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Indian Ocean tsunamis: environmental and socio-economic impacts in Langkawi, Malaysia

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We report the results of a study of the physical characteristics and socio-economic impacts of the Indian Ocean Tsunami of 26 December 2004 on the tourist island of Langkawi, Malaysia. In comparison with many other locations struck by the tsunami, the immediate physical and socio-economic impacts in Langkawi were relatively minor. A detailed survey of the watermark and ground elevations was undertaken in the worst affected area between Sungei Kuala Teriang and Sungei Kuala Melaka. Here, the tsunami reached a maximum elevation of 4.29 m as it crossed the coast, with a maximum flow depth of 2.0 m and a very consistent run-up elevation relative to mean sea level of 300 ± 10 cm. The tsunami inundated inshore areas for 300 m and penetrated inland along creeks for 500–1000 m. Structural damage to buildings was confined to within 50–150 m of the shoreline where about 10% of the houses were completely destroyed and 60–70% suffered significant structural damage. Damage was particularly severe in areas where there was no engineered coastal protection, but while coastal revetments did provide enhanced protection for houses at the waterfront, the coastline in the study area appeared to be more heavily impacted than elsewhere in Langkawi because wave energy was focused on the area by offshore breakwaters built to protect the Langkawi port and airport. Emergency response after the tsunami was rapid and efficient but would have been improved if the local police station had not been rendered inoperative by the first wave, and if a mechanism had been in place to ensure that informal advance warnings transmitted between Phuket (Thailand), Langkawi and Penang (Malaysia) by tourist operators could have been more widely disseminated.

KEY WORDS: Malaysia, Langkawi, tsunami, mangrove, tourism, emergency response, relief, reduction of vulnerability

Introduction

On Sunday, 26 December 2004 at 00:58:50 UTC (8:58:50 am local Malaysia time), the second largest earthquake ever instrumentally recorded, with a moment magnitude of 9.3, generated a disastrous tsunami up to 25 m high that caused destruction in 11 countries bordering the Indian Ocean (US Geological Survey 2005). The epicentre of the earthquake was at 3.298°N, 95.779°E, about 150 km off the west coast of Sumatra in Indonesia, and its focal depth was very shallow (much less

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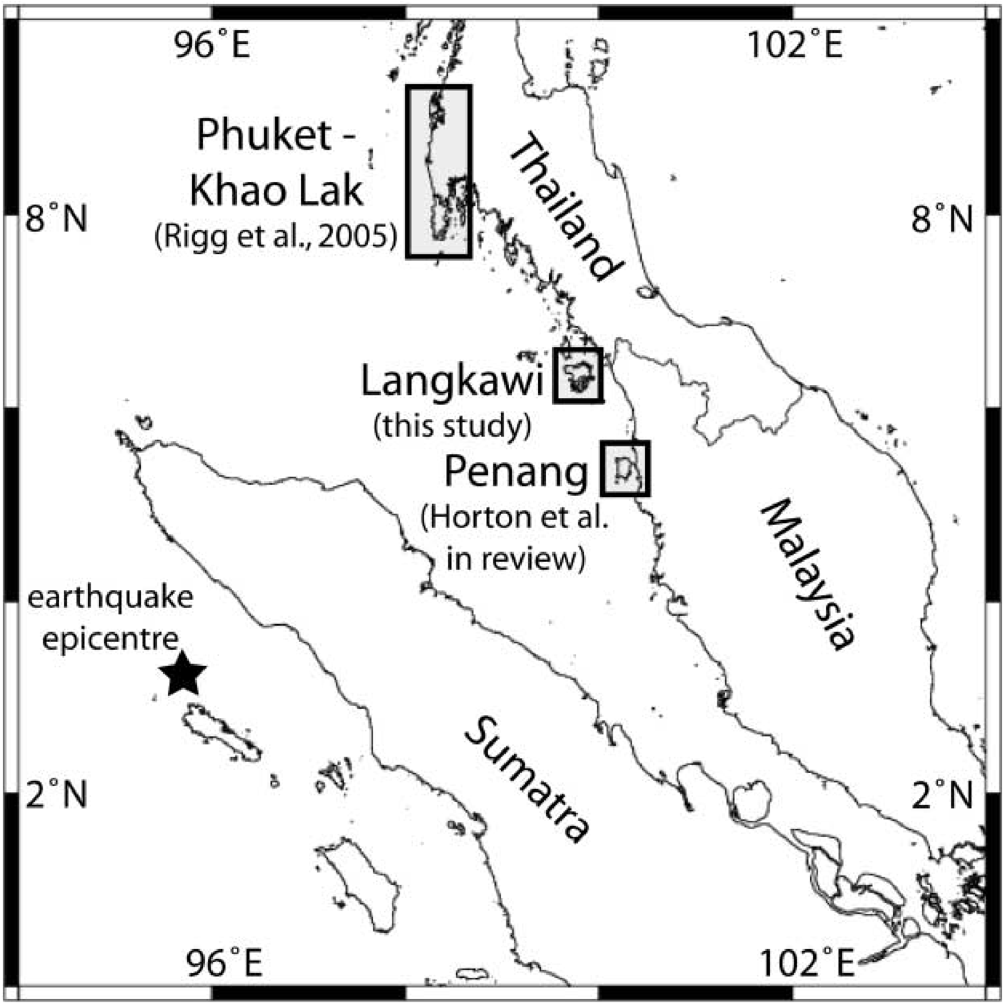

Figure 1 Map indicating the position of Lankawi relative to the earthquake epicentre west of Sumatra. Also shown are the study areas of Horton *et al.* (forthcoming) and Rigg *et al.* (2005), as discussed in the text

than 33 km – possibly about 10 km). The earthquake was widely felt in Sumatra, the Nicobar and Andaman Islands, Malaysia, Myanmar, Singapore, Thailand, Bangladesh and India (Ammon *et al.* 2005a 2005b; Banerjee *et al.* 2005; Okal and Stein 2005).

The 2004 tsunami left unique and perishable data that can be used to construct and interpret trajectories of environmental and socio-economic change in the tsunami-affected areas and to assess future risk (e.g. Adger *et al.* 2005). We chose Langkawi, Malaysia as a study site because the physical and socio-economic impacts were typical of less catastrophic, but more common, tsunami events. Thus, we aim to assist in efforts to understand better the impacts of tsunamis in general, and to mitigate the impacts associated with future events. Observational data, which have now been collected from several other locations in the Indian Ocean since the tsunami, can also assist in the refinement of models of tsunami generation and propagation (e.g. Narayan *et al.* 2005; Yalciner *et al.* 2005), and in developing tools for identifying tsunami deposits in the sedimentary record (Bishop *et al.* 2005). This study was conducted in tandem with similar studies conducted in Penang, Malaysia, 50 km south of Langkawi (Horton *et al.* forthcoming) and southern Thailand (Rigg *et al.* 2005; Buranakul *et al.* 2005), as shown in Figure 1.

The tsunami in Malaysia

Peninsular Malaysia, including Langkawi, is partly sheltered from tsunamis generated in most parts of the Indian Ocean by Sumatra (Choi *et al.* 2003), but is potentially directly exposed to tsunamis generated in the Nicobar–Andaman Islands region to the north of Sumatra (Pacheco and Sykes 1992; Ortiz and Bilham 2003). One of the strongest earthquakes ever recorded in this region occurred on 26 June 1941 (magnitude 7.7), and is known to have generated a tsunami that killed 5000 people along the east coast of India (Schiermeier 2005). An archival search of 'The Pinang Gazette and Straits Chronicle' over the two weeks following 26 June 1941 located no reference to a tsunami impacting anywhere along the western coast of Peninsular Malaysia. The occurrence of the earthquake itself was reported the day after the event, based on a wire service report from London along with events of comparatively trivial significance from elsewhere in Malaysia. This suggests that either no wave of significant size travelled southwest from the epicentre of the earthquake, or that any wave was attenuated to the point where it did not cause significant run-up on coasts bordering the Straits of Malacca. This further suggests that the tsunami of 2004 was the first event to cause significant damage in Malaysia in at least a century and probably considerably longer.

Despite being located close to the earthquake epicentre, the impact of the tsunami in Malaysia was substantially less than in areas located further afield. As of 9 January 2005, 68 deaths had been confirmed, with five people missing and 8000 displaced (Asian Development Bank 2005). Significant run-up occurred over 300 km of coastline from the Thai border south to the state of Selangor, with 4696 people evacuated from their homes in Kedah (including Langkawi) and 1600 evacuated in Penang (World Fish Centre 2005).

Fishing and aquaculture are important industries in these areas and were heavily affected. Across Malaysia, 155 fish farmers lost an estimated US$6.3 million from the damage to facilities and land and 5200 fishermen lost an estimated US$7.71 million in boats and other equipment (Aquaculture Magazine 2005; World Fish Centre 2005). Despite this, the relative economic impact on Malaysia was small, with the cost of the clear-up operation reported at US$25 million, compared with US$1.5 billion for Sri Lanka, US$600 million for the Andaman and Nicobar Islands, US$1.2 billion for India and US$4 billion for the state of Aceh in Sumatra (Asian Development Bank 2005).

The study area

Pulau Langkawi is the largest and most developed island (487 km^2; 62 000 inhabitants) of a group of 99 islands within the Andaman Sea known collectively as the Langkawi Islands. The islands are 30 km from the coast of the Malaysian state of Kedah, of which they are administratively a part, near the Malay–Thai border (Figure 1). The island is mountainous, and spectacular limestone cliffs, white sand beaches and fringing reefs mean that tourism is the main contributor to the local economy. The principal town and administrative centre is Kuah, located on the south coast of the island, but tourist development has primarily occurred along the beaches of Pantai Tengah and Pantai Cenang on the west coast (Figure 2).

Langkawi was the first location in Malaysia to be struck by the 2004 tsunami, and we concentrated this study on the area that sustained the most significant damage, along a confined 1 km stretch of coast between the Kampongs of Kuala Teriang and Kuala Melaka, north of the major coastal defences protecting Langkawi airport and Port Langasuka (Figure 2).

Approximately 3500 people live in these two communities and rely on fishing for the majority of their income. Sungei Ranggor Besar provides a small harbour at its mouth for Kampong Kuala Teriang at the north end of the study area, while Sungei Melaka provides a similar harbour at its mouth for the residents of Kampong Sungei Melaka at the southern end of the study area. A mangrove fringe used to stretch along the coast between these rivers, but the coast has been armoured by two rock revetments built to 2.7–3.0 m above sea level, one stretching from the north bank of Teriang Harbour, south in front of Kampong Kuala Teriang, the other stretching north in front of Kg. Sungei Melaka. These coastal protection works do not meet, and a 50 m stretch of natural coast with remnant mangroves remains between the two.

Single-storey, non-engineered concrete-frame, masonry-infill terrace-style housing, with corrugated iron tiled roofs, has been built approximately 5 m inland from the rock revetment along most of the frontage at Kuala Teriang. A mix of terrace-style housing, freestanding wooden and masonry bungalows and a single abandoned three-storey hotel occupy the foreshore at Kuala Melaka, all, in general, built further back from the coast than at Kuala Teriang. A main road built at about 3 m above sea level runs parallel to the coast and about 100 m inland as far north as Kuala Teriang, before turning inland and crossing Sungai Ranggor Besar at the head of the Kuala Teriang harbour. At the northern end of the study area, residences and a boatshed occupy the area behind the undefended sandy and rocky shoreline on the east–west trending coast west of Teriang Harbour. At the southern end of the study area, tourist resort complexes have been constructed inshore of the 3 m high, arcuate,

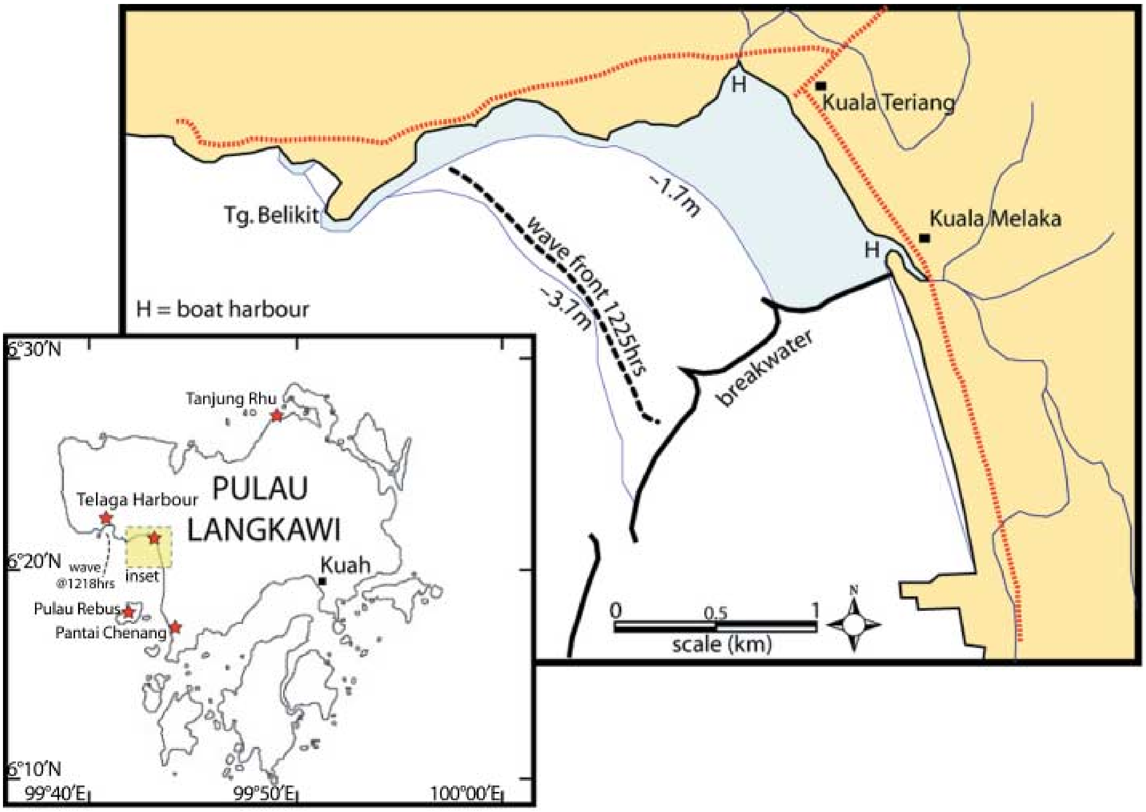

Figure 2 General location map for Kampong Kuala Teriang and Kampong Kuala Melaka showing coastline, bathymetry and the orientation of the first wave as it approached the coast. Inset map shows Pulau Langkawi and the main areas affected by the 2004 tsunami

rock breakwaters that protect Langkawi International Airport and Port Langusuka.

The seafloor fronting Kuala Teriang is a very gently shelving mud platform, which lies at approximately mean sea level (MSL) in front of the Kampong itself. Approximately 700 m of mud platform is exposed at lowest astronomical tide (LAT), and 2 km from the coast the seafloor is 3.5 m below MSL. The shallow gradient continues onshore, inland to the east of Kg. Kuala Teriang/Melaka, but, to the north, the land rises steeply to a series of hills 50 m above MSL.

Methods

Scientific field survey

We made measurements of local topography, tsunami flow depth and flow direction along cross-shore transects at Kuala Teriang (IOC 1998; Tsunami Technical Review Committee 2002; Schiermeier 2005). The concrete slab base of a telephone box provided a temporary benchmark (TBM; Figure 3) and the height above local sea level of the TBM was determined by staff and autolevel. This raw elevation was reduced to MSL by reference to the tide charts for Kuah for the time the measurement was taken. MSL is 1.64 m above the chart datum in use on Admiralty Chart 3485 and repeat measurements suggest the elevation of the TBM relative to MSL is accurate to ±20 cm. The location of each TBM was determined using a Leica SR530 GPS system to a horizontal accuracy of better than ±5 m.

From the TBM a series of levelling runs was conducted in order to establish the elevation of the major geomorphic features and the elevation of watermarks above local ground level and above MSL. Other features (roads, coast, vegetation) were mapped using a Trimble Geoxplorer XT GPS, or digitized from Admiralty Chart 3485 and Aster satellite imagery.

Watermarks defined by a thin film of mud and organic debris on trees and poles were taken as

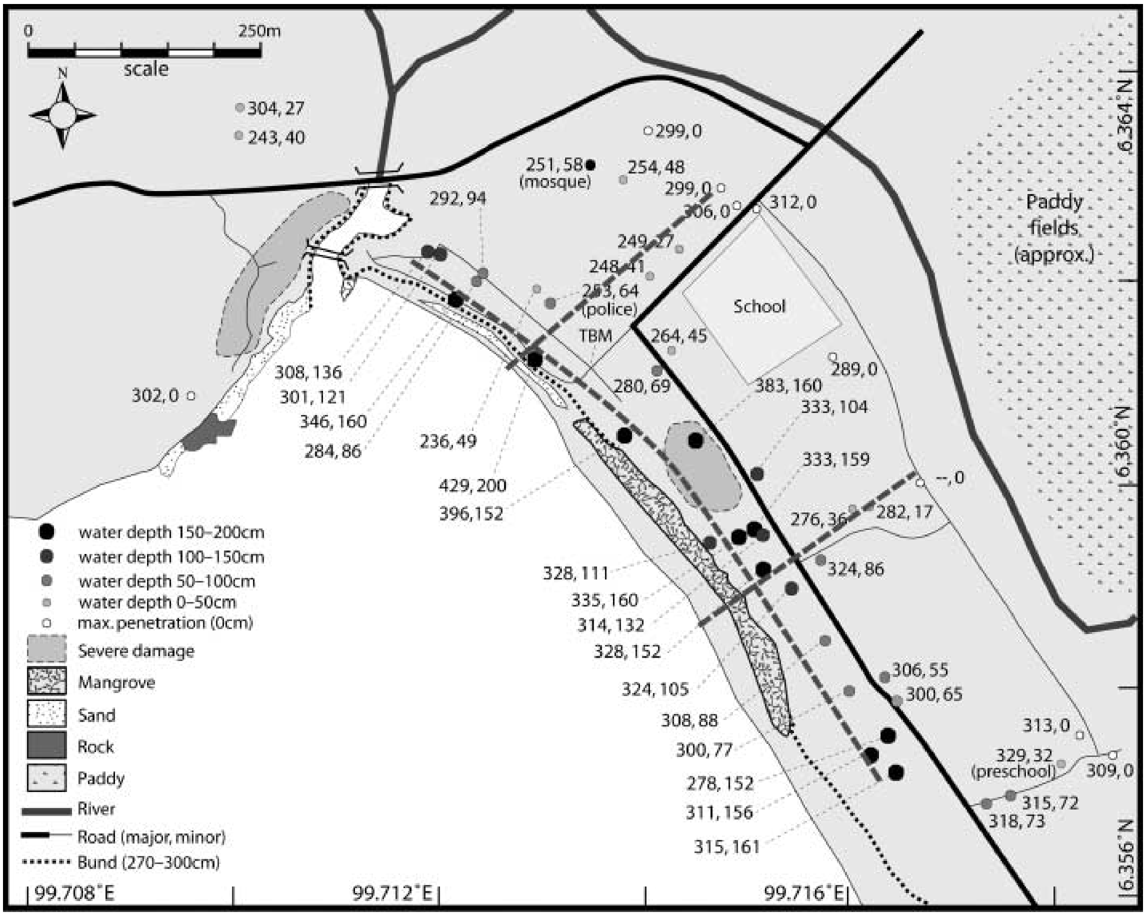

Figure 3 Detailed map of the Kampong Kuala Teriang study area with surveyed water marks indicated. The first number at each survey point represents the maximum height of the water above MSL in centimetres, the second gives water depth in centimetres. Ground elevation can be calculated by subtracting the second measurement from the first. Maximum penetration is indicated by a water level of 0 cm

direct indicators of maximum wave height. The interpretation of watermarks on buildings is less straightforward, as the height of watermarks on walls is dependent on the orientation of the wall relative to the direction of travel of the wave, with 'leading walls' facing the direction of wave attack bearing the highest watermarks and internal walls having the lowest watermarks (Horton *et al.* forthcoming). Watermarks on the outside walls, parallel to the direction of flow, provide the most reliable estimates of maximum water depth, as demonstrated by Horton *et al.* (forthcoming) and we report only these measurements where possible. While the sedimentary record of the tsunami was mapped and sampled as part of this project, these results will be presented elsewhere.

Social science field survey

We carried out this research using an interview approach that lies closer to the interpretivist end of the spectrum (e.g. Bryman 1988; Brannen 1992; Neuman 1997). This approach is typically used when there are specific research objectives, but it facilitates flexibility to enable exploration of unanticipated issues (Thomas 2003). Interviews were conducted with the aid of local representatives fluent in Malay and Penang Hokkien. The following core research questions acted as guidelines during interviews but did not inhibit the flow of conversation:

- What were the experiences and recollections of eye witnesses to the tsunami?

- How were the livelihoods of different groups affected and how did they respond?
- What were the immediate, medium-term and likely long-term effects of the event?
- How did institutions respond to the event (state, NGO and community organizations)?
- What was the response cycle over time?

We conducted formal interviews with 15 key informants, ranging from government officials (District Officer, emergency services, welfare and tourist development officers) to fishermen, business owners, NGO representatives and local residents. Identification of informants was carried out using a bottom-up approach leading to referrals. The fishermen of the villages associated with the study sites congregated at beach shelters at times when they were not out at sea. We used these meeting places as an opportunity to talk both informally and formally with the fishermen about the tsunami. The fishermen referred us to other key informants within the villages, such as village leaders, who, in turn, recommended others who had been most affected, and/or who had played a prominent role in the events following the tsunami.

Results

Tsunami timeline

The conditions on Langkawi immediately prior to the arrival of the 2004 tsunami were calm and clear, with the tide close to its maximum for the day at 2.2 m relative to LAT (about 0.5 m relative to MSL). Photos taken from the Langkawi cablecar, 500 m above and 20 km WNW of Kuala Teriang (Plate 1), indicate that the first wave approached the coast from due east, arriving off Telaga Harbour at

Plate 1 View looking ESE from the Langkawi cable car at 12:25 pm as the first wave approached the study area, which is just out of view in the top left. The wave has already entered the Telaga Harbour Marina in the centre of the picture, and is in the process of sweeping away both moorings and boats. The breakwater protecting the Langkawi Airport and Port Langasuka is visible across the top of the picture
Source: Photograph taken by an unknown individual and posted at http://www.langkawitsunami.net/Locations/Telaga/pages/1225-04a.htm

12:18 pm, 193 minutes after the earthquake, suggesting an average speed *en route* of at least 240 km/h. After passing Telaga Harbour, the wave refracted around Tanjung Belikit, aligning parallel with the coastline in the study area and travelling north-eastwards at 25–30 km/h through progressively shallowing water. A single, approximately linear wave crest was 2 km from Kuala Teriang at 12:25 pm and struck the coast approximately 4 minutes later, progressively constricted between the steep natural coastline to the north and the artificial breakwater that protects the airport to the south (Figure 2). The approach of the wave resulted in a drawdown of sea level that exposed a substantial proportion of the Port Langasuka breakwater 700 m offshore (Plate 1).

A series of photos taken in the Telaga Harbour Marina (see Figure 2 for location) provides a useful timeline for the arrival of subsequent waves in the study area. These photos indicate that mud-laden water associated with the first wave surged into the marina at 12:24 pm over a period of 2 minutes. This wave caused considerable damage to boats and moorings in the marina but did not overtop the marina wall. The water was running out by 12:27 pm and by 12:42 pm water levels were anomalously low. A second wave entered the harbour at 12:52 pm, after which time water levels fell by about 2 m in 4 minutes and stayed low until 13:27 pm. A third and final wave entered the harbour at 14:04 pm.

Eye-witness accounts

Due to its comparative proximity, the earthquake that generated the tsunami was widely felt by communities in Langkawi, where eye witnesses stated that the floor moved, vehicles swayed, standing water became unsettled and doors and windows rattled. None of the interviewees connected the ground shaking with the possibility of a tsunami.

Eye-witness accounts of the tsunami itself varied considerably. This was almost certainly the result of the general confusion that surrounded the tsunami, but it was also at least partially the result of each unique experience of the event (Hyman and Neisser 2000; Dengler and Preuss 2003). Most of the interviewees did not witness the tsunami first hand, and of those that did, the reported number of waves varied between three and five, highlighting the difficulty in interpreting such accounts without corroborating evidence. All confirmed that the waves arrived between 12.00 noon and 1.00 pm, with most saying that the first wave arrived at 12:15 pm, with 3–4 minutes between waves, although the timing appears to vary depending upon the location of the witness at the time. The third wave was most commonly considered the largest, with a height of approximately 2 m. One witness in Kuala Teriang said this wave was heavily laden with mud. Another reported that this wave 'ran well inshore and took three or four minutes to recede'. However, a witness from the Pelangi Beach Resort near Pantai Chenang, south of the study area, said an additional fourth wave was the largest and most destructive. He reported that this wave 'swept far into the resort complex and it picked up anything that wasn't fixed down. It damaged all the air conditioning units in the rooms on the lower levels, and it filled the pools with seawater and marine debris'.

Tsunami hydrodynamics

While a substantial clean-up and rebuilding had occurred in the study area during the five months between the tsunami and this survey, it was possible to determine the general form and extent of the tsunami from watermarks and physical damage, although it was not possible to recognize individual wave events separately. Figure 3 shows the watermarks surveyed for this study and locations where the maximum extent of inland penetration could be identified. The simple geometry of the offshore area, extending onshore as a comparatively simple coastal plain with an onshore gradient of about 1:100, means that the geometry of the tsunami was also comparatively uncomplicated. As the wave came ashore along the NW–SE shoreline, the crest of the highest wave was 120–200 cm above land elevation. Despite a variety of local obstacles including seawalls, road embankments and variable housing density, the wave ran inland for 280–320 m, to an elevation that was in all locations 289–313 cm above MSL. Yalciner *et al.* (2005) report that the tsunami caused inundation along the rivers of Sungai Teriang and Sungei Melaka for 500–1000 m upstream. We did not survey these creeks inland from the coast, but such penetration would be consistent with our observations from elsewhere in Malaysia (Horton *et al.* forthcoming). A rough indication of the response possible by individuals between the first warning that a tsunami was approaching and the arrival of the first wave is provided by the observation that an elderly fisherman at the seafront could move inland by about 150 m between the time the warning was given and the time at which he was overtaken by the first wave, at which point he could safely wade to higher ground without losing his footing.

It was more difficult to determine the wave characteristics west of Kuala Teriang Harbour as houses were completely demolished in this area and hence watermarks were not preserved. The

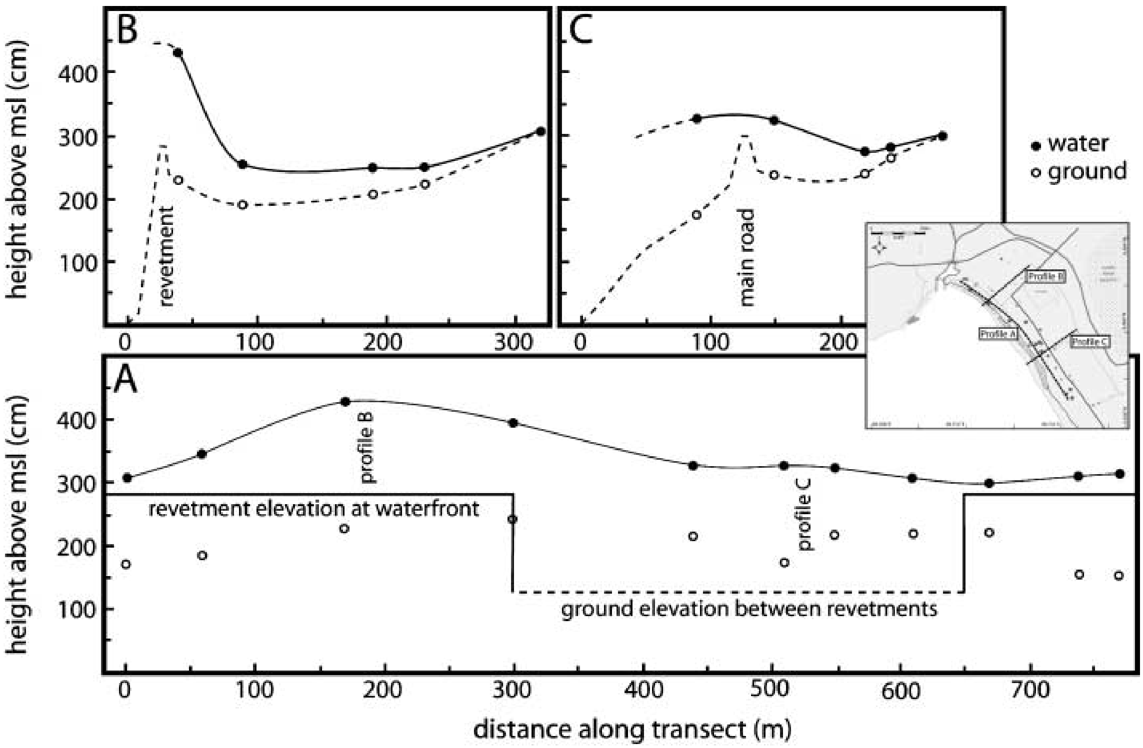

Figure 4 Cross sections of ground elevation and water depth (in cm above MSL) for the three transects indicated on the inset location map

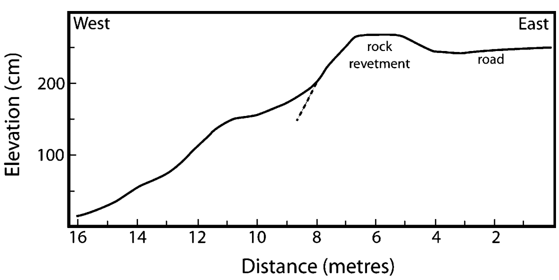

Figure 5 Detailed elevation profile on a transect from the TBM indicated on Figure 2, perpendicular to the coast across the coastal revetment and down to the shoreline

information that was available suggests that the wave was of a broadly similar size, based on the comparability of water depths with those in Kuala Teriang at a similar distance from the coast, and on the similar maximum elevation of inundation.

The longitudinal profile of the wave as it crossed the coast suggests that it was highest towards the centre of the northern revetment (Figures 4A and 5), with a maximum elevation of 439 cm above MSL, while north and south of this maximum the wave height was uniformly around 300 cm above MSL. Yalciner *et al.* (2005) report 'maximum flow depths' at Kuala Teriang of 2.9–4 m, which are broadly similar to the values for maximum wave height (not flow depth) reported in this study. The transverse profiles along the direction of flow (Figure 4B and 4C) indicate that maximum wave elevation was attained as the wave crossed the coast, after which point the tsunami shallowed rapidly to less than 100 cm in depth within 100 m of the coast, with the momentum of the wave carrying the shallowing water 'uphill' over the last 50–100 m of its run.

The zones of damage to infrastructure are not simply correlated with maximum wave depth, although the single death that occurred in Langkawi was within the area of maximum water depth in the study area, towards the southern end of the northern revetment (about 200 m along profile A in Figure 4). While rebuilding made it difficult to accurately estimate the extent of damage to housing and infrastructure, it was clear that structural damage to buildings was confined to 50–150 m of the coast. Within this area, around 10% of the houses were

Plate 2 Looking north at a watermark recorded as 383 cm (elevation of water above MSL), 160 cm (water depth) in Figure 2, in the zone of maximum damage between Kuala Teriang and Kuala Melaka. This is the only wall of this brick house that was left standing. The wall is oriented perpendicular to the flow, which was from left to right. A brown watermark slopes irregularly upward from 140 cm above the ground to the left (marked by an arrow), to 180 cm to the right. The main road through the Kampong is visible in the background

completely destroyed (two or fewer external walls standing), while around 60–70% suffered significant structural damage to one or two external walls and/or the roof, with the extent of damage decreasing rapidly away from the coast (Plates 2 and 3).

Two areas of severe damage were apparent (Figure 3) and both areas were outside the area protected by revetments. The area of maximum damage between the revetments fronting the coast was behind a 20–30 m thick mangrove fringe. Other studies have suggested that mangroves provided some measure of protection from the tsunami in other areas (Dahdouh-Guebas *et al.* 2005; Danielsen *et al.* 2005; Horton *et al.* forthcoming; Kandasamy and Narayanasamy 2005). In this case, while the mangroves may have moderated the force of the wave, it seems that the engineered coastal defenses were more effective in providing protection. This conclusion should be tempered by the observation that most of the houses in the 'severe damage' areas shown in Figure 3 were free-standing cement and wood buildings, whereas the houses behind the northern revetment in particular are terraced brick and wood structures, which may therefore have derived additional structural support from their attachment to adjacent properties.

It was not possible to apportion damage definitively between wave run-up and backwash. It seems likely that the combination of revetments at the shoreline and the road embankment inland meant that water that penetrated inland was effectively impounded and could recede only slowly through engineered drainage channels and culverts, suggesting that negligible damage was caused by backwash.

Socio-economic impacts in the study area

According to the Headman at Kuala Teriang, who was given responsibility for managing the victims

Plate 3 Damage in the immediate aftermath of the tsunami looking south from the main road at 6.3629°N, 99.7111°E, across Sungei Ranggor Besar (marked by rock revetments just exposed above the retreating tsunami water) and out to sea

in the three villages on the coastal stretch between Kuala Teriang and Pantai Chenang, a total of 250 houses were badly damaged, initially affecting around at least 1500 residents. Human casualties were minimal in Langkawi, with one reported death in the Kg. Kuala Teriang of an elderly disabled woman who lived in a house close to the shorefront. Two people were hospitalized because of their injuries.

The villages in the study area are economically dependent upon fishing, so the most significant immediate livelihood impact on the residents of these villages was from damage to their fishing boats, which were 4 m or less in length and made from fibreglass, with outboard motors providing power. The nature of the damage to boats has been described by Horton *et al.* (forthcoming) for Penang, but, in essence, moored boats were tossed inshore by the wave front, equipment onboard the boats was lost overboard and some boats were then washed out to sea as the wave receded. The typical cost for a hull was RM5000 (1 Malaysian Ringgit = US$0.26, GB£0.15) and RM6000 for the outboard motor. Fibreglass is a relatively brittle material and the shocks involved either cracked the hulls, or, in the more severe cases, the boats were broken completely in two. The motors were also often badly damaged either by seawater or mud. According to the chairperson of the local fishing association at Kuala Teriang, about 120 fishing boats were damaged and, of these, about 40 were damaged beyond repair. However, he also said that in total, 375 fishermen had lodged claims for new boats, suggesting that many more vessels were lost across Langkawi as a whole.

Impacts across Langkawi

Much of the Langkawi coast exposed to the tsunami is steep and thinly populated, hence damage across Langkawi was comparatively limited. The main

Table 1 Total tourist arrivals to Langkawi, 2004 and 2005

Month	Total arrivals 2004	Total arrivals 2005
January	173 780	107 943
February	159 238	133 136
March	172 892	142 205
April	156 378	120 478
May	195 977	139 538
June	207 961	172 592
July	165 284	152 100
August	194 767	174 504
September	157 079	151 221
October	130 756	101 720
November	185 401	–
December	280 136	–

Source: Langkawi Development Authority (2005)

areas affected, apart from the study area, were the tourist and beach areas of Pantai Chenang in the south and Tanjung Rhu in the north, as well as the marinas at Telaga Harbour and Pulau Rebus (Figure 2). No detailed physical survey was undertaken in these areas, but Yalciner *et al.* (2005) report maximum flow depths of 2–2.6 m at Pantai Chenang and inundation for 500 m inland along creeks behind the beach. Photos taken at Pantai Chenang in the aftermath of the tsunami show considerable debris, including wooden construction materials, wrecked boats and cars accumulated in Sungei Chenang, but structural damage to buildings, even immediately behind the beach, was comparatively slight.

The main socio-economic impact across Langkawi as a whole was felt in the tourism sector as it employs 90% of Langkawi's workforce, either directly or indirectly (LADA 2005, personal communication). Tourism arrival data reveal that the number of tourists visiting Langkawi in 2005 was down by around 25% compared with 2004 (Table 1). The most dramatic decline occurred in January 2005 immediately following the tsunami; cancellations resulted in a drop of visitors by more than 60% in that month. Numbers started to recover in February and March (down by 20 and 25%, respectively), but then fell again by 30 and 40% on the previous year in May and June, probably the result of the second earthquake that hit the region on 28 March 2005.

Most hotels on the affected west coast continued to operate their businesses as usual after the tsunami, although many of the 21 most notable hotels reported damage to beach facilities and the loss of free-standing equipment such as sunbeds and small boats. One of the most severely affected hotels was the Pelangi Beach Resort near Pantai Chenang. Of most concern to the manager of the resort was the worry expressed by guests at the time. Without any information about the severity of the tsunami and whether or not it was an isolated incident, he felt obliged to move all his guests to the local school as a precaution. No other hotel managers felt it necessary to do this and the next day, the guests moved back to the hotel, although many cancelled the remainder of their stay. The most significant impact, in the opinion of this hotel manager, was the high number of cancellations in the days that followed the tsunami, resulting in his hotel operating at just 30% of capacity when it had been full prior to the tsunami. The pattern of visitations to this hotel in the months that followed reflected the pattern discussed above for Langkawi. The income of the Pelangi Beach Resort Hotel was severely affected, partly because of low occupancy, but also because management chose not to make any hotel staff redundant in the months that followed the tsunami.

Marinas such as Telaga Harbour were also directly affected by the tsunami. The infrastructure of this marina suffered RM7 million in damage and its capacity was reduced to just 27 berths (a quarter of its original capacity). Most repairs had not been completed by summer 2005. The 78 yachts berthed in the marina also suffered significant damage, with nine sunk and three of these damaged beyond repair (worth RM650 000 each). It took management 2 days to recover all the yachts and none of the boat owners were covered by their insurance for damage as a result of the tsunami. There were also indirect economic impacts associated with the damage as local businesses in the marina area estimated that turnover was down by approximately 75% in May 2005 and was proving very slow to recover.

Emergency response

As there was virtually no official warning of the tsunami, the emergency response first operated in a bottom-up manner. The manager at Telaga Harbour Marina received a call from a colleague in Phuket at midday, less than half an hour before the first wave struck, leaving little time to warn those in and around the marina. The manager at the Pelangi Beach Resort also received a call from a colleague at a hotel in Phuket at about 12.30 pm telling him that they had been hit and to expect the same in Langkawi. The first wave arrived about 10 minutes later, again, providing very little time for the manager to evacuate the beach area at the resort. The senior police officer at Kuala Teriang police station received no advance notification, but once it was realized what was happening, the police headquarters was called. Instructions were to move local residents to higher ground, but this was hampered because the lines of communication were down.

As the police station was inundated by the first wave, the officer in charge moved his operations to the local school, which had become a temporary shelter because it was further inland and on higher ground. At around 2.30 pm, 2 hours after the first wave, the District Officer arrived in Kuala Teriang from Kuah and took control. The primary roles of the police force were to ensure that the roads were kept clear of onlookers so as to allow the free movement of emergency vehicles, and to ensure the security of evacuated property. According to the officer in charge at Kuala Teriang, looting did not become a serious problem in any of the affected areas of Langkawi.

Additional help from the Malaysian mainland arrived within a day of the tsunami. The vast majority of the emergency response focused on clean-up activities, organized primarily by the police with help from one of the local village headmen, and on providing food and water for those located in the temporary shelters. The officer was able to move back to his police station 4 days after the tsunami.

Relief

As described in Horton *et al.* (forthcoming) for Penang, the immediate concern following the tsunami in Langkawi was the provision of food, water and shelter for the 1500 residents made homeless. These people were temporarily accommodated in the local school at Kuala Teriang and other community buildings in the coastal villages. The main government agency involved in supporting these people was the Social Welfare Department (SWD), charged by the Disaster Emergency Committee (headed by the District Officer) with ensuring sufficient supplies of food, water, bedding and clothing for the victims. Support of this kind was also provided by a number of NGOs, perhaps most notably the Tzu Chi Buddhists. In due course, the SWD also had responsibility for registering victims' claims for compensation as a result of property damage.

Recovery

In Langkawi, 250 houses were badly damaged or destroyed by the tsunami. The SWD immediately provided RM500 to each affected family. Most families stayed in these emergency shelters for no more than 10 days, after which they were moved to temporary housing, with many able to stay with relatives and friends while their houses were being repaired. Unlike Penang, the government of Langkawi did not build 'long-term temporary' housing (Horton *et al.* forthcoming), but rather embarked on a building programme of permanent housing. When we interviewed the District Officer in May 2005, 27 of an intended 40 housing units had been constructed and were already occupied by displaced families. The District Officer quoted the cost of this housing at RM80 000 each (not including the cost of associated infrastructure such as roads and utilities); however, the victims were asked to pay a lesser amount of RM18 000 to gain occupancy, through an interest-free loan amounting to either RM50 or RM100 per month, depending upon how the occupants were assessed as victims by the SWD. The houses are of a relatively high design standard with two large bedrooms, a kitchen, a lounge room and a bathroom (Plate 4). However, the standard of construction for much of this housing is suspect, with clear evidence of subsidence in at least one of the houses and, according to its residents, theirs was not the only house to have major cracks appear in the walls since they were constructed. No family in Langkawi received compensation for the loss of electrical equipment or furniture, but families whose houses were destroyed did receive RM5000, while those whose houses were badly damaged received RM2500 towards the cost of repairs.

Compensation was also paid to the affected fishermen and details of the compensation structure were almost identical to arrangements in Penang (Horton *et al.* forthcoming): where boats were damaged beyond repair, compensation of RM1000 was paid to owners of small boats and RM3000 was paid to owners of medium or large boats; additional funds for repairs were supplied by the government, with owners required to pay back 50% of the loan where the loan exceeded RM2500 at 0% interest; other loans, such as those made by fishing associations, must be paid back in full generally over 8–10 years; and all fishermen (owners and crew) received RM500 each to help them cope with the period when they could not earn a living from fishing as a result of boat damage.

The hotel manager at the Pelangi Beach Resort hotel reported damage to the beach side of the hotel complex with a total repair bill of RM8 million, much of which was covered by insurance, with repairs complete by May 2005. However, as the hotel manager emphasized, 'what cannot be insured against is the impact the tsunami has had on tourist arrivals'. He felt that part of the reason for the slow recovery of the industry in Langkawi related to the publicity that surrounded the tsunami,

Plate 4 New housing adjacent to Sungei Ranggor Besar in Kuala Teriang, constructed to replace housing destroyed by the tsunami

much of which centred on Thailand, and Phuket's recovery in particular. He believes that this drew attention away from Langkawi, and, as a result, Phuket actually recovered better than Langkawi because tourists that had planned to go to Phuket did so in order to support recovery, while the same level of support did not manifest itself in Langkawi.

The Chairperson of the Malaysian Association of Tour and Travel Agents told us that his own local tourist business had seen a massive drop in demand for tours – down from around 35 persons per tour before the tsunami to just two or three in May 2005. Like many other small operators reliant on tourists, he was not able to absorb the loss of income without retrenching workers. Most retrenched workers were from mainland Malaysia and most had to return to the mainland to seek employment. For the businesses that have survived, all they can do is hope that there is a resurgence in tourist numbers before they too are forced to close. Clearly, the tourist industry in Langkawi has been severely affected, more by the image of disaster, than the reality of the tsunami, and it seems likely that it may take the industry many years to recover fully.

Discussion and conclusions

In comparison with many other locations impacted by the tsunami, the effects of the tsunami in Langkawi, in terms of physical damage and socio-economic disruption, were relatively minor. In the study area, three separate waves had a maximum flow depth of 2 m and a very consistent maximum run-up elevation of about 300 ± 10 cm, inundating inshore areas for 300 m and penetrating inland along creeks for 500–1000 m. The physical damage resulting from a tsunami of this size was limited to boats and to infrastructure within 150 m of the shoreline; the only loss of life resulted from exceptional circumstances. The scale of damage in the study area appears broadly consistent, or slightly more severe, than damage reported from other areas where the tsunami was of similar size. Run-up of 2–4 m along the coast of Tamilnadu in India resulted in 'partial collapse of walls and minor damage to few structures . . . little damage to few boats' (Narayan *et al.* 2005), although damage in these areas was being judged against other areas of Tamilnadu where a run-up of 10 m had caused catastrophic damage. Punching shear collapse of masonry and masonry infill walls due to the pressure of debris-loaded water (Ghobaraha *et al.* 2006), and collapse due to the failure of uprights in wooden buildings, was commonly observed, but comparatively little damage appeared to have directly resulted from debris loading in the water.

The distribution of damage in the study area suggests that the hard coastal defences provided a significant degree of additional protection to coastal buildings and infrastructure in comparison to areas that were either unprotected or were protected by a mangrove fringe. This is somewhat ironic, in that it also appears that most of the damage in Langkawi was concentrated in the study area as a result of a shallow offshore gradient coupled with funnelling of the tsunami between the steep coast to the north-west of the study area and the arcuate breakwaters protecting Langkawi International Airport and Langasuka harbour to the south (Figure 2). In the absence of the breakwaters, the energy of the tsunami would likely have been dissipated over a much greater length of shoreline and so damage would have been significantly reduced.

The response to the tsunami in Langkawi was rapid and well coordinated, partly because the impacts were not catastrophic and hence did not overwhelm the emergency services, and partly because the main administrative centre in Kuah was not itself affected by the tsunami. One factor that slowed the immediate local response was the fact that the police station in Kuala Teriang was itself inundated by the tsunami, degrading the effectiveness of local communications and coordination, and necessitating a time-consuming move to new premises.

A noteworthy observation is that informal warnings were received by several tourist operators from counterparts in Phuket prior to the arrival of the tsunami. Horton *et al.* (forthcoming) likewise found that similar warnings were passed on by tourist operators in Langkawi to counterparts in Penang. The lead time was around 15 minutes in Langkawi and up to 1 hour in Penang, allowing individuals to evacuate some coastal areas in both places. Thus there was a chain of warnings propagated ahead of the tsunami from locations that bore the first impact of the wave, but there was no mechanism by which this could be widely disseminated to areas potentially in the path of the tsunami.

There is some evidence that the people of Langkawi are now better prepared for tsunamis in the future. This is not so much because the Malaysian and Langkawi government administrations are better prepared, but because people on the coast have themselves taken initiatives to reduce their vulnerability. The managers of 32 hotels and resorts across four sectors on the west coast of Langkawi have come together to develop a 'Tsunami–earthquake emergency action plan'. Each sector has one hotel that is responsible for collecting and disseminating information about an earthquake and/or tsunami as soon as there is an indication that a wave may be approaching. The management of Pelangi Beach Resort has taken this initiative even further and installed a siren warning system along the hotel's beach.

Given the fact that the Indian Ocean region currently has no top-down tsunami warning system in place, this bottom-up approach could prove to be enormously useful in the future. Paradoxically, one factor that may reduce the likelihood of an informal warning ahead of a future tsunami is the greater public awareness that 'a tsunami' is likely to consist of several waves. This means that individuals who experience the first wave of a tsunami may be more inclined to evacuate immediately, in the expectation that there will be further waves, than take the time to call other locations.

The non-tsunamigenic earthquake that took place in the region, on 28 March 2005, and was felt in Langkawi, serves to demonstrate how aware citizens in Langkawi now are of the link between earthquakes and tsunamis. The deputy head of the police station at Kuala Teriang told us how, after the earthquake, a number of villagers came to the police station to seek information. The officer contacted both his Headquarters and the Meteorological Department for information, and was told that there would probably not be a tsunami. He passed this information on to the villagers who were satisfied that there was no need to evacuate to higher ground. The officer in charge at the local fire and rescue station was given similar information by his headquarters and told to be 'on alert'. Representatives of all the emergency services said they felt more confident about handling a tsunami in the future because of their recent experience.

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