Vol. 91: 167–175, 2010
doi: 10.3354/dao02261

DISEASES OF AQUATIC ORGANISMS
Dis Aquat Org

Published September 2

AS I SEE IT

# Words matter: recommendations for clarifying coral disease nomenclature and terminology

**C. S. Rogers***

**US Geological Survey, Caribbean Field Station, St. John, US Virgin Islands 00830, USA**

ABSTRACT: Coral diseases have caused significant losses on Caribbean reefs and are becoming a greater concern in the Pacific. Progress in coral disease research requires collaboration and communication among experts from many different disciplines. The lack of consistency in the use of terms and names in the recent scientific literature reflects the absence of an authority for naming coral diseases, a lack of consensus on the meaning of even some of the most basic terms as they apply to corals, and imprecision in the use of descriptive words. The lack of consensus partly reflects the complexity of this newly emerging field of research. Establishment of a nomenclature committee under the Coral Disease and Health Consortium (CDHC) could lead to more standardized definitions and could promote use of appropriate medical terminology for describing and communicating disease conditions in corals. This committee could also help to define disease terminology unique to corals where existing medical terminology is not applicable. These efforts will help scientists communicate with one another and with the general public more effectively. Scientists can immediately begin to reduce some of the confusion simply by explicitly defining the words they are using. In addition, digital photographs can be posted on the CDHC website and included in publications to document the macroscopic (gross) signs of the conditions observed on coral colonies along with precisely written characterizations and descriptions.

KEY WORDS: Coral · Disease · Syndrome · Nomenclature



## INTRODUCTION

Progress in coral disease research requires collaboration and effective communication among experts across many different disciplines, including genetics, physiology, cell biology, ecology, pathology, microbiology, and epidemiology. Consensus on the meaning of the terms used to describe coral diseases, including gross lesions and microscopic pathologies, and precision in the use of these terms will facilitate effective communication among scientists and between scientists and the general public. Unfortunately, even the most basic terms are not being used consistently, and formal standards for disease identification and nomenclature are lacking (Richardson 1998, Woodley et al. 2003, Raymundo et al. 2008). In addition, some of the terms, many from biomedical and veterinary sciences, are not always directly applicable to corals. Although some of the inconsistent use of terms in the recent literature on coral diseases is without doubt a reflection of how little we know about them, every effort should be made to standardize the terminology, the procedure for naming coral diseases, and the process for describing gross and microscopic lesions.

The objective of this opinion paper is to focus greater attention on the inconsistent and often confusing use of terminology and nomenclature in papers on coral diseases and to make specific suggestions that will help to address this problem. The intent is to improve communication and highlight the need for resolution of these issues so that progress can be made more quickly in coral disease research. As Bush et al. (1997) pointed

*Email: caroline_rogers@usgs.gov

out in their discussion of the use and misuse of ecological terms in studies of parasite communities, effective communication is paramount for scientists. They strongly encouraged scientists, whether or not they agreed with their suggestions, to define the intended meaning of terms they used.

## DEFINING DISEASE

There seems to be consensus on the definition of disease. Peters (1997, p. 114) states:

> Disease is defined as any impairment (interruption, cessation, proliferation, or other disorder) of vital body functions, systems, or organs. Diseases are usually characterized either by (1) an identifiable group of signs (observed anomalies indicative of disease), and/or (2) a recognized etiologic or causal agent, and/or (3) consistent structural alterations (e.g. developmental disorders, changes in cellular composition or morphology, and tumors).

This definition is based on the medical dictionary by Stedman (1976). Recent reviews have abbreviated this to 'disease is an interruption, cessation or disorder of body functions, systems, or organs' (Sutherland et al. 2004, p. 278) or, similarly, 'any impairment of an organism's vital organ, system and/or body functions' (Weil 2004, p. 35). Wobeser (1981, p. 1) defines disease as

> …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.

Woodley et al. (2008) include the following categories of disease: bleaching, non-infectious diseases, trauma, parasitic infections, growth anomalies, and infectious diseases.

However, scientists studying and discussing coral diseases do not always use the term disease in the broad sense of the definitions above from Stedman (1976) and Wobeser (1981) (e.g. see p. 18 of the Coral Disease Handbook by Raymundo et al. 2008). Physical damage to corals from storms or vessel groundings would fit the description of disease, but we do not refer to corals with this type of damage as diseased. (Likewise, if a truck runs over someone's foot, the person would certainly be impaired but most people would not say that he or she had a disease. The word trauma would be appropriate here.) As another example, predation by snails results in tissue loss, but we do not normally refer to areas where snails consume tissue as diseased. The Coral Disease Handbook (Raymundo et al. 2008) distinguishes between tissue loss from disease and injuries from predation, disturbance (physical damage), and competition.

Most scientists consider coral bleaching a disease. Bleaching is often a sign of exposure to many stressors including high sea water temperature and high irradiance levels. Bleaching reflects the breakdown (impairment) of symbiosis between the coral host and the endosymbiotic zooxanthellae. In 2 coral species, bleaching has been reported to be associated with pathogenic bacteria (Kushmaro et al. 1997, Ben-Haim et al. 2003, Rosenberg 2004). Although bleaching certainly affects corals adversely in terms of their physiology and has an associated pathology, it seems inherently different from several of the other conditions many scientists refer to as coral disease which involve tissue loss. It is very common to see phrases like 'coral bleaching and disease' in the scientific literature, implying that they are different. Even some of the scientists who acknowledge that bleaching is a disease omit it from their comprehensive lists of identified diseases. Some refer to bacterial-induced bleaching of a few coral species, but not widespread, massive bleaching over entire coral reefs, as a disease.

In the field, the external signs of bleaching and diseases such as white plague and black band are quite different: bleached corals are characterized by relatively large areas (sometimes over the entire colony) of live tissue where loss of zooxanthellae reveals underlying coral skeleton, whereas both black band and white plague have distinct lines of advance where tissue loss has exposed coral skeleton. In addition, bleaching is reversible — i.e. corals can regain their zooxanthellae (or zooxanthellar pigments) and no tissue loss is involved, at least initially. In contrast, conditions typically referred to as diseases are associated with loss of coral tissue, often (although not always) with little or no subsequent regrowth or regeneration (e.g. Bruckner & Bruckner 2006). Although scientists seem to agree on the broad definition of disease (based on Stedman 1976; see above), they do not consistently use the word to describe conditions such as physical damage and bleaching that would be incorporated in this comprehensive definition.

Peters' (1997, p. 114) distinction between biotic and abiotic diseases is helpful. She defines biotic diseases as 'those in which the etiologic agent is a living organism such as a pathogen or parasite'. An abiotic disease occurs after exposure to environmental stresses such as toxic chemicals or changes in salinity, temperature, sedimentation, or water quality. However, as Peters (1997) notes, some diseases have both biotic and abiotic components. An infectious disease is a biotic disease in which bacteria, viruses, or other causal agents can spread from one host individual to another (Peters 1997, Stedman 2000). A non-infectious biotic disease, in contrast, can be caused by a microbial agent, but it is not transmitted between organisms (Raymundo et al.

2008). Many people use the term infectious to describe the coral diseases of interest today, but we certainly do not have enough data to say that the diseases we are observing today on coral reefs are all infectious or even of biotic origin. An opportunistic infection is one 'caused by existing microorganisms not normally pathogenic' (Raymundo et al. 2008, p. 102). In other words, under stress, corals can become more susceptible to the microorganism. Furthermore, changes in the environment can result in the microorganism becoming (more) virulent.

An initial focus on specific pathogens that fulfilled Koch's postulates (especially difficult to prove in the case of corals) has broadened to encompass studies of the complex microbial communities associated with corals and shifts in such communities when corals become diseased. Recently, there has been much debate over the relative importance of primary (referring to an initial infecting agent) and opportunistic pathogens (Lesser et al. 2007, Work et al. 2008). Work et al. (2008, p. 63) state that such arguments

> …reflect the lack of data available to prove or refute such hypotheses and emphasize the need for coral disease investigations that focus on: characterizing the normal microbiota and physiology of the healthy host; defining ecological interactions within the microbial community associated with the host; and investigating host immunity, host-agent interactions, pathology, pathogenesis, and factors that promote the pathogenicity of the causative agent(s) of disease.

Furthermore, Work et al. (2008) point out how little is known about the interactions among host, agent, and environment in the causation of coral diseases. It is worth noting that the individual coral is comprised of the coral animal, zooxanthellae, and other associated microbiological organisms (the coral holobiont; e.g. Reshef et al. 2006). Diseases may involve or affect any of these components.

## WHAT IS A SYNDROME?

There continues to be confusion among coral biologists over the definition of a syndrome. Perhaps this is at least partly because both syndrome and disease have been used in the names of particular diseases and groups of diseases with similar signs (e.g. dark spot syndrome, white syndrome). The words syndrome and disease have been used interchangeably in many scientific papers, including the Coral Disease Handbook (Raymundo et al. 2008). In human medicine, the words disease and syndrome are often used as synonyms. Are the terms synonymous, or not? Weil (2004, p. 35) states:

> The term disease is used here for any affliction for which the causative agent has been identified, and syndrome for those afflictions for which the causative agent is not known.

However, the following is from Work et al. (2008, p. 64):

> Disease is an interruption, cessation or disorder of body functions, systems, or organs (Stedman 1976). A syndrome is the aggregate of signs or symptoms that together comprise disease (Stedman 1976).

Work et al. (2008, p. 64) then conclude:

> Given this hierarchy, and given that one need not know the etiology of something to call it disease, the proposal by Lesser et al. (2007) to employ the term 'syndrome' rather than 'disease' for coral diseases of unknown etiology is inappropriate.

Although signs may not be specific or distinctive enough to sufficiently characterize a particular disease, the term disease would still be appropriate.

The reality is that only 5 causative agents have been identified, and most were identified for only a few coral species from a few locations. For example, white plague, one of the most devastating diseases (Miller et al. 2009), has been linked to a pathogen for *Dichocoenia stokesi* in the Florida Keys (Denner et al. 2003) but not for numerous other coral species with the signs of the disease.

## INCIDENCE AND PREVALENCE: HOW DO WE BEST QUANTIFY DISEASE?

There are different ways to quantify the amount of disease on a reef. These include calculating incidence and prevalence or the amount of coral cover with disease from photographs and video; estimating the percent of tissue loss; counting the number and size of disease lesions; and estimating total area killed by disease. In all cases, the actual area of reef that is being examined should be provided to give a framework for the assessments. Prevalence is defined consistently by most investigators as the percent of diseased individuals in a population at a point in time (Stedman 2000). However, this concept has not been examined very critically in the case of corals. It depends on identification or differentiation of individuals. For some species of corals (e.g. *Montastraea annularis*, *Porites porites*, and *Acropora cervicornis* in thickets) it is difficult, if not impossible, to delineate individuals in the field.

For example, *Montastraea annularis* is the most abundant coral on many Caribbean reefs, and it is not at all straightforward to identify separate colonies of this species — in fact it may not be possible in some locations (Fig. 1). This species has colonies with multiple lobes or columns that can grow in such a high density that their bases are obscured, making identification of separate colonies infeasible. If we arbitrarily decide to consider each column (lobe) of a colony an individual (albeit not necessarily a separate genotype), there are still problems; 124 columns were counted

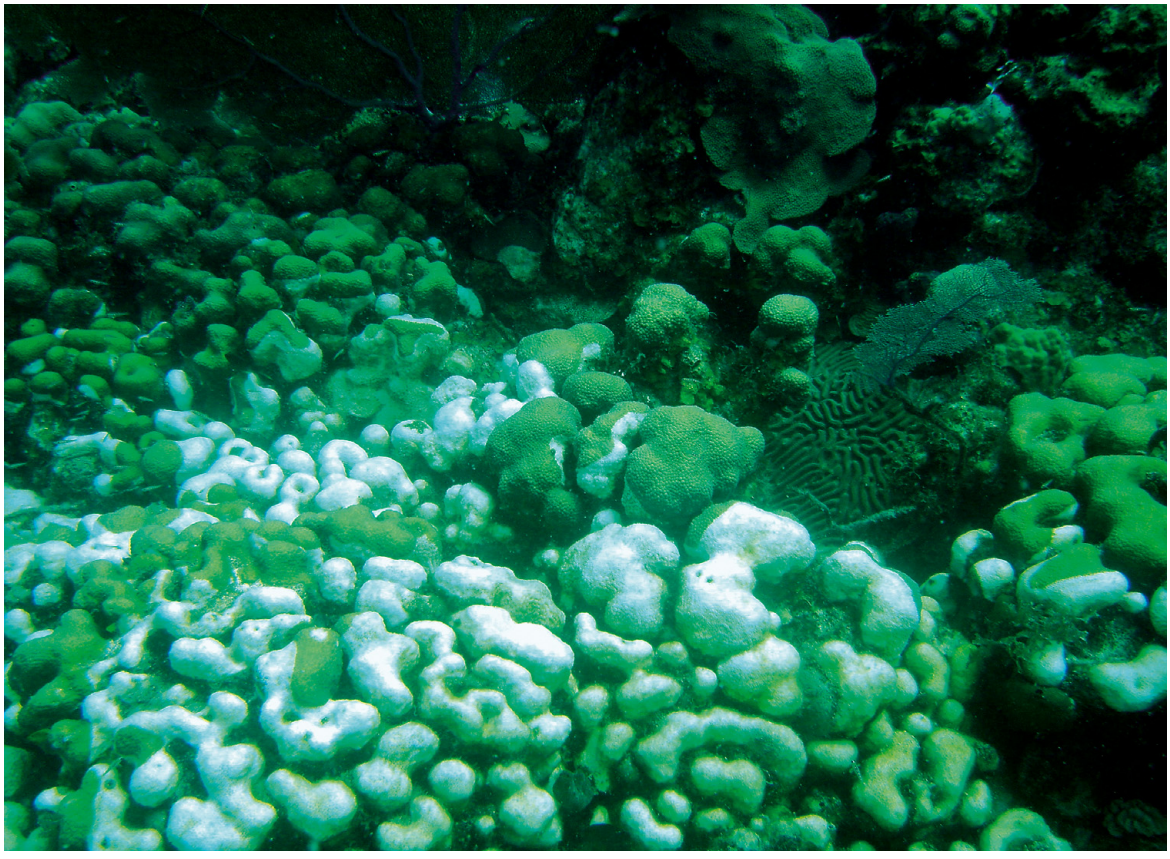

Fig. 1. *Montastraea annularis* colonies with signs of white plague disease, St. John, US Virgin Islands

in 1 $m^2$ at Tektite Reef, St. John, US Virgin Islands (J. Miller pers. obs.). The sheer number of columns in some study areas where this species is abundant and dense makes it prohibitively time consuming to determine a number of individuals for the calculation of prevalence. Also, the Atlantic and Gulf Rapid Reef Assessment (www.agrra.org) method excludes corals <10 cm in maximum dimension, which would omit many *M. annularis* columns but not necessarily all of the lobes/columns in what might generally be considered a single colony. Also, some *M. annularis* colonies have a combination of columns and other less regular structures that can make counting and keeping track of individuals very difficult. Even if counts are made just 0.5 m on either side of a transect (rather than 1 or 2 m on either side), the identification of individuals can be problematic at some sites. In addition, prevalence calculations typically reflect the number of genetically different individuals, whereas measurements of disease prevalence in corals will of necessity include genetically unique colonies as well as identical clones. Note also that prevalence of coral disease is usually calculated based on all coral species in the reef area of interest, not on just a single species.

There are options for evaluating diseases when doing field surveys in areas with multi-lobar colonies and thickets. In some cases, *Montastraea annularis* colonies (actually, groups of columns) may be small enough and isolated enough to be considered individual colonies. In cases where colonies cannot be clearly separated, it would be better to consider providing coral cover prevalence values. For example, if assessing random dots on still or video photographs, the coral cover prevalence value would be the percent of dots falling on diseased portions of corals divided by all dots that fall on live coral. These values could be compared over time for the same reef or compared to other reefs with similarly calculated values, but it would not be appropriate to compare them to values based on coral colonies rather than coral cover. In any case, people reporting results of disease surveys can reduce confusion and make it clear when comparisons are valid by carefully describing how they calculated disease prevalence in corals with problematic morphologies or growing in high density. When scientists report results from areas characterized by colonies with these morphologies or growing in high density, they can enable the reader to visual-

ize the study area by providing photographs and descriptions.

Stedman (2000) defines incidence as the number of individuals in a specified population with new cases of a disease during a specified time period. The emphasis here is on the word new, and the specification of a time period means that incidence is a rate. This statistic is used to convey the risk of developing the disease condition within a specified period of time. Because incidence depends on identification of individuals, the same problems arise as with the concept of prevalence when applied to corals. Also, most coral monitoring programs involve single annual surveys. The concepts of incidence and prevalence can become confusing when dealing with corals that are sampled that infrequently, and with diseases that stop and start across colonies. Prevalence is often a more appropriate term.

Prevalence and incidence are often misused. As Durfee (1978, p. 405) noted: 'Prevalence is what most people are talking about when they say incidence.' He provides excellent examples of both correct and misleading uses of these terms (see also Bush et al. 1997, their Fig. 1).

Numbers matter. A site where 1 out of 10 corals has disease has the same prevalence as a site where 10 colonies out of 100 have disease. The spatial extent is also important. What is the area of the reef that is being surveyed for disease? We have to be careful about comparing disease levels between reefs and especially between reefs in different regions, e.g. the prevalence of disease on the Great Barrier Reef vs. prevalence on a small patch reef in the Caribbean. Disease can be patchy (Borger 2003, Weil & Cróquer 2009), affecting one portion of a reef but not another; assigning a single number for prevalence and referring to the entire reef as having that prevalence can therefore be misleading. This problem can be resolved at least partially by indicating the total reef area that is being affected when comparing prevalence among regions. Another consideration is that most surveys are done once a year or only during outbreaks. However, prevalence can vary greatly even over short periods of time. We found monthly prevalence of white pox (white patch) disease ranging from 0 to 52% on *Acropora palmata* colonies off St. John (Rogers et al. 2008). Furthermore, use of different methods, e.g. exclusion of corals below a certain size, can lead to problems with comparisons even within the same geographic region.

Let's say that we have a study area with 100 colonies of 15 different species and let's pretend for the moment that we can actually count individual colonies. At the time of our first survey, 10 corals have disease, and 1 yr later at our second survey, 10 corals have disease. Prevalence is the same (10%), which might lead us to conclude that the diseases are not getting worse. However, we cannot have confidence in that statement even if we know that the same 10 colonies have disease in both Surveys because the disease could have advanced during the year, affecting larger portions of each infected colony. If the initial diseased colonies no longer had active disease but 10 different colonies were now diseased, the prevalence would remain the same but the disease would have affected twice as many colonies for the entire time period. In addition, different species could now be affected, and corals that initially had the disease could have lost over 95% of their tissue but still be present without active disease. This hypothetical example highlights the value of considering more than just prevalence when quantifying coral disease.

Prevalence is absence/presence per individual and does not give any indication of the severity of the disease, that is the number (and size) of the lesions that are present on individual colonies or the proportion of each colony that is affected. In other words, prevalence does not tell us about the quantitative effects of disease. It is possible for prevalence to remain the same while coral cover dramatically decreases. One way to quantify the severity of disease is to count the total number of disease lesions (observed on all coral colonies) and to calculate the actual total area of coral mortality in a defined study site by measuring the areas of all lesions and adding them together (Miller et al. 2009). This is very time consuming, but it allows for a much more accurate quantification of the severity of disease than calculations of prevalence alone.

## DISEASE OUTBREAKS

What is a disease outbreak? Can we quantify it? Does the word always imply that a large number of corals have been affected? If so, is there a threshold? Or can it just mean that suddenly we see disease where it has not been apparent before?

In the Coral Disease Handbook (Raymundo et al. 2008, p. 9), a disease is considered an outbreak when the rate at which new hosts become infected increases: 'Technically, an outbreak is defined as $R_0 > 1$. $R_0$ is the ratio of new infections to existing infections.' In their Field Manual for Investigating Coral Disease Outbreaks, Woodley et al. (2008, p. 5) state:

> 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.

These definitions may be sufficient in most cases. However, they do not indicate how much of an increase

in frequency would constitute an outbreak in practice. Note that an increase in $R_0$ could simply represent a slow rate of increase in the usual frequency of occurrence in the coral population rather than an outbreak. As noted in the Field Manual, few locations will have pre-existing data on the extent of disease before the outbreak. Neither of the definitions above has any specific sense of spatial or temporal scale. Reports of outbreaks should be accompanied by data that provide a rationale for using this term, for example indicating a large spatial area affected by active disease and/or the time period during which new disease lesions have appeared. For example, the word outbreak could refer to the first observation of disease in an individual coral species that is rare or common on a reef that has been studied for many years. If the coral is uncommon, the outbreak would likely be less damaging than if the coral is very abundant. An outbreak that persists for a month is less damaging than one that lasts for several months. A sense of spatial scale and time are required not only to determine if an outbreak is in fact occurring, but also to accurately gauge the possible outcome.

## NAMING OF CORAL DISEASES

Coral diseases to date have been named in a largely informal way, in the absence of any standards for nomenclature or any recognized authority with responsibility for names. In some cases, scientists have simply made up their own names to describe disease signs in the field. Work & Aeby (2006) proposed a framework for naming coral diseases, which includes the affected coral genus as well as the type of lesion. They note that it would be ideal to include the cause of the disease in the name as well, but acknowledge that the cause of coral diseases is not often known (Richardson 1998, Sutherland et al. 2004). Although their approach has many benefits, 1 potential problem is that some diseases have many hosts, causing a proliferation of names. White plague II signs have been observed on 41 coral species (Weil et al. 2006). Also, as noted earlier, only a few pathogens have been associated with diseases to date (Weil et al. 2006). Based on a single sample from 1 colony of *Dichocoenia stokesi* from Florida, Denner et al. (2003) reported that the pathogen for white plague II 'on Caribbean scleractinian corals' was *Aurantimonas coralicida*, a new genus and species. Subsequent research did not confirm the presence of this species in corals that apparently had this disease, suggesting that there may be a group of several diseases with similar signs in different coral species (Sunagawa et al. 2009, Polson et al. 2009).

Another complication that arises when naming diseases after the pathogen is that in some cases the reported pathogens do not continue to be pathogenic or they are not associated with what appears to be the same disease in different coral species or in different geographic locations. For example, Richardson & Aronson (2002) noted that colonies of *Dichocoenia stokesi* were partially killed during a white plague II outbreak in 1995; however, other colonies in this same population were subsequently not susceptible to the identified pathogen, possibly indicating that the corals adapted to the pathogen (Rosenberg et al. 2007). In another case, corals may have developed resistance to *Vibrio*-induced bleaching (Reshef et al. 2006). Patterson et al. (2002) suggested renaming white pox disease 'acroporid serratiosis,' a name which includes the host genus and the presence of the pathogen (*Serratia marcescens*). However, Polson et al. (2009) isolated bacteria from several *Acropora palmata* colonies in the US Virgin Islands and did not find *S. marcescens* in any of those that appeared to have white pox. Recently, Toledo-Hernandez et al. (2008) found that the fungus *Aspergillus sydowii* was not the pathogen associated with diseased sea fans in Puerto Rico. They point out that it is no longer appropriate to call this disease aspergillosis. In summary, naming coral diseases after the affected coral genus and the reported pathogen may make a great deal of sense, but this approach depends on the outcome of further research on the ability of corals to adapt to pathogens, the specificity of pathogens, and the role they play in coral diseases.

Also, because there are such a limited number of gross signs that characterize coral diseases, and the diseases are often not explicitly characterized in the literature, it is hard to be certain if scientists are consistently calling the diseases with the same signs the same name (e.g. Hayes & Goreau 1998). Bythell et al. (2004) note that white plague and white band are similar in gross appearance and have been separated based more on their host coral genera than on any definitive case definition. They discuss the confusion surrounding many similar white diseases and state the following (Bythell et al. 2004, p. 363):

> It appears that the visible signs of white band disease are well defined and distinct from those of WPII [WP = white plague] and white pox, indicating that there are at least three separate 'white' diseases. However, the distinction between WB [white band], WPI, WPIII patchy necrosis, rapid tissue necrosis and shut down reaction is unclear. No causal agent has been proven for these latter diseases, and until microbiological evidence is found to the contrary, we argue that the term 'white disease' should perhaps be used to collectively describe this set of signs on both massive corals and branched acroporid species.

Some people have argued that the 3 forms of white plague should not be separated. White plague I, II and III have been differentiated primarily on rate of advance, the coral genera that are affected, and, less

clearly, on gross appearance of the lesions (Richardson et al. 2001). We do not know if different rates of progression and different patterns of infection reflect different causal agents. White plague III is reported only for *Montastraea annularis* and *Colpophyllia natans* (Richardson & Aronson 2002), but it has been observed on *M. faveolata* in the US Virgin Islands as well (Patterson et al. 2006). It is also not clear if what some people now refer to as white plague I is similar to the general description of plague from the late 1970s (Dustan 1977).

Ainsworth et al. (2007) demonstrated the need to go beyond macroscopic signs when diagnosing disease. Only with histopathological and microbial investigation of *Favia* colonies from the Red Sea could black band disease be differentiated from what they termed 'atypical black band disease' which resembles 'white band/plague disease or white syndrome'.

The Coral Disease Handbook (Raymundo et al. 2008) is a very comprehensive and useful guide, which includes sections on describing and identifying diseases. Understandably, it does not resolve all of the confusion. In this guide, white band and white plague are described as being similar, with white band only seen on the acroporids and white plague on over 40 other coral species. It lists the following synonyms for white plague: plague type II, white plague type II, plague, white band disease, and white line disease. The guide refers to the field signs of white pox as 'white patch disease.' (Some investigators consider patchy necrosis and white pox to be the same disease and have replaced these names with white patch.) In addition, there is reference to 'Caribbean white syndrome.' This is described for acroporids and other species and characterized by 'tissue loss that is not characteristic of either white band or white plague.' For acroporids, it includes 'diseases that start within the colony and not at the base, and spread in irregular patterns.' The rates of progression are not available, and it is difficult to differentiate this from white patch disease on *Acropora palmata*. It is also not clear if this includes what has been termed 'rapid tissue loss' associated with a disease outbreak in 2003 in Florida (Williams & Miller 2005).

Over the last few years, with additional research, there has been an increased understanding of the complexity of these diseases, and a concomitant shifting away from more definitive disease names to more general ones (with a few exceptions). Caribbean white syndrome may be an appropriate term in some situations, but it sounds like 'North American human rash syndrome,' which can indicate poison ivy, dengue, measles, Lyme disease, and itchy wool sweaters. Only a limited number of signs are associated with coral diseases, and we are left with varying shapes (bands, blotches, spots, patches) and numbers of white, yellow, or dark lesions. That said, names are essential for discussions of coral syndromes and diseases, and they should be as descriptive as possible, moving from general to specific as research progresses and causative agents are identified. Photographs of the gross signs of disease should be included in all publications which propose disease names and which describe the effects of diseases on corals.

## CONCLUSIONS AND RECOMMENDATIONS

Given the inherent complexity of coral diseases and the current limited state of our knowledge, it is understandable that only further research will help to resolve some of these problems. However, consistent and precise use of basic terms will lead to more effective communication about coral diseases. As previously suggested (Woodley et al. 2003), a nomenclature committee could be formed under the auspices of the Coral Disease and Health Consortium (CDHC) and asked to reach consensus regarding definitions and proper usage, and to approve any new coral disease names that are proposed. After a review period, their decisions could be posted on the CDHC website along with a glossary of terms. This website could be a focal point for discussions including announcements of outbreaks, identification of new coral syndromes and diseases, publication of new papers, and so on. In addition, a workshop or special symposium session on coral disease terminology (nomenclature) should be held, and the proceedings published and posted on the website.

Scientists reporting the results of field research should always describe the lesions they observed, using terms presented in Work & Aeby (2006) and the decision tree provided in the Coral Disease Handbook (Raymundo et al. 2008, p. 20), and they should provide photographs of the disease lesions, even in cases where the signs look like already-described diseases. Subsequent monitoring of individual coral colonies with diseases is often very helpful, especially when trying to differentiate between similar diseases such as white band type I and white band type II.

Many scientists have pointed out the need to combine field work with laboratory analyses, including molecular and microbiological investigations, to better characterize coral diseases (e.g. Richardson et al. 2001, Ainsworth et al. 2007, Work et al. 2008). Work et al. (2008, p. 63) note:

> Investigating disease in corals should follow a logical series of steps including identification of disease, systematic morphologic descriptions of lesions at the gross and cellular levels, measurement of health indices, and experiments to understand disease pathogenesis and the complex interactions between host, pathogen, and environment.

Clearly, multi-disciplinary teams of scientists with the required (often very specialized) expertise are necessary if real progress is to be made.

One of the highest research priorities is to determine the links between coral diseases and human activities with the hope that management can reverse at least some of the global decline in coral reefs. Coral diseases often 'fall between the cracks' in overall assessments of stressors affecting reefs because they do not fit neatly into either of the 2 categories that are often used: human-related stressors and natural and climate-related stressors. Another research priority, as noted in the Coral Disease Handbook (Raymundo et al. 2008, p. 16), is the assessment of 'the global prevalence of coral disease'. It will be much easier for scientists to accomplish these objectives if we 'come to terms', literally, with how we communicate with each other and with the public.

*Acknowledgements.* Sincere appreciation to many friends and colleagues who have shared my confusion, and who have worked very hard to understand the ravages of coral diseases in the field and in the laboratory. Special thanks to L. Richardson for her encouragement over the years and for constructive comments on this paper. An anonymous reviewer provided an especially insightful and comprehensive review which provides ideas for future discussions. I thank C. Woodley and M. Lesser for particularly helpful reviews of earlier versions of this paper. Special thanks to J. Miller, E. Peters, G. Cook, E. Weil, C. Downs, E. Muller, M. Miller, and D. Williams for their suggestions and for lively discussions about coral diseases.

## LITERATURE CITED

Ainsworth TD, Kramasky-Winter E, Loya Y, Hoegh-Guldberg O, Fine M (2007) Coral disease diagnostics: What's between a plague and a band? Appl Environ Microbiol 73:981–992

Ben-Haim Y, Thompson FL, Thompson CC, Cnockaert MC, Hoste B, Swings J, Rosenberg E (2003) *Vibrio coralliilyticus* sp. nov., a temperature-dependent pathogen of the coral *Pocillopora damicornis*. Int J Syst Evol Microbiol 53: 309–315

Borger JL (2003) Three scleractinian coral diseases in Dominica, West Indies: distribution, infection patterns and contribution to coral tissue mortality. Rev Biol Trop 51 (Suppl 4):25–38

Bruckner AW, Bruckner RJ (2006) The recent decline of *Montastraea annularis* (complex) coral populations in western Curacao: A cause for concern? Rev Biol Trop 54(Suppl 3): 45–58

Bush AO, Lafferty KD, Lotz JM, Shostak AW (1997) Parasitology meets ecology on its own terms: Margolis et al. revisited. J Parasitol 83: 575-583

Bythell JC, Pantos O, Richardson LL (2004) White plague, white band, and other 'white' diseases. In: Rosenberg E, Loya Y (eds) Coral health and disease. Springer-Verlag, Berlin, p 351–365

Denner EBM, Smith G, Busse HJ, Schumann P and others (2003) *Aurantimonas coralicida* gen. nov., sp. nov., the causative agent of white plague type II on Caribbean scleractinian corals. Int J Syst Evol Microbiol 53:1115–1122

Durfee PT (1978) Incidence and prevalence defined. Aust Vet J 54:405–406

Dustan P (1977) Vitality of reef coral populations off Key Largo, Florida: recruitment and mortality. Environ Geol 2:51–58

Hayes R, Goreau N (1998) The significance of emerging diseases in the tropical coral reef ecosystem. Rev Biol Trop 46(Suppl 5):173–185

Kushmaro A, Rosenberg E, Fine M, Loya Y (1997) Bleaching of the coral *Oculina patagonica* by *Vibrio* AK-1. Mar Ecol Prog Ser 147:159–165

Lesser MP, Bythell JC, Gates RD, Johnstone RW, Hoegh-Guldberg O (2007) Are infectious diseases really killing corals? Alternative interpretations of the experimental and ecological data. J Exp Mar Biol Ecol 346:36–46

Miller J, Muller E, Rogers C, Atkinson A, Whelan K, Patterson M, Witcher B (2009) Coral disease following massive bleaching in 2005 causes 60% decline in coral cover on reefs in the US Virgin Islands (USVI). Coral Reefs 28: 925–937

Patterson KL, Porter JW, Ritchie KB, Polson SW and others (2002) The etiology of white pox, a lethal disease of the Caribbean elkhorn coral, *Acropora palmata*. Proc Natl Acad Sci USA 99:8725–8730

Patterson M, Rogers C, Schill B, Miller J (2006) Coral bleaching and disease deliver 'one-two punch' to coral reefs in the US Virgin Islands. National Park Service, Palmetto Bay, FL

Peters EC (1997) Diseases of coral reef organisms. In: Birkeland C (ed) Life and death of coral reefs. Kluwer Academic Publishers, New York, NY, p 114–136

Polson SW, Higgins JL, Woodley CM (2009) PCR-based assay for detection of four coral pathogens. Proc 11th Int Coral Reef Symp 1:251–255

Raymundo LJ, Couch CS, Harvell CD (eds) (2008) Coral disease handbook: guidelines for assessment, monitoring and management. Coral reef targeted research and capacity building for management program, University of Queensland, St. Lucia, QLD

Reshef L, Koren O, Loya Y, Zilber-Rosenberg I, Rosenberg E (2006) The coral probiotic hypothesis. Environ Microbiol 8:2068–2073

Richardson LL (1998) Coral diseases: What is really known? Trends Ecol Evol 13:438–443

Richardson LL, Aronson RB (2002) Infectious diseases of reef corals. Proc 9th Int Coral Reef Symp 2:1225–1230

Richardson LL, Smith GW, Ritchie KB, Carlton RG (2001) Integrating microbiological, microsensor, molecular, and physiologic techniques in the study of coral disease pathogenesis. Hydrobiologia 460:71–89

Rogers CS, Miller J, Muller EM, Edmunds P and others (2008) Ecology of coral reefs in the US Virgin Islands. In: Riegl B, Dodge RE (eds) Coral reefs of the USA. Springer, Dordrecht, p 303–374

Rosenberg E (2004) The bacterial disease hypothesis of coral bleaching. In: Rosenberg E, Loya Y (eds) Coral health and disease. Springer, Berlin, p 445–461

Rosenberg E, Koren O, Reshef L, Efrony R, Zilber-Rosenberg I (2007) The role of microorganisms in coral health, disease and evolution. Nat Rev Microbiol 5:355–362

Stedman TL (1976) Stedman's medical dictionary. William and Wilkins Company, Baltimore, MD

Stedman TL (2000) Stedman's medical dictionary. William and Wilkins Company, Baltimore, MD

Sunagawa S, DeSantis T, Piceno Y, Brodie E and others (2009) Bacterial diversity and white plague disease-associated community changes in the Caribbean coral *Montastraea faveolata*. Int Soc Microbial Ecol 3:1–10

Sutherland KP, Porter JW, Torres C (2004) Disease and immunity in Caribbean and Indo-Pacific zooxanthellate corals. Mar Ecol Prog Ser 266:273–302

Toledo-Hernandez C, Zuluaga-Montero A, Bones-Gonzalez A, Rodriguez JA, Sabat AM, Bayman P (2008) Fungi in healthy and diseased sea fans (*Gorgonia ventalina*): Is *Aspergillus sydowii* always the pathogen? Coral Reefs 27: 707–714

Weil E (2004) Coral reef diseases in the wider Caribbean. In: Rosenberg E, Loya Y (eds) Coral health and disease. Springer, Berlin, p 35–68

Weil E, Cróquer A (2009) Spatial variability in distribution and prevalence of Caribbean scleractinian coral and octocoral diseases. I. Community-level analysis. Dis Aquat Org 83:195–208

Weil E, Smith G, Gil-Agudelo DL (2006) Status and progress in coral reef disease research. Dis Aquat Org 69:1–7

Williams DE, Miller MW (2005) Coral disease outbreak: pattern, prevalence and transmission in *Acropora cervicornis*. Mar Ecol Prog Ser 301:119–128

Wobeser GA (1981) Diseases of wild waterfowl. Plenum Press, New York, NY

Woodley CM, Bruckner AW, Galloway SB, McLaughlin SM and others (2003) Coral disease and health: a national research plan. NOAA, Silver Spring, MD

Woodley CM, Bruckner AW, McLenon AL, Higgins JL, Galloway SG, Nicholson JH (2008) Field manual for investigating coral disease outbreaks. NOAA Tech Memo NOS NCCOS 80 and CRCP 6, NOAA, Silver Spring, MD

Work TM, Aeby GS (2006) Systematically describing gross lesions in corals. Dis Aquat Org 70:155–160

Work TM, Richardson LL, Reynolds TL, Willis BL (2008) Biomedical and veterinary science can increase our understanding of coral disease. J Exp Mar Biol Ecol 362:63–70

*Editorial responsibility: Alex Hyatt, Geelong, Australia*

*Submitted: February 4, 2010; Accepted: June 28, 2010*
*Proofs received from author(s): August 11, 2010*