goals that are considered significant to those affected by them. After this fundamental requirement is met, another essential ingredient in constituency building is public involvement. Public education and outreach can be one of the most effective management tools available. An aware, involved community is invested in the positive outcome of the management program. A supportive public voice can help to ensure the longevity of a program.

The LTMMP of the CNMI outlines the intent to periodically report the findings to the public on a quarterly and annual basis. However, to date, there is no public outreach component in the LTMMP. In May 1997, a public forum was held in order to provide information about coral reefs and the development of both the marine monitoring program and team. This was very well attended and received. It provided an opportunity to foster the momentum created by continuing to give the public the chance to be involved. Unfortunately, the opportunity created passed; that event was the only time to date that the public has been informed of or involved in monitoring activity.

An initial step towards constituency building on Saipan would be to add a fifth program goal of promoting stewardship with an objective of developing an outreach section of the monitoring program. One of the most effective approaches to involve the public in the LTMMP would be to incorporate a citizen volunteer monitoring program into the overall monitoring efforts. A global program that seems to be becoming more widely known and as a result is growing in effectiveness in terms of data collected and global accessibility of that information is Reef Check. This program was discussed in more detail in the Coral Reef Protection Strategies section. There are plans for Reef Check to be conducted in the CNMI on Rota during spring, 1999. Volunteers will be from the dive shops and the high school and will be coordinated by the MMT members. If it is successful, the intent is to repeat the effort yearly and expand it to both Tinian and Saipan.

Another popular awareness and stewardship promotion program has been the 'adopt a highway' clean up program in the United States. This idea could be adapted to coral reefs and incorporate volunteer groups from island organizations such as student groups from high schools and the Northern Marianas College, dive operators and their tourist clients, the Rotary Club, and any number of other community groups already in existence. The idea is that each group becomes responsible for the monitoring and stewardship of a section of reef.

A related purpose that public involvement serves, particularly significant to the CNMI, is reconnecting people with nature. As addressed in the socio-economic background section, the relatively recent influx of tourists produced socioeconomic imbalances created from their influence on the local economy. This shift caused local people to seek well paying government jobs rather than leading a traditional natural resource based subsistence lifestyle. This loss of connection with the natural resources may have advanced the trend towards land development for tourism uses. Public involvement in the monitoring program would instill the sense of stewardship of the marine ecosystem that has been lost.

Constituency building through the addition of a fourth marine monitoring goal of promoting public stewardship of the coastal and reef ecosystems would improve the likelihood of successful implementation of the CNMI coral reef monitoring program.

Evaluation Question 7.

Is there political support for the monitoring program and associated management regulations?

The LTMMP was created at the administrative level rather than the legislative level. The political sector of government activity has little awareness of the program and its potential value in both the evaluation of existing management strategies that have been adopted and development of new ones. For instance, the never implemented CNMI Marine Park Management Plan would have benefited from marine monitoring efforts. The LTMMP could have served to determine areas to designate and zone for different types and intensities of use within a marine park. Additionally, continued monitoring of park zones could reveal important information about effectiveness of management efforts. The fact that this Marine Park Management Plan was never adopted is evidence that environmental concerns are not high on the political agenda in the CNMI. However, with the promotion of citizen stewardship by the addition of a fourth program goal with stewardship as its target and the development of an active public outreach section of the MMT, it may become more important. What is important to the public generally becomes politically salient as well.

Another method of focusing political attention on the connection between monitoring and management relates to the answer described in question 5. The MMT needs to put the multi-level reporting model into action with special attention to ensuring the creation of publications targeted at the policy and decision-makers.

VIII. Conclusions

Coral reefs continue to decline globally due to the synergistic effects of natural and anthropogenic disturbances and stressors. An increasing awareness of the importance of coral reef ecosystems in providing valued functions and services to local and global human populations has heightened concern about preservation of reef areas. In response, coastal management programs in tropical and subtropical regions have begun to incorporate provisions for sustainable use and preservation of reef ecosystems. Effective marine monitoring programs are an important initial step in establishing and improving coastal management strategies.

On the CNMI, the Long Term Marine Monitoring Program has been implemented in an effort to track changes in the reef and coastal environment, identify sources of stressors and affect positive changes in marine management. The purpose of assessing the effectiveness of the LTMMP is to evaluate the likelihood of successful implementation. It is hoped that the program administrators will use this information to address the weaknesses of the program and enhance the strengths to ensure the long-term success of the program and its benefit to the coral reef environment of the CNMI.

At first glance, the coral reef monitoring program seems to have all the necessary components for successful implementation. However, upon further examination by using an implementation evaluation framework adapted from policy analysts including Sabatier and Mazmanian (1983), areas in need of improvement become more apparent. Certainly, if the issues identified by the evaluation questions are addressed and resolved, it does not guarantee successful implementation, but does greatly improve the likelihood of successful implementation.

IX. Recommendations

Coordination

The coral monitoring program has goals and objectives that are clear. However, there is little direct connection to the broader framework of the CNMI CZMP. Without coral reef management directives, it is unclear where monitoring results may be applied to improve or promote management strategies. Monitoring results should be used to aid the decision whether permits are granted. Currently, the incorporation of natural resource data into the permitting process is minimal if at all. The use of monitoring results in the permitting process would enable decision-makers to note important trends in the nearshore environment that may be affected by the proposed project. This would allow permit approval to be conditioned upon adherence to best management practices for the area.

Interagency coordination could be improved by informing MMT members about permitted projects occurring near monitoring sites. In addition to improved interagency communication, the potential benefits of this include ensuring that project methods used have the least possible impact on the reef ecosystem and allow the MMT to evaluate the effectiveness of current management strategies.

Although it is possible to link the monitoring parameters to potential causes of reef decline or improvement, there must be a mechanism present that serves to link the parameters and indicators to causal conditions or activities. The coral reef monitoring program on the CNMI is lacking such a mechanism. One approach that should be utilized on Saipan that works towards making this connection is the development of a tool that illustrates these linkages and the agencies responsible for regulation and action. Table 6 in the results section provides an example, on which to build, of a tool that makes the connections between monitoring, management and action. The development of a linkage guide may also serve to improve interagency cooperation and coordination.

The goals and objectives are to serve as targets for the desired direction of the monitoring program. Occasionally, changes in management needs may deem a shift in focus of the program. In order to determine whether changes in the monitoring program should be made, periodic evaluation is a useful tool. The set of evaluation questions used in this report may serve as a starting point for that process.

Recommendations:

- Incorporate the monitoring results into the coastal permitting process.
- Inform the MMT members about permitted projects occurring near monitoring sites.
- Develop a tool that makes the connections between monitoring, management and action based on the example of Table 6.
- Conduct periodic evaluations of the LTMMP to assess effectiveness of management actions; ensure that program goals are still desirable and are being worked towards; or to re-focus purpose of program.

Monitoring

The parameters and indicators used in the CNMI coral reef monitoring program are measured with sufficient frequency, duration, and extent to potentially provide an adequate measure for tracking coral reef health. They can allow the MMT to detect trends in change of the reef ecosystem. There are additional parameters that should be incorporated into the monitoring regime that would help provide a more complete picture of reef health; coral recruitment and nutrient levels. Measurements of both of these parameters can be obtained by methods that are easily learned, inexpensive and do not require significant technical equipment.

As discussed in the monitoring and protocols section, nitrogen and phosphorus are usually limiting nutrients in reef systems. However, nutrient runoff from roads, golf courses, agricultural fields, groundwater seepage, and residential areas can have a chronic effect on the reef environment. Excessive nutrient loads in nearshore ecosystems result in eutrophication of coastal waters leading to significant increase in algal growth and loss of live coral cover. Currently, none of the parameters measured by the monitoring team directly link to causes and sources of eutrophication.

The occurrence of new recruits on reef areas is thought to be a better measure of long-term reef health than coral cover. That is not to say that coral cover is a useless measure, but it may offer the best information in combination with coral recruitment surveys. If the reefs are severely damaged, there is no longer a local seed population of polyps. Coral larvae need reasonably solid, secure substrate on which to settle. If a reef area is overrun by mats of algae or heavy sedimentation, recruits that do drift in from outside sources will not settle and will most likely die due to the lack of suitable substrate. Recruitment surveys would offer an additional method to assess overall reef health (Pennisi, 1997).

Recommendations:

- Include measurement of nitrogen and phosphorus levels into the water quality parameters tracked.
- Add coral recruitment surveys to the parameters measured by the coral reef monitoring program.

Training

The CNMI LTMMP, at this point, has adequate funding for salaries, training, and equipment. The MMT members have been through two training programs that have developed and improved their marine monitoring techniques in the field. It would be beneficial to incorporate an on-going training and retraining schedule or plan to ensure opportunities for skill improvement and to minimize observation errors.

Recommendation: Incorporate and carry out an on-going training and retraining schedule or plan designed to improve skills and minimize observation errors.

Data Management and Reporting

One key determination of program effectiveness is whether it extends beyond data collection. In order to have the ability to affect positive change in marine management strategies, the decision-makers need to be equipped with the available information about system processes. This reporting and dissemination step is often left until after the program funding has diminished. The LTMMP outlines the procedure by which reporting is intended to be carried out. However, as with many natural resource plans, the current level is not sufficient to communicate results to the end users.

It is recommended that a multi-level phased reporting approach, modeled after that used by the Maryland Department of Environment Chesapeake Bay Program, discussed in the results section under question 5, is adopted by the CNMI DEQ. This reporting mechanism uses different levels of reporting to keep target audiences informed about the program goals and activity, the meaning of the collected data, what data remains to be collected, what analyses remain to be completed, and why additional data collection and analyses are needed.

It is important to recognize that different audiences respond to different communication methods. Methods in addition to the previously described reporting model that would be effective on the CNMI include press releases, quarterly newsletters and workshops. The audiences range from public to students to agency employees.

As detailed in the results section, the primary skill deficiency of the MMT occurs in the data management stage. Although there is a plan describing how monitoring data should be collected, stored and analyzed, it is not being followed. One explanation for this is the lack of clear data management responsibilities for the staff. Figure 6 provides a step-wise approach to managing monitoring data identifying staff responsibilities and necessary skills. The staff currently has some of the skills required for the data management process, though it is recommended that one of the DEQ staff be trained as a data analysis specialist. This will ensure that the data are analyzed in a timely manner as well as alleviate the time demands of the NPS Coordinator.

Recommendations:

- Adopt multi-level phased reporting approach, modeled after that used by the Maryland Department of Environment Chesapeake Bay Program.
- Use additional methods that will target broad audience ranges to communicate the results including press releases, quarterly newsletters and workshops.
- Train one of the DEQ staff as a data analysis specialist.

Public Education and Involvement

As described by Olsen (1993), the "constituency problem" often provides challenges to the successful implementation of coastal management programs. In addition to choosing program goals that are significant to those affected by them, public involvement is critical to constituency building. Public outreach is among the most effective management strategies available.

To breach the constituency problem on Saipan, it is recommended that an additional goal be added to the monitoring program goals and to solicit additional funding to incorporate a public outreach section into the LTMMP. The fifth program goal would be to promote stewardship of the nearshore ecosystem. Approaches to accomplish this goal include starting a citizen marine monitoring program to be overseen by the MMT. There are plans for the dive shop and high school on Rota to participate in Reef Check this spring. Reef Check should be viewed as an opportunity to use the momentum generated to develop an on-going volunteer monitoring program that involves local and tourist volunteers. Additional ways to build a constituency include educational and awareness building activities such as an adopt-a-reef program, development of school curriculum, education of dive operators, public forums, and athletic events like fun runs or swims.

Environmental issues are rarely the focus of political attention on Saipan. Due to this and the fact that the coral reef monitoring program was developed at the administrative level, there is little political awareness and as a result, support of the program. One method to garner political support is, again, the addition of a fifth goal to the monitoring program. This recommendation is based on the theory that if the public becomes concerned about the state of the reefs and their role in lessening anthropogenic impacts, then the issues will become more significant politically.

Another method to raise the political awareness is the multi-level reporting model discussed in response to evaluation question 5. The legislative levels must also be involved and informed in order to be able to make decisions with positive outcomes for the reef ecosystem. To reiterate a previous recommendation; the multi-level reporting model should be put into action to aid in bringing political attention and support to the LTMMP.

Recommendations:

- Add a fifth goal of promoting stewardship to the coral reef monitoring program goals.
- Incorporate a public outreach section into the LTMMP.
- Incorporate a volunteer monitoring program into the current coral reef monitoring program.
- Develop informational and participatory workshops for agency personnel, distribute quarterly newsletters to NMC, high schools and dive shops, and continue submitting periodic press releases to the newspaper.

X. References Cited

Adey, W.H. and R. Burke. 1977. Holocene bioherms of the Lesser Antilles-geologic control of development. *In* S.H. Frost, M.P. Weiss, and J.B. Saunders (eds.), *Reefs and related carbonates-ecology and sedimentology*, pp. 68-82. American Association of Petralogical Geology, Studies in Geology 4.

Badria, F. A., A.N. Guirguis and W.A. El-Naggar. 1997. Antibacterial and antifungal agents from Egyptian marine organisms. *International Journal of Pharmacognosy*, 35: 284-287.

Bak, RPM. 1978. Lethal and sublethal effects of dredging on reef corals. Marine Pollution Bulletin, 9:14-16

Birkeland, C. 1982. Terrestrial runoff as a cause of outbreaks of *Acanthaster planci* (*Echinodermata: Asteroidea*). *Marine Biology* 69: 175-185.

Birkeland, C. (ed.) 1997. *The Life and Death of Coral Reefs*. Chapman and Hall, New York.

Birkeland, C 1997. Status of Coral Reefs in the Marianas.. *In* R.W. Grigg and C. Birkeland (eds.), *Status of the Coral Reefs of the Pacific*. Sea Grant College Program, University of Hawaii.

Bischof, B. 1997. Reefs in Crisis. *Natural History* 106: 46-57

Bouchon, C., T. Lebrun, J.L. Rouvillain, and M. Roudier. 1995. The Caribbean scleractinian corals used for surgical implants. *In* D. Allemamd and J.P. Cuif (eds.) *The Proceedings of the 7th International Symposium on Biomineralization*. Musee Oceanographique, Monaco, 1993.

Brock, V.E. 1954. A preliminary report on a method of estimating fish populations. *Journal of Wildlife Management* 18:297-308.

Brown, B. E. and L. S. Howard. 1985. Assessing the effects of "stress" on reef corals. *Advances in Marine Biology* 22:1-63.

Burr, S. 1996. Long Term Marine Monitoring Plan for the Commonwealth of the Northern Mariana Islands. Division of Environmental Quality, Coastal Resources Management Division, Division of Fish and Wildlife and Northern Marianas College. unpublished draft.

Christie, H. 1985. Ecological monitoring strategy with special reference to a rocky subtidal program. *Marine Pollution Bulletin*. 16:232-235.

Coastal Resources Management Office, Commonwealth of the Northern Mariana Islands (CNMI). 1985. *CNMI marine parks management plan.* Prepared by Pacific Basin Environmental Consultants, Inc., Guam.

Coull, B. 1985. The use of long-term biological data to generate testable hypotheses. *Estuaries* 8:84-92.

Crosby, M. P. and E. S. Reese. 1996. *A Manual for Monitoring Coral Reefs with Indicator Species: Butterflyfishes as Indicators of Change on Indo Pacific Reefs.* Office of Ocean and Coastal Resource Management, National Oceanic and Atmospheric Administration, Silver Spring, MD. 45pp.

Dahl, C. 1995. Micronesia. *In* K. Hotta and I. M. Dutton (eds.) *Coastal Management in the Asia-Pacific Region: Issues and Applications.* Japan International Science Federation, Tokyo.

Davies P.J. and D. Hopley. 1983. Growth fabrics and growth rates of Holocene reefs in the Great Barrier Reef. BMR Journal of Australian Geology and Geophysics, 8:237-251.

De Vantier, L.M. 1986. Studies in the Assessment of Coral Reef Ecosystems. *In* Brown, BE (ed.) *Human Induced Damage to Coral Reefs*, UNESCO Reports in Marine Science, 40:99-111.

Dickenson R.E. and R.J. Cicerone. 1986. Future global warming from atmospheric trace gases. *Nature* 319:109-115.

Doulman, D. 1986. The tuna industry in the Pacific islands region, opportunities for foreign investment. *Marine Fisheries Review* 48(1): 15-32.

English S., C. Wilkinson, and V. Baker. (eds.) 1994. Survey Manual for Tropical Marine Resources. Townsville, Australia: Australian Institute of Marine Science, 1994.

Evans, C.W. and C.I. Hunter. 1992. Kaneohe Bay, an update on recovery and trends to the contrary. 7th International Coral Reef Symposium, Agana, Guam.

Evans, C.W., J.E. Maragos and P.F. Holthus. 1986. Reef corals in Kaneohe Bay six years before and after termination of sewage discharges. *Coral Reef Population Biology, Hawaii Institute of Marine Biology Technical Report,* 37: 76-90

Gates, W.L., J.F.B. Mitchell, G.J. Boer, U. Cubasch, and V.P. Meleshko. 1992. Climate modeling, climate prediction and model validation. *In* J.T. Houghton, B.A. Callender and S.K. Varney (eds.), *Climate change 1992: The supplementary report to the IPCC Scientific Assessment*, pp. 97-134. Cambridge University Press, Cambridge, U.K. as quoted in Sebens, 1994

Geister, J. 1977. The influence of wave exposure on the ecological zonation of Caribbean reefs. Proceedings of the 3rd International Coral Reef Symposium, Miami 1. Biology:23-29.

Ginsberg, R.N., P. Kramer, J. Lang, P. Sale, and R. Steneck. 1998. Atlantic and Gulf Reef Assessment Revised Rapic Assessment Protocol [online]. Available http://coral.aoml.noaa.gov/agra/rap-revised.html

Good, J.W. 1992. Ocean shore protection policy and practices in Oregon: An evaluation of implementation success. Ph.D. Dissertaion, Department of Geosciences, Oregon State University. 276 p.

Griffith, M. and J. Ashe. 1993. Sustainable development of coastal and marine areas in small island developing states: a basis for integrated coastal management. *Ocean and Coastal Management*, 21:269-284.

Hamnett, M. 1990. Pacific Island resource development and environmental management. *In* W. Biler, P. d'Ayala and P. Hein (eds.) *Sustainable Development and Environmental Management of Small Islands*., Parthenon Publishing Group, Paris.

Helfrich, P. 1975. An assessment of the expected impact of a dredging project for Pala Lagoon, American Samoa. University of Hawaii Sea Grant College Program Technical Report UNIHI-SEAGRANT-TR-76-02.

Hinrichsen, D. 1997. Coral Reefs in Crisis. *Bioscience.* October 1997 v 47 n9 p554.

Hodgson, G. In press. A Global Assessment of Human Effects on Coral Reefs. *Marine Pollution Bulletin.*

Hubbard, D.K. 1997. Reefs as Dynamic Systems. *In* Birkeland, C. (eds.) *Life and death of Coral Reefs*, pp. 43-67. Chapman and Hall, New York.

Hughes, T.P., D.C. Reed and M.J. Boyle. 1987. Herbivory on coral reefs: community structure following mass mortalities of sea urchins. *Journal of Experimental Marine Biology and Ecology*. 113-39-59.

Hunter, C.I. and C.W. Evans. 1993. *Reefs in Kaneohe Bay Hawaii: Two centuries of western influence and two decades of data*. Submitted manuscript.

Jokiel, P.L. and W. Tyler. 1992. Distribution of Stony Corals in Johnston Atoll Lagoon. *In* the Proceedings of the 7th International Coral Reef Symposium, Guam 2:683-692.

Kakazu, H 1994. Absorptive capacity and diversification of a small tourist economy: the Northern Mariana Islands. In *Sustainable Development of Small Island Economies*. Westview Press, Boulder.

Kenchington, R. A. 1990. *Managing Marine Environments*. Taylor and Francis, New York. 247 pp.

Kenchington, R.A. and C. Bleakely. 1994. Identifying Priorities for Marine Protected Areas in the Insular Pacific. *Marine Pollution Bulletin*, Vol. 29, n1-3, pp. 3-9.

Kleypas, J.A., R.W. Buddemeier, D. Archer, J-P Gattuso, C. Langdon, and B.N. Opdyke. 1999. Geochemical Consequences of Increased Atmospheric Carbon Dioxide on Coral Reefs. *Science* 284: 118.

Lapointe, B.E. and M.W. Clark. Nutrient inputs from the watershed and coastal eutrophication in the Florida Keys. *Estuaries* 15: 465-476.

La Pointe, B.E., W.R. Matzie and M.W. Clark. 1993. Phosphorus inputs and eutrophication in the Florida Reef Tract. Global aspects of coral reefs: Case histories. University of Miami Rosensteil School of Marine and Atmospheric Science.

Lesser, M. P., W. R. Stochaj, D. W. Tapley and J. M. Shick. 1990. Bleaching in coral reef anthozoans: Effects of irradiance, ultraviolet radiation, and temperature on the activities of protective enzymes against active oxygen. *Coral Reefs* 8: 225-232.

Lessios, H.A. 1988. Mass mortality of *Diadema antillarum* in the Caribbean: What have we learned? *Annual Review of Ecological Systematics*. 19:371-393.

Livingston, R.J. 1987. Field sampling in estuaries: The relationship of scale to variability. *Estuaries* 10: 194-207.

Lowry, K 1985. Assessing the implementation of federal coastal policy. *Journal of the American Planning Association*. Summer 1985: 288-298.

Loya, Y. 1978. Plotless and Transect Methods. *In* Stoddart, D.R. and R.E. Johannes, (eds.) *Coral reef research methods*. UNESCO 5:197-218. Paris.

Loya, Y. and B. Rinkevich. 1980. Effects of oil pollution on coral reef communities. *Marine Ecology Progress Series*, 3: 167-180.

Manton, S.M. and T.A. Stephenson. 1935. Ecological Surveys of coral reefs. *Scientific Report of the Great Barrier Reef Expedition 1928-29*. 3(10):273-312.

Maragos, J.E. 1972. A study of the ecology of Hawaiian reef corals. PhD. dissertation, University of Hawaii, Honolulu.

Maragos, J.E. 1993. Impact of coastal Construction on Coral Reefs in the U.S.-Affiliated Pacific Islands. *Coastal Management*, 21: 235-269.

Maragos, J.E., C. Evans, and P. Holthus. 1985. Reef corals in Kaneohe bay six years before and after termination of sewage discharges. Proceedings of the Fifth International Coral Reef Congress, Tahiti, (4): 189-194.

Miles, E.L. 1989. Concepts, approaches and applications in sea use planning and management. *Ocean Development and International Law*, 20:213-238.

Muller-Parker, G. and C.F. D'Elia. 1997. Interactions between corals and their symbiotic algae. *In* Life and Death of Coral Reefs, C. Birkeland (ed.). Chapman and Hall: NY, NY. pp. 96-113

Muna, M. 1999. Information Specialist, Coastal Resources Management Office, Commonwealth of the Northern Mariana Islands. Personal communication.

National Research Council, 1990. Managing Troubled Waters: The Role of Marine Environmental Monitoring. Committee on a Systems Assessment of Marine Environmental Monitoring, Marine Board, Commission on Engineering and Technical Systems,. Washington, D.C. National Academy Press

Nash, J.M. 1996. Wrecking the Reefs. *Time* v148 n 16 p 60(3).

Nichols, F. H. 1985. Abundance fluctuations among benthic invertebrates in two Pacific estuaries. *Estuaries* 8:136-144.

Office of Coastal Zone Management, NOAA and Coastal Resources Management Division, CNMI. 1980. *Commonwealth of the Northern Mariana Islands Coastal Resources Management Program and Final Environmental Impact Statement.* Washington DC: Office of Coastal Zone Management.

Olsen. S.B. 1993. Will Integrated Coastal Management Programs be Sustainable; the Constituency Problem. *Ocean and Coastal Management* 21: 201-225.

Paine, R.T. and S.A. Levin, 1981. Intertidal landscapes: Disturbance and the dynamics of pattern. *Ecological Monographs* 51:145-178.

Pastorak, R.A. and G.R. Bilyard. 1985. Effects of sewage pollution on coral reef communities. *Marine Ecology Progress Series* 21: 175-189.

Paulay, G. 1997. personal communication. University of Guam Marine Laboratory.

Pennisi, E. 1997. Brighter Prospects for the World's Coral Reefs. *Science* July 1997 v275 n5325 p491.

Putt, A.D. and J.F. Springer. 1989. Policy research: concepts, methods, and applications. Englewood Cliffs, N.J. : Prentice Hall.

Randall, J.E. 1963. An analysis of the fish populations of artificial and natural reefs in the Virgin Islands. *Caribbean Journal of Science*, 3: 31-47.

Randall, J.E. 1995. Zoogeographic analysis of the inshore Hawaiian fish fauna. *In* J.E. Maragos, M.N.A. Peterson, L.G. Eldredge, J.E. Bardach, and H.F. Takeuchi (eds.), *Marine and coastal biodiversity in the tropical island Pacific region*, vol 1, Species systematics and information management priorities, pages 193-203. East-West Center, University of Hawaii, Honolulu.

Richmond, R. H. 1993. Coral Reefs: Present Problems and Future Concerns Resulting from Anthropogenic Disturbance. *American Zoologist*, 33:524-536.

Richmond, unpublished

Rinkevich, B. 1989. The contribution of photosynthetic products to coral reproduction. *Marine Biology* 101: 259-263.

Rogers, C.S. 1985. Degradation of Caribbean and western Atlantic coral reefs an decline of associated fisheries. Proceedings of the Fifth International Coral Reef Congress, 6:491-496.

Rogers, C.S. 1990. Responses of coral reefs and reef organisms to sedimentation. *Marine Ecology Progress Series*, 62: 185-202.

Rogers, C.S. 1997. Implementation Plan, Virgin Islands/Florida Inventory and Monitoring Program. Virgin Islands National Park, St. John, USVI.

Rogers, C.S., Garrison, G., Crober, R., Hillis, Z.M., and M.A. Franke. 1994. Coral Reef Monitoring Manual for the Caribbean and Western Atlantic. Virgin Islands National Park, St. John, USVI.

Rosen, B.R. 1982. Darwin, coral reefs, and global geology. *BioScience*, 32:519-525.

Sabatier, P.A and D.A. Mazmanian. 1983. *Can Regulation Work? The Implementation of the 1972 California Coastal Initiative.* Plenium Press, New York; London.

Salvat, B. 1992. Coral reefs-a challenging ecosystem for human societies. *Global Environmental Change* 2: 12-18.

Sebens, K. 1994. Biodiversity of Coral Reefs: What are We Losing and Why? *American Zoologist*, 34:115-133

Smith, S.V. 1978. Coral reef area and the contribution of reefs to processes and resources in the world's oceans. *Nature* 273: 225-226.

Sobel, J. 1993. Conserving biological diversity through marine protected areas. A global challenge. *Oceanus*, 36(3):19-26.

Sorokin, 1993. *Coral Reef Ecology*. Berlin; New York: Springer-Verlag.

Stewart, W. 1997. The US Commonwealth of the Northern Mariana Islands, Saipan: A-Z. Saipan Datacom, Inc [online]. Available http://www.saipan.com/cnmiinfo/.

Sudekum, A.E., J.D. Parrish, R.L. Radtke, and S. Ralston. 1991. Life history and ecology of large jacks in undisturbed, shallow, oceanic communities. *Fisheries Bulletin* (U.S.) 89: 493-513.

Viles, H. and T. Spencer. (eds.) 1995. Coastal Problems: geomorphology, ecology and society at the coast.

Walbran, P.D., R.A. Henderson, A.J.T. Jull, and M.J. Head. 1989. Evidence from sediments of long-term *Acanthaster planci* predation on corals of the Great Barrier Reef. *Science* 245: 847-850.

Walker, N.D., H.H. Roberts, L.J. Rouse, and O.K. Huh. 1982. Thermal history of reef-associated environments during record cold-air outbreak event. *Coral Reefs* 11: 83-88.

Wilkinson, C. R. 1993. Coral reefs are facing widespread extinctions: Can we prevent these through sustainable management practices? Proceedings of the 7th International Coral Reef Symposium, Guam., 1993.

Wilkinson, C.R. and R.W. Buddemeier. 1994. Global climate change and coral reefs: Implications for people and reefs. Report of the UNEP-IOC-ASPEI-IUCN Global Task Team on the implications of climate change on coral reefs. Marine Conservation Development Report, IUCN, Gland, Switzerland. 134 pp.

Williams, D.M. and A.I. Hatcher. 1983. Structure of fish communities on outer slopes of inshore, midshelf, and outer shelf reefs of the Great Barrier Reef. Marine Ecology Progress Series. 10:239-250.

SUPPLEMENTAL REFERENCES

The following list includes sources that, although not cited, were reviewed and are considered to have contributed to the general knowledge of the author.

Coastal Resources Management Office, Commonwealth of the Northern Mariana Islands (CNMI). 1992. *Section 309 Coastal Zone Enhancement Grants: Final Assessment and Strategy*. Unpublished grant proposal submitted to the US Office of Coastal Resource Management, National Oceanic and Atmospheric Administration. Saipan, CNMI.

Crosby, M.P., G.R. Gibson, and K. W. Potts (eds). 1996. *A Coral Reef Symposium on Practical, Reliable, Low Cost Monitoring Methods for Assessing the Biota and Habitat Conditions of Coral Reefs*, January 26-27, 1995. Office of Ocean and Coastal Resource Management, National Oceanic and Atmospheric Administration, Silver Spring, MD.

Culliton, T. 1998. Implementation Plan. *South Florida Ecosystem Monitoring Integration Project*. SEA Division, ORCA, National Ocean Service, National Oceanic and Atmospheric Administration, Silver Spring, MD.

Gilman, E. 1997. Community Based and multiple purpose protected areas: a model to select and manage protected areas with lessons from the Pacific Islands. *Coastal Management*, 25:59-91

Grigg, R. W. and S. J. Dollar. 1990. Natural and anthropogenic disturbance on coral reefs. *In Z. Dubinsky (ed.) , Coral Reefs*, 439-452. Elvesier Science Publishers B. V. Amsterdam.

Kenchington, R.A. and B. Hudson. 1988. *Coral Reef Management Handbook.* UNESCO Regional Office for Science and Technology for Southeast Asia, 321 pages.

Kylstra, P.L. 1997. The Commonwealth of the Northern Mariana Islands Long Term Marine Monitoring Program: current status and recommendations. Project Report for the University of Oregon Micronesia and South Pacific Program.

Ohlhorst, S.L., Liddell, W.D., Taylor, R.J., Taylor, J.M. 1988. Evaluation of reef census techniques. Proceedings of the 6^{th} International Coral Reef Symposium 2: 319-324.