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Link between sewage-derived nitrogen pollution and coral disease severity in Guam

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ABSTRACT

The goals of this study were to evaluate the contribution of sewage-derived N to reef flat communities in Guam and to assess the impact of N inputs on coral disease. We used stable isotope analysis of macroalgae and a soft coral, sampled bimonthly, as a proxy for N dynamics, and surveyed *Porites* spp., a dominant coral taxon on Guam's reefs, for white syndrome disease severity. Results showed a strong influence of sewage-derived N in nearshore waters, with $\delta^{15}N$ values varying as a function of species sampled, site, and sampling date. Increases in sewage-derived N correlated significantly with increases in the severity of disease among *Porites* spp., with $\delta^{15}N$ values accounting for more than 48% of the variation in changes in disease severity. The anticipated military realignment and related population increase in Guam are expected to lead to increased white syndrome infections and other coral diseases.

1. Introduction

In nearshore systems, sources of nitrogen (N) include land-based run-off, offshore upwelling, and atmospheric deposition. As in many places around the world, the last century has seen an unprecedented increase in N inputs from land-based sources to the nearshore waters around Guam, first from synthetic fertilizer use in agriculture beginning in the 1950s and more recently from land-use shifts resulting in huge increases in sewage inputs from expanding coastal populations (Baker et al., 2010). N pollution in nearshore systems leads to eutrophication, which can alter ecosystem structure and function (Howarth et al., 2000), including phase shifts in which reefs once dominated by corals become dominated by algae (Hughes et al., 2007). In addition, there is evidence to suggest that corals are directly affected by elevated N in the environment. In a review of the literature, Fabricius (2005) noted that nutrients (both N and P) negatively affect coral physiology by reducing calcification rates, fecundity, fertilization success, and larval development.

N has also been suggested as an important influence on coral diseases. For instance, proximity to sources of sewage-derived material is thought to be responsible for increases in the severity of black-band and white plague diseases of scleractinian corals (Kaczmarsky et al., 2005; Walker and Ormond, 1982). Similarly, Kim and Harvell (2002) suggested that aspergillosis of sea fans was correlated with dissolved inorganic nitrogen (DIN), and Kuta and Richardson (2002) noted higher levels of nitrite associated with prevalence of black-band disease. Experimental evidence linking nutrients and coral disease was provided by Bruno et al. (2003), who showed that the severity (% tissue affected) of aspergillosis of sea fans and yellow-band disease of a scleractinian coral increased in the presence of elevated DIN and phosphate (P) concentrations. Similarly, Baker et al. (2007) found a positive relationship between disease severity and the ratio between dissolved inorganic nitrogen and total phosphate (DIN:TP).

Determining the provenance of N from various point and non-point sources is necessary for managing and controlling the impacts of N pollution on health of coastal environments. Quantifying the ratio of the isotopes of N ($^{15}N/^{14}N$) relative to a standard (i.e., $\delta^{15}N$) has become a particularly useful tool in this regard because trophic enrichment and microbial processing result in high $\delta^{15}N$ in human sewage effluents (Savage, 2005), whereas nitrogenous fertilizers and atmospheric deposition yield ^{15}N-depleted

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compounds that result in lower $\delta^{15}N$ values (Barile, 2004; Marion et al., 2005). For example, in a retrospective analysis of corals from the ENCORE experiments conducted on One Tree Island, Australia, Hoegh-Guldberg et al. (2004) documented a significant drop in $\delta^{15}N$, from 3.5‰ to 1.0‰ in both corals and their symbionts, from exposure to synthetic nitrogenous fertilizers. Nitrate in raw or partially treated sewage-contaminated groundwater can have $\delta^{15}N$ values much greater than 10‰ (Katz et al., 2004). In contrast, N from upwelling has lower $\delta^{15}N$, averaging 4–7‰ (Leichter et al., 2007), while N fixed by diazotrophs is relatively depleted, averaging −1‰ to 0‰ (Karl et al., 2002). Thus, $\delta^{15}N$ can be used to track N pollution on coral reefs (Risk, 2009; Risk et al., 2009), and sewage-derived N can be easily distinguished from natural marine sources and fertilizer, especially when sewage N comprises a major proportion of the total N pool. It should be noted that interpreting $\delta^{15}N$ values requires some understanding of N sources contributing to the N pool in a given area. In particular, Baker et al. (2010) note that in order to use $\delta^{15}N$ as a correlate for N source, one must assume that the local pool of N is derived from a single dominant source; otherwise, mixing among sewage, agricultural effluents and other N sources can make interpreting $\delta^{15}N$ problematic.

The main objectives of the current study were to evaluate the contribution of sewage-derived N to coastal dynamics of Guam's reef flat communities using stable isotope analysis and to assess the impact of elevated N on white syndrome, a coral disease. Guam is the southernmost island of the Mariana Islands chain, and is the largest (541 km^2) and most populated of this island chain, with more than 180,000 residents (Fig. 1). Guam supports more than 100 km^2 of fringing, patch, and barrier reefs that encircle the island, as well as over 100 km^2 of coral on offshore banks (Kirkendale, 2003). These reefs are home to more than 400 species of corals and 1000 species of fish (Myers and Donaldson, 2003). In total the coral reefs of Guam comprise an economic value of US$127 million a year in tourism and fishing revenue (van Beukering et al., 2007). Despite the economic importance of Guam's reefs, the past 40 years have witnessed a steady decline in their health and vitality (Bruno et al., 2007; Colgan, 1987). The most urgent threats are low water quality, predator outbreaks (e.g., Crown-of-Thorns), overfishing, and, more recently, disease (Burdick et al., 2008).

The primary reef builder and most abundant coral in Guam's reefs is the genus *Porites*; it is also the genus most affected by

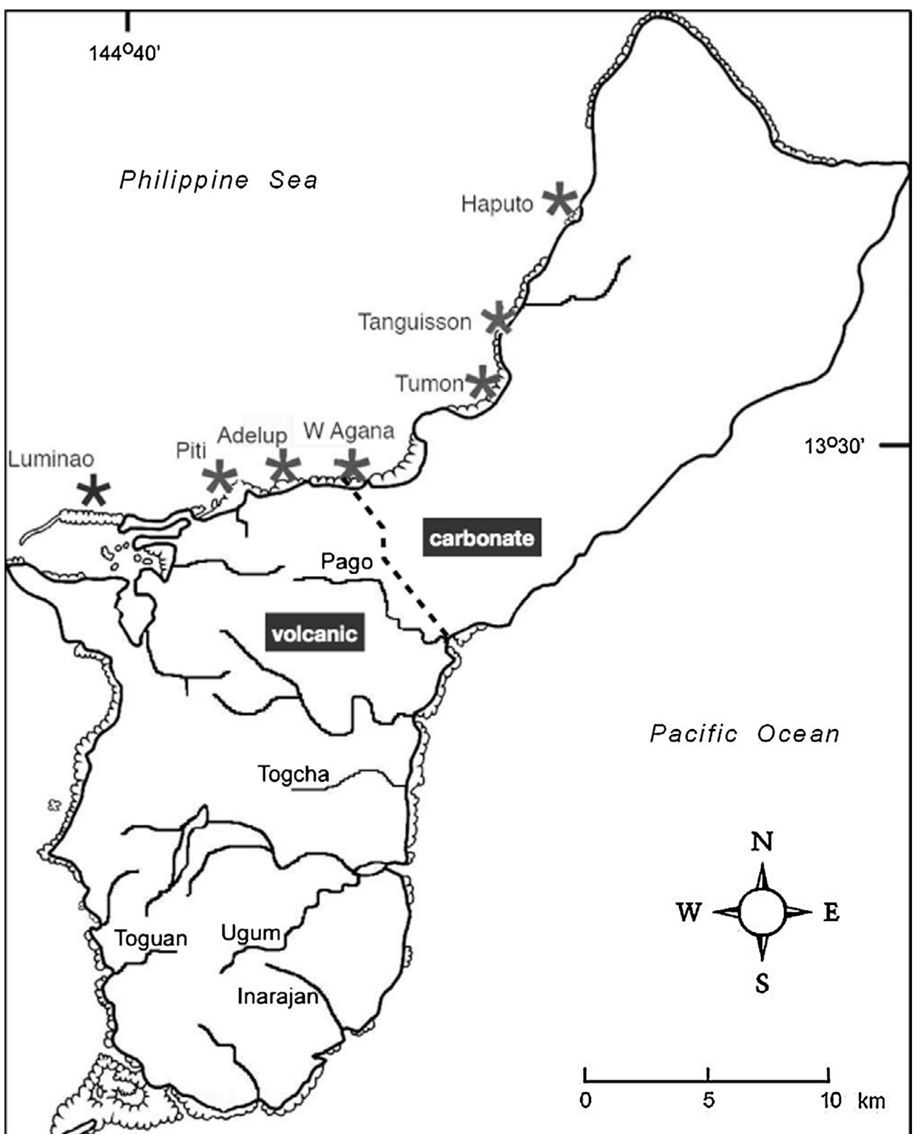

Fig. 1. Map of Guam showing location of monitoring sites. Site abbreviations: Luminao (LUM), Piti (LIT), Adelupe (ADE), West Agana (WAG), Tumon (TUM), Tanguisson (TAN), Haputo (HAP). Dashed line notes the approximate boundary between carbonate and volcanic terrain. (see Taborosi et al., in press).