NEWS

Coral Poaching Worsens Tsunami Destruction in Sri Lanka

PAGES 301, 304

Observations of the trail of destruction of the Sumatra tsunami of 26 December 2004 indicate remarkable, small-scale spatial variations, of the order of a few kilometers, of water inundation and destruction in southwestern Sri Lanka [*Shiermeier,* 2005; *Liu et al.*, 2005] that are much smaller than the tsunami wavelength of ~100 km.

For example, the town of Peraliya, was awash with an approximately 1.5-km water inundation from a wave of 10 m in height; the inundation there carried the passenger train Samudra Devi (the "Ocean Queen") inland some 50 m, killing 1700 people. Yet, ~3 km south, in Hikkaduwa, there was a mere 2–3 m wave height, 50-m inundation and no deaths.

In the southwestern stretch of Sri Lanka from Galle to Ambalangoda (Figure 1, inset), this inundation "patchiness" was unrelated to obvious coastline features such as headlands, embayments, and river channels. Through hundreds of eyewitness accounts, diver observations, and wave measurements, it was possible to conclude that illegal coral mining along unsupervised beaches had created defenseless "low-resistance paths" that allowed focused water jetting into the land and intensified destruction.

While eastern Sri Lanka received the brunt of the tsunami, the southwest, which is in the island wake (or the shadow zone), was also severely affected through a complex mix of processes. Analysis of wave and tidal gauges, eyewitness accounts, and debris observations clearly point to the arrival of two or three refracted and diffracted waves from the southern tip of Sri Lanka at Dondra Head between 0915 and 1010 LT and a reflected wave from either the Indian coast or the Maldives islands at about 1200 LT.

Although the tsunami amplitudes in the eastern part of Sri Lanka were reasonably well predicted by available computer models [e.g., *Liu et al.,* 1995], amplitudes in the southwest were underpredicted. This indicates that many subtleties are unaccounted for in the models, most possibly as a result of numerically unresolved kilometer and sub-kilometer-scale processes.

The glaring absence of small-scale spatial features in wave and coastline records in southwestern areas that are characterized by patchy destruction led to the investigation of the inhomogeneity of the coastal ocean

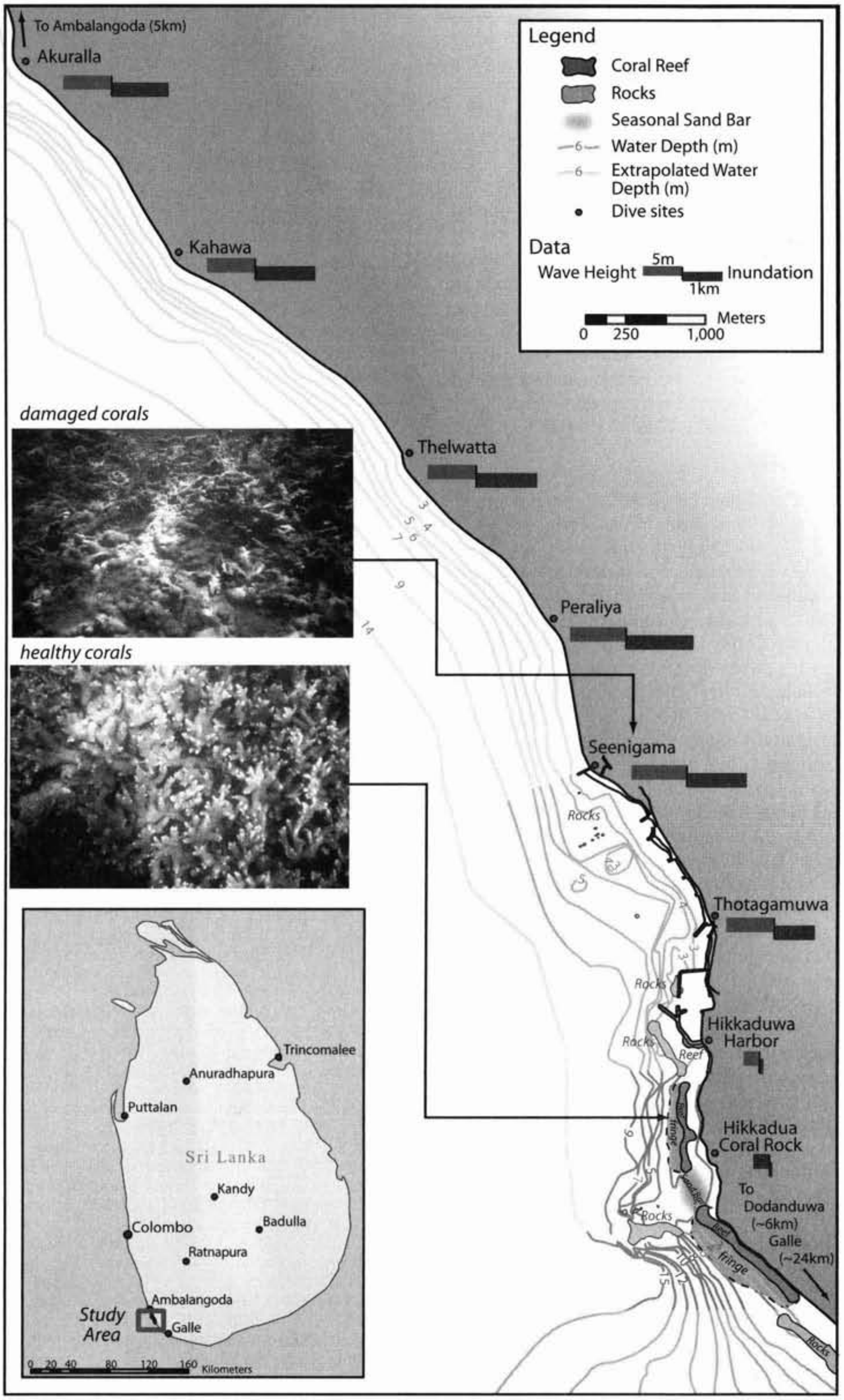

Fig. 1. Map of the coastal study zone along southwestern Sri Lanka, from Dodanduwa (six km south of Hikkaduwa) to Akuralla. The red square in the inset shows the location of the study area on the island coastline. The wave height measurements are indicated in green bars (meter scale), and the inundation is indicated in blue (kilometer scale). The dark blue bathymetric contours have been redrawn based on a 2002 high-resolution mapping program of the Sri Lanka National Aquatic Resources Research and Development Agency, and the light blue contours are extrapolations made based on sparse observations. Dive sites, coral reefs, sandbars, and rock reefs are also shown. The fringe of coral reefs indicates areas where corals are thin and distributed. Typical diver photographs of the areas are also shown. Original color image appears at the back of this volume.

bottom as a candidate for the spatial intermittency of destruction.

On a research visit to the area during 15–18 February 2005, several of the authors, accompanied by documentary filmmakers, made detailed measurements of the tsunami wave amplitude and water inundation in contiguous severely and mildly affected areas along the southwest coast, from Akuralla to Dodanduwa (Figure 1). (The British Broadcasting Corporation's Horizon program provided financial support for the February visit. The lead author was a consultant for the program's resulting documentary, "Tsunami: Anatomy of a Disaster," which aired on BBC1 on 1 March and will soon be released for wider distribution.) Diver observations were also made in selected sites. These measurements, which followed standard procedures [*Tsunami Technical Review Committee*, 2002], complemented those conducted earlier by an International Tsunami Survey (ITS) team during 10–16 January in Sri Lanka [*Liu et al.*, 2005].

The ITS team had consisted of eight scientists from the United States (including the lead author) and one from New Zealand, supported by four Sri Lankan scientists (including the second author). The U.S. National Science Foundation, the Earthquake Engineering Research Institute, and the U.S. Geological Survey provided travel funding for the U.S. scientists.

The team measured maximum tsunami heights and runup, inundation, and areas of inundation along the east and southwest coasts of the island, and performed a limited aerial survey along the southwest coast. Team geologists collected soil samples from tsunami deposits and inferred some hydrodynamic characteristics of the tsunami. The team also interviewed hundreds of eyewitnesses and sifted through rubble to collect any residual information (e.g., stopped clocks to determine the time of wave arrival).

The ITS team, however, did not conduct high-resolution measurements in kilometer-scale spatial increments or diver observations, and had only a few data points for wave height and wave inundation in the study area described in this news article.

The high spatial resolution information shown in Figure 1 was obtained during the 15–18 February visit to the area. The earlier measurements of the ITS team are broadly consistent with the more recent observations, although only a few ITS measurements are available from Akuralla to Dodanduwa.

The recent observations show that only modest damage—only some structures destroyed and few or no deaths—occurred from Hikkaduwa to Dodanduwa. This area is partly fronted by rock reefs, and the Hikkaduwa hotel strip is further sheltered by coral reefs that local hoteliers protect and nurture.

Extensive damage, indicated by the propensity of property and human loss, was evident from north of Hikkaduwa to Akuralla. There, dozens of interviewed local residents indicated that coral reefs have been decimated by illegal mining, especially with explosives that allow coral and fish harvesting. Extensive diver observations corroborated this coral damage (Figure 1).

A striking correlation was found between the water inundation and the extent of the coral and rock reef cover (Figure 1). Eyewitnesses from a local beachfront diving school reported on a visible reduction of the speed of the "water wall" associated with the wave and its lateral (alongshore) deflection as the tsunami approached the coral reef. Given that the corals cause drastic wave attenuation (as much as 80–95%) and act as submerged breakwaters [*Lugo-Fernandez et al.*, 1998; *Frihy et al.*, 2004], it appears that the water flow impeded by the corals found its way to the land with greater intensity through nearby "low-resistance" paths created by anthropogenic coral removal, much the same way as water jetting through dead vegetation in wetlands [*Granata et al.*, 2001].

The damage to corals in Hikkaduwa by the tsunami appears to be not so significant, given that they were generally found to be in a healthy state during the survey, except for some isolated patches of damage and uprooting due to debris impact. This observation is consistent with the broad assessment made by the nonprofit Coral Cay Conservation organization that only about 8% of the coral coverage before the tsunami was destroyed during the event [*Ebert*, 2005; see also *Pennisi*, 2005].

The significant beach defenses offered by coral reefs, which were evident from the observations presented in this news article, may also explain why certain Maldivian islands surrounded by coral reefs were spared from destruction even though they were in the path of the tsunami.

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FORUM

Manned Space Exploration Can Provide Great Scientific Benefits

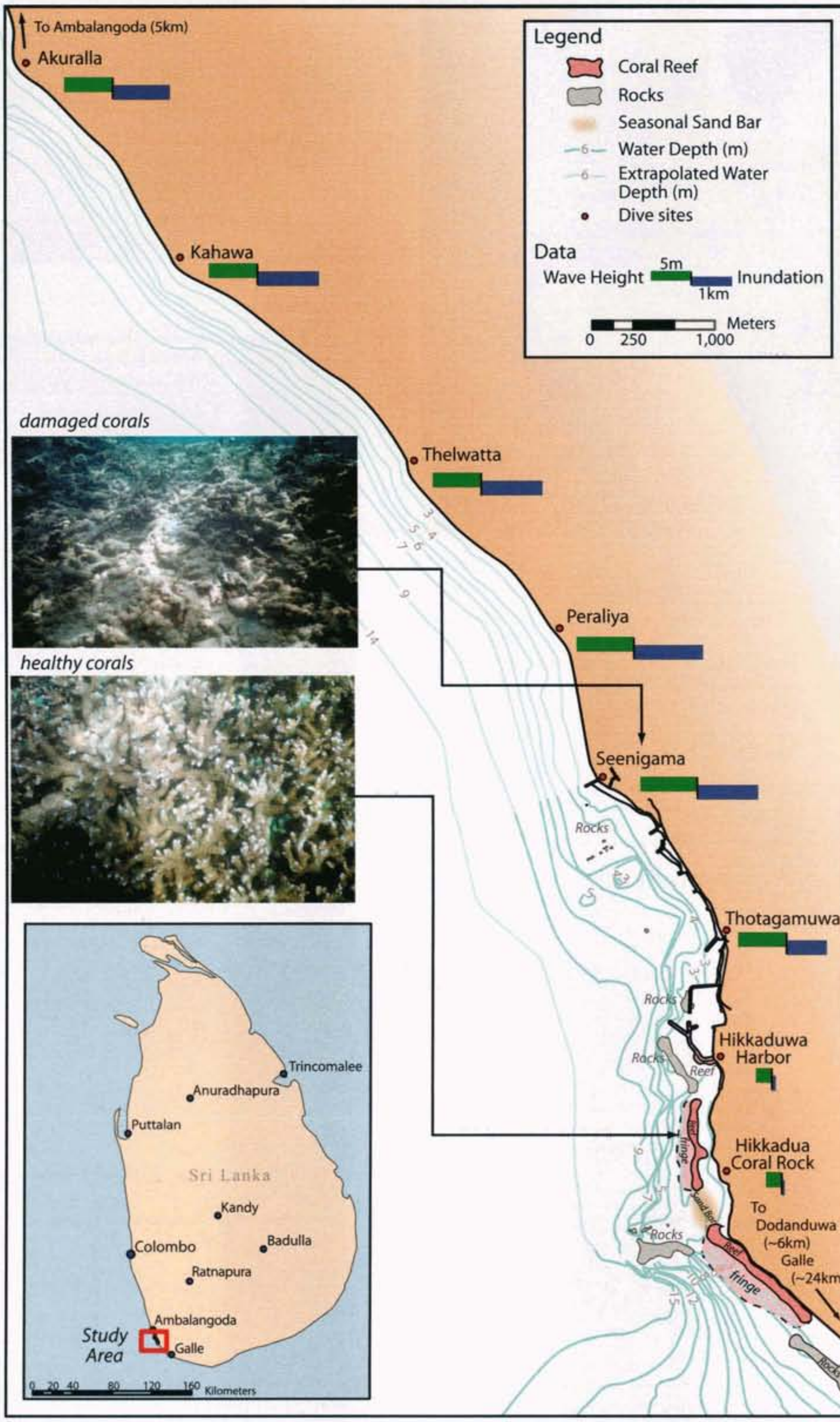
PAGE 302

An AGU Council statement (NASA: Earth and space sciences at risk, available at http://www.agu.org/sci_soc/policy/positions/earthspace_risk.shtml) and an *Eos* editorial [*Barron*, 2005], addressing NASA's envisioned manned Moon-Mars initiative, implicitly assume a zero-sum situation between manned and unmanned space programs. They also imply that the NASA initiative will not contribute significantly to science but will "impact on the current and future health of Earth and space science research." I wish to respond to these concerns.

It is generally agreed that the International Space Station and shuttle program have limited value and need to be terminated. But one should not assume that funds freed up by elimination of manned programs will accrue to unmanned programs. On the contrary, without a manned component, NASA will probably cease to exist. Congress likely will not continue to fund unmanned planetary exploration over the long term, and Earth and space researchers will then have to compete for support with scientists using non-space techniques.

I can personally testify to the value of unmanned programs, as an early developer of satellite instruments [*Singer*, 1956], researcher of magnetosphere and solar-terrestrial effects [*Singer*, 1997], former director of the U.S. National Weather Satellite Service (now the U.S. National Oceanic and Atmospheric Administration's National Environmental Satellite Data and Information Service), and most recently as a principal investigator on the Long Duration Exposure Facility (LDEF) satellite experiment on orbital debris.

Nevertheless, there are certain scientific problems that benefit from direct human intervention [*Singer*, 1969]. As a consequence,



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