are especially critical in the near-field, where tsunami travel times were less than 5 minutes.

Differences in indigenous knowledge led to mortality variations in villages with similar tsunami magnitudes (Figure 2e). None of Pailongge's indigenous population died, yet 13 people died in Titiana, where Gilbertese immigrants from Kiribati, who migrated there in the 1950s, have no cultural recollection of tsunamigenic earthquakes. Immigrant children were exploring the emptied lagoon when they were overwhelmed by the tsunami. In Pailongge, however, members of the community headed for higher ground after the shaking stopped, demonstrating an effective use of life-saving indigenous knowledge.

Long-Term Impacts

After 1 year, the coastal ecosystems (coral, fisheries, mangroves, as well as human) remain the most affected by the geologic changes associated with this earthquake and tsunami. Vast stretches of coral killed by the earthquake's shaking and uplift are slowly recovering; however, the longer-term ecologic and economic impacts remain to be seen. Coastal uplift also changed the hydrologic regime of estuaries, causing widespread mangrove forest mortalities.

Damage to these ecosystems' nursery services will likely affect fish stocks for years to come, and the situation needs to be closely monitored. Declining fish stocks not only affect the region's food security but also have broader economic implications associated with a potential decline in the dive tourism industry. Postdisaster recovery efforts need to consider these implications to properly plan redevelopment options.

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Ocean Color Reveals Increased Blooms in Various Parts of the World

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The magnitude of phytoplankton blooms has increased significantly in many areas of the world during the past 11 years, as shown in data from ocean color sensors on board satellites. These areas with increased blooms are likely to be environmentally stressed and undergoing undesirable environmental changes such as a higher frequency of harmful algal blooms and oxygen depletion in bottom layers of oceans, estuaries, and lakes. These changes can disrupt traditional fisheries and recreational use in many coastal areas.

An algal bloom is a rapid increase in the concentration of phytoplankton algae that occurs when conditions turn favorable for algal growth. A typical example of a bloom is the phytoplankton spring bloom. Algal blooms are natural phenomena that remove dissolved carbon and nutrients. In addition, they produce new biomass that supports higher trophic levels including fish and fisheries. However, the blooms also lead to excessive turbidity, oxygen depletion in the bottom layers, and the possible death of fish, benthic animals, and bottom vegetation.

Satellite measurement of spectral reflectance (ocean color) is a cost-effective method to monitor phytoplankton by its proxy, chlorophyll *a* concentration (the green pigment that is present in all algae, Chl-*a*). Understanding the effects of the increasing atmospheric carbon dioxide concentrations and higher surface temperatures on ocean biota is a major theme of NASA's Ocean Biology and Biogeochemistry Program [*McClain et al*., 2006]. In September 2007, the NASA Sea-viewing Wide Field-of-view Sensor (SeaWiFS) completed 10 years in orbit (and efforts to revise the sensor are still under way following an incident on 1 January 2008 that has prevented data downlink). SeaWiFS, together with its predecessor, the Japan Space Exploration Agency's Ocean Color and Temperature Scanner (OCTS), which operated for only 8 months prior to a power failure, provide approximately 11 years of high-quality global ocean color observations.

While measurements of Chl-*a* of individual blooms are variable (blooms are very patchy in both space and time) and satellite sensors miss some blooms due to persistent cloud cover, the monthly mean composite Chl-*a* is representative of the mean phytoplankton concentration. It is well known that satellite estimation of Chl-*a* in nearshore waters is complicated and that other optically active substances, such as detrital material, dissolved organic substances, and suspended sediments, can interfere in this process. In spite of these potential errors, the monthly composite Chl-*a* is a robust index of water quality and corresponds to the combined effects of Chl-*a* and other optically active substances.

We used global Chl-*a* data from OCTS and SeaWiFS processed to 9-kilometer pixel resolution, and we found the highest monthly Chl-*a* value for each year and each pixel. We then compiled time series of these annual maxima from 1997 to 2007. We interpret the time series of the annual maxima as a change in bloom magnitude. We calculated the Sen slope, which is a nonparametric estimate of the slope, to detect trends in bloom magnitude and their significance. Estimates of the slope of bloom magnitude were also obtained with the linear least squares regression, but the Sen slope estimator is preferable due to its insensitivity to outliers. In Figure 1, areas of increased bloom magnitude are shown in red and those with decreased bloom magnitude are shown in blue. The global map of increased bloom magnitude is shown at http://spg.ucsd.edu/blooms.png, and a Google™ Earth version is shown at http://spg.ucsd.edu/blooms.kmz.

Phytoplankton Blooms

During the past 11 years, bloom magnitudes have increased in extensive areas of eastern boundary upwelling currents along the Washington-Oregon-California coast off North America, the northern Peru coast off South America, sections of the coast of Namibia off Africa, and off the southwestern tip of India. Eastern boundary currents are characterized by upwelling of nutrientrich waters that makes these areas very productive and important for fisheries. Increased blooms also are evident in enclosed and semienclosed basins such as the Baltic Sea, Lake Maracaibo in Venezuela, the Sea of Azov, and the northeastern area of the Caspian Sea. In the Baltic Sea, the Chl-*a* algorithm is known to have large errors and the bloom magnitude primarily reflects the abundance of surface-floating cyanobacteria [*Kahru et al.*, 2007].

Increased blooms are also observed in the northern Arabian Sea and the Gulf of Oman, as well as in outflow areas of big rivers such as Brazil's Amazon and Tocantins and Africa's Congo. In the Mississippi River outflow area, blooms have increased in the western part of the outflow and decreased in the eastern part. In East Asia, blooms have increased off Shanghai and along the west coast of Korea. In the Yellow Sea and the adjoining Bohai Sea, blooms have actually decreased, due possibly to increased turbidity. Blooms have also decreased in the outflow area of the Po River in the Adriatic Sea, likely as a result of efforts to control pollution. Significant changes (i.e., increases or decreases in bloom magnitude) over large areas are evident at high latitudes (the Barents and Bering seas, the Sea of Okhotsk, and so forth), but the reliability of these estimates is less certain due to persistent cloud cover and infrequent satellite measurements of these areas.

In summary, ocean color data from 1997 to 2007 show increased phytoplankton bloom magnitude in eastern boundary upwelling systems and in a number of areas with known eutrophication. Increased blooms in eastern boundary currents may be caused by increased upwelling, but we are unaware of any direct evidence supporting that. The increased blooms off Oregon are linked to the increase in the "dead zones" of oxygen-depleted water [*Service*, 2004, 2007]. It has been suggested [*Goes et al.*, 2005] that the intensification of the southwest monsoon due to global warming has increased the productivity in the Arabian Sea, but this has been disputed by *Prakash and Ramesh* [2007]. Figure 1 shows that the increase in bloom magnitude is observed in the relatively narrow region of the Gulf of Oman and in nearshore areas of the northern Arabian Sea. Some of the observed trend in bloom magnitude is attributable to the strong El Niño of 1997–1998 in the start of the time series. However, bloom magnitudes have increased in many areas even after 1997–1998. We hope that experts familiar with conditions in specific areas can interpret these patterns using local data.

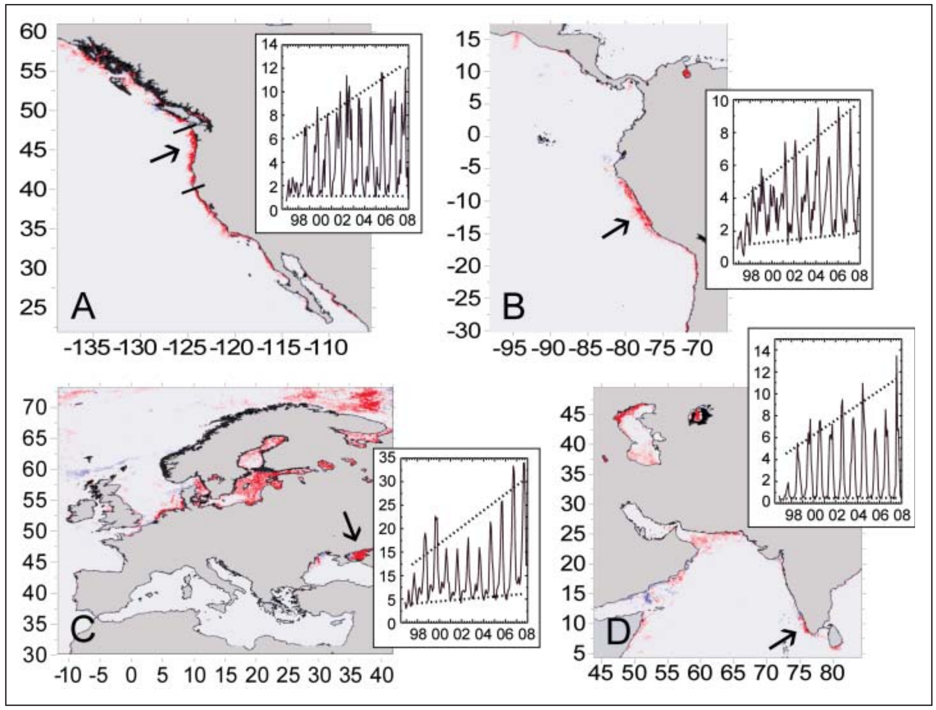

*Fig. 1. Areas of increased (red) and decreased (blue) phytoplankton bloom magnitude. The trend and its significance are estimated using the Sen slope test at 95% confidence level. Individual time series (from about 1997 to 2008) of spatially averaged Chl-*a *(milligrams per meter cubed) are shown as insets for the 50-kilometer nearshore band (a) off the Washington-Oregon-California coast, (b) off northern Peru, (c) in the Sea of Azov, and (d) off southwest India.*

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