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

The Indian Ocean Dipole (IOD) caused anomalous upwelling, low sea surface temperatures, and low sea surface heights along the north-eastern Indian Ocean in 1997 (Fig. 1). Abram *et al*. (*1*) suggested that coral mortality occurred along a 400-km stretch of Indonesian coastline (Mentawai Islands) because of the synergistic effects of the 1997 IOD-induced upwelling and atmospheric fallout from the Indonesian wildfires. Here, I show that coral mortality occurred on the coral reefs of Bali—a considerable distance from the wildfire smoke plume—primarily as a consequence of the IOD upwelling.

Abram *et al*. (*1*) examined *Porites* corals for chemical signals, but reported circumstantial evidence from local reports that all coral species—not just those in shallow water—died: "In late 1997, near the peak of the IOD, close to 100% of the coral and fish in the Mentawai reef ecosystem were killed" (*1*). Their empirical evidence stems from the death of 48 *Porites* coral colonies and the enhanced geochemical traces within the skeletons just prior to their death. Abram *et al.* argued that while the IOD upwelled nitrogen- and phosphorous-enriched waters, which increased surface productivity, the 1997 IOD was not unusual when compared with paleoupwelling events during the past 7000 years (traceable as geochemical anomalies in coral $\delta^{18}O$ and skeletal strontium/calcium ratios). They suggest that while the enhanced nutrients clearly stem from the upwelling event, the primary productivity rates of 1.6 g of C m^{-2} day^{-1} (from a derived chlorophyll a concentration of 5 mg m^{-3}) could not be sustained by upwelled or aeolian iron (Fe) because the average deposition in the area amounts to only 3 μg m^{-2} day^{-1} (*2*)—and thus, additional Fe may have stemmed from the wildfires. They conclude that a synergy between the IOD and the wildfires caused exceptionally high concentrations of phytoplankton in the water that led to reef death by asphyxiation. However, in figure 1 in (*2*), Gao *et al.* showed that this part of Indonesia receives approximately 20 mg m^{-2} $month^{-1}$, or 0.66 mg m^{-2} day^{-1}, of atmospheric deposition of Fe from September to October. Given a high correspondence between atmospheric mineral composition and downward flux through the water column, and a conservative estimate that 25% of the Fe was dissolved and bioavailable (*3*), 165 μg m^{-2} day^{-1} of Fe should have been readily available in the water column. In combination with the upwelled nutrients, this concentration would have been high enough to sustain the red tides independent of atmospheric fallout from wildfires (*1, 4*).

Furthermore, reduced sea surface height, low sea surface temperatures (SST), and phytoplankton blooms with three times the chlorophyll a concentration observed around the Mentawai Islands, were evident to the south east (off Java and Bali, Indonesia) in September 1997 (Fig. 2). The chlorophyll a concentrations ranged from 10 to 15 mg m^{-3}, which converts to 2.2 to 2.8 g C m^{-2} day^{-1}. Java and Bali were not in the direct plume of the wildfires [figure 1c in (*1*)]. Therefore, extra Fe from wildfires may not have been necessary to stimulate the blooms, and the proximity of the land may have been sufficient to sustain the high primary productivity rates observed. Along with regional upwelling, which led to nutrient enrichment and phytoplankton blooms off the coast of Bali, there was also evidence of macroalgal blooms on the Balinese reefs [(*5*–*7*); Fig. 3]. Coral mortality was a consequence of direct physical smothering by these macroalgae. *Acropora* and pocilloporid corals were particularly vulnerable. These corals are among the most ubiquitous, but are also the most susceptible corals in the Indian and Pacific Oceans, and are usually first to respond to any form of perturbation (*8, 9*).

Other direct evidence of coral mortality stemming directly from the 1997 IOD is seen in Phuket, Thailand, also in the absence of wildfire fallout. Instead, the anomalously low sea levels associated with the IOD caused direct and prolonged aerial exposure, which lead to considerable coral mortality (*10*). Therefore, while the wildfires may have exacerbated phytoplankton blooms off the coast of Sumatra (around the Mentawai Islands),

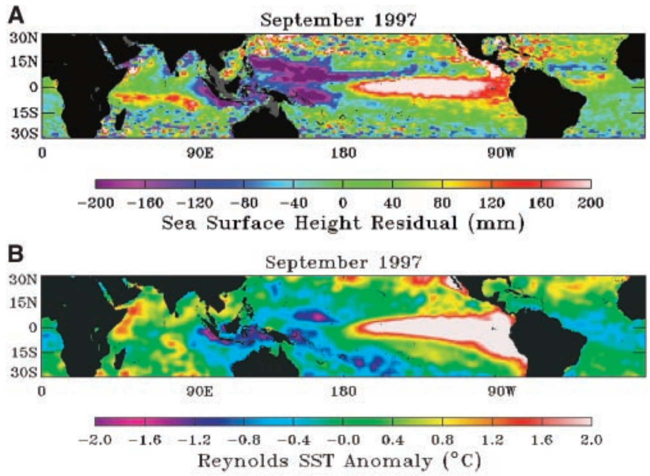

Fig. 1. (**A**) Global residual sea surface height for September 1997. Notice the 200-mm decline along the southwestern Indonesian coastline (Topex_Poseidon, http://oceanesip.jpl.nasa.gov/). (**B**) Global SST anomalies for September 1997. Notice the -2°C decline along the southwestern Indonesian coastline (http://podaac.jpl.nasa.gov/sst/).

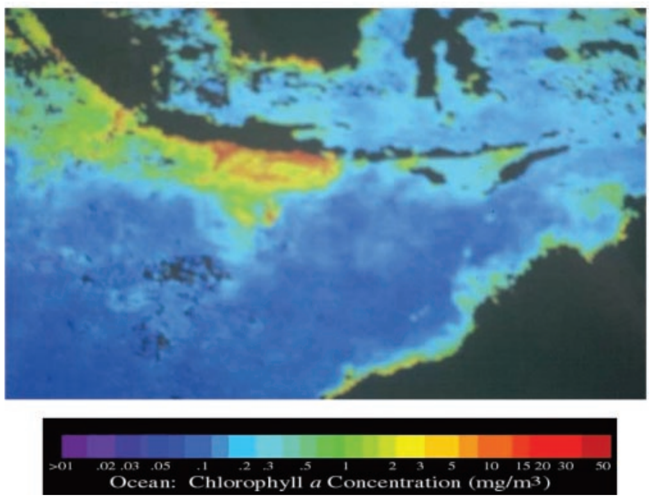

Fig. 2. Sea-viewing Wide Field-of-view Sensor (SeaWiFS) image from September 1997 showing high chlorophyll a concentrations off Java and Bali (http://seawifs.gsfc.nasa.gov).

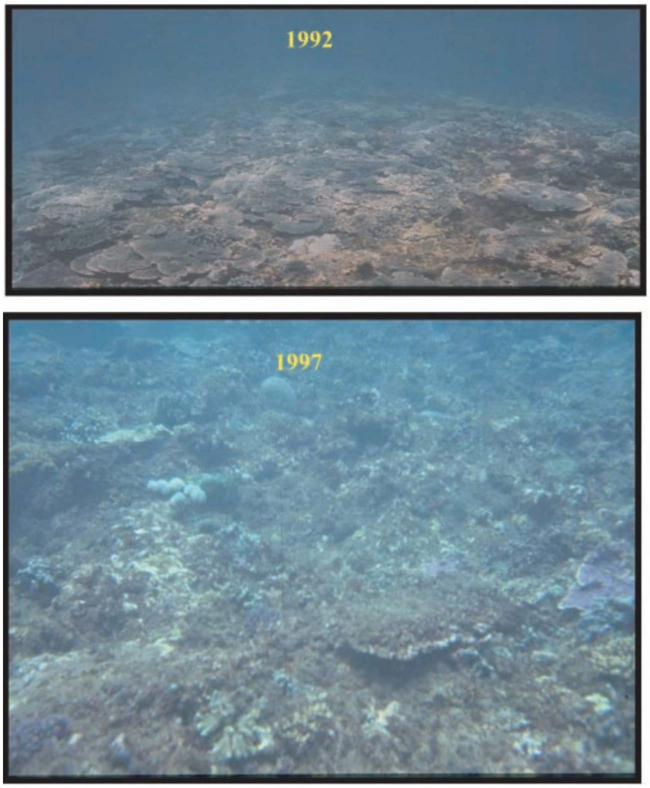

Fig. 3. Coral communities off southeastern Bali in (**top**) September 1992 (**bottom**) and September 1997. Macroalgae growing over live coral can be seen in (bottom).

the IOD-related upwelling, independent of the wildfires, caused significant coral mortality that may have extended for at least 4000 km—an order of magnitude larger than the mortality recorded near the Mentawai Islands (*1*).

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7. Three study sites separated by several km were established on the southeastern reef of Bali (South 08° 40.886′, East 115° 16.146′) in September 1992. At each site, I established two stations within 100 m of each other and quantitatively examined the benthic reef components at 3 m and 7 m (using 10 randomly placed 20-m line transects at each depth; total $n = 120$). Corals were identified and resurveyed in September 1997. Data were analyzed by ANOVA with time as an effect (independence was established because of the random nature of the transect placement and by using change over time for each taxa). Prior to the upwelling, the upper reef slopes (Sanur and Nusa Dua) supported >30% coral cover and a high coral diversity. The average diameter of *Acropora* spp. and *Seriatopora* spp. colonies, the dominant corals in terms of abundance, was 17 to 42 cm. The same reefs supported 2- to 3-cm colonies in September 1997, approximately 15% coral cover, and the reef had become dominated by macroalgae. All study locations showed major declines in hard coral cover except the 3-m slope at Sanur, near a river discharge. ANOVA showed significant differences in coral cover over time ($F_{.0001[1,\ 228]} = 170.9$), among locations ($F_{.0001[2,\ 228]} = 37.4$), among depths ($F_{.01[1,\ 228]} = 8.9$), and for time*location ($F_{.001[2,\ 228]} = 8.5$) and time*location*depth ($F_{.01[2,\ 228]} = 5.5$). These major changes were apparent at Nusa Dua and at Sanur.
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