

D. PREVENTING AND RESPONDING TO CORAL DISEASE IN THE PACIFIC REGION: MANAGEMENT PERSPECTIVES

Background

Coral reefs are biologically diverse ecosystems that provide numerous economic and social benefits including sources of revenue and jobs as well as a variety of ecosystem services such as shoreline protection, recreation and ecotourism. In addition, they provide biomedical, minerals, chemicals, food, curios and ornamentals, and building materials to over 100 developing and developed countries. Impacts associated with landscape changes that introduce sediments and pollutants (e.g., agriculture, industry, coastal development and physical alteration of habitats) and over-exploitation of coral reef resources are among the most pervasive localized stressors. Furthermore, localized impacts are being compounded by threats from global climate change such as increased sea water temperatures, elevated UV radiation and changes in ocean acidity. While we already know these ecosystems are easily damaged, we are only beginning to understand what can be done to prevent continued degradation. The complexity of these ecosystems, along with a growing list of human activities and demands placed on them by multiple user groups, is an enormous challenge for managers, who must find a balance between protection and continued use.

One of the most widely recognized management systems for long term sustainable use of coastal resources involves integrated coastal zone management (ICZM). To achieve ICZM, concurrent steps are undertaken that address anthropogenic threats to coastal watersheds, including implementation of coastal development policies, measures to reduce industrial discharges, environmentally friendly agricultural practices, and sewage treatment measures. To be successful, these measures must be applied in concert with other actions to ensure sustainable commercial and recreational fishing and tourism. For example, typical efforts to mitigate land-based sources of pollution have focused on tertiary treatment of wastes, regulated use of fertilizers and pesticides, controlling nutrient loss and sediment run-off by replanting native coastal vegetation, and environmentally friendly development, dredging and beach renourishment practices. An excellent example of successful coral reef ecosystem management is provided by the Great Barrier Reef Marine Park, where multi-use zoning limits or prohibits specific activities. Fishing, curio collecting and tourism are permitted in certain areas by designating different intensities of use through the establishment of habitat protection zones (e.g., MPAs), National Parks, preservation areas, and general use zones. Together, these steps can help address localized human impacts to reefs; however, successful implementation requires strong government, industry and community support and participation, a strong lead agency, and sufficient capacity in planning, monitoring, education and enforcement.

General efforts to mitigate anthropogenic stressors are likely to reduce pressures enabling coral reef ecosystems to better tolerate natural stresses and more resilient to climate change and bleaching. However, biodiversity at genetic, species and ecosystem levels differs among locations and localized impacts to coral reefs are often site specific and may influence a coral reef's ability to resist disease and/or recover from impacts. These factors require consideration when implementing management strategies. Furthermore, the state of knowledge regarding diseases and disease impacts is highly variable between Pacific and Atlantic regions, and between local jurisdictions. It is likely that additional targeted management measures need to be derived specifically for each jurisdiction, territory, state or country to identify, understand, and respond appropriately to disease events on their reefs. These measures could be identified through an assessment of multiple factors such as the types of reefs and their distribution, biodiversity, social

and economic uses of reef resources, existing human and environmental stressors and current state of knowledge of these ecosystems. Management needs for coral diseases should initially focus on 1) building infrastructure and capacity to proactively respond to disease outbreaks; 2) increasing public awareness about diseases and their potential impacts; and 3) collaboration between managers and scientists to fill critical gaps in our understanding of disease in the Pacific. In addition to key proactive management responsibilities, reactive measures geared towards addressing impacts and restoring degraded coral reef ecosystems are also a critical responsibility of the management community.

What do we need from the managers?

1. **Better defined response process**
2. **Monitor the response**
3. **Quarantine the reef or eliminate certain activities**
4. **Restrict or modify activities that may be problematic**
5. **Policy and regulation changes**
6. **Possible depopulation of the reef**
7. **Treatment**
8. **Prevention**
9. **Community outreach**

State of coral disease understanding and management in the Pacific

Coral diseases have been reported on 39 genera and 148 species from 63 countries. The vast majority of all observations to date (86%) are from the wider Caribbean, with only 14% of the records from the Red Sea and Indo-Pacific. Coral diseases (BBD and WBD) were first reported from the Indo-Pacific and Red Sea during the late 1970's and 1980's by a single researcher (Antonius 1977; Antonius 1982; Antonius 1985) working in three countries (Philippines, Egypt and Saudi Arabia). By 1994, diseases had only been reported from six countries, including several new conditions first observed on reefs in Australia. Indo-Pacific diseases appear to be exhibiting a rapid expansion in range and in the types of disease since 2000. For instance, recent surveys conducted in Australia (Willis et al. 2004), western Indian Ocean (Mc Clanahan et al. 2004), Philippines (Raymundo et al. 2005; Raymundo et al. 2003), Red Sea (Loya et al. 2004), Palau (Sussman et al. 2006), Hawaii (Aeby 2005; Aeby 2007) and American Samoa (Work and

Rameyer 2005) illustrate the widespread, global distribution of coral diseases. Through annual and semi-annual monitoring programs, researchers are also identifying coral diseases on a greater number of reefs and species, and at higher levels since the late 1990's, suggesting that diseases have become more prevalent in the Indo-Pacific over the last five years (Kaczmarzsky 2006; Raymundo et al. 2003; Willis et al. 2004). This includes reports from new regions that were previously presumed to be unaffected (South Africa and Solitary Islands, Australia), a higher percentage of reefs with disease and recent increases in disease incidence in certain locations (e.g., Great Barrier Reef in Australia), and an emergence of several new conditions.

Based on lessons learned from dealing with disease and the devastating effect disease has had in the Caribbean, coordinated and strategic preventative measures, with a focus on maintaining overall ecosystem health, need to be taken *now* in the Pacific Region. Managers need to be engaged with the scientific community 1) to better direct and assist with research efforts, 2) to identify possible options for responses to disease outbreaks, and 3) to identify realistic management strategies for Pacific coral reefs. While efforts to document diseases has certainly increased in the Indo-Pacific, the numbers of trained experts and the numbers of jurisdictions with routine coral disease monitoring programs remains very low. Furthermore, few research activities are directed towards an understanding of causative agents, sources of pathogens, linkages with environmental stressors, monitoring of the impacts of diseases on the physiology/biology of affected corals, or the role of disease in structuring coral reef communities. Some of these limitations may be overcome through educational programs targeted towards graduate students and researchers, and development of centers of excellence in Pacific jurisdictions with the necessary staff, infrastructure and training to process samples and identify and develop specific tools and informational materials directed at coral diseases.

Approaches undertaken to manage or mitigate coral diseases have been limited in scope and the effectiveness of these measures is not fully understood. For instance, massive corals affected by black-band disease have been "treated" by aspirating the microbial band and covering the affected area with clay or underwater epoxy, while antibiotics have been successfully applied to diseased corals in aquarium environments. Pilot experiments involving the removal of corallivores (e.g. crown of thorns starfish and corallivorous gastropods) have been undertaken to reduce predation pressure on corals, secondarily eliminating potential vectors of disease. Reintroduction of the herbivore, *Diadema antillarum*, is being undertaken in parts of the Caribbean to stem increases in macroalgae, which may also improve the health of corals, thereby indirectly reducing the likelihood of disease. Researchers are also attempting to identify disease resistant clones of certain species of corals, with the goal of propagating and transplanting these into degraded areas. In 2003, the Florida Keys National Marine Sanctuary (FKNMS) closed a portion of the reef to recreational divers in attempt to prevent transmission and spread of a disease affecting *A. cervicornis* (Federal Register 2003). Other efforts have focused on improving resilience of reefs, such as the implementation of no-take MPAs and reduction in the discharge of certain land-based stressors to specific locations; these measures have not been implemented as a strategy to mitigate disease, but they may indirectly reduce morbidity and enhance the health and resistance of corals.

Challenges and Recommendations

There are numerous factors that have hindered recognition by the management community of the importance of diseases and the need for management actions directed towards an improved understanding of diseases, surveillance of the occurrence, distribution and impact, and responsive (proactive and reactive) actions to address diseases. This includes the existence of very limited basic knowledge on locations and species affected by diseases, numbers of different diseases and their abundance, causes, and links to other anthropogenic and natural stressors. Moreover, few studies from the Pacific have quantified the extent to which disease has or could contribute to overall reef decline.

The general lack of knowledge on Pacific coral diseases severely limits our ability to gauge the severity of the problem. In light of current and future funding limitations and a paucity of information on diseases, managers may be reluctant to direct their limited available resources towards implementing proactive measures to address disease and in so doing, fail to protect unimpacted coral reefs from possible disease outbreaks. We need to develop a dialogue with managers that will communicate the urgency to prevent Pacific coral reefs from being thrust on the same trajectory as their Caribbean counterparts; improving our understanding of diseases through strategic research and surveillance as well as developing and implementing proactive conservation measures can help avert this impending threat to Pacific reefs. Engaging stakeholders, and raising their awareness to the benefits of prevention rather than treatment is not only cost-effective but more likely to be successful than efforts to treat diseases and/or restore reefs after diseases have degraded coral reef habitats.

The goal for the managing coral disease should focus on the maintenance or improvement of coral ecosystem health, using a comprehensive ecosystem-based approach through implementation of adaptive management practices. In general, coordination and communication among research scientists and managers can be facilitated with an inter-disciplinary approach that brings scientists and managers together to work closely to address disease, using a single ecosystem approach to science and management that exemplifies the land-sea connection since many potential stressors are believed to be land-based. This includes support for:

What do managers need to know with regards to disease outbreaks?

- 1. What is it?**
- 2. What is affected?**
- 3. Location of infection within the reef, and where is the reef?**
- 4. Time frame, seasonality?**
- 5. What are the population impacts?**
- 6. Is it transmissible?**
- 7. What causes the disease?**
- 8. What should be done?**
- 9. How widespread is the disease in neighboring areas?**

- a. **Monitoring and assessment** of the current state of coral reefs and condition of important reef building corals. Current efforts to monitor disease are minimal, and typically include attempts to gather baseline data or opportunistic reporting of disease signs noticed during field research or other routine monitoring. There is a need for adopting standardized disease protocols to ensure signs and stages of disease are reported consistently as well as uniform reporting guidelines to ensure the information is being communicated to the correct management agencies. Institution of these standardized procedures would enhance the opportunity to obtain the funding required to support long-term monitoring efforts.
- b. **Research geared towards an improved understanding of potential stressors, causes and sources of disease** such as identification of specific vectors, sources of pathogens, and measurable indicators of change in the health status of corals (e.g., specific biomarker expression). Existing efforts have been primarily directed towards counts of corals with and without specific disease signs, with few studies focused on understanding physiological changes in coral health before the coral manifests visible signs of mortality. Data pinpointing disease sources are also lacking, making it difficult to convince managers, politicians and the public to care about and seek management alternatives to address coral disease.

In other disciplines, such as in most veterinary practices and management of wild animal (terrestrial) populations, cost-benefits of proactive and precautionary management measures have been fruitful. Some of the major actions that have improved animal health without actually treating a disease have included addressing contaminated sources of water, good cleanliness practices. Management of human activities is likely to be the key to improve the health of coral reefs, taking into account social systems and considerations of the regulatory/legislative framework, and whether managers are able to be proactive.

Our ability to characterize and address coral disease in the Pacific is hampered by a paucity of spatially and temporally relevant epizootiological data, an incomplete understanding of underlying mechanisms responsible for the occurrence, spread and impact of diseases, and limited technical information and few diagnostic tools to help managers evaluate, track, predict or mitigate diseases. In an attempt to identify specific management needs that can help address coral disease on Pacific coral reefs, the Management Working Group (MWG) identified a series of broad strategic objectives and accompanying recommendations for actions to achieve these objectives.

Vision: To understand and manage impacts to reef ecosystems from climate change, bleaching and disease for increased resistance and resilience by:

- a. Understanding the types of diseases present and their distribution;
- b. Monitoring the prevalence, incidence and impacts of disease with emphasis on stakeholder participation in monitoring and reporting of bleaching and disease;
- c. Determining existing legal mandates and identifying new authorities as necessary to address priority gaps and research needs for diseases and human impacts known to affect the health of corals and other reef organisms;

- d. Identifying and mitigating manageable factors that exacerbate the occurrence of diseases and testing the effectiveness of these measures by employing an adaptive management approach;
- e. Increasing public awareness regarding diseases;
- f. Improving policy support to address diseases and enhance communication among managers, scientists, and policy makers;
- g. Implementing training and capacity building programs for managers, graduate students, scientists and other stakeholders with the goal of improving research and management capacity directed towards disease; and
- h. Developing tools and technologies to respond to and mitigate diseases and their impacts.

General Recommendations

- **Address management needs for coral disease outbreaks in the U.S. Pacific through the U.S. Coral Reef Task Force Local Action Strategy Process**

The U.S. Coral Reef Task Force (US CRTF 2008) developed a National Action Plan in 2000¹ to improve our understanding of coral reefs and implement actions to mitigate human impacts to these ecosystems. As part of this plan, Local Action Strategies (LAS) were developed in partnership with the U.S. All Islands Coral Reef Committee during the fall of 2002 to help increase and link the goals and objectives of the National Action Plan to Conserve Coral Reefs (U.S. Coral Reef Task Force 2000) with priorities and actions that are relevant for particular areas. The LAS are locally driven, short-range roadmaps for collaborative and cooperative efforts among federal, state, territory, and non-governmental partners to identify and implement priority projects that reduce key threats to valuable coral reef ecosystems in each region. Together, the LAS from the seven U.S. coral jurisdictions (American Samoa, the Commonwealth of the Northern Mariana Islands (CNMI), Florida, Guam, Hawaii, Puerto Rico, and the U.S. Virgin Islands) have identified projects to address five priority threats to coral reef ecosystems: land-based sources of pollution; overfishing; recreational overuse and misuse; lack of public awareness; and climate change, coral bleaching, and disease. Hawaii and Guam are the first jurisdictions to complete a LAS for coral disease and bleaching. There is a key need for other U.S. Pacific jurisdictions to create LAS that identify key activities, partners and funding needed to tackle coral disease-related issues throughout the region.

¹ The US Coral Reef Task Force National Action Plan was the first national blueprint for US action to address the loss and degradation of US and international coral reef ecosystems. Based on input from government and non-government organizations, scientists, resource managers and other. <http://coralreef.gov/>

- **Unify the coral disease research community with emphasis on efforts to bring together the World Bank Coral Disease Working Group (DWG) and the CDHC.**

The World Bank Coral Disease Working Group (DWG) has identified a number of needs and activities to address coral diseases globally, many of which overlap with priorities outlined in the CDHC National Research Plan (Woodley et al. 2003). For example, both groups recognize the need for standardized methodologies, nomenclature and diagnostics to improve the comparability of coral disease reports across jurisdictions and among different researchers. One of the most cost-effective ways to address gaps in knowledge and to facilitate the development of tools, technologies and informational products that can help resource managers respond to disease is through an enhanced collaborative partnership between the CDHC and DWG. This is a key step to help advance the field of coral disease research and ensure accurate and comparable results of coral disease research efforts.

- **Develop web-accessible database and informational resources for Pacific coral diseases**

In the coral reef arena there is often a period of several years between conducting a research project and publication of its findings, with limited communication of pertinent results to the management community by researchers. Furthermore, these findings are most often published in peer-reviewed journals that may be highly technical in nature, with inclusion of few management options in response to the findings. Managers need to have information presented in a manner that will enhance:

- a. Recognition of the need for management actions in response to coral diseases;
- b. Understanding the risks posed by diseases and risks associated with lack of management actions;
- c. The ability to determine the state of their coral reefs, including baseline levels of diseases, changes in disease prevalence or linkages between disease occurrence and manageable human impacts; and
- d. A comparison of what is happening in waters under their jurisdiction to surrounding areas, including status, trends, types and benefits of proposed and implemented management actions.

- **Develop a manager's guide for coral disease**

The MWG requested that the CDHC develop a guide that brings together the latest scientific knowledge and management experience to assist managers in responding effectively to coral disease outbreaks. This guide might be modeled after the Reef Manager's Guide to Coral Bleaching (Marshall and Schuttenberg 2006) and should include: a) survey/assessment protocols; b) outbreak response protocol; c) protocols for post-disease response actions; d) guidelines for research involving live organisms including safety and biohazard containment strategies; e) disease identification guides and standardized nomenclature and diagnostics; f) possible management responses to reduce the occurrence of disease and control spread; and g) resource materials for managers.

Strategic Objective D.1: Enhance the state of knowledge of coral diseases.

Recommendation D.1.1: Conduct baseline surveys on coral diseases throughout the region.

The accurate and thorough documentation of the type, prevalence and geographic distribution of diseases currently present in each jurisdiction is fundamental to attempting to effectively manage these diseases. As a first step, baseline surveys are needed at relevant spatial scales (e.g., different depths, habitats, reef types, and at varying distances from land within each jurisdiction) to identify what diseases are present now, how common they are and what coral species and/or other marine organisms are being affected. These surveys could be easily incorporated into existing survey efforts that examine the community structure and cover of corals, other benthic invertebrates, commercially and ecologically important mobile invertebrates (e.g., lobsters and crabs), and coral reef dependent fishes.

At minimum, efforts to characterize the baseline prevalence of diseases should include parameters that address:

- Coral species diversity at lowest possible taxonomic resolution (e.g., genus or preferably species level data)
- Coral community structure including size class and other population parameters
- Coral cover and colony condition
- Abundance of diseases and presence of possible disease vectors (e.g., gastropods, crown of thorns, fireworms)

In order to collect comparable data, the group recommended that coral disease surveys be conducted using standardized methodologies, disease nomenclature and forms.

Strategic Objective D.2: Develop and implement proactive management strategies.

Recommendation D.2.1: Develop a disease monitoring program for Pacific reef areas or integrate disease into an existing monitoring program.

Long-term monitoring of coral disease using standardized techniques is essential to detect and assess changes in disease prevalence, types, and organisms affected and to provide regular, up-to-date information to managers. Most areas in the Pacific with established monitoring programs do not include disease monitoring in their protocols. Furthermore, in areas where disease monitoring is occurring, survey approaches are highly variable, allowing only limited comparisons between programs and jurisdictions. The development of a disease monitoring program capable of assessing changes and trends in reef ecosystem health is recommended. This program should be appropriate for the specific reef areas of each jurisdiction and record comprehensive data exceeding current efforts at presence/absence of disease. It is further recommended that the effort be integrated into

existing monitoring programs whenever possible. Regular long-term monitoring, that includes disease surveys along with surveillance of high priority environmental stressors, can potentially be used strategically to identify and address emerging threats to specific areas (anthropogenic and natural threats).

The MWG identified some of the basic information that should be included in the disease monitoring program and recommended four documents that could serve as a starting point for the development of an integrated, Pacific-wide disease assessment and surveillance effort:

- IOC/UNESCO Coral Reef Targeted Research & Capacity Building for Management (CRTR) Program; Coral Disease Working Group assessment protocol
- A Reef Manager's Guide to Coral Bleaching (Marshall and Schuttenberg 2006)
- CDHC's Field Manual for Investigating Coral Disease Outbreaks (Woodley et al. 2008)
- Priorities for Effective Management of Coral Diseases (Bruckner 2002)

Recommendation D.2.2: Identify potential stressors that may influence susceptibility or resistance to disease and the potential to recover following disease outbreaks

Ecosystem condition, including biological attributes such as coral cover, condition and biodiversity, other ecosystem parameters (e.g., abundance diversity and structure of associated fish and invertebrate communities), and environmental attributes such as water quality, influence the resistance of corals and resilience of coral reef ecosystems. Variations in the local environments, including unusual exposure to heat stress, excessive sedimentation and nutrient loading, can play an important role in triggering coral disease outbreaks by increasing the susceptibility of corals to disease and potentially increasing the virulence of coral pathogens. Environmental stressors, along with other factors such as connectivity can also influence the ability of corals to recover from disease as well as the ability of degraded reef ecosystems to recover through recruitment. *While managers can do little to address increasing sea water temperatures and other stressors associated with global climate change, it is possible to manage and mitigate local or regional human impacts such as unsustainable removal of keystone species (through fishing and other activities), excessive input of pollutants and sediments, boat anchoring and other physical impacts to reef ecosystems, and marine pollution associated with recreational and commercial vessels.*

There is a growing body of evidence linking environmental stressors to coral disease outbreaks. However, few programs are conducting detailed monitoring of water quality in concert with disease studies, and few attempts have been made to tease out relationships between specific stressors and occurrence of disease, or the threshold of these stressors that will trigger a change in the health of corals and/or manifestation of disease signs. Through concurrent water quality monitoring, it may be possible to statistically compare disease abundance at single time points with the concentrations of specific stressors, as well as relationships between changes in input of stressors (e.g., during periods of high rainfall vs low rainfall) and the incidence of disease. For sites

known to be affected by specific contaminants or environmental stressors, it may also be possible to identify specific physiological/biochemical responses of the coral host that can be used as an indicator for that parameter. The MWG proposed a number of actions that could help to elucidate the responses of corals to various stressors and ultimately identify those stressors that can be managed to reduce disease occurrence:

- Identify stressors in specific area(s) of concern (i.e., water quality: content of nutrients, suspended sediments, agricultural or industrial chemicals, pharmaceuticals, secondary petroleum products, temperature, recreational uses) and characterize their effect and impact on corals and coral reef ecosystems. As a first step to identify possible stressors that may exacerbate diseases, monitoring programs could be established along a gradient including reefs adjacent to a known impact (e.g., adjacent to a sewage outfall) and sites varying distances upstream and downstream. If adverse effects were detected, this could be supplemented with more detailed studies on responses of individual corals to those stressors (i.e., bioaccumulations targeted biomarkers analyses and ecotoxicological assays).
- Identify site-specific stressors of major concern and determine “threshold for action” based on clearly defined acceptable/unacceptable percent change.
 - Metrics or parameters should be selected that are appropriate for the local area and acceptable/unacceptable percent change should be defined.
 - Natural fluctuations should be considered when selecting metrics.
- Scientists and managers should be encouraged to work together in developing general guidelines to reduce specific stressors of concern. A guidebook for “best management practices” (BMP) for addressing key environmental stressors should be created and encompass alternative management practices such as limiting development to specific low-impact places, reducing recreation in sensitive areas, and offering other protocols for addressing specific problems in a given area. In areas where these BMP guidelines or manuals already exist, scientists and managers should work to reference, communicate and apply this information in management activities.

Recommendation D.2.3: Develop disease education and outreach materials and incorporate these as components of existing educational programs (knowledge, attitude, behavior).

Most communities know that their coral reef resources are steadily being depleted but often they do not understand why. Local citizens in the Pacific Region are generally unaware of the presence of coral disease and therefore the potential impacts that disease could have on the coral ecosystem. This lack of understanding poses a challenge to the coral disease research community in that they may have difficulty in convincing the public, politicians and managers that they should care about coral diseases and consider preventative actions to address coral diseases and their impacts.

Educational efforts should include some very basic messages about coral disease and why they should care about disease, with a strong emphasis on encouraging stakeholders to take actions designed to improve overall coral ecosystem health. Because governments

usually do not have sufficient resources to enforce regulations effectively, education and awareness programs should target all stakeholders, emphasizing the need for local citizens to take ownership of the resources, including steps to address harmful activities they are responsible for, and to promote community based management. An essential component of education is actual participation, including involvement in assessing and monitoring status and trends of coral reefs and diseases.

Four very basic messages for local citizens and tourists were identified by the working group:

- Diseases can and do kill coral reefs. Death of these keystone species has caused major shifts in community structure in some locations which results in losses of valuable ecosystem function and services.
- Corals are living animals that often have algal symbionts. They are susceptible to disease, as all animals are, and therefore can get sick and die.
- Exposure to stressors can make corals more vulnerable to disease; the stressors include physical damage, land-based pollution and overfishing. Many of these stressors can be reduced or eliminated through adoption of best management practices.
- Disease can kill reef organisms, including corals, and in some locations has caused major shifts in community structure and concurrent losses of ecosystem function.

Additionally, specific educational materials should be developed for targeted agency administrators, policy-makers, managers and legislators that:

- Improve their general understanding of coral biology and factors as well as consequences associated with declining health of corals
- Provide detailed information on:
 - Interconnected relationships between corals and manageable environmental stressors,
 - Effects of these stressors on coral organisms and reef ecosystems,
 - Importance of understanding when and why changes to reefs and ecosystems are occurring, and
 - Rationale for taking action before visible signs of disease appear (e.g., tissue loss).
- Identify consequences of non-action in addressing disease situations, including economic ramifications of coral mortality and reef degradation.
- Communicate lessons learned from other reef areas – including regulations, legislation issues, and management responses that helped mitigate disease and/or improve the resistance and resilience of corals and associated organisms.
- Encourage local stakeholder advocacy to decision-makers.

Recommendation D.2.4: Identify management actions needed to reduce other stressors that may make corals more vulnerable to disease

A variety of natural and anthropogenic factors place substantial stress on reef building corals long before any visible signs of disease appear. These can include:

- a. Contaminants and pollutants associated with degraded water quality that directly affect the growth, reproduction and ability of the coral to resist pathogens, such as certain chemical contaminants;
- b. Excessive growth of macroalgae and cyanobacteria that affect the long term survival of the coral and future recruitment potential (due to top-down factors such as loss of key herbivores or bottom up factors such as increased nutrients);
- c. Injuries to corals caused by physical impacts associated with ship groundings, anchoring and diver contact that provide an entry point for a pathogen;
- d. Population explosions of coral predators such as crown of thorns sea stars and corallivorous snails which may serve as vectors for disease;
- e. Increases in temperature and UV radiation as a result of climate change that affect the resistance of corals; and
- f. Direct introduction of pathogens through run-off, discharge of human sewage, atmospheric deposition, subsequent transport to reef ecosystems via water circulation as well as ship traffic (hull microbial communities and bilge water).

Reefs are likely to be affected by several of these factors simultaneously, making it extremely difficult to tease out the importance of any specific factor(s) or a critical threshold for individual factors in terms of the relationship with coral disease. Furthermore some of these factors (e.g., temperature change) may be out of direct control by managers. However, management efforts geared towards reducing specific human impacts negatively affecting a given reef system (i.e., nutrient loading, sedimentation, overfishing, recreational and other human activities) may increase the local survivorship of corals and the resilience of reef ecosystems, thereby improve their resistance to infections and recovery following disease outbreaks. Therefore, it is crucial that initial management actions target efforts to reduce known land-based stressors by implementing best-management practices.

Recommendation D.2.5: Develop and implement training modules for coral disease and health surveillance methodologies, field and laboratory research, and potential management actions in the Pacific Islands

There is a critical need to develop and deliver training programs for multiple audiences covering a variety of topics related to coral health and disease in the Pacific Region. Effective training programs are needed to identify various coral disease research methods and to promote adoption of standardized methodologies across the region to allow comparative analysis of data to reveal regional patterns and trends, and allow comparisons among locations affected by different stressors. The WG suggested that the CDHC lead these efforts with assistance from the U.S. All-Islands Coral Reef Coordinating Committee².

² The US All Islands Coordinating Committee is a collaboration of marine resource managers working together with federal agencies to strengthen the conservation and protection of coral reef ecosystems in the United States. <http://allislandscorals.org/>

Key training areas identified by the WG include:

- a. Basic survey methodologies for coral disease;
- b. Disease outbreak incidence response protocols;
- c. Disease identification and standardized nomenclature (The workgroup suggests creating “disease-cards” that depict and describe distinctive disease signs, and diagnostic criteria to distinguish these signs, along with general information on coral species that are typically affected, reef areas where the disease may be observed, and how/where to report disease sightings);
- d. Advanced curriculum on coral disease-related topics with emphasis on field and laboratory investigation, including surveillance and sampling procedures, coral histology and physiology studies, disease epidemiology, and molecular methods including biomarker and toxicology studies;
- e. Management practices and options for coral disease prevention and outbreak response. Coral and natural resource managers in the Pacific would tremendously benefit from training on recommended management alternatives and lessons learned from Caribbean experiences, including the “A Reef Manager’s Guide to Coral Bleaching”, and management efforts in Australia. Instruction and guidance is also needed to assist agency personnel with determining whether the existing infrastructure in each jurisdiction is appropriate for managing disease events. This would include an assessment and evaluation of existing agency mandates and legislation, current regulatory processes and enforcement capabilities.

Strategic Objective D.3: Develop a management program to respond to disease outbreaks.

Recommendation D.3.1: Evaluate local agency mandates and existing legislation, regulations and legal framework for addressing disease

Many aspects of coral reef research and monitoring, responses to unusual events or emerging issues, and proactive management actions can be delayed or obstructed due to lack of existing authorities to conduct an activity, complications with a permit process or policy documents with unclear provisions for disease-related activities. Existing mechanisms for permitting and implementing various coral reef activities, especially those directed at coral disease research and management should be evaluated to determine whether they are adequate and allow timely implementation of actions. Managers can participate by assisting responders with specific permitting processes and permissions and regulatory responsibilities that are required to allow rapid responses in the event of disease outbreaks. If existing permits or policies are insufficient, action can be taken to work with administrators, legislators, and local authorities to establish authority for timely and thorough responses to a disease outbreak to allow experts to conduct surveillance efforts, collect and transport appropriate specimens quickly, and take appropriate emergency response measures. This may include the establishment of a Memorandum of Agreement between responsible agencies.

Recommendation D.3.2: Develop local and regional infrastructure to respond to disease outbreaks and unusual mortality events.

While the MWG recognized the need for and benefits of proactive management responses for diseases, they also acknowledged the likelihood of future disease outbreaks and the need to obtain timely information on the occurrence, extent, cause and impact of these events. The MWG also recognized the advantages of an organized, systematic approach to create diagnostic case definitions of the disease (e.g., What is it?), identify risk factors (Where did it come from? How is it spreading?), formulate possible measures to control and manage the outbreak, and predict the consequences under various scenarios. Currently, one of the largest limitations in our ability to respond is a lack of appropriate infrastructure, including:

- People capable of identifying and reporting unusual outbreaks when they first occur;
- Standardized surveillance and sampling protocols;
- Trained response teams;
- Capacity (e.g., boats, supplies, diagnostic laboratories) to respond in an effective and timely manner; and
- Existing system for reporting observations.

The MWG was supportive of the CDHC's proposed Incident Command System for responding to disease outbreaks. For this effort to be successful the MWG acknowledged the importance of outlining the desired response process, assigning roles and responsibilities, creating necessary response protocols, databases and communication mechanisms, and identifying gaps in permitting procedures and funding sources. The MWG recommended the following infrastructure elements:

- a. Develop a local response protocol following the CDHC basic response framework;
- b. Create local **"Eyes of the Reef"** initiatives including public education on various aspects of response such as disease identification, reporting, and volunteer monitoring (divers, reef check, NGO's, academics);
- c. Create a response team with defined roles and responsibilities and identify training, equipment and permissions needed to be a responder;
- d. Define the communication structure between the response team and coral reef managers;
- e. Set up a central system and/or database for reporting observations and data;
- f. Explore mechanisms for setting up permits for emergency response and mitigation to include standard permits for defined coral disease responses; and
- g. Identify additional funding sources needed for a fully functional response system (i.e., response activities, communications, data analysis).

Additionally, based on a cursory evaluation of agency mandates, legislation and regulatory processes there may be a need to revise or create clear policy guidelines that will allow for immediate decision making and response activities in the event of a disease incident. We recommend that proactive steps be taken, if needed, to develop appropriate policy statements and Memorandums of Agreement between local agencies that would

allow immediate resource-based decision making to implement timely response activities and protective measures, such as temporary closures or activity restrictions in critical areas.

The CDHC model response protocol (Woodley et al. 2008) follows a tiered approach for responding which allows the level of response to be determined based on an assessment interview of the original observer of the disease outbreak (Level I response).

If a Level II or Level III response is deemed appropriate, the MWG identified the need for timely reporting of findings to managers to allow implementation of possible management actions in a timely manner. This includes a recognized need for follow-up surveys to determine impacts on affected corals, fisheries resources and the ecosystem in general. The MWG identified the importance of adopting standardized monitoring protocols and ensuring sufficient human and financial capacity to support post-incident monitoring before the disease event occurs. Moreover, a communication plan should be outlined to ensure that critical post-incident monitoring information reaches coral managers in a timely manner so suitable management decisions can be made and corrective or protective actions can be implemented.

Recommendation D.3.3: Identify ecological and economic cost and benefits of various management actions in response to disease outbreaks.

In response to a disease outbreak or incident specific management actions may be called for to control the potential exchange of disease vectors to other reef areas during outbreaks, to minimize long-term damage to the ecosystem and to allow for enhanced recovery of the affected reef.

Recommended actions to be considered by managers to enhance reef recovery:

- **Modify MPA boundaries or zoning**
- **Temporary closures, activity restrictions**
- **Containment of affected area and adjacent reef area**
- **Decrease or limit adjacent land use and development for specified times**
- **Use the permit process to control field activities related to coral disease**

Strategic Objective D.4: Identify priority coral disease and health research needs to aid in management.

The MWG also recognized the need for enhanced collaboration with and support for local scientists conducting coral reef research with emphasis on encouraging activities that will lead to increased understanding of coral disease and disease processes.

Recommendation D.4.1: Create a CDHC Pacific Research Plan that emphasizes regional disease priorities.

The MWG identified the need for additional meetings involving both scientists and managers to:

- More thoroughly review existing knowledge of coral diseases in the Pacific;
- Identify specific critical gaps hindering effective responses to disease outbreaks and management actions to mitigate diseases; and
- Identify a strategy to address these information gaps.

As a starting point, the Strategic Objectives originally laid out in the 2003 CDHC National Research Plan (Woodley et al. 2003) should be revisited and reviewed to identify outstanding research priorities that apply nation-wide and identify an approach to fill these gaps. Eight regional research needs were identified by the MWG which will ultimately provide essential information to make better management decisions for preventing, responding to and managing disease outbreaks in the Pacific include:

- Conduct economic valuations of coral reef ecosystems and associated resources where valuations have not been completed yet.
- Explore the potential to incorporate disease factors into modeling.
- Investigate how Pacific island cultural and social practices enhance or detract from management efforts and how are they can be better incorporated into management strategies.
- Conduct targeted disease transmission experiments under controlled conditions.
- Develop research projects to explore potential treatments and possible cascading effects of disease.
- Conduct research aimed at developing feasible and effective recommendations for action and mitigation strategies and establishing thresholds for action.
- Establish links between ecosystem health and organism health in coral reef ecosystems.
- Encourage interdisciplinary research following a watershed approach to link land-based stressors to coral disease.

Strategic Objective D.5: Environmental and Human Health Safety Issues.

Inherent in disease studies is some measure of risk to human and environmental health. Those working with diseased organisms and putative infectious agents must recognize that a potential exists for humans to become infected (though most likely a small risk) or they and/or their equipment may serve as inadvertent vectors to other corals and to other

locations. Just because coral disease occurs in an aquatic environment, does not make it completely safe to study and without risk. There are common practices that medical science adheres to when dealing with potentially infectious disease outbreaks (of known or unknown origin) or toxic events and are applicable, regardless of whether the focus is human disease or coral disease. Preventative containment measures are a logical option to mediate risk. Containment measures are relatively easy to apply in the aquatic environment and therefore should be included as part of each response activity particularly to limit the possible spread of infectious agents. The three recommendations listed below target important areas where managers can assist in coral disease management.

Recommendation D.5.1: Create an awareness of the dangers of outplanting aquaria raised corals.

There are significant issues related to placing captive animals into the wild. If not closely scrutinized catastrophic consequences can occur, even with the best of intentions. Though restoration efforts are important considerations for reef management in certain locations, it is also important to conduct a hazards analysis to avoid bringing modified organisms (through captive conditions) into the wild that may present an unacceptable risk to other wild species within the ecosystem. To fully explore the benefits and dangers will require a focus group to evaluate this issue and provide recommendations.

Recommendation D.5.2: Develop requirements for containment measures needed for conducting disease transmission studies

Bio-safety and bio-containment are critical issues when conducting disease research. Veterinary research facilities for aquatic and terrestrial animals have rigorous guidelines for handling sick and diseased organisms, as do domestic (e.g., U.S. Department of Agriculture) and international groups (OIE, World Organization for Animal Health). The guidelines and practices of these groups should function as a role model for adopting similar guidelines tailored for coral disease research. Development of these guidelines will require a team of coral disease researchers to interface with experts and practitioners of animal health, bio-security and bio-containment to develop methods appropriate for tropical marine systems.

Recommendation D.5.3: Develop recommended methods for decontamination of dive gear.

This is a specific project that can have wide spread management applications and is an obvious follow on to Recommendation 5.1. Determining the risk associated with dive gear in transmitting disease to either humans or marine organisms is vital to provide a basis for risk management options. Once the risk level is determined it is important to provide a means of decontamination that is safe and effective for both the user and the environment. Results of such a focused study can provide an unambiguous tool to help manage coral disease on a local level.

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