The geologic and economic effects of the 2 April 2007 Solomon Islands earthquake and tsunami are distinctly visible a little more than a year after the event. Coral reef colonies that were sheared off and uplifted are slowly recovering, and many new earthquake-triggered landslides remain mobile. Large volumes of sediment created by the earthquake and mobilized by the tsunami have been flushed from the lagoons between the reef and shoreline into deeper water, although significant quantities remain on land. Sediment from the lagoons covers piles of shattered coral that the tsunami moved from the lagoons to the base of channels in the barrier reef. These shattered corals have a higher chance of preservation as paleotsunami deposits than the material deposited on land.

The long-lasting effects of the damaged reef on the local economy—which relies heavily upon fisheries and dive tourism—remain to be seen. Coastal residents are still in refugee camps due to the slow pace of aid delivery and are fearful of another event.

Our team, consisting of geologists (from the United States; the Solomon Islands government; and the regional Pacific Islands Applied Geoscience Commission, known as SOPAC) and local dive experts, has been working with local government officials, nongovernmental organizations (NGOs), and business owners to assess the effects of this event on the local environment. The geologists arrived in the affected area 1 month after the event, coordinating with a team of civil engineers that had arrived 2 weeks earlier to collect ephemeral data such as wave heights [Fritz and Kalligeris, 2008] and assess sites of potential geologic interest. We documented the earthquake-triggered landslides using aerial surveys and field verification, and we documented the offshore effects of the tsunami and earthquake using a combination of scuba diving and side-scan sonar. Our initial assessments were shared with local officials and NGOs via the National and Provincial Disaster Councils at Gizo (the capital of Western Province of the Solomon Islands), and via the National Disaster Management Office in the national capital of Honiara.

The Earthquake and Tsunami

The magnitude $M_w = 8.1$ earthquake on 2 April 2007 (0739 local time) caused shaking that lasted for more than 1 minute. As soon as the shaking stopped, lagoons emptied into the ocean, which was quickly followed by tsunami waves surging onshore. The event was responsible for 52 deaths.

We visited severely damaged villages on the islands of Ghizo (Figure 1), Ranongga, and Simbo, as well as several small, uninhabited reef islands (Njari, Makuti, and Nusa Aghana, Figure 2a). Damage in the villages varied despite similar tsunami wave heights, suggesting variations in the waves’ power. At Pailongge and Titiana, on Ghizo, several vehicles along with homes made of thatched grasses and palm fronds were floated tens of meters inland (Figure 2b) and deposited with surprisingly little damage, suggesting that the waves came in not as a turbulent bore but as a rapidly rising tide. It is possible that the steep morphology of the barrier reef reflected some of the tsunami energy back out to sea, and that the long wavelength provided the considerable amount of water that spilled over into these lagoons and onto land. At Tapurai, where the barrier reef/lagoon system is not as well developed, all structures in the tsunami-affected area were destroyed, suggesting more powerful waves.

Damage to coral colonies in the lagoons fronting these villages was caused primarily by the earthquake, not by the tsunami. Strong shaking sheared off delicate colonies of branching and table corals (Acropora sp.), along with Porites sp. coral heads that have evolved to thrive in low-wave-energy environments. Most colonies fell near their original growth positions, while only on rare instances were they transported inland. Had the tsunami been...
responsible for the damage to coral colonies, we would have expected more evidence of transport in a current, such as battering of coral edges or transport away from original growth locations.

We observed further evidence of strong coseismic accelerations on the reef front at Nusa Aghana, where large boulders (~2 meters in diameter) were broken off and deposited in deeper water underneath a fine layer of sediment. This fine layer of sediment has been washed away during the past year, and new coral is starting to recolonize damaged areas.

The coseismic land level changes that further damaged the coastal ecosystems were particularly acute on Ranongga Island. The uplift, which exceeded 3 meters in the southeast, killed a swath of coral more than 100 meters wide surrounding the island, affecting access for transportation and fishing (Figure 2c). At Kolokukunde, the estuary and associated mangrove swamp are now disconnected from the sea, which will affect the offshore fish nurseries. These ecosystems will take much longer to recuperate.

The earthquake triggered thousands of coastal and interior landslides. On Ranongga, two people were killed on a reactivated landslide complex at Mondo; and at Leona village, on Vella Lavella, a landslide from the hill backing the village destroyed a health clinic (Figure 2d). Numerous villages across the region are at risk of future landsliding triggered by aftershocks and rainfall. Debris-choked streams present additional hazards as sediment has been mobilized following significant rainfall events. The Solomon Islands government is considering relocating many of these villages.

The geologic record of this event is a mélange of sediment mobilized by the earthquake, transported by the tsunami, and reworked by routine geomorphic processes. The incoming tsunami deposited sediment from the lagoons and beaches inland. At Tapurai, this marine sediment is combined with boulders from the hillside that backs the village. The exiting tsunami removed sediment from land, depositing some of it in the lagoon. Following the rainy season, additional material from interior landslides made its way into the coastal zone, further disturbing the equilibrium.

Over the course of the past year, littoral processes continued to redistribute sediment, moving it into deeper water via chutes and channels in the barrier reef. The coarser material shaken loose by the earthquake and moved by the tsunami is being covered with a finer layer of sediment. It is this deeper-water deposit that has the highest potential for being preserved in the geologic record.

Local Population

Socioeconomic vulnerability and physical remoteness of the affected region left the population acutely exposed to this hazard, and the risk from future events depends largely on recovery from this one. While the earthquake/tsunami hazard has been temporarily reduced, reactivated landslides and debris-clogged streams continue to pose additional hazards to numerous villages. Damaged infrastructure, ecosystems, water supplies, and coastal access will have to be assessed, thoughtfully repaired, and monitored with these hazards in mind.

Rapid and sustainable economic recovery has the potential to mitigate the effects of the disaster and limit damage from future events. While it is critical that people resume economic activity as soon as possible, all involved need to keep in mind their interactions with the environment. For example, it is unclear how damaged coastal ecosystems will affect the region’s fishing and dive tourism industries or if measures (such as mangrove replanting) should be undertaken to aid in the rehabilitation of these industries.

Education remains one of the most effective tools for disaster mitigation. The most successful scientific, educational, and outreach efforts were made by officials from the Solomon Islands government working in concert with SOPAC and NGOs in the affected area. The local authorities speak the local Pijin dialect and recognize cultural subtleties that take varying degrees of indigenous knowledge into consideration for future mitigation efforts [McAdoo et al., 2006]. Local educational efforts such as these...
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 tsunamiigenic 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 ecological 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.

**Acknowledgments**

Thanks to the Solomon Islands government, B. Manele and J. Thomas (WWF Gizo), L. Kong (UNESCO), and D. and K. Kennedy and G. Griffiths in Gizo. This work was funded by the U.S. National Science Foundation (NSF) Small Grants for Exploratory Research program (EAR-0734982 and CMS-0646278) and UNESCO (IOC-4500034222) with a NSF Partnership in International Research and Education grant (OISE-0530151).

**References**


**Ocean Color Reveals Increased Blooms in Various Parts of the World**

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 favor 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 [McCain 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 blooming 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 nutrient-