Zooxanthella Distributions in the Major Reef-Building Coral of the Mesoamerican Reef, *Montastrea annularis*: a tool for understanding historical bleaching patterns and predicting future reef resilience

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Executive Summary

The Mesoamerican Reef includes the longest barrier reef in the western hemisphere, with a diverse array of associated reef types. The core of this reef system in Belize did not suffer a major bleaching event until 1995, when approximately 52% of corals were affected and 10% of colonies suffered at least partial mortality (McField 1999). More recently there have been dramatic declines in live coral cover attributed to the 1998 bleaching, including nearly 100% loss on central lagoonal reefs and 50% loss at 12 fore reef sites, associated with the combined effects of bleaching and a hurricane (Aronson et al. 2000; McField 2002). Several regional threats assessments have identified coral bleaching associated with climate change as a primary threat to the region (Kramer and Kramer 2002; FAO 2000).

In response to concerns about the future of this reef ecosystem, World Wildlife Fund (WWF) and Scripps Institution of Oceanography (SIO) are collaborating to understand the variability in response observed during bleaching events using knowledge of the coral-zooxanthellae symbiosis and to determine whether this knowledge may inform resilience-based management in the region. Although differential bleaching patterns have been explained by patterns of zooxanthella diversity (Knowlton and Rowan 1995; Rowan et al. 1997), zooxanthella diversity has never been used to understand patterns of bleaching across a spatial scale as large as the Mesoamerican Reef or in the context of managing reef resilience.

Ecosystem resilience is the ability of an ecosystem to undergo changes, but maintain the ecosystem structure and function (Nystrom and Folke 2001; Holling 1995). Corals of the same species that host different clades of zooxanthella (*Symbiodinium*) respond differently to stress, or have different levels of resistance and/or resilience. This results in patterns of coral bleaching that often cannot be explained by coral taxonomy alone (Rowan et al. 1997). Experimental bleaching of corals and studies of the distribution of zooxanthellae provide two potential mechanisms for the observed patterns of bleaching (Toller et al. 2001a,b). First, corals may resist bleaching by associating with stress tolerant zooxanthellae. Second, corals may be able to survive bleaching through repopulation with stress tolerant zooxanthellae (Toller et al. 2001b, Baker 2001).

In 2003, Melanie McField (WWF-Belize) and Sheila Walsh (SIO) began to study the coral-zooxanthellae symbiosis across the Mesoamerican Reef in order to understand historical patterns of coral bleaching and contribute to the prediction of future reef resilience. In the first phase of the program, Melanie McField and Sheila Walsh designed a sampling scheme that would allow them to compare patterns of zooxanthella diversity to the well described patterns of bleaching observed by Melanie McField in the 1995 mass-bleaching event (see McField 1999). Melanie McField's study of the 1995 mass-bleaching event was unique because of its rapid initiation (2 weeks after start of mass bleaching) and its broad spatial coverage of a major Caribbean reef system. During the 1995 mass-bleaching event, colonies of the *Montastrea annularis* complex were the most affected corals across the region (76%). The extent of bleaching observed across the region was most similar within habitat types based on a Bray-Curtis similarity analysis

(backreef ~ 1m, 60-75% similarity; forereef ~ 12m, 50-75% similarity). Five of the ten most common scleractinian corals exhibited significant differences in bleaching across habitats. *M. annularis* and *S. siderea* were more bleached in forereef sites, while *Porites porites*, *Agaricia tenuifolia*, and *Agaricia* were more bleached in backreef sites. Also, corals previously reported to host *Symbiodinium* C (Baker and Rowan 1997), were significantly more bleached (P = 0.005) than corals reported to host *Symbiodinium* B (Baker and Rowan 1997). Although *Montastrea annularis* is the dominant reef-building coral and was the most affected during the bleaching event, it could not be included in this analysis because it is capable of hosting all four clades of *Symbiodinium*. Without knowledge of the distribution of zooxanthellae hosted by *Montastrea annularis* on the Mesoamerican Reef, the observed patterns of bleaching in *Montastrea annularis* and the general spatial pattern of bleaching across the region could not be fully explained in terms zooxanthellae conferred resistance to bleaching.

However, Sheila Walsh's analysis of the distribution of zooxanthellae hosted by colonies of *Montastrea annularis* has now provided some insight into these patterns. Sheila Walsh sampled corals at seventeen sites across the Mesoamerican Reef that were chosen to represent the main regions of reef system: northern, central, and southern barrier reef and atolls. At each location, samples were collected from colonies of *Montastrea annularis* in each of the available reef habitats. Zooxanthella distributions were found to differ significantly across habitats (n = 56, $X^2 = 9.41$, P < 0.01). In backreef habitats, 11% of colonies host *Symbiodinium* A, while 89% of colonies host *Symbiodinium* B. However, in forereef habitats, 79% of colonies host *Symbiodinium* B, while 21% of colonies host *Symbiodinium* C. Using the ranked fitness of these zooxanthella clades under bleaching conditions (A>B>>C) (Rowan et al. 1997), this observed distribution of zooxanthellae would have predicted the bleaching patterns observed in 1995. *Montastrea annularis* was more bleached in forereef sites likely because a higher percentage of colonies host stress in-tolerant zooxanthellae (*Symbiodinium* C) and less bleached in backreef sites because a higher percentage of colonies host stress tolerant zooxanthellae (*Symbiodinium* A). The pattern in *Montastrea annularis* may have also accounted for the general pattern of bleaching to be more similar within habitat types because *Montastrea annularis* is the dominant reef-building coral and was the most affected during the 1995 mass-bleaching event.

The second phase of this program is to field-test our ability to predict coral resilience based on our knowledge of zooxanthella distributions. The World Wildlife Fund and Scripps Institution of Oceanography are planning to team-up with researchers from The Nature Conservancy and Wildlife Conservation Society to field-test a variety of factors that are responsible for the variability observed during bleaching events and determine which factors can be used in designing a resilience-based management strategy for the region. TNC's Reef Resilience (R^2) Toolkit will be used as a framework for designing and field-testing this conceptual model of reef resiliency, based on natural variations in key environmental conditions and incorporating of the latest research on reef connectivity.

This research program will contribute to the conceptual understanding of the factors controlling the resilience of corals to bleaching while informing the design of a resilience-based management strategy. Understanding the actual characteristics that confer resilience to corals is critical to management because it allows managers to measure specific parameters and adapt their management strategies based on known relationships. Resilience-based management will provide specific solutions to the problems that climate change has posed to coral reef management.

Publications

Walsh, S. and M. McField. (in press). Understanding patterns of bleaching in the Mesoamerican Reef: A collaborative effort to support resilience-based management. H. Schuttenberg and P. Marshall, eds. Responding to global change: a reef manager's guide to coral bleaching. NOAA, Washington, D.C.

Walsh, S., M. McField, and N. Knowlton. (in preparation). Zooxanthellae community structure across the Mesoamerican Barrier Reef explains historical bleaching patterns.