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Short Contribution

Acanthaster planci Outbreaks in Vanuatu Coincide with Ocean Productivity, Furthering Trends throughout the Pacific Ocean

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This study identifies linkages between regional ocean productivity and the emergence of large *Acanthaster planci* starfish populations in Vanuatu. Positive correlations were found between wind stress, chlorophyll-a, and upwelling during January–February 2009, corresponding with coral-eating starfish occurrences. Further, temporal associations have existed between monthly wind stress and upwelling since 2000, and were predictors of past starfish events. Links between starfish emergence and oceanographic features are discussed, drawing upon evidence from other asteroid echinoderms. High regional productivity associated with anomalous oceanographic conditions in Vanuatu, and globally, can be used as early warning indicators of probable, future starfish emergence to aid the foundation and success of local management efforts.

Keywords:
· *Acanthaster planci*,
· outbreak,
· ocean productivity,
· upwelling,
· coral-reef management.

1. Introduction

In January 2009 large populations of *Acanthaster planci* emerged on Vanuatu's reefs, impacting expanses of modern coral assemblages and resulting in social and political debate regarding their causes, consequences, and long-lasting impacts. Since 2000, these unusually large, coral-eating seastar populations have been noted on the reefs surrounding Efate, Epi (2006 to present), and Santo (2003–2004) islands in Vanuatu (Fig. 1) (Pakoa, 2004; JR, pers. comm.). Because these predator starfish have the ability to ingest vast expanses of living coral (Chesher, 1969), more insight into the topic is desirable from many perspectives.

This study focused on improving the contemporary knowledge surrounding outbreak events in Vanuatu, and globally, by furthering affinities between ocean productivity and high starfish populations, following the hypothesis of Houk *et al*. (2007). Briefly, Houk *et al*. (2007) described linkages in the North Pacific Ocean whereby a sustained, anomalous, low-latitude influence of the transition zone chlorophyll front (TZCF) triggered the emergence of large populations of adult starfish in parts of Hawaii since 1969. In turn, the southernmost extent of the TZCF significantly predicted secondary outbreaks, not associated with any chlorophyll fronts, in the Marshall and Mariana Islands over the past decade, where both satellite-derived chlorophyll and macroinvertebrate abundance data were available. In a separate example from Palau, their study showed a different, unnamed chlorophyll front originating from the Mindanao eddy in 1998, corresponded with the emergence of adult starfish.

2. *Acanthaster planci*

The causes, consequences, and predictions of *Acanthaster planci* outbreaks have a long history of investigation, rooted by the major outbreak events throughout the Pacific during the late 1960's and early 1970's (Birkeland and Lucas, 1990; Sapp, 1999). Lucas (1982) initially suggested that reproductive success and optimal larval development were critical elements for understanding outbreak causes. Simultaneously, Birkeland (1982) showed that terrestrial runoff, leading to productivity spikes in nearshore waters that are beneficial for larvae (Yamaguchi, 1974), may be linked to starfish outbreaks. These initial ideas spawned a great deal of laboratory and field study in the ensuing decades that generally supported these initial hypotheses (Ayukai *et al*., 1997; Brodie *et al*., 2005); namely that starfish emergence and larval sur-

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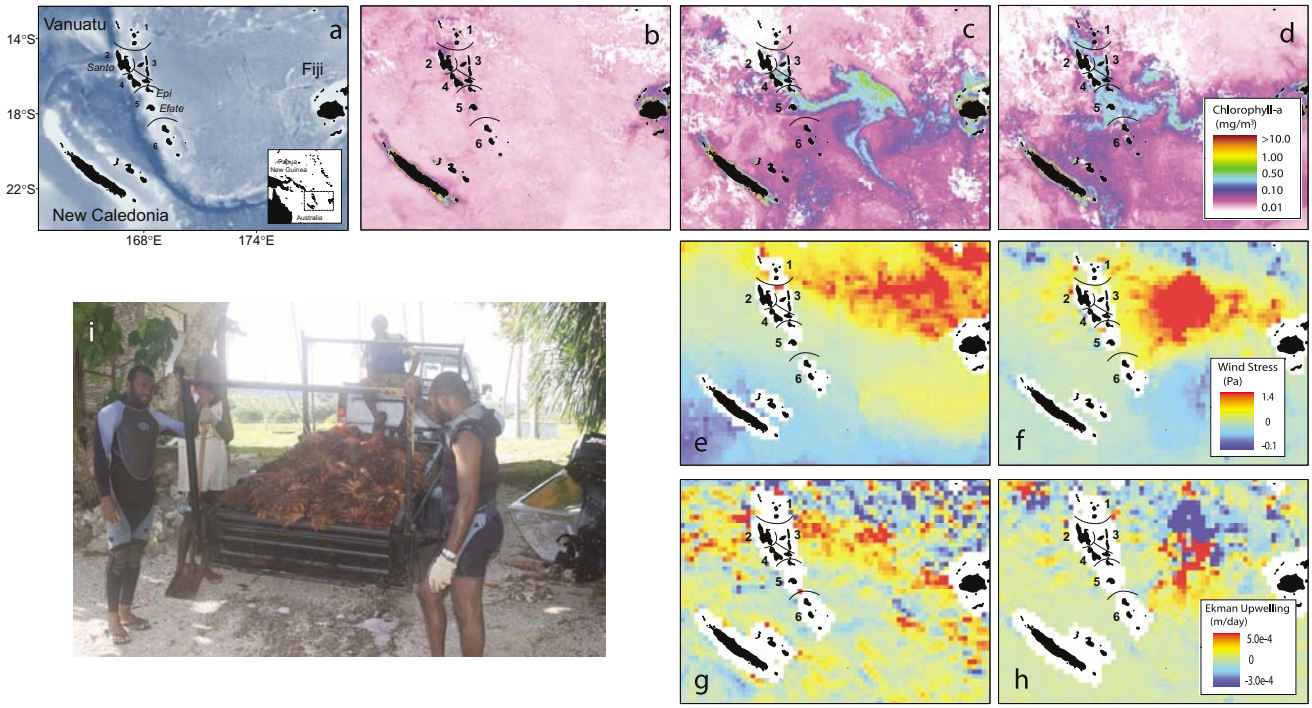

Fig. 1. Satellite-derived data from Vanuatu showing (a) the 6 main districts: 1-Torba, 2-Sanma, 3-Penama, 4-Malampa, 5-Shefa, and 6-Tafea, with labels next to the main islands. Map also shows bathymetry; lighter shades indicate shallower waters. Chlorophyll-a concentrations (14-day averages, MODIS platform) are low during most years, shown for data centered on 16 January 2005 (b); however a large phytoplankton bloom was evident on 3 January 2009 (c), which bathed several of Vanuatu's islands by 10 February 2009 (d). These high-productivity events were correlated with high westerly wind stress in January (e) and February (f), as well as high Ekman upwelling (g), (h) (14 day averages, same dates as above, QuikSCAT platform). In response to high starfish populations removal efforts were instituted; collections shown (i) for "Devils Point", Efate, 6 June 2008.

vival are linked with plankton-rich waters. The recent work by Houk *et al.* (2007) showed that upwelling can enhance the productivity of nearshore waters to a degree comparable with major terrestrial input events, such as those described in Australia (Brodie *et al.*, 2005).

"Emergence", as used here, is hypothesized to be a migration of adult starfish from deep (50–200 m) to shallow (0–50 m) waters upon detecting favorable conditions for reproduction and/or larval survival (Lucas, 1982; Okaji *et al.*, 1997; Houk *et al.*, 2007). While only anecdotal information and limited observations exist to document deep-water occurrences of *A. planci*, similar population dynamics have been noted for other asteroid seastars with planktotrophic larvae. Freeman *et al.* (2001) suggested that *Astropecten irregularis* populations migrate offshore into deeper waters during winter, and subsequently emerge in the spring/summer when prey and larval survival are maximized, corresponding to peak fecundity. Gallagher *et al.* (2008) found similar dynamics for *Asterias rubens* populations that migrate onto mussel beds (i.e., prey) each spring, coinciding with high productivity and mussel harvesting activities. Given that asteroids share many life history characteristics, it seems probable that *A. planci* have similar migration dynamics, despite a lack of unequivocal observational evidence.

3. Satellite-Derived Oceanographic Data

The Republic of Vanuatu consists of six main provinces located in the South Pacific Ocean, centered around 16°S and 158°E (Fig. 1). This study examined oceanographic features associated with recent outbreak events from Efate and Epi (2006 to present), and Santo (2003–2004) (Pakoa, 2004; JR, pers. comm.) using satellite-derived environmental data for the region. Chlorophyll-a data originated from the SeaWiFS and MODIS platforms, while wind and upwelling data originated from the QuikSCAT platform. Rainfall data were collected from the "Merged Analyses of Precipitation" project conducted by the National Weather Service. These data were derived from several microwave satellite sensors, along with ground validation measurements. All data are available through the National Oceanic and Atmospheric Administration (NOAA) Oceanwatch program (www.oceanwatch.noaa.gov).

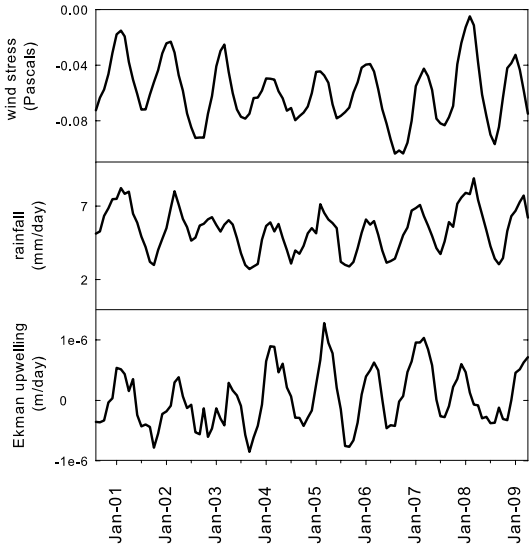

Fig. 2. Temporal trends in upwelling, rainfall, and wind stress (higher values indicate greater westerly influence) in the vicinity of Vanuatu since 2000. Satellite-derived, weekly data were averaged for a geographic box encompassing 13–18°S and 164–174°E (QuikSCAT platform derived data).

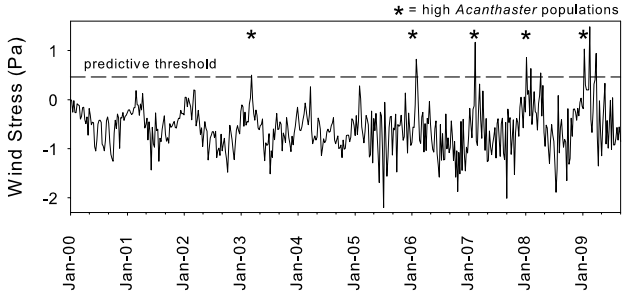

Fig. 3. Three-day wind stress data averaged for a geographical box (13–18°S, 164–174°E) in the vicinity of Vanuatu since 2000 (QuikSCAT platform derived data). Stars (*) indicate reported starfish emergence and dashed line represents the minimum wind stress value predicted for anomalously high oceanic productivity ($P < 0.05$, logit regression).

4. *A. planci* and Oceanographic Features in Vanuatu

During the January 2009 upwelling event there was a positive relationship between high-chlorophyll, westerly wind stress, and Ekman upwelling indices in a geographic box encompassing 13–18°S and 164–174°E (R = 0.35 and 0.39, respectively for chlorophyll-wind and chlorophyll-upwelling, $p < 0.001$, pixel-based spatial correlations using 14-day averaged values centered on 3 January 2009, Fig. 1). While similar spatial couplings have been noted since 2000, universal trends were hampered by large gaps in satellite-derived, ocean color data because of high cloud cover. Clouds associated with rainfall were consistently generated during westerly wind events (R = 0.64, correlation between weekly wind stress and rainfall since 2000, $P < 0.001$, Fig. 2), and inhibit the ability of satellite platforms to collect ocean color data. However, wind stress and Ekman upwelling data are available throughout the decade at high temporal resolution, regardless of cloud cover, because they are derived from satellite sensors using microwave frequencies (Fig. 2). These relations suggest that the occurrence of anomalous westerly winds, and subsequent convergence with typical eastward trade winds, are the best predictors of upwelling and high regional productivity.

5. Predictability of High-Resolution Wind Stress Data

There was a significant relationship between reported starfish emergence and regionally averaged, 3-day wind stress values above ~0.45 Pa (logit regression between the occurrence of anomalously high starfish populations and 3-day wind stress values, $P < 0.05$, Fig. 3). Indeed, a review of available ocean color data during high westerly wind stress events since 2000 confirms that high regional productivity often emerges in the oceanic basin between Fiji and Vanuatu. However, the location and movement of productive waters to the coral reefs surrounding Vanuatu often hinges upon the horizontal transfer of productive waters from subsequent, easterly trade winds. Thus, wind stress appears to be a useful predictor of probable starfish emergence, but predictions for individual provinces within Vanuatu depend upon the location and transfer of productive waters.

6. Discussion and Summary

This note supports the ability of real-time satellite-derived data to predict *A. planci* outbreaks in Vanuatu, thereby providing valuable information to resource managers to take proactive measures of their choosing. Cumulatively, there are now three examples linking oceanically-derived phytoplankton blooms with the emergence of coral-eating starfish. In Hawaii, Bograd *et al.* (2004) summarized the existence and migration of the transition zone chlorophyll in relation to surface current convergence originating from contrasting western and eastern winds, migrating seasonally from ~30–40°N. In Palau, horizontal transfer of chlorophyll-rich surface water was evident from a westward extension of the Mindinao Eddy following an El Niño (Heron *et al.*, 2006). In both instances these events were tied to the emergence of coral eating seastars (Houk *et al.*, 2007).

Further resources should be allocated to making real-time data and associated predictions available to local coral-reef managers, providing for insight comparable to coral bleaching and disease warning products (http://coralreefwatch.noaa.gov/satellite/virtual_stations/

index.html). In Vanuatu, the aquarium industry has been speculatively implicated (socially and politically) over the course of the past two years as the cause of recent outbreaks. While the cascading, ecological impacts of the aquarium fishing industry are unknown in Vanuatu, it does not appear that any affinities with starfish emergence exist, although high commercial fishing pressure has recently been linked with high occurrences in Australia (Sweatman, 2008).

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References

Ayukai, T., K. Okaji and J. S. Lucas (1997): Food Limitation in the growth and development of Crown-of-Thorns starfish larvae in the Great Barrier Reef. *Proc. 8th Int. Coral Reef Sym.*, **1**, 621–626.

Birkeland, C. (1982): Terrestrial runoff as a cause of outbreaks of *Acanthaster planci* (Echinodermata: Asteroidea). *Mar. Biol.*, **69**, 175–185.

Birkeland, C. and J. S. Lucas (1990): *Acanthaster planci: Major Management Problems of Coral Reefs*. CRC Press, Boca Raton, Florida, 257 pp.

Bograd, S. J., D. G. Foley, F. B. Schwing, C. Wilson, R. M. Laurs, J. J. Polovina, E. A. Howell and R. E. Brainard (2004): On the seasonal and interannual migrations of the transition zone chlorophyll front. *Geophys. Res. Lett.*, **31**, L17204.

Brodie, J., K. Fabricius, G. De'ath and K. Okaji (2005): Are increased nutrient inputs responsible for more outbreaks of Crown-of-Thorn starfish? An appraisal of the evidence. *Mar. Poll. Bull.*, **51**, 266–278.

Chesher, R. H. (1969): Destruction of Pacific corals by the seastar *Acanthaster planci*. *Science*, **165**, 280–283.

Freeman, S. M., C. A. Richardson and R. Seed (2001): Seasonal abundances, spatial distributions, spawning and growth of *Astropecten irregularis* (Echinodermata: Asteroidea). *Estuar. Coast. Shelf Sci.*, **53**, 39–49.

Gallagher, T., C. A. Richardson, R. Seed and T. Jones (2008): The seasonal movement and abundance of the starfish, *Asterias rubens* in relation to mussel farming practice: a case study from the Menai Strait, UK. *J. Shellfish Res.*, **27**, 1209–1215.

Heron, S. F., E. J. Metzger and W. J. Skirving (2006): Seasonal variations of the ocean surface circulation in the vicinity of Palau. *J. Oceanogr.*, **62**, 413–426.

Houk, P., S. Bograd and R. van Woesik (2007): The transition zone chlorophyll front can trigger *Acanthaster planci* outbreaks in the Pacific Ocean: Historical confirmation. *J. Oceanogr.*, **63**, 149–154.

Lucas, J. S. (1982): Quantitative studies of feeding and nutrition during larval development of the coral reef asteroid *Acanthaster planci* (L). *J. Exp. Mar. Biol. Ecol.*, **65**, 173–193.

Okaji, K., T. Ayukai and J. S. Lucas (1997): Selective feeding by larvae of the Crown-of-Thorns starfish, *Acanthaster planci* (L.). *Coral Reefs*, **16**, 47–50.

Pakoa, M. K. (2004): Status of coral reefs in Vanuatu. p. 225–265. In *Status of the Coral Reefs in the South West Pacific: Fiji, Nauru, New Caledonia, Samoa, Solomon Islands, Tuvalu and Vanuatu*, ed. by R. Sula, Suva, Fiji.

Sapp, J. (1999): *What is Natural? Coral Reef Crisis*. Oxford University Press, New York, 304 pp.

Sweatman, H. (2008): No-take reserves protect coral reefs from predatory starfish. *Curr. Biol.*, **18**, R598–599.

Yamaguchi, M. (1974): Growth of *Acanthaster planci* (L.) in the laboratory. *Pac. Sci.*, **28**, 123–138.