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Nerilie J. Abram, *et al.*

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Response to Comment on "Coral Reef Death During the 1997 Indian Ocean Dipole Linked to Indonesian Wildfires"

The comment by van Woesik (*1*) discusses other cases of reef death in the eastern Indian Ocean region during 1997 and concludes that while wildfires may have exacerbated phytoplankton blooms off the coast of Sumatra (Mentawai Islands), upwelling related to the Indian Ocean Dipole (IOD)—independent of the fires—caused significant coral mortality that may have extended for at least 4000 km. These other cases involve semi-intertidal corals affected by sea level decreases at Phuket, Thailand (*2*), and phytoplankton and macroalgae blooms during ocean upwelling at Bali, Indonesia (*1, 3*). In the case of the Phuket reefs, mortality primarily affected the upper surfaces of corals growing in the intertidal zone, leaving the surviving colony sides to re-grow rapidly (*2*). A similar feature is seen in *Porites* microatolls from the Mentawai reefs, where sea level decreases during the 1961 and 1994 IOD events can be seen as a drop in the height of the upper living surface of coral colonies (*4*). However, unlike the partial mortality of Mentawai coral microatolls during previous IOD events, and in contrast to the rapid recovery rates observed on the Phuket reefs following the 1997 IOD (*2*), the 1997 red tide in the Mentawai Islands region resulted in complete death of coral colonies. The significant coral mortality observed in Bali at the time of the 1997 IOD upwelling was also coincident with phytoplankton and macroalgae blooms (*1, 3, 5*), and adds to a growing body of evidence that algal blooms can have devastating consequences for coral reef ecosystems (*6, 7*). It is unclear, however, whether the algal blooms in Bali were related solely to the oceanic upwelling of nutrients or if additional anthropogenic factors contributed to the coral death during 1997 (*3*). The survey data presented also does not allow for an assessment of any similar blooms and possible coral mortality associated with similar upwelling conditions in 1994.

One of the key findings of our coral-proxy study (*8*) was that the oceanic conditions in the Mentawai Islands region during 1997 were not unprecedented; upwelling events with similar magnitude were recorded by Mentawai corals in 1877, 1961, and 1994, and cooling events up to 50% stronger than the 1997 upwelling were preserved in fossil corals. However, no evidence was found for large algal blooms or mass coral death during any of these previous IOD upwellings. This finding implies that an additional source of nutrients beyond the IOD upwelling and ambient atmospheric sources (*9*, *10*) must have existed to fuel the unusual red tide that killed the Mentawai reefs in 1997.

The 1997 wildfires in Indonesia were the worst in recorded history, due to the combined effect of drought and increasing human disturbances, and represented an anomalous and large additional nutrient source to the Mentawai region (*8*). Indeed, measurements of aerosols during November 1997 at a nearby site recorded atmospheric particulates (with a high pyrogenic component) at levels 4.7 times the long-term average, and atmospheric Fe levels 3.3 times the average for this site (*11*). While our study focused on the effects of the Sumatran fires on the Mentawai reefs, wildfires also burnt in Kalimantan, Papua New Guinea, and northern Australia during late 1997, and their smoke affected much of the Indonesian archipelago. Satellite data indicates that Bali did experience some wildfire smoke fallout (*12*), and although not as intense as in the Mentawai region, additional nutrients from this smoke may have played a role in the phytoplankton and macroalgae blooms on the Bali reefs during the 1997 IOD upwelling event (*1, 3*). Alternatively, local eutrophication at the Bali reef sites may have exacerbated the effect of regional upwelling (*3*).

What is clear from the comment by van Woesik on additional sites of coral mortality during the 1997 IOD is that these climatic events have the potential to stress reef ecosystems over a broad region of the eastern Indian Ocean. The severe mortality observed on the Mentawai reefs following the 1997 wildfires further shows that when these climatic stresses are combined with additional human disturbances, the effects can be devastating for coral reefs.

Nerilie J. Abram
Michael G. Gagan
Malcolm T. McCulloch
John Chappell
Research School of Earth Sciences
The Australian National University
Canberra, ACT 0200, Australia
E-mail: nerilie.abram@anu.edu.au

Wahyoe S. Hantoro
Research and Development Center for Geotechnology
Indonesian Institute of Sciences (LIPI)
Bandung 40135, Indonesia

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