Vol. 87: 1–3, 2009
doi: 10.3354/dao02177

DISEASES OF AQUATIC ORGANISMS
Dis Aquat Org

Published November 16

Contribution to DAO Special 5 'The role of environment and microorganisms in diseases of corals'

INTRODUCTION

The role of environment and microorganisms in diseases of corals: overview of DAO Special 5

Kiho Kim[1,*], Cathie A. Page[2], C. Drew Harvell[3]

[1]Department of Environmental Science, American University, Washington, DC 20016, USA
[2]School of Marine and Tropical Biology and ARC Centre of Excellence for Coral Reef Studies, James Cook University, Townsville, Queensland 4811, Australia
[3]Department of Ecology & Evolutionary Biology, Cornell University, Ithaca, New York 14853, USA

ABSTRACT: Coral reefs are in decline worldwide. In the last several decades, bleaching and disease in a warming ocean have emerged as dominant drivers of ecological change on coral reefs. This special issue of DAO presents papers based on presentations from the 11th International Coral Reef Symposium (2008, Fort Lauderdale, Florida, USA). The articles herein document disease outbreaks involving novel hosts, pathogens and/or locations, experimental studies investigating processes and mechanisms underlying pathogen dynamics, and the application of increasingly sophisticated laboratory and modeling approaches to understanding disease epizootiology.

KEY WORDS: Coral · Disease · Bleaching · Climate change · Epizootiology · Modelling

Coral reefs are in decline worldwide. Subject to multiple, anthropogenically-derived stressors, corals have been declining for centuries, although the nature of the stressors has changed (Pandolfi et al. 2003). In the last several decades, bleaching and disease in a warming ocean have emerged as dominant drivers of ecological change on coral reefs (Harvell et al. 2002). The growing concern and interest in the field of coral disease are reflected in the doubling of the number of papers given on this topic over the last 2 International Coral Reef Symposia. In recognition of this, the very first *Diseases of Aquatic Organisms* Special (Vol. 69, No. 1) was dedicated to papers on coral diseases from the 10th International Coral Reef Symposium (2004, Okinawa, Japan) and this current Special to papers from the 11th International Coral Reef Symposium (2008, Fort Lauderdale, Florida, USA).

It has been a decade since Richardson (1998) noted both the nascence of the field of coral disease ecology — as indicated by the lack of common protocol for describing the various 'diseases' affecting corals — and optimism about progress being made on the few syndromes for which the pathogen had been identified. That the field has matured since then is reflected in the shift from descriptive to experimental studies investigating processes and mechanisms underlying disease dynamics, and the application of increasingly sophisticated laboratory and modeling approaches. This special issue represents a sampling of these efforts.

Several years ago, Ward & Lafferty (2004) used a meta-analysis of the published literature to support the prevailing thought at the time that diseases of marine organisms were on the rise. However, they found that for corals, the increase is supported only if bleaching is included. Sokolow (2009, this Special) reports that if more recent studies are included, coral diseases do indeed appear to be on the rise, even without the inclusion of bleaching. Sokolow (2009) also shows that ocean warming is a key feature of coral disease dynamics. If this is the case, we would expect that proximity to human activity (i.e. local drivers) should not be a prerequisite for disease. Indeed, Bruckner &

*Email: kiho@american.edu

Hill (2009, this Special) found that coral reefs of Isla Mona, a remote island west of Puerto Rico, are in a disease-driven decline in spite of being some distance from any human activity. Part of the decline appears to result from the reproductive failure among *Montastrea faveolata,* an important framework species in the Caribbean, infected with yellow band disease (Weil et al. 2009, this Special).

Although disease and bleaching have generally been viewed as different, there is growing appreciation that perhaps they are linked through the effects of environmental stress (Harvell et al. 2001). A commonly held hypothesis is that bleaching taxes the coral host metabolically, thus increasing its disease susceptibility. Support for this hypothesis comes from Croquer & Weil (2009, this Special) who show that intensity of bleaching was correlated with subsequent disease prevalence. They note, however, that the bleaching–disease relationship is complicated, being sensitive to habitat (e.g. depth) and coral species. A more thorough treatment of the bleaching–disease hypothesis requires knowledge of the mechanism of pathogenesis. This knowledge, however, has been slow in coming due to the difficulty of identifying causative agents of disease and a limited understanding of host disease resistance mechanisms, among other things.

For the few confirmed host–pathogen disease systems, understanding the microbial ecology of the coral surface has yielded new insights into pathogenesis. The nutrient-rich mucus layer of the coral surface supports a diverse assemblage of bacteria whose role is not yet entirely clear. One hypothesis is that the resident or commensal bacteria prevent colonization or uncontrolled growth of potential pathogens. In support of this, Krediet et al. (2009, this Special) showed that pathogens such as *Serratia marcescens* utilize carbon sources which are unused (or underused) by the commensal microbiota. One implication of this is that factors which 'open up' niches (e.g. temperature-mediated shifts in the commensal surface microbiota) will increase disease susceptibility.

Once established, the pathogen is likely to face a gauntlet of host defenses including elevated levels of lysozyme-like activity and the production of antibacterial peptides, as is the case in the Caribbean coral *Montastrea faveolata* (Mydlarz et al. 2009, this Special). In the case of black band disease (BBD) of Caribbean corals, Richardson et al. (2009, this Special) showed that toxic sulfides are required for BBD initiation, though not for disease progress. However, much is still unknown. Although BBD is among the best characterized of all coral diseases, Rasoulouniriana et al. (2009, this Special) report on the discovery of a novel constituent of the microbial consortium responsible for BBD in the Red Sea.

Although the Caribbean has been the main focus of coral disease research for several decades, coral diseases are now increasingly being reported from other regions around the world. Until recently, the general lack of data from the tropical Pacific (Page & Willis 2006) has been especially conspicuous given the importance of this region as a center of coral abundance and diversity. Surveys carried out by Myers & Raymond (2009, this Special) indicate that in Guam, diseases of *Porites*, which are dominant reef building species, are having a significant impact on the reefs. In contrast, Haapkylä et al. (2009, this Special) found very low disease prevalence among reefs in Sulawesi, Indonesia; however, they express concern regarding high rates of disease progression among the acroporids, which are also important framework species.

Determining whether diseases are in fact a significant threat to the long-term health of coral reefs requires the ability to predict rather than simply document change. In this regard, models can be powerful tools, but the challenge is to appropriately construct and parameterize them. Using 6 yr of field monitoring data, Brandt & McManus (2009, this Special) describe the development of an individual-based model aptly named SICO to predict the long-term disease-driven decline of coral reefs in the Cayman Islands, British West Indies. Models can also inform the identification and assessment of potential intervention strategies, which makes such efforts essential.

From an environmental management perspective, an important tool is the marine protected area (MPA). Although there is compelling evidence for the efficacy of MPAs in reconstituting fish populations, it is unclear whether they offer similar benefits to other ecosystem components. In Palau, Page et al. (2009, this Special) did not find clear support for a positive effect of MPAs on coral disease; however, the authors note the potential role that fish diversity can play in reducing coral disease, and call for additional studies.

Much has been accomplished since Richardson's (1998) landmark paper: this special issue gives a broad overview of some of the progress made in the field. But much more needs to be done given that diseases are now conspicuous features of coral reefs worldwide, and their impact is only expected to increase. While useful for baseline data collection, more observational research alone is insufficient; controlled experimental studies are now required to develop a clearer understanding of the problem (i.e. causes and consequence), in order to devise and prioritize intervention and management efforts when opportunities arise. In this regard, it is of special note that we present this entire issue as an Open Access document. We believe this will better facilitate the sharing of this important knowledge, especially given that the information is

often most needed in places least able to access it in a timely manner. It is our sincerest hope that 10 yr from now, we will be able to reflect on the success of efforts to protect and preserve our planet's coral reefs.

Acknowledgements. We acknowledge the tremendous work of the organizing committee of 11th International Coral Reef Symposium. We are also grateful for the assistance from DAO in pulling this special issue together. Finally, support from NOAA FLK-2006 to K.K.; Palau International Coral Reef Centre, James Cook University and the ARC Centre of Excellence for Coral Reef Studies to C.A.P.; and the Coral Reef Targeted Research Program to C.D.H. is greatly appreciated.

LITERATURE CITED

Brandt ME, McManus JW (2009) Dynamics and impact of the coral disease white plague: insights from a simulation model. Dis Aquat Org 87:117–133

Bruckner AW, Hill RL (2009) Ten years of change to coral communities off Mona and Desecheo Islands, Puerto Rico, from disease and bleaching. Dis Aquat Org 87:19–31

Cróquer A, Weil E (2009) Changes in Caribbean coral disease prevalence after the 2005 bleaching event. Dis Aquat Org 87:33–43

Haapkylä J, Unsworth RKF, Seymour AS, Melbourne-Thomas J, Flavell M, Willis BL, Smith DJ (2009) Spatio-temporal coral disease dynamics in the Wakatobi Marine National Park, South-East Sulawesi, Indonesia. Dis Aquat Org 87: 105–115

Harvell CD, Kim K, Quirolo C, Weir J, Smith GW (2001) El Niño associated bleaching in *Briareum asbestinum* (Gorgonacea) and subsequent mortality from disease in the Florida Keys. Hydrobiologia 460:97–104

Harvell CD, Mitchell CE, Ward JR, Altizer S, Dobson A, Ostfeld RS, Samuel MD (2002) Climate warming and disease risks for terrestrial and marine biota. Science 296: 2158–2162

Krediet CJ, Ritchie KB, Teplitski M (2009) Catabolite regulation of enzymatic activities in a white pox pathogen and commensal bacteria during growth on mucus polymers from the coral *Acropora palmata*. Dis Aquat Org 87:57–66

Mydlarz LD, Couch CS, Weil E, Smith G, Harvell CD (2009) Immune defenses of healthy, bleached and diseased *Montastraea faveolata* during a natural bleaching event. Dis Aquat Org 87:67–78

Myers RL, Raymundo LJ (2009) Coral disease in Micronesian reefs: a link between disease prevalence and host abundance. Dis Aquat Org 87:97–104

Page C, Willis B (2006) Distribution, host range and large-scale spatial variability in black band disease prevalence on the Great Barrier Reef, Australia. Dis Aquat Org 69: 41–51

Page CA, Baker DM, Harvell CD, Golbuu Y and others (2009) Influence of marine reserves on coral disease prevalence. Dis Aquat Org 87:135–150

Pandolfi JM, Bradbury RH, Sala E, Hughes TP and others (2003) Global trajectories of the long-term decline of coral reef ecosystems. Science 301:955–958

Rasoulouniriana D, Siboni N, Ben-Dov E, Kramarsky-Winter E, Loya Y, Kushmaro A (2009) *Pseudoscillatoria coralii* gen. nov., sp. nov., a cyanobacterium associated with coral black band disease (BBD). Dis Aquat Org 87:91–96

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

Richardson LL, Miller AW, Broderick E, Kaczmarsky L, Gantar M, Staniç D, Sekar R (2009) Sulfide, microcystin, and the etiology of black band disease. Dis Aquat Org 87: 79–90

Sokolow S (2009) Effects of a changing climate on the dynamics of coral infectious disease: a review of the evidence. Dis Aquat Org 87:5–18

Ward JR, Lafferty KD (2004) The elusive baseline of marine disease: Are diseases in ocean ecosystems increasing? PLoS Biol 2:e120, doi:10.1371/journal.pbio.0020120

Weil E, Cróquer A, Urreiztieta I (2009) Yellow band disease compromises the reproductive output of the Caribbean reef-building coral *Montastraea faveolata* (Anthozoa, Scleractinia). Dis Aquat Org 87:45–55