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Bleaching in foraminifera with algal symbionts: Implications for reef monitoring and risk assessment

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Reef-dwelling larger foraminifers share key characteristics with reef-building corals: both groups are prolific producers of calcium carbonate, both groups are physiologically dependent upon algal endosymbionts, and representatives of both groups have suffered bleaching episodes in recent decades. Bleaching was first observed in *Amphistegina* spp., which host diatom endosymbionts, during laboratory experiments aimed at determining optimal culture conditions. Bleaching in field specimens was first noted during a coral post-bleaching survey in the Bahamas in 1988. Since 1991, bleaching has been observed in populations of *Amphistegina* in all subtropical oceans, with peak bleaching in 1992 and a secondary peak in 1998. *Amphistegina* populations exhibiting chronic, intermediate-intensity bleaching characteristically show anomalously high incidences of shell breakage, shell deformities, evidence of predation, and microbial infestation. Asexual reproduction is profoundly affected; broods from partly bleached parents typically have fewer individuals, many of which are anomalous in shape and size; sometimes whole broods fail to calcify. Two key differences between bleaching in corals and *Amphistegina* are:

1) corals typically bleach by expelling their symbionts, while *Amphistegina* bleach when damaged symbionts are digested; and
2) mass coral bleaching requires high light but correlates most consistently with elevated temperatures, while bleaching in *Amphistegina* is induced by light.

Amphistegina exposed to chronic photoinhibitory stress in laboratory cultures exhibit visible bleaching that is cytologically indistinguishable from bleaching in field specimens. *Amphistegina* appear to be particularly sensitive to the shorter (300-490 nm) wavelengths of solar radiation, which have increased in intensity relative to longer visible wavelengths (>490-700 nm) in clear reef waters over the past 30 years as a consequence of stratospheric ozone depletion.

The FoRAM Photic Index is proposed as a low-cost risk-assessment tool based upon densities and visual assessments of *Amphistegina* populations. These protists are sensitive to environmental conditions over days to weeks, and provide a method to quickly distinguish between water quality (local) and photo-oxidative (global) stresses. Low abundances on reef rubble, with little or no bleaching, indicate unsuitable local conditions. Abundances of *Amphistegina* relative to bleaching prevalence and intensity indicate presence and degree of photooxidative stress. Risk assessments based on the combined use of *in situ* measurements and low-cost bioindicators can provide resource managers with essential information to decide when more costly chemical or molecular procedures are needed to determine local sources of stress. Such information can facilitate management actions to protect or restore reef resources.