PORITES PATHOLOGY: THE PREVALENCE OF INFECTION AND PATHOGEN EXPOSURE ON THE REEFS OF MO'OREA

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Abstract. Among the threats to coral reefs are emerging diseases. *Porites* spp., a common coral genus on Mo'orea, exhibits non-normal, pink pigmentation on normally yellow coral. Because its histological changes are linked to an immune response, abnormally pigmented tissue may be used as an indicator of infection. Colony edges have reduced defense mechanisms, so I determined the relationship between algal cover and pigmentation along coral-algal margins. In addition to pigmentation along colony edges, *Porites* shows raised, pigmented nodules on the coral surface indicating greater infection, so I compared the percent cover of pigmentation on barrier reefs and fringing reefs. I noted the invertebrates that most increased *Porites*' susceptibility to infection. Algal cover was related to pigmentation along margins, and medium algal cover showed the highest pigmentation. There was no significant difference in pigmentation coverage between barrier and fringing reefs at all sites but two. Invertebrate-related pigmentation was primarily caused by vermetid gastropods at all sites but one, where burrowing mussels were the main cause.

Key words: coral infection; pigmentation; Porites*; Mo'orea, French Polynesia*

INTRODUCTION

Scleractinian or stony corals are vital structural, biological, and biochemical components of reef communities around the world. Coral reefs cover less than 1% of the ocean floor (Spalding and Grenfell 1997) but support almost one third of the world's marine fish species (McAllister 1991 in Moberg et al. 1999). Corals precipitate half of the calcium that is deposited into the ocean every year to form calcium carbonate reefs (Smith 1978 in Moberg et al. 1999) that shelter land, lagoons, and form sand (Trudgill 1983 in Moberg et al. 1999). They support the lifecycles of multiple marine organisms and are important food sources in many food webs (Moberg et al. 1999). However, they are at risk from chronic bleaching, predation, and disease (Garfield 2001, Hughes et al. 2003, Kalish 1994). One third of world's reefs are already severely damaged, and some experts fear that two thirds of coral reefs will be gone by 2030 (Wilkinson 2002 in Hughes et al. 2003).

Among the threats to coral reefs are emerging infectious diseases. Understanding coral pathology and immunity will help improve coral reef conservation. The basic structure of a scleractinian coral colony is composed of fleshy polps embedded in a calcium carbonate exoskeleton. The epidermis of these polyps has a mucociliary system to trap and dispose of possible infectious agents that land on the coral surface (Mullen, Peters, & Harvell 2004). Mucosecretory cells are generally reduced or absent at coral margins. Phagocytosis appears to be the primary defense mechanism coral (Mullen et al. 2004). Granular cells, which are normally present in the gastrodermis of coral polyps, are thought to be phagocytic. These cells also contain melanin, which may form a defensive barrier separating the pathogen from the rest of the coral (Palmer, Mydlarz, & Willis 2008).

Studies have compared pigmented tissue with normal tissue in *Porites* spp., a common and often dominant scleractinian coral on Mo'orea (Title 2009, Garfield 2001), and have found the changes to be consistent with a generalized immune response (Raymundo, Rosell, Reboton & Kaczmarsky 2004). In normal yellow tissue, the gastrodermis has high levels of zooxanthellae, and both the gastrodermis and epidermis have melanin-containing granular cells in low densities (Palmer, Roth, & Gates 2009, Ravindran & Raghukumar 2006a&b). In pigmented tissue, the gastrodermis of coral polyps has no zooxanthellae. The epidermis has a much higher density of melanin-containing granular cells, indicating either a migration or upregulation of these cells to the epidermis (Palmer et al. 2008, Palmer et al. 2009). In addition, there appears to be red fluorescent protein in the epidermis that pigments the tissue (Palmer et al. 2009).

Because its histological changes are linked to an immune response, abnormally pigmented tissue may be used as an indicator of foreign particle invasion. I determined the relationship between algal cover and pigmentation along coral-algal margins. I hypothesized that greater algal cover would occur with greater pigmentation along coral margins because colony edges are more exposed to pathogens.

I observed raised, pigmented nodules on the coral surface that indicated that pathogens could infect coral in areas other than their margins. I compared the percent cover of pigmentation on barrier and fringing reefs. I hypothesized that because the fringing reef was more susceptible to land runoff and anthropogenic impact, there would be a more pathogenic agents that could attack coral, and the coral surface would show more inflammatory responses to pathogens.

I also noted the invertebrates that most increased *Porites*' susceptibility to infection. I hypothesized that different invertebrates had varying effects depending on the site.

METHODS

Study sites

There were a total of six field sites, three at barrier reefs and three at fringing reefs. Fringing reefs were identified by their close proximity to the island of Mo'orea. Barrier reefs were identified by their separation from the island by a lagoon. Paired barrier and fringing reef sites were located at Motu Tiahura ([1] in Fig. 1) and Hauru Point [2], Cook's Bay Pass [3] and the Gump Station [4], and Temae Public Beach [5,6].

FIG. 1. Paired study sites of fringing and barrier reefs around Mo'orea, French Polynesia. © 2010 Google Earth.

Pigmentation assessment

At each site, ten 4x4m quadrats were randomly placed using transect tape and marker flags. Within each quadrat, the number and size of massive *Porites* spp. was documented. For the purpose of this experiment, coral was only identified to genus. Corals of the genus *Porites* were identified by their yellow, occasionally purple color, corallite structure, and growth massive form. Individual patches of *Porites* spp. on the same substrate were counted as one coral. All pigmentation was noted as pink areas on normally yellow or purple coral.

Algal-coral margins

To determine the relationship between algal cover and the percent of pigmented coral margins, I recorded the percent algal cover on each *Porites* spp. and estimated the percent of algal boundaries that showed pigmented tissue. Data for algal cover was separated into five categories: 1-20%, 21-40%, 41-60%, 61-80%, and 81-100% cover. Data for pigmented margins was separated into four categories: no pigmentation, 1-10%, 11-20%, and 21-60% pigmentation along boundaries.

The X^2 test for independence was used to analyze data.

Barrier vs. fringing reefs

To determine the relationship between pigmentation and the location of the reef, either barrier or fringing, I estimated the percent cover of pigmented nodules unassociated with coral margins on each *Porites* spp. Data was separated into eleven pigmentation ranks, starting with no pigmentation and increasing in cover by 10% with each consecutive rank.

The X^2 test for independence was used to analyze data.

Invertebrate effects

To determine the correlation between site and invertebrate-related pigmentation, I estimated the percent cover of invertebrates that showed pigmentation surrounding them and noted the invertebrate that primarily showed pigmentation on each coral. The vermetid gastropod *Dendropoma* and the burrowing mussel *Lithophaga* were identified from previous studies. Other genera noted were *Tridacna* and *Spirobranchus* as well as

unidentified mollusks, but for data analysis these were labeled as "other" invertebrates.

RESULTS

Algal-coral margins

The X^2 test of independence shows that algal cover and pigmentation along coral margins are related for pigmentation along 20% or less of the margins.

The p-value is 0.028 with a degree of freedom of 8, and X^2 value is 17.2, which is greater than the critical value of 15.05 at p = 0.05. The null hypothesis that algal cover and pigmentation along coral-algal boundaries are independent can be rejected.

Medium levels of algal cover show the highest levels of pigmentation along boundaries (Fig. 2).

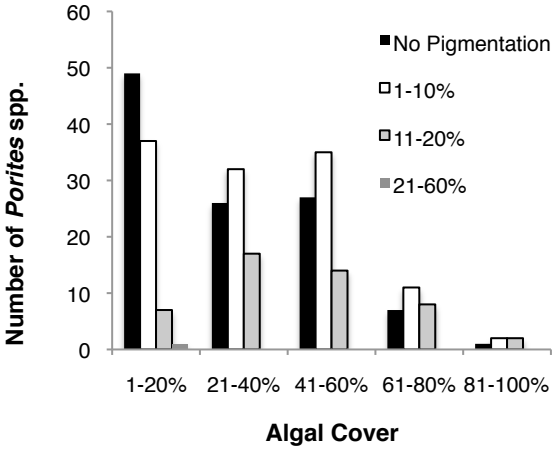

FIG. 2. Pigmentation along coral-algal boundaries. Algal cover and the percent pigmentation along coral margins are related.

Barrier vs. fringing reefs

The X^2 test of independence shows that the type of reef, either fringing or barrier, and percent cover of pigmented spots are only related at the Cook's Bay and Gump Station paired sites for 30% pigmentation cover or less. The null hypothesis that the type of reef and percent cover of pigmented spots are independent cannot be rejected for Tiahura/Hauru and Temae. For Cook's Bay/Gump Station, the p-value is 0.001 with a degree of freedom of 3, and X^2 is 15.432. For Tiahura/Hauru, the p-value is 0.359 with a degree of freedom of 3, and X^2 is 3.217. For Temae, the p-value is 0.058 with a degree of freedom of 3, and X^2 is 7.465. The critical value at p = 0.05 for all three sites with 3 degrees of freedom is 7.815.

The maximum pigmentation coverage varied at each site (Fig. 3). The maximum coverage at Tiahura barrier reef was 50%, while the maximum coverage at the paired Hauru fringing reef was 20%. The maximum coverage at Cook's Bay barrier reef was 60%,

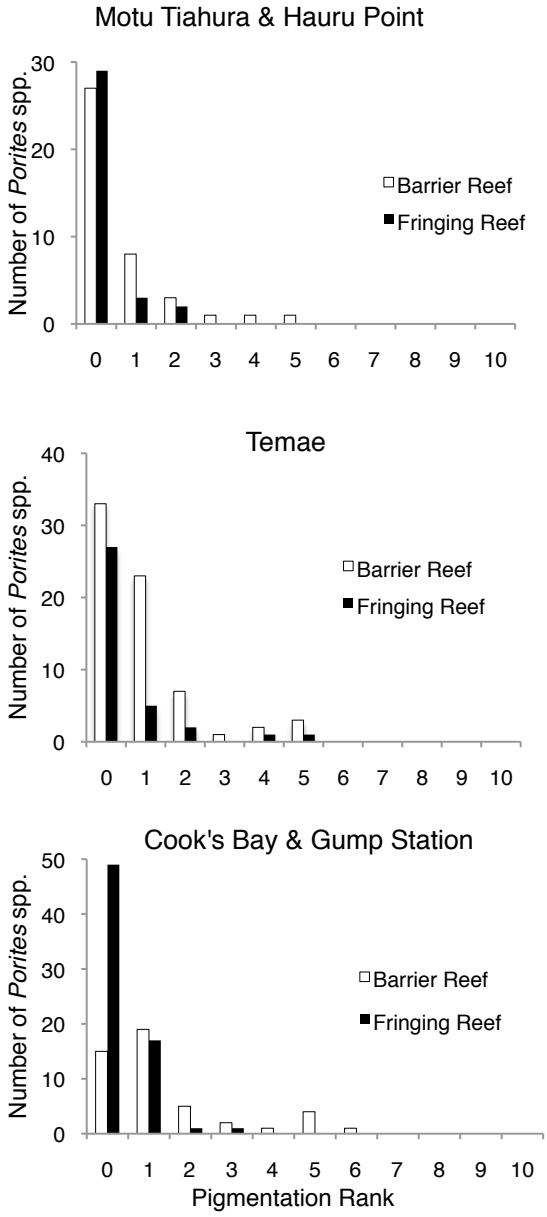

FIG. 3. Percent cover of pigmented nodules at paired sites. Type of reef and pigmentation are related at Cook's Bay & Gump.

while the maximum coverage at Gump fringing reef was 30%. At Temae the maximum for both barrier and fringing reefs was 50% coverage.

Invertebrate effects

The X^2 test of independence showed that type of invertebrate and site location were related for the two sites with the most invertebrate-related pigmentation, Temae and Cook's Bay fringing reefs. The p-value is $1.1x10^{-5}$ with a degree of freedom of 2, and X^2 is 22.845, which is greater than the critical value of 5.991 for $p = 0.05$.

Vermetid gastropods were surrounded by pigmentation at all sites but Hauru Point's fringing reef (Fig. 4). Burrowing mussels were only found with pigmentation at the Gump fringing reef. Invertebrate-related pigmentation did not cover more than 25% of any coral at any site.

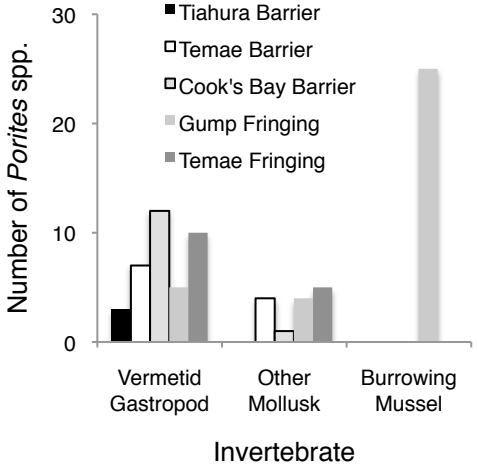

FIG. 4. Invertebrate-related pigmentation.

DISCUSSION

Algal cover can only be statistically correlated to pigmentation along margins when 20% or less of the margin is pigmented. Graphing the data indicates that medium levels (40-60%) of algal cover show the highest levels of pigmentation in this range. For example, coral with 1-20% algal cover was the most likely to have no pigmentation along the algal boundaries. The majority of corals found with 20-80% algal cover showed non-normal pigmentation along at least 1-10% of the coral-algal boundaries. Coral with the most pigmentation along the boundaries had between 20-60% algal cover. At lower levels of algal coverage, there are fewer margins created, and at higher levels of algal coverage, perhaps the coral is damaged in other ways or is in too small of patches to become infected.

Although the type of reef can only be statistically correlated to percent cover of pigmented nodules at Cook's Bay and the Gump Station, graphing the data suggests that there is a slight difference between the prevalence of pigmented nodules on *Porites* spp. in barrier and fringing reefs at all six sites on Mo'orea. At Temae, there were more corals found with pigmented nodules on the barrier reef than on the fringing reef. Corals on the barrier reef also showed higher coverage of pigmented nodules. At Tiahura, corals on the barrier reef were found to have up to 50% coverage of pigmented nodules, while corals on the fringing reef only had up to 20% coverage. At Cook's Bay barrier reef, corals were found to have up to 60% coverage of pigmented nodules, but only up to 30% coverage on the fringing reef at Gump Station. The majority of corals found on the fringing reef contained no pigmented nodules. These results suggest that corals on barrier reefs have more pigmentation than fringing reefs. More pigmentation may not indicate more pathogens in the water, but may instead indicate healthier coral and stronger immune systems. Future studies looking more closely at total reef health are needed to understand the relationship between polyp health and strength of the inflammatory response.

Certain invertebrates are more likely to be surrounded by pigmented tissue than others. Vermitid gastropods were the primary invertebrate to be surrounded by pigmented tissue at all sites except for the Gump fringing reef, where burrowing mussels were the primary cause. Vermitids are known to destroy coral tissue and reduce coral survival (Shima, Osenberg and Stier 2010), so the results of my research add to the current knowledge of vermitids' effect on corals. All invertebrate-related pigmentation covered less than 25% of any coral, so as long as invertebrate populations do not grow extensively, they should only minimally expose coral to pathogens.

Future research looking more closely at the microbial causes of pigmentation is needed to understand coral pathology and immunology and contribute to reef conservation. There has been little research done on global environmental change and its

effects on pathogen virulence, although warmer ocean temperatures and acidification harms coral health in other ways (Bruno 2007, Harvell et al. 2007). Few studies have examined the recovery rates of coral after severe infection. Photosynthesis is reduced at inflammation sites, so chronic inflammation may permanently cripple polyps. This research contributes to the understanding and awareness of coral infection, and will hopefully inspire others to protect the world's remaining coral reefs.

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