Chapter 1

Perspectives on Coral Disease and Outbreak Investigations

1.1 The Issue

Found in seas of over 100 countries, coral reefs cover an estimated 284,300 km^2 (ICRIN 2000b). Per unit area, they are one of the World's most valuable ecosystems in terms of ecological, economic and cultural resources, yet coral reefs are among the world's failing ecosystems. We are losing them at an accelerating rate (Wilkinson 2002). Recent predictions indicate that 58–70% of coral reefs globally are directly threatened by human-associated activities (Bryant et al. 1998; Goreau et al. 2000; Hoegh-Guldberg 1999; Wilkinson 1999), while over 80% of the Caribbean coral-reef cover has disappeared in the last 30 years (Gardner et al. 2003). According to estimates in 2004, 20% of the world's coral reefs have already been degraded beyond the potential for recovery, 24% are under imminent risk of collapse, and another 26% are under a longer term threat of collapse (Wilkinson 2004).

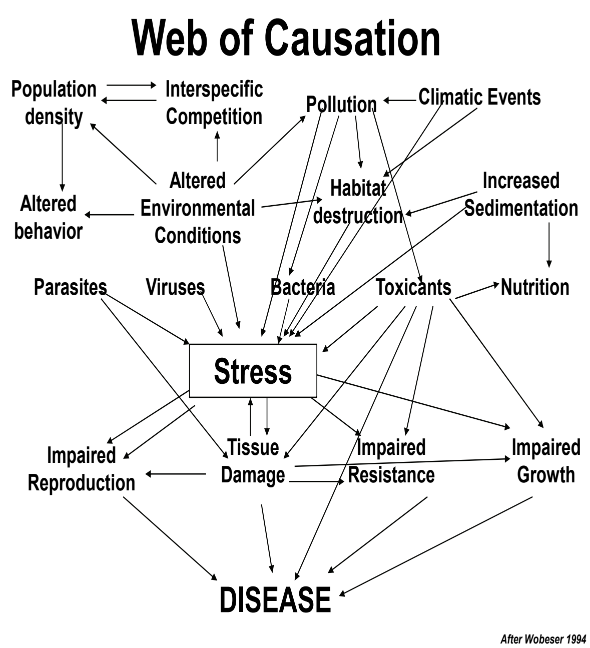
In both terrestrial and marine systems, wildlife disease outbreaks and mass mortality are recognized as important indicators of ecological disturbances. The role of diseases in regulating a species' survival has escalated due to environmental changes such as 1) alterations in habitat (e.g., fragmentation or loss, pollution, climate change); 2) shifts in populations (e.g., introduction of new species; change in predator/prey relations); and 3) changes in disease ecology (e.g., loss of endemic stability; virulence and pathogenicity of agents; density of susceptible hosts) (Deem et al. 2001; Morner et al. 2002).

Similarly, coral reef declines are viewed as sentinels for a degraded ocean condition. The causes have only been described in broad sweeping terms implicating coastal urban and industrial development, agricultural runoff, sedimentation, overfishing, marine pollution, climate change and disease (Bellwood et al. 2004; Bryant et al. 1998; Risk 1999; Turgeon et al. 2002; Walker and Ormond 1982). These threats have contributed to losses of apex predators, removal of key herbivorous fishes and invertebrates, precipitous declines in coral cover as corals become stressed and die, and ecosystem shifts to dominance by macroalgae on reefs and similar disruptions in other ocean systems.

Coral disease is manifested in a number of different forms from acute mortality leading to a rapid loss of diversity and abundance, to chronic partial mortality resulting in progressive tissue loss, with non-acute, sub-lethal effects. The outcome of various disease states may result in reduced growth, reduced reproductive effort and recruitment, increased incidence of various coral disease conditions and mortality, ultimately cascading into ecosystem deterioration (CRMP 2001; Hoegh-Guldberg 1999; Knowlton 2001; Nystrom et al. 2000; Patterson et al. 2002; Porter and Tougas 2001; Richmond 1993). Coral disease whether infectious or noninfectious in nature is a significant challenge to conserving and protecting coral reefs. Definitive root causes to these diseases, however, remain elusive and the increasing frequency and distribution throughout the world pose major threats to reefs and challenges to reef managers to combat these threats.

> Health is relative occurring along "…. a continuum between two endpoints: absolute health (a state in which all functions are optimal) and death, which occurs when functions are so severely compromised that life is impossible. Between the two points there is a region of relative health that blends imperceptibly into a region that we can define as disease." (Wobeser 2006)

1.2 Defining Coral Disease



It is tempting to assume that coral "disease" refers only to clearly visible signs of infection by a pathogen; however, disease can be caused by abiotic factors as well as a response to biotic stressors. We have adopted the definition of Wobeser (1981) that states disease is *'any impairment that interferes with or modifies the performance of normal functions, including responses to environmental factors such as nutrition, toxicants, and climate; infectious agents; inherent or congenital defects, or combinations of these factors'* to characterize disease in its full meaning. For diseases of coral, we know that in addition to biological agents, many other risk factors exist, such as climate change, environment degradation, toxicants and physical damage. Therefore, it is more appropriate to consider coral diseases to result from a *'web of causation'* with many factors and co-factors ultimately contributing to disease (Wobeser 1994), rather than one distinct agent. To determine causation a more holistic perspective must be adopted that includes the host, the agent, and the environment. In the case of coral, this includes the animal, plant symbiont and microbial flora, collectively referred to as the holobiont (Wegley et al. 2004).

Diseases of stony corals and gorgonians can fall into several categories:

- **Bleaching -** loss or degradation of zooxanthellae due to biotic (bacteria) or abiotic (e.g., temperature, UV radiation, salinity, toxicants) causes

- **Non-infectious diseases** – physiological and morphological (e.g., tissue loss or discoloration) changes due to agents such as toxins or toxicants, sedimentation, pollution, and other environmental stressors

- **Trauma –** physical damage (e.g., groundings, fish bites, snail predation)

- **Parasitic infections** – infestation by protozoans (e.g., ciliates, amoeba), metazoans (e.g., trematodes, flatworms, flukes) or parazoans (e.g., sponges)

- **Growth Anomalies** - abnormal growth and development, including hypertrophy, hyperplasia, neoplasia, tumors

- **Infectious diseases -** partial and whole colony mortality caused by bacteria, fungi, viruses and other microorganisms

1.3 Why Study Coral Disease?

The short answer is to determine the cause(s) in order to identify management options that can help control disease or mitigate its impacts to protect corals more effectively.

Disease can cause significant effects on the ecology, structure and function of coral reef ecosystems. In the Caribbean, coral disease has caused extensive losses of living coral cover, shifts in coral community structure, and extirpations of certain key reef-building species. For conservation to be effective, it is imperative not only to understand biogeographical patterns, community structure, population dynamics and individual behavior (i.e., biology) of the host species (Deem et al. 2001), but also the threats affecting these species and the health effects (i.e., consequences of the threat). Only when health parameters are incorporated into conservation models and synthesized into knowledge, will managers have more robust management options. For stony corals, basic information on biogeographic distribution and community structure is known, baseline assessments of biodiversity, population dynamics, and cover have been completed in representative locations, and the broad threats impacting reef communities have been identified. However, specific data on the prevalence and impacts of diseases and relationships between coral mortality and other stressors are available for relatively few locations. A handful of the better known diseases have been only partially characterized, and effective management responses are currently unknown. Too often the study of coral disease is viewed more as an academic exercise rather than an avenue to developing successful conservation measures. In fact, local management agencies often view diseases and bleaching as a global problem that is "*just a normal part of life that we can't do anything about anyway*". As we look at the scope of disease effects----"*any* *impairment that interferes with or modifies the performance of normal functions, including responses to environmental factors such as nutrition, toxins, and climate; infectious agents; inherent or congenital defects, or combinations of these factors*" (Wobeser 1981) it is the organism's failure to resolve these 'impairments' (or injury), at the cellular physiological or tissue level that results in the dysfunction we recognize as disease. These dysfunctions then are driving the decline of corals (and other wildlife) by affecting individual responses, population dynamics, community structures and biogeographical patterns (Deem et al. 2001). In other words, the long-term existence of corals and their ability to fulfill their ecological roles are being compromised by disease. It is critical that health and disease are no longer allowed to be a limiting factor in coral conservation efforts. Therefore, every effort should be made to understand the factors controlling coral reef health conditions and the impact of diseases on coral reef system dynamics, and incorporate this information into the construction of conservation programs.

The marked increase in disease incidence, the severity of the impacts being observed, and 'signatures' of recently emerged coral disease were not documented before the 1990's. Together, these changes mark an alarming threat to coral biodiversity, ecosystem stability and sustainability of reefs for the future (Daszak et al. 2001). To understand the causes of disease and their significance, and to identify control and management measures will require a broad integration of relevant disciplines that include health specialties (i.e., veterinary and medical sciences, pathology, medical microbiology, toxicology, epidemiology) together with ocean sciences (i.e., wildlife and marine ecology, marine biology, oceanography), basic sciences (i.e., biochemistry, cell physiology, microbiology, toxicology) and social and economic sciences involving those who help interface with the public and politicians (i.e., resource managers, sociologists, economists).

The gaps in our understanding of many factors affecting coral health are vast. Most coral diseases have no known etiology nor have the diseases been rigorously classified. There is little in the way of diagnostics or field tests for disease surveillance. Investigations of coral diseases often occur without guidance from veterinary scientists, cell physiologists, toxicologists or epidemiologists. A valuable shift in how coral disease is studied would be the application of the integrated principles of epidemiology and risk analysis to coral health assessments. An epidemiologist is usually not trained in one specific discipline, but is *"a master of 'lateral thinking', trying to see connections between what are probably isolated observations of completely different natural phenomena"* (Halpin 1975 as cited by; Wobeser 1994). Epidemiology is a powerful tool that can identify predictors (risk factors) for changes in coral health and ecosystem condition, quantify the strength of those associations, and focus diagnostic efforts toward identifying etiology. Since most disease in coral is likely to be multi-factorial, identification of risk factors and use of ecological risk assessment methodologies can direct and prioritize management strategies toward risk reduction without requiring knowledge of specific etiologies. While risk assessment is a process that assigns probabilities to adverse effects of human activities or natural damaging events, it does not address health assessment which is concerned with determining the occurrence and causes of impairments of nonhuman populations and communities, a field known as ecological epidemiology (Suter 2006). Thus, integrating ecological epidemiology (biological assessment and causal analyses) with risk assessment (risk models that link alternative decisions to future conditions) provides a systematic means to improve an understanding of the causal chain of events, identifying factors on a quantitative basis for informed management decisions (Suter 2006) and a logical, systematic approach to understand the complexities of disease. Investigations require astute observations and critical thinking drawing on many disciplines and types of information to develop quantitative comparisons among groups and various factors. The synthesis of this information can then be used to solve one of three basic problems: causation, significance or control (Wobeser 1994).

Our goal in studying coral disease is ***conservation*** of our world's reefs, but to do this we must be able to:

- ***Describe*** new diseases
- Determine ***causation***
- ***Identify the source*** of current outbreak
- ***Determine risk factors*** and ***conduct risk analysis*** for informed decision making
- Implement disease-specific ***surveillance*** measures
- ***Evaluate existing prevention/control*** measures
- ***Reduce risk*** of future outbreaks

Effective management of coral health will require being equipped to recognize new and reemerging infections, non-infectious disease conditions, and understand the factors involved in disease emergence, prevention, and elimination. This requires adopting a methodology appropriate for assimilating and synthesizing numerous and diverse data, such as those developed in the fields of risk analysis and ecological epidemiology. The broad areas that have been shown to influence emergence of disease include: 1) microbial adaptation and change, 2) human demographics and the consequences of that behavior, 3) technology and industry, 4) economic development and land-use practices, 5) international travel and commerce, and 6) the breakdown of health measures. In summary, we first need to study this major problem in a detailed, standardized manner and share the findings with the research and resource management communities.

1.4 Why Establish a Response System for Coral Disease Outbreaks?

"Stopping investigation in the here and now, will leave you vulnerable to why and how!"
(AAZV 2008)

An outbreak is commonly defined as an unexpected increase in disease or mortality in a time or place where it does not normally occur or at a frequency greater than previously observed. For coral, an outbreak may also be defined as disease occurring in a particular species of interest or manifesting signs not previously described. Outbreaks are usually transitory and short-lived and should be treated with a matter of urgency to collect as much information as possible while it is available. In contrast, insidious, chronic diseases can have equally devastating effects on populations and communities, yet their covert nature make them hard to detect and difficult to garner support for an investigation. Nevertheless it is critically important to investigate. Developing a Response System to investigate coral disease outbreaks provides the opportunity to methodically collect a range of data to assist in determining its significance, epizootiology and causal linkages, to test the adequacy of wildlife disease protocols to diagnose the principal cause, and to evaluate the findings, develop prediction models and present options for future research and mitigation to resource managers in a timely manner.

Outbreak investigations are designed to determine the extent and impact of the event, causative agent(s) and its reservoir or source, and transmission routes. They can also be used to identify knowledge gaps, help formulate hypotheses for further study and focus research goals, and help identify control or management strategies. Outbreak investigations are most important when almost nothing is known about the disease(s) (as is the case for most coral diseases) or when a new disease is discovered. An organized, systematic approach helps create both clinical and diagnostic case definitions, identify risk factors, and formulate hypotheses to target control and management strategies. When the cause of an outbreak has been clinically determined by identification of a known pathogen (e.g., white plague II), but the source (reservoir) or route of transmission remains unknown, there often remains much investigative work to be done (as was the case with *Vibrio shiloii,* the causative agent of one type of bacterial bleaching). Investigations can then focus on filling the knowledge gaps in the ecology of the disease to better guide future control and management efforts. Therefore a Response System, using a standardized approach helps answer the 'big picture' questions:

- **What is it? (well recognized or emerging disease?)**
- **What species are being affected in the area?**
- **What species are NOT being affected in the area?**
- **Where did it come from? (reservoir)**
- **How is it spreading? (transmission)**
- **How common is it? (prevalence)**
- **What impact is it having on affected species and populations? (effects)**
- **How can you control it? (stop spread)**
- **What risk factors (i.e., biological, chemical or physical) are co-occurring with the disease? (prediction)**
- **What about future management?**

1.5 Anatomy of an Outbreak Investigation

(from Pavlin 2003; Reingold 1998; Wobeser 1994)

There are 10 basic steps that are common to most disease outbreak investigations:

- **Establish the existence of an outbreak and develop case definitions. [Epidemiological Investigation]**

This is the same as starting any case description with the signalment (i.e., description of distinguishing features, signs, and information related to the organism being examined) and history of the animals and/or group of animals. This should include information such as their environment, proximities to potential contaminant sources or recent activities or weather or climatic events that may contribute to the outbreak. The case definition is a standard set of criteria applied to arrive at an initial, preliminary diagnosis and determine whether the reported information meets the criteria for an outbreak.

- **Establish endemic level (background rate) of disease**

Determining if the disease occurrence or prevalence is higher than background levels, spatially (i.e., for that particular location, reef or habitat) and temporally (i.e., for the specific time period when the presumed outbreak is reported) is a key to defining 'unusual'. This can only be accomplished through disease surveillance (e.g., monitoring of seasonal trends in abundance). This type of information is rarely available for coral disease.

- **Characterize the outbreak in terms of who, what, when and where.**

The objective is to identify common factors that are associated with the disease that don't occur when and where the disease is absent. Thus it is important to standardize collections in terms of data and types of samples because developing causal links may take weeks to years.

- **Examine the descriptive epidemiological (or epizootiological) features of the case.**

Descriptive epidemiology involves determining the number of cases and mapping them to determine the distribution of cases in space and time and contrasting this with past events, including cross species comparisons with life stages and associated environmental factors. This information can provide valuable leads as to the source or nature of the agent or routes of exposure.

- **Generate tentative hypotheses.**

A tentative hypothesis is developed to explain the most likely cause(s), source and risk of spread of the cases.

- **Test hypotheses**

Once the hypothesis is generated it can be evaluated against the known facts about the potential agent(s) (i.e., analytical epidemiology). The goal is to assess the relationship between a given exposure and the observed disease, determine if it is statistically significant and biologically meaningful. Several iterations of hypothesis development may be required.

- **Collect and test environmental and biological samples [Environmental Investigation]**

The findings of the 'epidemiological investigation' should guide the collection and testing of specimens and samples. The basis for these analytical tests is to compare affected and non-affected populations. These new data are added to previous data and information to accept or reject the prevailing hypothesis and develop a new one if rejected. This is essentially the differential diagnostic process.

- **Confirm or verify the diagnosis and the cases are 'real'.**

This is not necessarily immediate. Review clinical and laboratory findings for consistency and confirm or reject suspected diagnosis based on these analyses.

- **Prepare a written report**

It is important to summarize the investigation in a report that includes the reason for the investigation; general characteristics of the investigation, the clinical descriptions, results, conclusions on the nature of the disease, source of outbreak and method of transmission, and any possible recommendations for control or management.

- **Implement control/management strategies**

Disease management strategies for coral reefs must recognize the three basic determinants of disease: the host, the agent and the environment. The key to effecting disease outcomes is through successful manipulation of disease determinants and management or mitigation of related human impacts.