Natural Warning Signs of Tsunamis: Human Sensory Experience and Response to the 2004 Great Sumatra Earthquake and Tsunami in Thailand

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Natural warning signs of tsunamis include ground shaking from earthquakes and unusual sea-level fluctuations, wave forms, and sounds. These signs can alert people to impending tsunamis, but no research has explored the recognizability of these signs or the social-cognitive factors that affect human behavioral response to them. Of 663 interviewees, 24% felt ground shaking during the earthquake; 69% saw something unusual about the ocean before the first wave reached land, mostly a receded shoreline; and 55% heard something unusual. Despite these levels of observation, most people did not evacuate. In fact, 65% saw other people in the danger zone at the time of the tsunami impact. Most respondents had to run for their lives but could not identify a safe place. There are major differences in experience among north, central, and southern coastal Thailand, reflecting social, topographical, and hydrological factors. [DOI: 10.1193/1.2206791]

INTRODUCTION

The arrival of tsunamis in coastal areas is often preceded by natural phenomena that can be used as an alert (Darienzo et al. 2005, Dudley and Lee 1998, Gonzalez 1999, Gregg 2005, Gregg et al. 2006, Shuto 1997). For example, the arrival of a negative wave or trough causes a shoreline to recede (Lander and Lockridge 1989), exposing portions of the ocean floor that are not normally visible, even during low tides. Unusual wave forms can also precede the arrival of the real tsunami onshore. Such forms have been described as a wall of water, a rising tide-like flood, or a large breaking wave (Gonzalez 1999). These and other natural phenomena constitute natural signs of tsunamis and have served as effective alerts to impending danger in historic events (Gregg 2005).

Natural signs can complement and help fill in a missing link in mechanical tsunami warning systems that are designed to provide an early alert to vulnerable communities

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through the use of sirens, loudspeakers, and so on. In the case of locally generated tsunamis, mechanical warning systems, which rely on information collected by seismometers, tide gauges, tsunami pressure sensors, and eyewitness observations, cannot always provide alerts to official agencies—and thus to the public at large—before damaging waves arrive onshore. For example, after the events of 26 December 2004, officials in the United States indicated that tsunamis could not be reported in less than about 15–20 minutes from the time the waves are generated. Natural warnings may be the first and only alert before the first wave arrives onshore.

Local tsunami warnings have been issued within several minutes of earthquakes but often leave little chance for an effective response. The Japan Meteorological Agency announced the 1993 Hokkaido earthquake in Japan within about 3 minutes of the earthquake, which generated local tsunamis that destroyed Okushiri Island, Japan; however, the official warning was not received by some members of the public for a variety of reasons, including difficulties with faxes and phones and the fact that fiber optic communications lines were severed by ground shaking from the earthquake (Dudley and Lee 1998). Some residents, in fact, used ground shaking from the earthquake as an alert of an imminent tsunami and reacted by evacuating to safe ground. People living in coastal inundation zones near the source of tsunamis must therefore be familiar with and posses a capacity to recognize the natural signs of tsunamis and immediately respond by evacuating to safe areas, if the loss of life is to be minimized in future tsunamis. Similar effective responses to natural signs (e.g., a receded or frothy ocean) were made by people in Thailand in 2004, namely, the indigenous Moken people and a 10-year-old English visitor.

A concern about using natural warning signs as an alert of impending tsunamis is the lack of a systematic study to identify and explain the ways in which humans observe and respond to the phenomena. Available data, which are often anecdotal in nature, suggest that responding is often problematic and that people do not link the precursors to the damaging hazards that will probably follow—or, if people do link the precursors with the hazards, they ignore the precursors. In many events, people have intentionally gone to the shoreline and either have become fatalities or have survived only because no damaging waves were generated. Thousands of people gathered at the Indian Ocean shoreline when the sea receded during the December 2004 tsunami.

We know more about *how* people respond to official warnings of hazard events (Lachman et al. 1961, Mileti and O'Brien 1992) and less about *why* they do and what factors influence whether they attend to natural warning signs or official warnings. For tsunamis specifically, we simply know little about the causes of people's behavior and their response to the signs of tsunamis, especially how people recognize and interpret the signs and how their response changes as danger escalates. What we know about human observation and response before and during tsunamis comes from a few observations in historic events (e.g., in Hawaii, Japan, and Chile). We need insight into the reasoning processes that explain observations and behaviors. In the absence of a systematic analysis of the perception and interpretation of natural warning signs and how such perception and interpretation influence response actions, it will be impossible to develop effective risk reduction strategies to enhance this capacity in populations that are susceptible to locally generated tsunamis. The physical sciences have made great inroads into identifying precursors and the mechanisms that govern tsunamis. To fully utilize this knowledge, it is important to understand how communities interpret and use it. In this way, we can ensure better knowledge transfer and more-informed and better-prepared communities.

Here we describe preliminary data collected in the disaster zone of Thailand after the devastating M=9.3 Great Sumatra earthquake (Lay et al. 2005) and tsunami events of 26 December 2004. We report observations from field reconnaissance and frequency counts of responses to closed-ended questions (yes-or-no questions). The data were collected during a large and unprecedented social science interview survey conducted in all six of Thailand's affected provinces. Specifically, we report on (1) the extent to which ground-shaking was felt; (2) observations of unusual sea-level changes, wave forms, and sounds linked to the tsunami; and (3) evacuation experience. We close with a discussion of the findings to support the use of natural warning signs of tsunamis in official tsunami warning systems. We begin by providing additional background on the natural warning signs. An important component and complement to this study is an investigation of experience with the magnitude M=8.7 Nias earthquake and subsequent tsunami warning and evacuation on the night of 28 March 2005. Much of the open-ended data collected about the December and March events is still being translated and will provide an important complement to the data presented here.

NATURAL WARNING SIGNS OF TSUNAMIS

Research on the relationship between natural warning signs of tsunamis and human behavior is scarce. There are, however, numerous ad hoc references to individual phenomena in historic events and their ability to serve as warning signs of impending tsunamis. Darienzo et al. (2005) summarized some aspects of local and official warnings in the state of Washington. However, Gregg et al. (2006) described how literature on natural warnings of tsunamis is ambiguous and seldom specific enough to be useful. While this latter study was not an exhaustive literature search, it highlighted a need for more consistent messages about natural signs of tsunamis and how people should respond to them. It also highlighted the idea that the inconsistency of messages may be explained, at least in part, by a limited understanding of the physical behavior of tsunamis in shallow water. Gregg et al. (2006) also described public expectations of future warnings (i.e., warnings from natural versus official sources) among the residents of Hilo, Hawaii, who have been impacted by tsunamis more than any other community in the United States. However, no systematic studies have addressed the human perception of, and response to, natural warning signs in any specific historic event.

The lack of research on human response to natural signs of tsunamis elevates the importance of physical and social scientists working together on matters relating physical characteristics of tsunamis to attitudinal and behavioral characteristics of people likely to be affected by tsunamis. Information that is ambiguous or is perceived as being not specific enough will not be used by people and will undermine trust in the sources of that information (Paton et al. 2006). Identifying warning signs that people perceive as relevant is important not just as a trigger to action that can protect life, or as a way for people to confirm a previous warning (e.g., an official warning, as described in Mileti and O'Brien 1992), it is also important from the perspective of maintaining good working relationships among scientific and civic agencies and community members. Achieving the former requires that we understand how people interpret natural signs and the social and psychological mechanisms that link those signs to protective action. This paper provides a systematic overview of the community members' perceptions of, and responses to, natural warning signs of tsunamis using the earthquake and tsunami events of 26 December 2004 as a case study.

PRECURSORS TO THE 26 DECEMBER TSUNAMI

After the catastrophic events in the Indian Ocean occurred on December 26, it was soon recognized that, in the absence of mechanical warning systems, people in the danger zone required an alternative warning mechanism to survive the waves. In other words, the people needed to use observations of natural warning signs of tsunamis. This applied to people both near and far from the wave source, from Indonesia to Kenya to Thailand. Natural warnings existed in many places, and the fact that thousands of people were reported to have flocked to the shore when the ocean receded (e.g., in Thailand and Sri Lanka) is a testament to the cross-cultural salience of this phenomenon.

The waves were preceded by naturally occurring signs of tsunamis, such as ground shaking from the earthquake, sea-level withdrawal, and unusual waves and sounds. Ground shaking from the earthquake provided about 2 hours of forewarning in Thailand, while other natural signs provided considerably less forewarning (tens of seconds to a few minutes).

Some people were alerted to the waves by cell phone and land line calls from friends and family members who had already learned of the disaster, but many of these messages arrived too late to be useful. The messages did not provide sufficient time to alert others to the danger and convince them to seek higher ground. Furthermore, the messages sometimes had the opposite effect of what was intended—they prompted the recipient to go to the beach to see the big wave rather than evacuate.

People across the Thai-Malay peninsula felt slight ground shaking from the earthquake, but the salience of the shaking was less than in the areas closer to the earthquake epicenter. Shaking in Thailand was weak to moderate (MM I–V [USGS 2005]), and reconnaissance work in the affected coastal regions of Thailand indicated that the cause of the shaking was not attributed to an earthquake, but to other phenomena, such as wind, a passing truck, or a neighbor shaking the house (many people were home at the time, and the houses—especially of many fishing people—are small and structurally weak, so a neighbor can easily shake a house). This provides an important clue as to why it is difficult for ground shaking and other natural signs to serve as an effective alert about tsunamis. When faced with environmental data, people interpret it in ways consistent with their normal frames of reference. These may not be appropriate for the atypical response required for tsunami hazards. This view suggests a need for closer relationships between scientific agencies and communities, to help the latter understand the hazards they could face and the relevance of those hazards for their well-being and economic resilience. Using a process of community engagement to build a better understanding of the relationship among hazards, warning signs, and behaviors that are specific to the various hazards will increase the likelihood of effective response to warnings.

Prior to the arrival of destructive tsunami crests in Thailand, the shoreline retreated hundreds of meters as a tsunami trough arrived in shallow waters. Our review of videos and of conversations with eyewitnesses show, not surprisingly, that many people observed the receded shoreline and unusual walls of frothing water forming and traveling landward at least 3.5 minutes before the first positive wave arrived onshore. The people eagerly went out onto the exposed seafloor to explore what had been hidden by the high tidal waters minutes before. Unaware that the receded ocean meant tsunami crests were building up above sea level further offshore, many people were later overcome when those waves arrived onshore. By the time some people realized the danger posed by the waves, it was too late to have a high degree of success in escaping the waves. However, before these people were overcome, other signs (alerts) of the approaching tsunami were also provided by nature and seen or heard by many people. These alerts included the tossing and/or sinking of boats, as well as sounds that were linked to the tsunami.

Some people made the link between signs of a tsunami and imminent danger. Among the knowledgeable people were the indigenous Moken people of the Andaman Sea area and a 10-year-old English girl, Tilly Smith, who was on vacation in Phuket during the tsunami. The Moken recognized the receded sea as a sign of an imminent tsunami and successfully evacuated to safe areas on higher ground (Marx 2005). However, Tilly Smith recognized that the sea was bubbling on the horizon during drawdown, similar to what she had recently seen in a film of the 1946 tsunami that struck Hawaii (BBC News 2005). The significance of these two examples is how the people involved learned of the natural signs of tsunamis before the December 26 event. The Moken learned about the connection of a receded sea and tsunamis through traditional knowledge handed down through informal education, whereas Tilly Smith learned of the connection between a receded shoreline or bubbly sea and tsunami through formal education in a geography class. An unknown number of people around her evacuated because she recognized the receded shoreline as a tsunami warning sign and informed her parents of the impending danger. This example, combined with the observations of the Moken people, highlight the ability of a receding shore and unusual wave forms to provide effective early alerts that allow people minutes of valuable time to evacuate to safe areas. The difference in the channels (informal versus formal) through which the Moken and Tilly Smith learned of the natural signs of tsunami, and how to respond, highlights the need to combine community members' traditional knowledge with formal scientific education and training.

We know from reconnaissance work that, where shorelines were irregular, local residents heard sounds linked to the tsunami before the crests approached from around headlands and into bays. These sounds have been previously described as being like thunder, a train, a booming sound, a helicopter, or a jet (Shuto 1997). However, at this time we cannot confirm the relative timing of the visual detection of tsunami phenomena and of their aural detection where the shoreline was several kilometers long. The timing of the detection of these sounds meant that people in the danger zone probably had less time to take protective action than those who earlier had recognized a receded shoreline

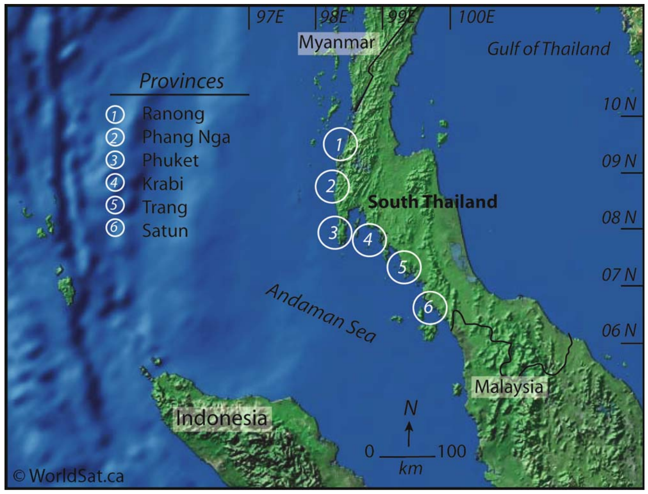

Figure 1. Locations of the six Thai provinces where surveys were conducted in relation to the regional geography of the Andaman Sea (base map from WorldSat.ca).

or a wall of water 1–2 km offshore. For example, one report from a tsunami survivor visiting Thailand from the United States indicated that he saw people running from the beach and then heard an "explosion" that sounded like "cannon fire," which was followed by the sight of "a black mass of water" (Oberle 2005). The report indicated that there were mixed interpretations of the cause of the water, including a sewer line breaking, a dam failure, and a terrorist attack. The author reported that the explosion-like sounds were due to the tsunami slapping the fronts of hotels as the wave successively reached different points up the beach. This suggests a need to build knowledge of sounds into peoples' models of tsunamis and people's response to these sounds. This is necessary to reduce the tendency to explore novel environmental stimuli out of curiosity, because response times are short once tsunami sounds are detected.

TSUNAMI DAMAGE AND THE THAILAND ECONOMY

Six provinces along Thailand's Andaman coast border the Indian Ocean; all were affected by the tsunami, but to different degrees. These provinces include Ranong in the far north along the border with Burma, Phang Nga, Phuket, Krabi, Trang, and Satun near the Malaysian border in the south (Figure 1). In terms of the number of human fatalities and damage to buildings, the most impacts were in the central and northern provinces of Krabi, Phuket, Phang Nga, and Ranong. At least 5,395 people were confirmed dead in Thailand, and 2,845 remained missing (Miller 2005). The number of people affected by the tsunami in Thailand includes 58,550 people from 12,480 families in 412 villages (UC Berkeley and East-West Center 2005).

The economy in the tsunami-affected provinces is driven by fisheries, shrimp farming, the rubber industry, various agricultural crops (such as watermelons), and, in some places, tourism. The tourist sector is mostly limited to Phuket and isolated areas of Phang Nga (e.g., Khao Lak) and Krabi (e.g., Phi Phi Don Island), although relatively small tourism developments can be found throughout the coastal areas. Tourism was hit hardest in the provinces of Phuket, Phang Nga, and Krabi. In Phuket, wide west-facing bays on the west side of Phuket Island (one of Thailand's premier tourist areas) suffered damage, but the damage was mostly limited to the areas very near the shore. In another major tourist area, Khao Lak, extreme damage was experienced along a 0.7–1.5-km swath of low-lying coastal land where development was concentrated. A few islands in Krabi also suffered heavy damage, such as Phi Phi Don Island, but also including Lanta Yai Island. Phi Phi Don Island was particularly hard hit, suffering severe damage to structures and heavy loss of life, all in a low-lying isthmus several hundred meters wide and 1 km long that connects two elongated ridges that rise steeply out of the Andaman Sea. The tsunami waves entered bays on opposite sides of the isthmus, completely washing over the densely developed area.

Communities built around small-scale fisheries suffered heavily because they were in the coastal zone, where the tsunami was most damaging. Hat Thap Tawan and Ban Nam Khem in Phang Nga were hard hit, as well as Hat Prapat, Ban Thale Nok, and Ban Hat Sai Khao in Ranong. Much of the Thai-Andaman coastline is very rural and undeveloped. Thailand's wealthy social class does not generally reside in or seek recreation in the coastal zone; instead, this class lives in higher-elevation areas above tsunami inundation zones. Had the wealthy class occupied the danger zone, the economic impacts would have been exacerbated.

THE SURVEY

SURVEY DESIGN AND DATA COLLECTION

An oral questionnaire was prepared by a multinational and multidisciplinary research team from Thailand, Australia, New Zealand, and the United States. The researchers initially prepared the survey instrument in English and then had it translated into Thai in preparation for a pretest of the questionnaire beginning on 29 March 2005. However, the magnitude 8.7 earthquake that occurred late in the night of 28 March provided the opportunity to include new survey questions that measured human sensory awareness of, and response to, the ground shaking of this event, in addition to eliciting accounts of the respondents' experience in the December event. Because the 28 March earthquake prompted a tsunami warning and evacuation for coastal Thailand, additional questions were included to measure how people received the warnings and how they responded to them. Six researchers were then recruited from universities in Thailand. The ethnic origin of one of these researchers was Urak Lawoi; the Urak Lawoi are a formerly semi-sea nomadic people of Thailand. After the researchers were trained in the methodology to be used in the survey, a modified version of the original questionnaire was pretested in two villages in Satun province on 29–30 March 2005.

Two of the authors, an American geologist (C. Gregg) and a Thai social scientist (S. Wongbusarakum), then spent 12 days in the field conducting reconnaissance work to identify potential communities to survey. The two-member team was aided by a third member (Somyos Tolang) who worked for the Federation of Small-Scale Fisheries in Trang, Thailand. S. Tolang acted as a facilitator, because his network of community connections gleaned from intimate knowledge of the Thai culture and links to numerous small-scale fishing people provided easy access to community leaders and administrators of local nongovernment organizations (NGOs), government organizations, and nonprofit agencies. In each community visited, we spoke with people such as village leaders, prominent business leaders, boat repair leaders, disaster response and recovery organization workers, fishermen, and residents at large. The aim of this reconnaissance work was to identify survey locations, inform community leaders of our project, and obtain their input concerning the project and the 26 December and 28 March events. Survey locations were selected on the basis of factors including the relative extent of damage and loss of life, tsunami runup and inundation, and coastal topographic and geomorphologic features (e.g., steep headlands, bays, linear beaches, and islands).

After the reconnaissance, in communities spanning the six affected provinces, the questionnaire was again modified to reflect changes in research focus as a result of the consultation with affected community members. The six Thai graduate field researchers, recruited because of their ability to speak southern Thai and their experience with survey research, were then further trained in data collection methods.

Next, 663 questionnaires were completed during the survey period from 10 April to 6 May 2005. Questionnaire responses were obtained via two sampling schemes, a snowball approach and convenience sampling. In the former scheme, a community resident was selected and interviewed and then asked for the names and locations of other residents who were in the disaster zone and who might be able to participate in the study. In the latter scheme, people were approached randomly in the survey communities and asked whether they had been in the disaster zone and would like to participate in the study. The number of questionnaires completed ranged from 73 in Satun to 186 in Krabi (Table 1). Only 38 residents refused to participate in the survey or were unable to complete the interview.

In order to assess the behavior of people in the danger zone, we asked survivors how many people they saw in the danger zone and what those people were doing just before the waves impacted the shore. We also collected and observed various media for this same purpose. Such media included photos, video (downloaded from the Internet), local newspapers, and other print media.

One question linked to the integrity of the data collected involves the accuracy of the respondents' memories in April and May, which was several months after their experience in 26 December 2004. While the effects of disaster trauma on human memory are undetermined; it is known that memory accuracy declines with time and after intervening events (Neisser and Hyman 1999). However, a study examining people's memory as a result of direct experience in the 1989 Loma Prieta, California earthquake, versus indirect experience via the news media, found that persons with direct experience had virtually perfect recall 1.5 years later, as compared with much poorer recall by persons who had learned of the event via the news in a distant community in the state of Georgia (Neisser et al. 1996).

Table 1. Location of surveys and number of questionnaires completed

Province and village/community	Damage	Questionnaires completed	Percent of total
Ranong (Ban Hat Sai Khao/Hat Prapat, Ban Thale Nok)	Severe	75	11
Phang Nga (Ban Bang Sak/Hat Thap Tawan, Ban Nam Khem, Ban Tung Wa)	Severe	144	22
Phuket (Ban Laem Tukkae, Ban Patong, Ban Kamala)	Moderate	102	15
Krabi (Ko Lanta Yai: Ban Hua Laem, Si Raya, Sangka U; Ko Phi Phi Don: Ban Phi Phi; Ko Pu: Ban Ko Pu; Ban Laem Pong)	Moderate	186	28
Trang (Ko Muk: Ban Ko Muk)	Low	83	13
Satun (Ban Bo Chet Luk, Ban Rawai Tai)	Low	73	11
Total	–	663	100

[a] Relative damage from the tsunami in terms of fatalities and damage to property. Generally, damage to property and fatalities increased northward to Ranong from the far south of Satun.

All of our respondents were in the 26 December disaster zone. To test the accuracy of their recall, we will seek funding to reinterview the same 663 respondents in 2006. We will also use inter-rater reliability to compare reports of experiences of respondents who were close to one another during the tsunami events. The greater the agreement among questionnaire responses from people in similar areas is, the greater the accuracy of those responses can be assumed to be. Such reports will be cross-checked with newspaper reports, videos, and photos.

The questionnaire contained 91 questions consisting of about 42 closed-ended (yes-or-no) questions and 49 open-ended questions. The questions covered demographics and experience with the events of 26 December (e.g., what respondents felt, saw, heard, and so on, and how they responded, evacuated, and so on) and 28 March (i.e., the earthquake and tsunami warning and evacuation). Other data pertaining to prior knowledge of tsunamis were also collected (i.e., whether respondents had heard or read stories of tsunamis prior to 26 December). Finally, 15 semiquantitative questions were asked, to evaluate perceptions of societal capital and adaptive capacity to respond to tsunamis.

The closed-ended data have been entered into a software program, the Statistical Package for the Social Sciences®, enabling us to report some preliminary and basic frequency data for selected experiences. However, the open-ended questions are still being translated from Thai into English. These open-ended data are the key to more fully understanding the perceptions and behavior of the survivors of the tsunami.

Table 2. Respondents who noticed unusual shaking on 26 December

	Province						
Reply	Satun (%)	Trang (%)	Krabi (%)	Phuket (%)	Phang Nga (%)	Ranong (%)	Total (%)
Yes	48	21	22	39	10	15	24
No	52	79	78	61	90	85	76
Total	100	100	100	100	100	100	100

[a] Pearson chi-square (χ^2)=56.923, df (degrees of freedom)=5, p (probability)=0.000

RESULTS

Demographics

The number of male respondents was slightly higher than the number of female respondents (54% male versus 46% female). The ethnicity of respondents was Thai (86%), Chao Lay (14%; chao means "people" and lay means "sea"), and other (<1%). The mean age of respondents was 42 years (sd=13.6). Some 51% of respondents were Muslims, and 49% were Buddhists. Some 86% of respondents were married, 10% were single, and 4% were widowed or divorced. The respondents' number of children ranged from 0 to 12, with a mean of 2.6 (sd=2.1). Some 16% of respondents had no children, 15% had one child, 25% had two children, 19% had three children, and 25% had 4–12 children. On the average, respondents had received 5.5 years of schooling (sd=3.7).

Experience with the 26 December Earthquake

Ground shaking from the 26 December earthquake preceded the arrival of the tsunami along Thailand's Andaman coast by about 2 hours. While the intensity of, and damage from, the ground shaking was minor, the earthquake was felt across much of Thailand. The shaking could have served as a natural warning sign of a tsunami if people had recognized it as such, but media reports and our field reconnaissance suggests that the earthquake-tsunami link was not established among the Thai people. The time frame and access to warning signs were adequate for all those on the coast to evacuate safely.

In order to assess whether or not people noticed the ground shaking on 26 December, we asked survey participants, "Did you feel or notice any unusual shaking the day of the *kluan yak*?"; the people were calling the tsunami *kluan yak*, which means "giant wave." On the average, about 24% indicated that they felt unusual shaking. Table 2 shows the distribution of responses by province. Ground shaking was more salient in the southern provinces between Satun and Phuket than in other provinces. A cursory review of open-ended data describing how people interpreted the cause of the shaking indicated that a few people interpreted the source of the shaking as an earthquake, but none linked the shaking to a tsunami. Most people attributed the shaking to a variety of other natural or anthropogenic causes.

Given that most people misinterpreted the cause of the ground shaking on the morning of 26 December, an interesting question relates to people's ability to distinguish

Table 3. Perceptions of ground shaking duration during the 26 December earthquake

Perceived duration (minutes)	Percent of respondents	Cumulative percent of respondents
1	21.1	21.1
2	24.6	45.8
3	6.3	52.1
4	1.4	53.5
5	21.8	75.4
7	0.7	76.1
10	17.6	93.7
15	2.8	96.5
20	0.7	97.2
30	2.8	100
Total	100	100

earthquake-generated shaking from other sources of shaking. Distinguishing earthquake-generated ground shaking from other natural sources (e.g., wind) or anthropogenic sources (e.g., mining explosions or passing automobiles) is related to the greater duration of shaking from large earthquakes than from other sources. About 75% of the respondents who indicated that they felt unusual shaking also indicated that it lasted for 5 minutes or less (Table 3). Sixteen of these respondents indicated that the ground shaking lasted for a range of minutes. However, 81% of these 16 respondents indicated that the upper limit of the duration was 4 minutes. An issue here is the range of perceived shaking that emerged. Informing people that the duration of shaking can differentiate seismic from other sources of shaking assumes that people posses a capacity to differentiate lengths of duration. These data suggest that this is an area requiring additional research. Analysis of interview transcripts may be informative in this regard.

Observations of Unusual Phenomena on 26 December

We were interested in evaluating whether people made visual observations of unusual sea-level patterns (e.g., a receding or rising sea level) or unusual wave forms (e.g., a frothy wall of water on the horizon) prior to the impact of the tsunami in Thailand. Over two thirds of the respondents indicated that they saw something unusual before the tsunami arrived on land (Table 4), but reconnaissance data indicate that these people did not make the connection between these natural signs and the tsunami. Translation of several subsequent questionnaire responses will provide valuable insight into people's visual observations and interpretations of sea-level drawdown and unusual waves. Table 4 suggests that far fewer people from Ranong, and especially Phang Nga, observed visual indications of something unusual about the ocean just before the first wave made landfall than did people from other provinces further south. Ranong and Phang Nga suffered high casualties during the tsunami, but this is probably related to higher runups and in-

Table 4. Respondents who saw something unusual about the ocean just before the first wave made landfall

	Province						
Reply	Satun (%)	Trang (%)	Krabi (%)	Phuket (%)	Phang Nga (%)	Ranong (%)	Total (%)
Yes	79	89	72	88	40	59	69
No	21	11	28	12	60	41	31
Total	100	100	100	100	100	100	100

[a] χ^2=99.051, df=5, p=0.000

undation rather than to shorter precursory activity. For example, Khao Lak had the highest recorded runup in Thailand ($>$10 m), and observations from amateur video suggest that the first tsunami crest offshore of Khao Lak was a frothy, elevated, and conspicuous wave front visible for at least 3.5 minutes before making landfall. The mean percentage of respondents from Khao Lak who saw something unusual with respect to the ocean just before the tsunami made landfall was 69%. This is the highest percentage recorded for observations of the natural signs of tsunamis.

Close to 50% of the respondents from each province also indicated that they heard something unusual just before the first wave made landfall (Table 5). Again, the percentage of respondents who heard something unusual before the first wave made landfall was low in Phang Nga, but such reports were also low in Phuket. The mean percentage of respondents across all provinces who heard something unusual was 55%, which is slightly less than the 69% who reported seeing something unusual.

Unusual animal behavior during the earthquake and tsunami events was a focus of media reports. Table 6 indicates that few respondents observed such animal behavior. Furthermore, responses to an additional question that asked, “Was there anything unusual before 26 December that you believe is related to the tsunami?” indicate that, on the average, only 14% of respondents agreed. The range was a low of 9% in Krabi to 22% in Trang.

Table 5. Respondents who heard something unusual just before the first wave made landfall

	Province						
Reply	Satun (%)	Trang (%)	Krabi (%)	Phuket (%)	Phang Nga (%)	Ranong (%)	Total (%)
Yes	77	59	59	45	46	54	55
No	23	41	41	55	54	46	45
Total	100	100	100	100	100	100	100

[a] χ^2=24.111, df=5, p=0.000

Table 6. Respondents who noticed unusual animal behavior just before the first wave made landfall

	Province						
Reply	Satun (%)	Trang (%)	Krabi (%)	Phuket (%)	Phang Nga (%)	Ranong (%)	Total (%)
Yes	39	26	18	18	17	16	21
No	61	74	82	82	83	84	79
Total	100	100	100	100	100	100	100

[a] $\chi^2=17.882$, df=5, p=0.003

People in the Danger Zone 26 December

Our study evaluated survivors' observations of other people who were in the danger zone when the first wave made landfall. We asked survivors how many people they saw in the disaster zone and what those people were doing at two separate times: (1) just before the first wave made landfall and (2) while the first wave was making landfall. Most of these data are yet to be translated, but respondents from each of the six affected provinces indicated that they observed many people (tens to several hundred, including whole villages) in the danger zone when the first wave made landfall (Table 7).

Number and Size of Waves Observed

Noteworthy questions relate to the number and size of waves that people noticed on 26 December. Although the number of waves noticed by respondents was recorded, the data must be treated with caution, because some respondents may not have been able to observe the ocean during the total duration of the tsunami event. Nevertheless, most respondents indicated that they observed 1–3 waves (Table 8). Only about 11% indicated that they observed 4–12 waves.

Data indicate that the largest wave observed varied from the first wave to the third wave across the six provinces. More specifically, in Ranong and Phang Nga, the largest waves appeared to be the first and second waves (Table 9). By contrast, in provinces

Table 7. Respondents who saw other people in the path of the tsunami when the first wave made landfall

	Province						
Reply	Satun (%)	Trang (%)	Krabi (%)	Phuket (%)	Phang Nga (%)	Ranong (%)	Total (%)
Yes	74	89	56	81	47	64	65
No	26	11	44	19	53	36	35
Total	100	100	100	100	100	100	100

[a] $\chi^2=60.380$, df=5, p=0.000

Table 8. Number of waves observed by respondents

Number of waves observed	Province						
	Satun (%)	Trang (%)	Krabi (%)	Phuket (%)	Phang Nga (%)	Ranong (%)	Total (%)
1	7	8	18	19	34	43	21
2	46	24	26	39	34	27	31
3	38	57	39	34	30	18	36
4	3	6	5	6	2	3	5
5	3	3	4	2	0	3	3
6	0	1	2	0	0	0	1
7	3	1	5	0	0	1	2
8–12	0	0	1	0	0	5	1
Total	100	100	100	100	100	100	100

[a] One respondent each from Krabi and Trang indicated that the number of waves was possibly 2–3 and 3–4, respectively.

further south, the second and third waves were reported to have been larger. Our reconnaissance work in early April indicated that many people, especially in the province of Trang in southern Thailand, went down to the ocean before the first wave arrived. These people stayed on the beach as the first wave came ashore but evacuated to high ground after the second wave washed up to a higher elevation than the first wave. This was fortunate, because the third wave in Trang was reported, both from our reconnaissance work and from interview data in Table 9, to have been the wave with the highest runup, completely inundating the areas that people had explored during the first two waves.

Evacuation

Some 89% of respondents indicated that they had to evacuate the coastal danger zone during the tsunami (Table 10). Furthermore, additional questions revealed that, of the 591 respondents represented by Table 10, a majority had to run as fast as they could

Table 9. Which wave was perceived as being the largest

Largest wave	Province						
	Satun (%)	Trang (%)	Krabi (%)	Phuket (%)	Phang Nga (%)	Ranong (%)	Total (%)
First	17	13	25	11	41	57	27
Second	68	39	34	74	48	36	48
Third	13	46	40	15	10	7	24
Fourth to seventh	2	2	1	0	1	0	1
Total	100	100	100	100	100	100	100

Table 10. Respondents who had to evacuate a danger area during the tsunami event

	Province						
Reply	Satun (%)	Trang (%)	Krabi (%)	Phuket (%)	Phang Nga (%)	Ranong (%)	Total (%)
Yes	88	88	86	98	91	85	89
No	12	12	14	2	9	15	11
Total	100	100	100	100	100	100	100

to escape danger (Table 11). On the average, nearly a quarter of the respondents evacuated by some means other than by foot, including 50% of those from Ranong (cited in the "Other" category of Table 11).

One third of the 591 respondents in Table 10 who had to evacuate did not know where to go to find a safe place (Table 12). Additional analyses of data being translated will provide insight about why people could not identify a safe place. The answer may relate to their lack of understanding of what to expect in terms of tsunami runup or inundation, underestimation of the force of the moving water, or the unavailability of high points (hills, multistory houses, or hotels) to serve as evacuation points. These data indicate that information about natural signs of tsunamis should be accompanied by information about the appropriate response to warnings and a capacity to act on them immediately once they are received. In particular, locally generated events will provide insufficient opportunity for information about appropriate actions to be acquired after receiving a warning. Understanding the behavior of tsunamis onshore can thus help inform people about appropriate actions to safeguard themselves and others. The importance of this issue is evident in the data reported in the next section.

Knowing where to find a safe place and how to successfully reach it are important considerations for evacuating tsunami inundation zones. Occasionally, people reach an initially safe place but are subsequently forced to evacuate a second or perhaps third

Table 11. Speed with which respondents evacuated the danger area

	Province						
Response	Satun (%)	Trang (%)	Krabi (%)	Phuket (%)	Phang Nga (%)	Ranong (%)	Total (%)
Walked normally	11	3	13	1	1	0	6
Walked fast	6	1	7	3	9	2	5
Ran normally	6	13	14	12	9	0	10
Ran as fast as possible	35	68	47	62	62	48	54
Other	42	15	19	22	19	50	25
Total	100	100	100	100	100	100	100

[a] This category includes those who evacuated by vehicles, including cars, trucks, and small motorcycles.

Table 12. Whether respondents who evacuated knew where to find a safe place

	Province						
Reply	Satun (%)	Trang (%)	Krabi (%)	Phuket (%)	Phang Nga (%)	Ranong (%)	Total (%)
Yes	67	70	82	63	52	64	67
No	22	15	12	23	41	28	23
Uncertain	11	15	6	14	7	8	10
Total	100	100	100	100	100	100	100

[a] χ^2=46.166, df=10, p=0.000

time when successively higher waves arrive or the sheltering structures start to collapse. Another difficulty in evacuating relates to knowing alternative evacuation points to account for dynamic changes in the tsunami hazard, such as successively higher waves that inundate more land with each wave. Dynamic mass human behavior, including overcrowding of initial evacuation points, poses additional concerns. The data in Table 13 indicate that, again, of the same 591 respondents who evacuated, nearly everyone had to evacuate again because the area became unsafe. Some 59% had to evacuate at least twice, and nearly one-third had to evacuate three or more times. Our reconnaissance work indicated that people sometimes had to punch through rooftops to escape flooding houses, even in houses with two or more levels.

People in the Danger Zone 28 March

Data indicate that a majority of respondents who were in the danger zone of the 26 December event were also in the danger zone of the 28 March event (Table 14). The reconnaissance team was sleeping in a seaside hut near Satun when the latter earthquake occurred. The team evacuated with locals to high ground after first hearing of the earthquake by cell phone calls from friends, who were on the seventh floor of a hotel in south

Table 13. Number of times that evacuees had to leave what they considered a safe place

	Province						
Number of evacuations	Satun (%)	Trang (%)	Krabi (%)	Phuket (%)	Phang Nga (%)	Ranong (%)	Total (%)
1	2	0	1	0	0	0	0
2	53	76	58	74	37	75	59
3	24	21	30	16	30	16	25
4	2	0	7	6	16	0	7
5–11	2	0	0	0	1	0	0
Could not remember	17	3	4	4	16	9	9
Total	100	100	100	100	100	100	100

Table 14. Respondents who were in the 26 December danger zone during the 28 March event

	Province						
Reply	Satun (%)	Trang (%)	Krabi (%)	Phuket (%)	Phang Nga (%)	Ranong (%)	Total (%)
Yes	79	74	64	36	31	55	55
No	21	26	36	64	69	45	45
Total	100	100	100	100	100	100	100

Thailand and felt the building shake. Translation of open-ended data will provide insight into how many people felt the ground shaking and how they interpreted and responded to it, or to news of the earthquake, as compared with their behavior after the 26 December event. The data will also show how people interpreted and responded to news of the subsequent official tsunami warning and to the evacuation order that were issued for Thailand.

Our reconnaissance work identified mixed interpretations and responses to the March event. For example, conversations with four men on Muk Island, in Trang province, during our reconnaissance work indicated that they had heard of the earthquake or the warning and evacuation in four unique ways: (1) one man said he had heard about the earthquake when a friend called him on his cell phone from Malaysia, (2) one man heard about it when his neighbor came over and told him about it, (3) one man saw the warning announced on television, and (4) one man felt his house shake. Also on Muk Island, we were informed by a well-known former village leader that the men in the village (Ban Ko Muk) evacuated their families to high ground in the rubber forest when they felt the earthquake and heard of the tsunami warning and evacuation order, but that, after the families were so evacuated, the young and the strong men returned to the shore to watch the tsunami come in. In contrast, at Ban Nai Rai, in Phang Nga province, we were informed that everyone in the village panicked when they felt the earthquake, that the villagers had great fear of a tsunami, and that everyone attempted to evacuate, including the young and the strong men. However, the evacuees still did not know where to evacuate to, and the uncertainty contributed greatly to their fear.

In the March event, the disparity in response between Trang and Phang Nga may have been related to the relative extent of damage in each province during the December event or the proximity to high ground. In Ko Muk, safe ground was 100 m from the shore, and damage was less severe in December than in Ban Nai Rai, where high ground was 1–2 km or more from the beach where people lived.

Prior Exposure to Tsunami Information

We were interested in evaluating the Thai people's level of exposure to tsunami-related information. The media reported that, except for the indigenous people of

Table 15. Whether respondents had heard or read stories about tsunamis before 26 December

	Province						
Reply	Satun (%)	Trang (%)	Krabi (%)	Phuket (%)	Phang Nga (%)	Ranong (%)	Total (%)
Yes	21	29	32	65	65	45	44
No	79	71	68	35	35	55	56
Total	100	100	100	100	100	100	100

[a] $\chi^2=77.942$, df=5, p=0.000

Thailand occupying islands in the Andaman Sea, the Thai people had no knowledge of tsunamis. We sought to understand the frequency and types of tsunami stories (written and oral) to which people had been exposed. Some 44% of respondents had either heard or read stories of tsunamis prior to 26 December (Table 15), but data describing the content and source of these stories are still being translated. These are important topics to follow up because, even though many people indicated that they had heard or read stories of tsunamis before the December event, the warnings provided by ground shaking and by the ocean alerted very few people to the arrival of the tsunami. These topics are also important to follow up through additional research, because it is becoming increasingly apparent that discourse about hazards and how to respond to them plays an important role in facilitating hazard knowledge and how to respond to hazards (Paton et al. 2006).

CLOSING REMARKS

We have conducted a novel and unprecedented systematic study of human sensory experience of, and response to, the natural warning signs of tsunamis, including ground shaking from earthquakes, sea-level changes, wave forms, sounds, and animal behavior. Until now, the understanding of what people have noticed and how they have responded to these signs was based on loosely constructed reports from a few historic events. This study confirms that different naturally occurring and recognizable signs preceded the arrival of the tsunami in coastal Thailand and that these signs could have served as alerts or cues to the tsunami danger, had they been recognized as such. However, they were not so recognized, and the death toll was correspondingly, but unnecessarily, high. The natural signs were noticed by about 25–33% of the community members throughout the affected provinces. Ground shaking from the 26 December earthquake was felt, albeit weakly to moderately, throughout the coast of Thailand by nearly 25% of the surveyed population about two hours before the tsunami waves arrived in coastal Thailand. However, perhaps more importantly, changes in sea level and wave forms, especially the receded shoreline, were observed by substantially more people (69%). Furthermore, a majority of people heard various sounds linked to the tsunami. Ongoing translation of open-ended data will shed more light on how people interpreted and responded to these phenomena.

Many people did not recognize a safe area that they could evacuate to and therefore were at increased risk from the tsunami when they were forced to leave inundated areas. The reasons for their inability to locate a safe place are not clear but may include a lack of understanding of the force of tsunamis in coastal areas, a lack of awareness of the likely runup and inundation waves, or the absence of nearby areas of high ground. People's difficulty in initially identifying a safe place to evacuate is underscored by the finding that some 79% of the total population surveyed had to evacuate multiple times to reach a safe area, which perhaps hints at poor initial judgment about safe areas, or simply the fact that tsunamis are complex and dynamic and that the first wave to arrive may not be the biggest wave. Indeed, the second and third waves were reported to be the largest waves in many areas. These findings underscore a need for development of scrupulous tsunami evacuation plans and should be echoed in educational outreach about how to select evacuation points for oneself.

These data, surprisingly, suggest that tsunamis were more widely known throughout the Andaman coast than what has been assumed by the media and by officials, albeit through stories of tsunamis rather than personal experience with real events. People may have been aware of tsunamis through exposure to information prior to 26 December, but there was a distinct disconnect between this reported awareness and their actions as a result of exposure to natural warning signs of the 26 December tsunami. Understanding the history of how tsunami information has been translated from generation to generation in Thailand and elsewhere (i.e., traditional knowledge) may be an important consideration for the formation of effective risk communication messages.

These data highlight the important role that information about hazard characteristics should play in risk reduction strategies, including, but not limited to, settlement of areas within tsunami inundation zones and evacuation plans. However, such strategies must be developed in ways that integrate them within the contexts of the communities at risk. Knowledge of how people perceive, interpret, respond to, and use physical science data is important to ensure that such data can be used in the manner intended within a sustainable warning and response process. Consequently, it will be necessary for physical scientists, social scientists, and emergency management agencies to work together in ways that include their active engagement with the communities that are susceptible to hazard impacts.

These data will be refined, pending their use in analyses involving the open-ended data that are currently being translated. This task involves nearly 7,000 pages of interview data. We appreciate any correspondence about how the data may be of use in models of land use planning and evacuation, hazard, and risk maps. The data will eventually be publicly available through the San Diego Supercomputer Center as part of a project funded by the National Science Foundation (NSF) to provide a long-term repository of data collected about this unprecedented human catastrophe.

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