The fate of coral reefs in the Andaman Sea, eastern Indian Ocean following the Sumatran earthquake and tsunami, 26 December 2004

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The Sumatran–Andaman earthquake was the second largest earthquake in the instrumental record, with shifts in the sea floor displacing more than 30 km^3 of seawater and generating a tsunami that was recorded worldwide (Bilham 2005). The scale of the resultant human tragedy and damage to coastal infrastructure was almost incomprehensible and is it was not surprising that many scientists anticipated extensive damage to coral reefs along affected coastlines in the Andaman Sea. It is perhaps noteworthy that since 1833 over 35 tsunamis have been recorded around the neighbouring Indonesian archipelago (Carey *et al.* 2001), which is home to the most diverse coral reefs in the world, but there is no reference to tsunami-related damage on coral reefs in the scientific literature. This brief account summarizes the effects of the earthquake and the tsunami on coral reefs in the Andaman Sea region in the eastern Indian Ocean as far as they are known at present.

Fringing reefs dominate the coastlines of the Andaman Sea, being very well developed on the northern tip of Sumatra, in the Andaman and Nicobar Islands, the Mergui Archipelago of Myanmar, and the west coast of Thailand and northern Malaysia. While the reefs of north Sumatra, the Andaman and Nicobar Islands, and Mergui are poorly documented, those of Thailand and Malaysia have been relatively well studied. The region is well known for its extensive shallow reef flats that extend up 200–500 m from the shore, particularly in the Nicobar Islands. Living coral generally extends from the shoreline to the reef edge with reef flats in sheltered locations being dominated by massive species (mainly poritidae and faviidae) interspersed by patches of branching *Acropora* and *Montipora* species. In more high-energy settings the reef flats are dominated by branching species. The overall diversity of stony corals on reef flats ranges between 60 and 80 species. Comprehensive study of reef slopes is restricted to Thai waters, with reefs along the mainland being found down to depths of 5–15 m, and those on offshore islands at depths down to 30 m. Reef slopes on the Andaman Sea coast of Thailand tend to be dominated by a mixture of massive and branching corals (Phongsuwan and Chansang 1992).

The impacts of the events on 26 December 2004 on coral reefs in the region can be ascribed to (a) the earthquake and (b) the ensuing tsunami. The earthquake registered 9.3 on the Richter scale and caused uplift and subsidence of coral reefs along 1000 km of the boundary between the Indian plate and the over-riding Burma–Andaman–Sumatra plate (Bilham 2005). The east coast of South and Middle Andaman sank by 2.5–3 m, with subsidence increasing southward to a maximum of 4.2 m at the southern tip of Great Nicobar Island (Searle forthcoming). On the west coast of the Andamans the island coastline rose by up to 2 m, raising reef flats to above the present day high tide mark; similar uplift of shallow fringing reefs was observed on the SW coast of Simeulue Island on the west coast of Sumatra (Sieh 2005). It is estimated that at least several tens of square kilometres of shallow water reef are now dead along the rupture zone from Sumatra to the northern tip of North Andaman. Subsidence will likely have had little long-term detrimental damage on reefs, though some may have been affected by heavy sedimentation following the tsunami.

In terms of tsunami-related damage to coral reefs, the best documentation in the region comes from the west coast of Thailand where the Department of Marine and Coastal Resources acted instantly to mount a rapid assessment survey in December 2004. Four days after the tsunami occurred teams of government and university scientists, who were already familiar with particular sectors of the coastline, were despatched to field sites. They visited fringing reefs on both the mainland and offshore islands and surveyed 174 reef sites along the 700 km long coastline between Mynamar and Malaysia. Results indicated that 105 sites were unaffected or showed very little damage (11–30% coral cover affected), 16 displayed moderate damage (31–50% coral cover affected) and 23 were severely damaged (>50% coral cover affected) (Department of Marine and Coastal Resources 2005; Satapoomin *et al.* forthcoming). In other words, only 13% of all sites studied were severely damaged, with 60% of sites showing little or no damage at all. A subsequent detailed survey of sites, where long-term monitoring of coral reefs had been in place for over 20 years, confirmed results of the earlier rapid assessment survey with very few locations showing serious damage (Phongsuwan and Brown forthcoming).The greatest damage had taken place along the northern most coastline and its offshore islands (the provinces of Ranong and Phang-gna), although sites in the southern province of Krabi (Phi Phi Island) were also badly damaged. Tsunami wave heights were estimated to be approximately 10 m on the northern most coastline and 5 m around Phi Phi island. Shallow reefs on wave-exposed islands and shorelines were most vulnerable to wave-induced damage, with the destructive impact of the tsunami being dependent on degree of exposure to the waves, the surrounding sea bottom topography and the depth of water over the reef. Types of reef damage included overturned massive corals, broken branching corals and smothering of live coral tissues in areas where the tsunami waves had generated increased sedimentation.

Similar damage from waves generated by the 26 December tsunami has been recorded on reefs around Banda Aceh on the northern tip of Sumatra (Baird *et al.* 2005) and also in the Andaman and Nicobar Islands (Anon 2005). In both locations damage from the tsunami had been highly localized and overall quite limited (Baird *et al.* 2005; Searle forthcoming). Indeed, Baird *et al.* comment that long-term human mismanagement of reefs in Banda Aceh has been much more destructive than the effects of the tsunami on reef structure.

In terms of recovery potential, the prognosis for reefs along the Thai coastline is good, with natural regeneration likely over the next 5–10 years. The reasons for such a confident prediction are based on three facts. Firstly, the very high growth (skeletal extension rate) of corals in the region; secondly, previous rapid reef recovery following damage from storm surges; and thirdly, the present generally good condition of reefs in the Andaman Sea (see Phongsuwan and Brown forthcoming for review). Such rapid recovery does, however, depend on reefs not being subject to widespread mortality from exposure to elevated sea temperatures during a severe El Nino event. It has been predicted that worldwide coral bleaching events, which result from exposure of corals to elevated sea temperatures, are increasing in intensity and frequency (Hoegh-Guldberg 2004) though shallow reefs in the Andaman Sea have suffered little to date from bleaching-related mortality. Although sea temperature is rising on average at a rate of 0.16°C per decade in the Andaman Sea, the extensive shallow reef flats are composed of corals with remarkable physiological tolerances because of their regular intertidal exposure (Brown forthcoming). In this context the greatest concern for the region should be the loss, as a result of the earthquake, of many thousands of physiologically robust corals that have evolved over the last 6000 years in a unique environmental setting along the Sumatra–Andaman plate boundary. Although uplift of reefs in this region has occurred in past centuries (Bilham *et al.* 2005), the threat of global warming and the need to conserve such an important gene pool were never important priorities in these much earlier times.

Overall, then, the greatest damage to coral reefs in the Andaman Sea has been in north-west Sumatra and throughout the Andaman and Nicobar Islands where corals have been subject to the effects of both the earthquake and tsunami. The losses due to uplift, as a result of the earthquake, are irreversible but tsunami-related damage will recover given favourable environmental conditions over the next decade. Along the Thai coastline, where reefs were subject to only the influence of the tsunami, natural regeneration of reefs should result in complete recovery over a similar time scale. Unfortunately, we know very little of the fate of reefs in the Mergui archipelago of Myanmar but dive tour operators who were in the region at the time of the tsunami report very little damage to reefs in the region.

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The Indian Ocean tsunami: socio-economic impacts in Thailand

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Introduction

On the morning of 26 December 2004 large areas of coastal southern Thailand were transformed when a tsunami, generated by a powerful submarine earthquake in the Indian Ocean, swept ashore. Officially, there were 5395 confirmed deaths in Thailand with another 2932 people listed as missing.

In February 2005 a team led by Dr Ben Horton of the University of Pennsylvania was awarded an SGER grant by the National Science Foundation to undertake exploratory research on the tsunami in Malaysia and Thailand. This report summarizes the preliminary conclusions of the social science element of the Thai fieldwork. The team undertook fieldwork in three main sites during July 2005: Koh Lanta, Koh Phi Phi and Khao Lak. We chose Koh Phi Phi as a small, tourist (backpacker)-oriented island economy with high levels of damage and casualties; Koh Lanta as a site with a significant population of fisherfolk with a long presence in the area; and Khao Lak as a mainland site with the highest number of casualties in Thailand and with a mixed tourism–fishing economy.

Themes

We gathered, through interviews, a rich database of qualitative information on the tsunami and its impacts and effects, and on patterns of rehabilitation and recovery. We were told of people's frantic