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Priorities and strategies for addressing natural and anthropogenic threats to coral reefs in Pacific Island Nations

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Abstract

Marine habitats and resources have been assumed to be almost unlimited, and that if one habitat became degraded or a particular fisheries resource depleted, there always would be another to replace it. The importance of coral reef ecosystems, in particular, may be seen in their numerous ecological, aesthetic, economic and cultural functions. Pacific islanders recognize that healthy reefs are essential for creation, support, protection and repair of their islands, and serve as a living pantry for the subsistence harvest and consumption of many reef organisms. The ability of coral reef ecosystems to exist in balanced harmony with other naturally occurring competing/limiting physico-chemical and biological agents has been severely challenged in the last several decades by the dramatically increased negative and synergistic impacts from poorly managed anthropogenic activities. In addressing these threats, a paradigm shift may be occurring in the evolution of the role of scientists in society from simply observers of the natural world with tenuous linkages to resource managers and the public, to partners in modern society's quest for answers to pressing questions related to sustainable use and conservation of coral reef resources. Management principles are beginning to include human motivation and responses as part of coral ecosystems being studied and managed. Managers of coral reef resources face the challenge of balancing conservation and development objectives in the context of the inherent uncertainty of natural systems and the political and social pressures of human systems. Working together, scientists, managers and policymakers can develop priorities and strategies for societal and economic decisions that are strongly coupled with an increasingly comprehensive understanding of the environment. This in turn will lead to *both* socio-economic health and coral ecosystem health. Employing this new paradigm for interactions between scientists, managers and policymakers, participants of

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the Pacific Regional ICRI Symposium in Noumea, New Caledonia developed three principal sets of recommendations for addressing natural and anthropogenic threats to coral reefs in Pacific Island Nations: (1) develop and implement a new overarching Participatory Island Ecosystem Management System (PIEMS) for each of the Pacific Island Nations; (2) improve existing, as well as design and implement new, capacity-building programs; and (3) improve scientific understanding of coral reef ecosystems with effective translation and transfer of information. Details for each set of recommendations are provided in this paper. Published by Elsevier Science Ltd.

1. Introduction

The importance f coral reef ecosystems may be seen in their numerous ecological, aesthetic, economic and cultural functions [1]. Atoll and barrier reef islanders recognize that healthy reefs are essential for the creation, support, and repair of the coral islands upon which they live. Coral reefs also protect coastlines from shoreline erosion, and serve as a living pantry for the subsistence harvest and consumption of many reef organisms. The cycle of reef accretion and erosion maintains beaches, and provides habitat for seagrasses and mangroves. Coral reefs are important recreational resources for most of the world's people having the privilege of living near them. In the modern era coral reefs passes and channels provide safe navigation channels for boats, and harbors are often sighted on reefs because they provide natural protection from heavy wave action. Coral reefs are fast becoming the main attraction for visitors to many tropical island and coastal destinations. Coral reefs are also the favorite sites of many governments and developers for construction materials, and reef rock is mined in many countries to provide armor stone and building materials. Few aspects of these activities, especially modern uses, are beneficial to reefs. Scientists, managers and other stakeholders are now fast realizing that coral reefs are fragile and are threatened in many areas in the world from chronic anthropogenic reef disturbance.

The International Coral Reef Initiative (ICRI) is a partnership among nations and organizations seeking to implement Chapter 17, Agenda 21 of the Convention on Biological Diversity and other international Conventions and agreements to promote the sustainable use and conservation of coral reef resources for future generations. ICRI is a voluntary partnership mechanism that brings together representatives of over 80 developing countries with coral reefs to sit in equal partnership with major donor countries and development banks, international environmental and development agencies, scientific associations, the private sector, and non-governmental organizations (NGOs) to decide on the best strategies to conserve the world's coral reef resources.

The May 2000 Pacific Regional ICRI Symposium was held in Noumea, New Caledonia for the purpose of (1) summarizing the status of Pacific coral reefs, and (2) identifying the most appropriate tools and methods for improving the management, long-term sustainable use and conservation of coral reef resources in the Pacific

Islands. This manuscript summarizes the discussions and recommendations from one of the three principal workshop sessions of this symposium entitled: *Defining priorities and strategies for addressing natural and anthropogenic threats to coral reefs in Pacific Island Nations*.

1.1. Background

Not only is the coral reef structure itself composed of and built by a diversity of organisms, but the reef structure serves as the basis for one of the highest diversity ecosystems in the world [1, 2]. Coral reef ecosystems generally have high species diversity, although many associated species tend to exhibit low endemism and broad distributions [3]. There are over 700 coral species alone in the Indo-Pacific [4,5]. When speaking of biological diversity, it is indeed appropriate to refer to coral reef ecosystems as the rain forests of the marine realm. Reef fishes, sea urchins, coralline algae and many additional species of plants and animals contribute to healthy reef ecosystems and play a significant role in helping maintain the resilience, stability, and accelerated coral reef recovery following natural and anthropogenic disturbances. The Pacific region is so large that many islands and reefs have never been visited by reef scientists. However, some tropical Pacific coral reef ecosystems are documented to contain over 1300 species of reef fishes [6]. Most coral reef studies have taken place near the approximately 20 urban centers in the region [7,8].

Not only are coral reef ecosystems an important resource in terms of their biological diversity and productivity, they are also the foundations of coastal protection, tourism, subsistence economies, and in many areas serve as focal points for cultural and community heritage. For example, in American Samoa, coral reefs play a central role in all aspects of traditional culture, from land tenure to diet, and account for more than 50% of all fish caught locally. For Guam and the Northern Mariana Islands, which lie in the track of "Typhoon Alley", reefs provide protection from extraordinary ocean action that would otherwise devastate whole communities, and result in the expenditure of tens of billions of dollars in government disaster assistance.

The incredible diversity of organisms found associated with coral reefs also holds great promise for improving the quality of life for the human species. In the ever-evolving field of biotechnology, chemical extracts derived from coral reef associated sponges and tunicates have been indicated to have potent anti-viral activity [9]. In addition, several sponge and nudibranch species found in coral reef ecosystems are capable of producing terpenes, a broad class of aromatic compounds used in solvents and perfumes and known to deter feeding by fish. Extracts derived from these same species have also demonstrated powerful insecticidal activity against grasshoppers and the tobacco hornworm [10]. *Porites* and other species of New Caledonian reef coral have been used as bone grafts for people requiring maxillo-facial and cranial surgery [11], and pieces of Gorgonian corals have also been used successfully [12].

Pacific Island indigenous communities are particularly vulnerable to changes in coral reef biodiversity because their cultural lifeways are tied directly to the quality of, and access to, marine resources. Marine resources are used for food, medicine,

cultural and religious customs. The sharing of these resources among family and neighbors during gatherings (e.g., birthdays, weddings, funerals) reinforces important cultural and social relationships. Spiritual relationships to ancestors and gods are renewed through experiencing natural phenomena at marine and coastal areas or through the offering of marine resources in religious ceremonies. Any change in the quality, amount, integrity, accessibility, boundaries, buffers, or ownership of a marine or coastal resource can potentially have an impact on the indigenous population of the coastal region. Hence, cultural values and historical indigenous uses should be an integral consideration in developing coral reef management strategies in sites with significant indigenous populations.

1.2. Threats

The transboundary influences both to and from coral reef ecosystems are not limited by political boundaries. Just as ocean currents are potential carriers of pollutants from one country to another, larval and adult life stages of coral reef organisms may travel from reef to reef across national borders. Hence, large-scale regional and global perspectives are important for all nations to take when addressing threats to coral reefs. A comprehensive overview of threats to Pacific Island coral reefs may be found in [1], and Wilkinson [13,14].

The most serious documented disturbances to Pacific coral reefs are concentrated in the urban centers: (1) soil erosion and sedimentation off volcanic islands, (2) coastal construction, (3) sewage and industrial discharges, (4) overfishing of subsistence resources and excessive commercial exploitation of other fisheries, (5) increased flooding and discharge of fertilizers and toxic chemicals and (6) vast destructive fishing techniques, especially explosives. Military training and testing activities have also been conducted in the Line Islands, Marshall Islands, and French Polynesia (for nuclear weapons testing), with additional islands in Hawaii and elsewhere used for bombing. Tourism activities are increasing rapidly in many island groups resulting in overuse, trampling, anchor damage, and souvenir collections. On remote islands, primarily Asian fishing boats are illegally harvesting rare and depleted species, especially giant clams, groupers, sharks, and sea turtles. Destructive fishing practices such as the use of dynamite, poisons, and illegal gear is often conducted beyond the watchful eye of concerned governments and residents. Remote atolls and submerged shallow reefs attract more than their share of shipwrecks, oil spills, and groundings; many are tiny and nearly invisible beyond a few kilometers, and navigation charts in remote areas are not as accurate.

Overall the status of most reefs in the Pacific region cannot be ascertained due to a paucity of information. It is likely that many coral reefs, especially on remote or uninhabited islands and atolls are still in an undisturbed condition. Natural disturbances to Pacific reefs include typhoons and crown-of-thorns starfish outbreaks. El Nino southern oscillations may often result in warm water temperatures and coral bleaching events. Volcanic eruptions, earthquakes, subsidence and emergence are other less frequent natural disturbances. Global

climate change may lead to further coastal degradation and damage to coral reefs from flooding, sea level rise, and increased incidence and intensity of storms.

2. Methods

The evolution of the classic 'scientific method' over the past millennium led to a dominant, and appropriate, culture within the scientific community that sought to be objective and avoid any 'outside' influence that may bias their experimental design and results [15]. While it is imperative that scientific study should seek to always be objective and unbiased, a perspective has developed within the scientific community that management-oriented science and environmental policy are influenced by public pressures and politics more than by scientific considerations [16,17]. This in turn led to a very negative stigma being attached to science endeavors labeled as being 'applied' (with perhaps a notable exception of the medical research community), and a dogma within the research community (until fairly recently) that 'real researchers' do not do monitoring, assessment work, or management-oriented science.

The classic approach of the scientific method lacks mechanisms for data and information exchange between managers, policy-makers, scientists, NGOs and other interest groups. Contrasting perspectives between scientists, managers and policy makers in how they view and deal with similar parameters is a likely reason for this barrier to meaningful information exchange being difficult to overcome [15]. This classic approach to the scientific method, for the most part, is no longer viable in most research communities (unless a researcher is independently wealthy or has a very generous and supportive sponsor). Over the past several decades the realities of the financial costs of conducting science have created somewhat of a partnership between funding agencies and the research community. However, even under this more recent paradigm for the role of science in our society, results of science studies are often not transferred to managers and policy makers in a user-friendly format. Managers are rarely included in designing scientific studies to ensure products will be of use in their decision making processes, and specialists capable of translating technical information to managers and expressing management and policy needs/gaps in a scientific forum are lacking.

Development of effective coral reef management strategies must include facilitated meetings and discussions that include key representatives of the science and management communities along with other stakeholders (i.e., environmental NGOs, local community groups commercial and recreational interests, and indigenous peoples). First and foremost, scientists and managers must recognize that the systems they are studying and managing include people and occasionally unique cultures. Cultural parameters are especially important to consider in areas having significant populations of indigenous peoples with traditional connections to the marine environment. The Pacific Regional ICRI focused workshop reported on here, sought to make significant steps in the implementation of a new paradigm for improved interaction between scientists, managers and the broader stakeholder communities, which is essential to overcome the all too common situation of political

goals and misinformed public pressure driving priorities of coral reef science support and resource management policy.

3. Results

The following recommendations were developed by the workshop participants as an integrated set of components. Much like individual variables and catalysts in a chemical reaction, these recommendations are mutually dependent on each other to achieve the desired end product. In this case the end product is a comprehensive and integrated strategy for addressing threats to Pacific Island coral reef ecosystems that employs a new paradigm for interactions among scientist, managers and the public.

3.1. Develop and implement a new overarching Participatory Island Ecosystem Management System (PIEMS) for each of the Pacific Island Nations

- PIEMS will be manifested (ideally with legislative backing of the island government) through an advisory group composed of pertinent governmental agencies and institutions, with representatives from non-governmental entities, private sectors, and user-groups.
- PIEMS will coordinate and integrate all of the current and future island resource uses, management and protection plans, policies and regulations that impact coral reef ecosystems.
- The PIEMS Advisory Group will develop an overarching plan that will be based on the participatory process, follow adaptive management principles, and includes entire watersheds from the top of the mountains to the outer reaches of the coral reefs, taking cognizance of existing traditional boundaries.
- The overarching PIEMS plan and Advisory Group will have the authority to direct individual agencies and institutions to modify or revise regulations and policies impacting coral reef ecosystems. However, individual governmental agencies and institutions will maintain their current lead role(s) for managing, regulating, studying and protecting resources.
- Individual island governments should seek to develop a priori strategies for recovery from catastrophic events such as coral bleaching and ship grounding, and implement a pan-regional network of coral reef marine and coastal protected areas with comprehensive multi-use zonation management strategies.
- Re-evaluation of the PIEMS plan will occur every five years and be modified as appropriate based on new information supplied by improved understanding of coral reef ecosystems.

3.2. Improve existing, as well as design and implement new, capacity-building programs

- Implement a preliminary assessment phase involving the local, national and regional communities, which addresses: capacity and skills that are already in use;

gaps in training; most appropriate and effective methodologies for use in the particular community; and highest priority needs from the point of view of the local user-groups.

- Incorporate information from the preliminary assessment into the planning and content of the training program. Provision should also be made for follow-up activities that measure performance success and provide periodic tutorial reviews to the newly trained personnel.
- Develop instructional and support materials, including visuals, which are provided in local languages.
- Implement training in zoning methodologies that includes: delineation of local village or municipal waters; rapid ecological assessment; and coordination of policies at the provincial/national level, taking cognizance of existing traditional boundaries.
- Build capacity for science and management through:

(i) Education and outreach for locals and visitors; technical training for managers; awareness programs for policymakers, legislators and judicial sector.
(ii) Outside assistance in the form of: infrastructure, equipment, and financing.
(iii) Availability of attachments, assistantships and fellowships for qualified students to obtain advanced technical and scientific skills for leading in-country coral reef monitoring and assessment programs.

- Create regional rapid assessment and response teams to deal with the effects of catastrophic events. Such teams should represent both local and regional expertise in the fields of ecological assessment, resource management, and enforcement issues. These teams need to coordinate their activities through the affected local communities, and appropriate territorial and national bodies.

3.3. Improve scientific understanding of coral reef ecosystems with effective translation and transfer of information

- By the year 2010, all Pacific Island countries should develop geo-spatially referenced maps of their coral reef ecosystems to a depth of 20 m and a horizontal resolution of 20 m.
- Each island nation should build onto their coral reef maps additional geo-spatially referenced data layers that include ecological, socio-economic, and other thematic information pertaining to coral reefs, including long-term monitoring data and information on human use of resources.
- The resulting GIS databases should meet standard data management guidelines yet be user friendly to managers, policy makers and the public at large.
- Individual island nations' coral reef GIS databases should be integrated through a virtual data management center and available to each country as an additional management tool in at least a summary format. An entity such as the Global Coral Reef Monitoring Network (GCRMN) could serve this central role and help set regional standards for data management.

- Efforts should be implemented to develop an improved scientific understanding of what constitutes representative "healthy" coral reef ecosystems and natural fluctuations in those ecosystems.
- Efforts should be implemented to better understand the ecological and socio-economic impacts of coral reef management strategies, and illustrate how sociological, cultural and economic factors (i.e., the human dimension) can be integrated into coral reef science analyses.
- Management agencies and other environmental funding institutions must make a commitment to the long-term support of specifically management-oriented research and monitoring programs, and the translation and transfer of the information in formats that are understood by the different user groups.
- Academic institutions must encourage and recognize researchers for successfully conducting management-oriented research and monitoring studies.
- The importance of translation and transfer of information among and between scientist, managers and the public is critical to the implementation of all of the above recommendations. Hence, there is a need for a new generation of professionals to be trained and employed by each country as "translators" in order to bridge the gap in the cultural "personalities" of these different communities.

4. Discussion

4.1. Develop and implement a new overarching Participatory Island Ecosystem Management System (PIEMS) for each of the Pacific Island Nations

The paradigm for managing coral reef resources and ecosystem health must shift from a fragmented to an integrated approach, from a site-specific to an ecosystem-wide context, and from a reactive to pro-active mode [15]. It is realized that ecosystem health problems are complex and that solutions will require a comprehensive, multi-disciplinary approach. A stronger public education program will help residents understand the impact of land use change on associated marine habitats. Ultimately, however, humans decide how resources will be used, attribute value or importance to various parts of the environment, and determine what will be conserved or destroyed. Key to controlling the loss of long-term sustainability of healthy marine and coastal ecosystems is understanding how these decisions are made in the realms of social, economic and political systems. Therefore we must also identify and understand the economic and social driving forces behind the loss of biodiversity and the destruction of these ecosystems. In addition, there is a need to develop incentives to maintain and enhance ecological goods and services.

One of the most difficult socio-economic issues in marine management is restricting user group access to marine resources. Attempts to limit access to these resources, especially fishing rights, has the potential to disrupt the socio-economic stability of coastal communities and result in conflict among user groups with competing interests over the same limited resources. Local public acceptance is often

a significant factor in the extent of the access management restrictions that are developed. Several tools are available (see [18]) to evaluate local perceptions and attitudes including: stakeholder focus group discussions; interviews with key stakeholders; random sample phone survey of residents in the affected geographic area; and surveys of user groups.

The demographic and ethnic composition of an area will likely influence the degree of acceptance or opposition to new or revised coral reef management strategies. Before implementing a management strategy, a manager should evaluate both the socio-economic and ecological data of the area [18]. Although the scientific evidence supporting more restrictive access management strategies may be strong, access restrictions will not become a reality without significant stakeholder support. Experience from other parts of the world suggests that fishermen's attitudes towards "no take" fishery reserves in particular, may change over time [19 in 20,21]. Community opposition to management strategies that restrict user access to coral reef resources can be strong. Unsuccessful management strategies can often be attributed to an attempt to police the local community instead of getting the community involved in supporting the strategy (this can be especially the case when viewed as being imposed on locals by "outsiders").

Community residents can be a valuable source of information. Local residents may have knowledge of traditional resource use, historical levels of resource consumption, and can provide insight into potential management or enforcement hurdles. The investment in community involvement at the outset of devising a coral reef management strategy can avoid unnecessary disputes and delays as the process proceeds. During the planning of new access strategies, the community should have the opportunity to express its views about any proposed changes to the use of coral reef resources through written comment and at public meetings. However, simple public meetings are usually not enough to generate support from all user groups. Local communities should be given real tangible responsibility throughout the process so that they develop a sense of ownership for coral reefs, and are motivated to observe the regulations that they helped to establish. Local and community governing bodies can establish 'ad hoc' advisory groups to address particular issues of interest to local citizens. The citizen advisory groups provide an opportunity to involve local citizens in the decision-making process. Members may include community leaders, people whose livelihoods are associated with coral reefs, businesses linked with coral reef resources, members of environmental groups, scientists, and representatives of local government.

The new PIEMS process being discussed here requires a collaborative effort involving representatives from all of the stakeholder groups in the development of coral reef management strategies and in the actual management of the coral reef. NGOs generally have strong relationships with local communities in promoting environmental awareness and should be consulted. Volunteer groups generally come from all the different sectors: local, academic, commercial, recreational, and indigenous. They traditionally provide support and continuity for public activities involving coral reefs. Volunteers can be an integral piece of the success of the program and should have a voice in decision-making. Local community support for

management plans will be largely dependent upon ongoing consultation to determine the likelihood of tangible economic, social, cultural and conservation benefits from the establishment of such plans. "Access management strategies" are generally thought to imply limited or restricted entry for user groups. There is a need to lay out different approaches to managing coral reefs, and then attempt to reach a happy medium involving human stakeholders and natural resource management. The tourism sector can aid in protecting environmental quality by demanding adequate pollution prevention measures as well as by educating tourists about the environmentally detrimental effects of certain types of recreational activities.

4.1.1. American Samoa—a case study for the implementation of PIEMS

Indigenous peoples have maintained sustainable yields while harvesting coral reef resources for generations. Traditional indigenous management practices ought to be respected and considered when establishing management strategies for coral reefs. A 'case study' for the implementation of the PIEMS that integrates traditional management practices is the American Samoa Coral Reef Initiative. In 1995, America Samoa established a Coral Reef Advisory Group (CRAG) that is composed of the key institutions dealing with coral reef science, management and education/outreach (Table 1). The mission of the CRAG is to "preserve and protect the biodiversity, health, heritage, economic, social & traditional values of coral reef ecosystems and marine environment in American Samoa".

The CRAG was established by direction of the Governor and reports directly to him. It is responsible for formulating coral reef management plans and strategies for the Territory, and coordinates all coral reef related activities. The CRAG essentially directs all actions related to funding and oversight of coral reef projects in American Samoa, including the establishment of coral reef marine protected areas. With the full support of the Governor, the CRAG has the authority to direct individual agencies to modify or re-direct activities impacting coral reefs, and has had a number significant accomplishments (Table 2).

In developing a Territory-wide comprehensive strategic plan to develop coral reef marine protected areas in American Samoa, the CRAG is utilizing both traditional community-based and more western agency-driven approaches. Community and agency roles and funding allocations were identified with the recognition that

Table 1
Member institutions of the American Samoa Coral Reef Advisory Group

- American Samoa Department of Commerce Coastal Management Program
- American Samoa Department of Commerce Fagatele Bay National Marine Sanctuary
- National Park of American Samoa
- Department of Marine and Wildlife Resources
- American Samoa Community College
- American Samoa Environmental Protection Agency

Table 2
Initial accomplishments of the American Samoa Coral Reef Advisory Group

- Developed population report and action plan for American Samoa Government to address impacts of population growth
- Removed 9 Longliner fishing vessels that were abandoned and grounded on coral reefs in 1991
- Banned SCUBA fishing and live rock extraction
- Implemented 5-year coral reef management plan
- Initiated coral reef monitoring program
- Implemented 5-year community fishery management plan
- Implemented education/outreach program

an integrated land–sea approach is essential. American Samoa is utilizing the PIEMS approach to meet the Territory's socio-economic needs in protecting sites representative of biological diversity at various levels of ecological organization, while also incorporating traditional approaches to managing marine resources.

4.2. Improve existing, as well as design and implement new, capacity-building programs

Although a few developed countries have coral reef resources (the United States, France, Australia, and Japan, among others), the majority of these resources are in developing countries. Most of these countries are aware of their rich and rapidly deteriorating coral reef resources. A key component to promotion of healthy coral reef ecosystems is ensuring that economic development is managed in ways that maintain biodiversity and long-term productivity for sustained use of coral reef resources and ecosystems. Working in partnership at regional, national and local scales, Pacific Island institutions and agencies should integrate their operational management activities with an increased level of education and outreach (for better public understanding), monitoring and assessments (to provide better information for decision-makers), and pro-active research efforts (to enhance our predictive capabilities for changes in coral reef ecosystems).

One of the key components of CRAG in American Samoa is its ability to work as a coordinated team to develop a comprehensive approach to coral reef management for the Territory. At its inception in 1995, one of its first tasks was to develop a video to provide information and awareness on the importance of coral reefs to local island ecosystems. A number of public awareness campaigns and workshops have been completed to date, which compliment ongoing coral reef protection efforts. At each workshop or public awareness event, opportunities exist to have local community members (i.e. fishermen, coastal residents, etc.) participate and provide input to the development of management plans and outreach programs. Community involvement at the outset is the key to CRAG's success with such events in order to not only provide information, but also establish a "sense of ownership" in the final coral reef resource management plans that are implemented. Public Coral Reef awareness

programs in the villages of American Samoa have taken the form of local theatre group performances, and talks at schools and community events. Currently CRAG is formulating a program targeting population growth and it's impacts on coral reef ecosystems. A 2 min television public service announcement has been developed and is broadcast on local stations.

Many Pacific Island nations need to strengthen their scientific and managerial expertise to adequately assess, monitor and manage their resources. Particularly needed are training programs aimed at strengthening the working relationship between non-government and government institutions and agencies, and integrating components of research/monitoring and education/outreach programs. Target subjects should be coral reef mapping, database use/management, communications technology, coral reef ecology, volunteer monitoring and resource conservation principles and management strategies. A high priority for capacity building is developing synergy between classic science and technology (S&T) approaches and techniques, and more traditional community based knowledge and management approaches as a way to assist in economic development that promotes long-term sustainable use of Pacific coral reef resources. Emphasis should be focused on the smaller Pacific Islands Nations, Territories and Commonwealths.

Capacity-building, focusing particularly on the concept of integrated coastal zone management, is an important part of an effort to reverse the deterioration of coral reefs globally. The destruction of cultural and historical remnants in Pacific Islands generally leads to a decline in tourism and the loss of cultural heritage for future generations to experience. The establishment of multi-use zonation marine and coastal protected areas (MACPAs), as part of integrated coastal zone management programs, can prevent or mitigate the impact of commercialization and development of marine and coastal resources for indigenous communities, provided that traditional access and subsistence harvesting rights are recognized and allowed.

The application of traditional methods of conservation in the monitoring and management of marine resources can result in sustainable resource use even where subsistence harvesting is allowed in a protected area. Where there is continuing local use or custody over marine resources, the likelihood of establishing effective coral reef management strategies depends to a very large extent on voluntary acceptance of the management measures. With few exceptions, examples of effectively managed MACPAs give responsibility to local users in the management process [22,18]. The use of traditional skills in the management of coral reef MACPAs should be encouraged.

An International Expert Group on MACPAs [23,24] have agreed that MACPAs:

- have a critical role in the management for long-term conservation and sustainable use of marine and coastal biological diversity;
- function as focal points for development of governance for coastal and ocean systems; and
- provide for local community education and training in the importance of conserving marine and coastal biodiversity.

4.3. Improve scientific understanding of coral reef ecosystems with effective translation and transfer of information

To facilitate the incorporation of new and existing knowledge into coral reef management and policy decisions, a new paradigm for the interaction and role of integrated, multi-disciplinary science, management and education/outreach efforts must be developed [15,25,18]. Implementing this new paradigm requires that applied research and technical development become a priority within the research community. Scientists and managers must work together as a team to identify and understand the ecological, economic and social driving forces behind the loss of marine biodiversity and the destruction of marine and coastal ecosystems. In partnership with the broader stakeholder community (see previous Section 4.1), both groups need to develop incentives to maintain and enhance ecological goods and services [26,27]. Cultural or spiritual parameters are especially important to consider in areas having significant populations of indigenous peoples with traditional connections to the marine environment, such as in the Pacific Islands [28–32,18].

If one were to review the basics of classic scientific method in the context of MACPAs (see [15]), it is clear that the classic approach lacks mechanisms for data and information exchange between MACPA managers, policy-makers, scientists, NGOs and other interest groups. Contrasting perspectives between scientists, managers and policy makers in how they view and deal with similar parameters is a likely reason for this barrier to meaningful information exchange being difficult to overcome. However, even under the more recent paradigm for the role of science in our society, which has created somewhat of a partnership between funding agencies and the research community, results of science studies are often not transferred to managers and policy makers in a user-friendly format such as described by Gault [33] (for a more detailed discussion, also see [15]). Managers are rarely included in designing scientific studies to ensure products will be of use in their decision making processes, and specialists capable of translating technical information to managers and expressing management and policy needs/gaps in a scientific forum are lacking.

The CRAG seeks to address this gap by meeting regularly, twice a month to discuss progress on projects, update members on the National US Coral Reef Task Force and regional activities, and review new projects for fiscal year funding opportunities. The CRAG hired a "Coral Reef Coordinator" who is charged with administering CRAG activities (tasked with spearheading public awareness, formulation of AS' comments on National Coral Reef Task Force reports, advisory summaries to the Governor, coordinating workshops and meetings etc.). The principal role of this person is to keep the group informed, focused and aligned with its duties, and report to the Governor. Information and data exchange is being facilitated by this person, through the ongoing development of a comprehensive database on coral reef related research, monitoring, resource management, and education/outreach information and activities in American Samoa.

A scientific approach must be coupled with the development of improved coral reef management strategies in order to fully sustain these vital ecosystems. There is a need to make the full spectrum of data and information required to better

understand and conserve coral reef biodiversity and ecosystem processes available and accessible to scientists, decision makers, and the public. However, it is essential that user-friendly information and validated analytical models that can be used to explore the possible consequences of alternative management and policy decisions be available. Hence, in order to facilitate the incorporation of new and existing knowledge into management and policy decisions, there must be incentives for scientists to become more involved in the translation and transfer of technical information to managers and other stakeholders [18]. Partnerships at the national and local government levels should integrate operational management activities to increase monitoring, conduct assessments to provide better information for decision-makers, provide education and outreach to increase public understanding, and undertake a more pro-active effort in understanding and conserving coral reef biodiversity.

Successful implementation of this new paradigm is built on a foundation of improved communication and partnership, and cannot achieve its goals without integrating its activities with other key governmental players in the management of coral reef ecosystems. Coordination is also critical to information sharing and joint scientific research. The lack of routine and formalized communication between key stakeholders is one of the biggest barriers to efficient management of ecosystems. American Samoa has addressed this problem, in part, by requiring all the Directors of CRAG's membership participate in the locally held workshops (science base or plan oriented) and actively participate in regular meetings of CRAG. The Deputy Director of the Department of Commerce, Director of Marine and Wildlife Resources and Director of the Environmental Protection Agency are active members of CRAG who funnel necessary policy directives to the Governor for adoption and approval. The Governor's attendance at the National US Coral Reef Task Force meetings has spawned significant positive awareness locally as well as nationally for active participation in coral reef management issues. Fortunately, American Samoa currently has a pro-active Governor for the environment, who has advocated his position nationally, regionally and locally to alleviate policy hurdles that would otherwise inhibit the conservation and long-term sustainable use of coral reef resources.

Lack of inter-agency or inter-institutional cooperation in budget planning is yet another of the many budget-related barriers to comprehensive coral reef management. In addition, overall funding levels for environmental trend analyses is sparse, and overall, there are general difficulties associated with securing funds for, and managing, large-scale restoration and ecosystem management projects. Agencies should develop coordinated, long-term budget initiatives that focus on coral reef ecosystem management-oriented science. The CRAG again serves as an example for this essential variable in the PIEMS approach.

5. Conclusion

Evidence supports the consensus that island ecosystems are not only experiencing changes but are also being stressed and destroyed through increasing anthropogenic

perturbations. Economic demands and heightened island population growth have imposed unforeseen strains on their coral reef ecosystems including resource exploitation, loss of biodiversity, marine-based and coastal nonpoint source pollution.

Efforts to achieve holistic management must consider not only the fish and the coral reef resources but also the ecological, social, economic, and political aspects that involve all stakeholders. A key component of such a strategy would be promotion of healthy coral reef ecosystems by ensuring that economic development in the Pacific Islands is managed in ways that maintain biodiversity and long-term productivity for sustained use of these systems.

An equally important principle in the interaction of science and policy concerning coral reef ecosystem management and biodiversity conservation is the precautionary principle. By employing the precautionary principle, management of coral reefs goes from reactive to proactive, from responding to damage and threats to avoiding negative impacts. Given the growth of human populations and accompanied resource demand and the limited effectiveness of international efforts to conserve global biodiversity, the presumption that the health of marine ecosystems will continue to deteriorate seems accurate. In such an environment, MACPAs provide an opportunity to apply the precautionary principle in a physical setting and protect marine resource from the dangerous threats of over exploitation, habitat destruction, and pollution. By employing a framework for the application of "adaptive management," MACPAs can establish and maintain feedback loops between science and policy. Finally, multiple-use MACPAs address the differing sets of objectives of a myriad of stakeholders, thereby providing a framework for resolving conflict between various users of marine and coastal ecosystem services.

The ability of coral reef ecosystems to exist in balanced harmony with other naturally occurring competing/limiting physico-chemical and biological agents has been severely challenged in the last several decades by the dramatically increased negative and synergistic impacts from poorly managed anthropogenic activities [1]. Globally, scientists are now working together and with other groups to promote assessment, monitoring, other research, protection, and restoration of coral reefs. Establishment of coral reef management initiatives at the local community, national and regional levels are essential for long-term sustainable use and conservation of these critically important habitats. The focus of these initiatives should be on assisting culturally, economically and politically diverse peoples around the world in their development of integrated coastal zone management with emphasis on local community involvement and leadership. An essential requirement for any Pacific Island coral reef initiative will be for coral reef managers, researchers, and educators to work together as equal partners in furthering the conservation and stewardship of coral reefs. Equally important will be the need for capacity building to improve management, monitoring, research, and education regarding coral reefs among the island governments and academic/research institutions of the tropical Pacific.

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