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Danger in the Lowground: Historical Context for the March 11, 2011 Tōhoku Earthquake and Tsunami　低地の危険性―2011年3月11日東北大地震と津波の歴史的背景 •Japanese translation available

Gregory Smits

Danger in the Lowground: Historical Context for the March 11, 2011 Tōhoku Earthquake and Tsunami [Updated June 13, 2011]

A Japanese translation is available here.

Gregory Smits

The March 11, 2011 Tōhoku Earthquake and the tsunami it generated was a classic case of natural hazards such as severe ground motion and seismic sea waves coming into contact with human society to produce a multi-dimensional natural disaster. Throughout Japanese history, writers often initially referred to such events as "unprecedented." As time passed, other commentators would point out that in fact such events were "normal" in that they occurred repeatedly in the past. Similarly, this paper seeks to provide historical context for the recent disaster in two broad senses. First, I examine the earthquake and tsunami as part of a long, ongoing sequence of geological events. Then I focus on the human reaction to earthquake-tsunami combinations similar to those of 2011, with particular attention to events that took place in the modern era.

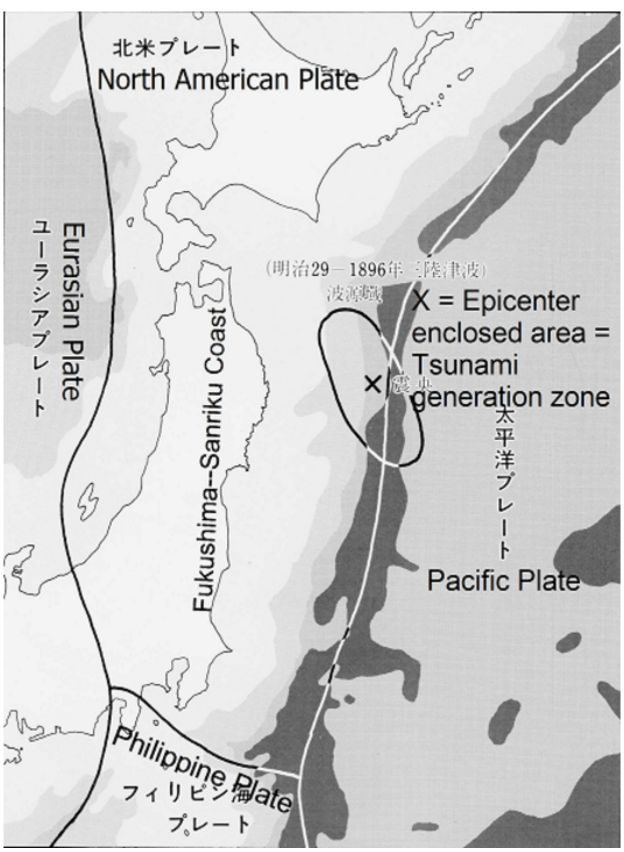
Tsunamigenic earthquakes originating near the Japan Trench have occurred periodically. The edge of the Pacific Plate subductuing under a portion of the North American Plate sometimes called the Okhotsk Plate creates the Japan Trench. Strong earthquakes originating in this offshore region typically generate sequences of seismic sea waves called tsunamis. Tsunamigenic earthquakes originating near the Japan Trench usually, but not always, cause severe ground motion, as was the case on March 11, 2011. This M9 earthquake is the strongest known earthquake to have shaken any part of Japan, and tsunami heights approached 38 meters in some areas. In the absence of knowledge of the seismological history of the Tōhoku region and adjacent offshore areas, the recent disaster may appear unprecedented. Instead, however, it was a recurrence of past seismic events. Waves as high as 38 meters demolished precisely the same coastal areas in 1896, and waves as high as 28 meters caused vast destruction along the Sanriku coast (Pacific coast areas of Aomori, Iwate, and Miyagi prefectures) in 1933.

This paper examines past tsunamigenic earthquakes striking the Sanriku coast as context for the March 11, 2011 disaster. For added perspective on the importance of historical memory, I discuss a tsunami disaster in Osaka in 1854 in connection with the Ansei Nankai Earthquake. A close examination of reactions to the 1896 Meiji Sanriku Earthquake and the 1933 (Shōwa) Sanriku Earthquake suggests that fundamental changes in regional patterns of settlement and building would mitigate any future disaster. If the past is any guide to the future, however, it is unlikely that in the longer term people will avoid dwelling in tsunami-prone areas.

Geographical and Geological

Considerations

The Tōhoku region is subject to shaking from fault ruptures in four types of locations: 1) ocean trench earthquakes off the Sanriku or Fukushima coast, 2) intra-plate earthquakes originating under northern Honshū or the Pacific, 3) shallow-focus inland earthquakes; 4) intra-plate earthquakes originating under the Sea of Japan. Three of these four types of earthquakes often generate tsunamis.[1] Along the Sanriku coast, the geographical interface between human settlements and the sea has often amplified the destructive power of tsunami waves. The coastline is deeply indented, and many of its bays and inlets are shaped roughly like a bugle whose the bell end opens to the ocean. Fishing villages have been located at the narrow interiors of these bays at the precise point where tsunami wave height would be highest because of a fixed quantity of water being forced into an increasingly narrow, shallow area.[2]



Map 1. The Tōhoku region, nearby tectonic plates, and the locus of the 1896 earthquake and tsunami. Adapted from Yamashita Fumio, *Shashin to e de miru Meiji Sanriku ōtsunami* (1995), p. 16.

One important phenomenon that occurs in perhaps 10% of seismic events in the Tōhoku region is that an earthquake causing only mild ground motion produces a large, destructive tsunami. These dangerous events are known as "tsunami earthquakes," a term coined in 1972 by Hiroo Kanamori of the California Institute of Technology. The destructive Keichō Tsunami of 1611 and the Meiji Sanriku Earthquake and tsunami of 1896 are two examples of the earth shaking so mildly that people did not expect the massive tsunamis that followed. Kanamori has identified six causal factors for tsunami earthquakes. The two especially relevant to the Meiji Sanriku Earthquake are that the fault rupture takes place slowly and that the rupture breaks and displaces accumulated sediments at the plate boundary. The presence of these sediments can function to slow the speed of the fault rupture. Moreover, the movement of large quantities of sediments can displace water and contribute to the size of the tsunami. It is possible to calculate the magnitude of a tsunami using tide gauges to measure the total width and distance between the epicenter of the earthquake and points on shore the tsunami reaches. Ordinarily, tsunami magnitudes closely track the magnitudes of the earthquakes that generate them, but a tsunami earthquake can be defined as an event in which the tsunami magnitude is significantly higher than the earthquake magnitude.[3]

If the sea floor moves too slowly as a fault ruptures, there will be no tsunami. Within the range of speed necessary to generate a tsunami, an increase in rupture time will decrease the magnitude and intensity of shaking, but it will not decrease the size of the tsunami. As a rough rule, tsunamis tend to occur from rupture speeds ranging from several tens of seconds to about 100 seconds. In the case of the Meiji Sanriku Earthquake, the best estimate is that a portion of the fault about 250 kilometers long ruptured over the course of about 100 seconds. The resulting seismic land waves would have had such a long period that people would barely have felt them. The relatively slow fault rupture pushed unconsolidated sediments upward to produce a massive tsunami. In this case, the earthquake magnitude was roughly 7.2, but the tsunami magnitude was 8.6.[4]

The 2011 Tōhoku Earthquake was not a tsunami earthquake. Ground motion was severe, which ideally should have prompted an immediate flight to high ground for those capable of doing so. Initial reports indicate high survival rates in localities that heeded the warning that the shaking provided.[5] The maximum height of the tsunami was roughly the same in 2011 as it was in 1896, approximately 38 meters at the village of Ryōri in Iwate Prefecture (today, Ōfunato-shi, Sanriku-chō, Ryōri).[6]

Map 2. Tsumani heights at coastal locations in 1896 and local fatalities. Adapted from Yamashita Fumio, *Shashin to e de miru Meiji Sanriku ōtsunami* (1995), p. 30.

Overall History

The Sanriku coast and nearby areas in the Tōhoku region have a long history of large earthquakes and tsunamis. At night, on July 13, 869 (Jōkan 11, 5m, 26d) an earthquake with an estimated magnitude of 8.3 shook the area, and the tsunami tore through Taga Castle, drowning approximately 1,000 according to *Nihon sandai jitsuroku* (Veritable records of the three reigns of Japan). Considering the relatively sparse population at the time, 1,000 deaths was a major human disaster. Geologists have recently discovered a sand layer in the Sendai Plain dating to the time of this event.[7]

In the early afternoon of December 2, 1611 (Keichō 16, 10m, 28d) very mild shaking that many did not feel was the only harbinger of a massive tsunami that struck around 2pm. Precise written records indicate the extent to which the series of three waves penetrated inland, farther even than occurred as a result of the Meiji Sanriku Earthquake. The Keichō tsunami death toll approached 3,000 in the Sanriku area and over 3,000 in the Nanbu-Tsugaru area. Considering that the population at the time was ¼ what it was during most of the Shōwa era, the human disaster was roughly on a par with the events of 1896 or 2011. There was no loss of life or significant damage from the shaking, and this lack of warning surely added to the death toll.[8] In a study of the Keichō event, Hirakawa Arata of Tōhoku University has recently concluded that massive tsunamis have flooded the Sendai Plain every few centuries. Moreover, the stops along the Tokugawa period coastal highway corresponded to areas just beyond the reach of the water from the 1611 tsunami. Hirakawa claims that in the midst of post-Meiji development modern people in the region have lost their acute sense of tsunami danger.[9]

One item of lore developed in connection with the 1611 tsunami sheds light on a broader trend in Japanese earthquake-related culture. The previous year, there had been reports of fishermen catching giant sized *ayu* (sweetfish) and sardines in the area. In hindsight, this apparent ecological anomaly seemed significant to many local residents as a precursor to the tsunami.[10] Throughout Japan's premodern and modern history, there has been a tendency to suppose links between earthquakes and the behavior of fish or other marine life. An April 1, 1932 *Yomiuri shinbun* article, for example, announced that Tōhoku University professor Hatai Shinkishi had demonstrated that when catfish swim in a certain way, an earthquake occurs within 12 hours. The fish in Hatai's lab had allegedly predicted almost 100 earthquakes.[11] The media excitement over Hatai's research soon faded. Despite much research attention during the twentieth century, nobody has developed any useful way to employ fish or other animals as earthquake predictors. Such interest continues to this day. Reminiscent of the *ayu* and sardines in 1610, a recent newspaper article explained that the squid catch was unusually high prior to several earthquakes between 1946 and 2011, implying some kind of link.[12]

Reports of unusually bountiful fish catches appeared in connection with an earthquake and tsunami that struck the Sanriku coast late in the morning of February 17, 1793. The earthquake damage was moderate, and only twelve people died in the shaking, but many more died in the tsunami that struck around 10am. Because the 1611 disaster and the one in 1793 had occurred in the winter, a local folk theory developed such that tsunamis only strike when leaves are not on the trees. This notion was part of popular lore in August 23, 1856, when a strong offshore earthquake shook the Sanriku area. Because the trees were full of leaves, some people delayed making their way to high ground and were caught by the four tsunami waves that soon came sweeping through coastal areas.[13] In this case, historical memory contributed to an inaccurate and potentially deadly folk theory. More generally, it has long been customary in Japan to assume links between atmospheric phenomena and earthquakes or tsunamis, and seismologists searched for such links well into the twentieth century. The gradual acceptance of plate tectonics by Japan's scientific community during the 1970s put an end to lingering seismological interest in the role of atmospheric phenomena and earthquakes.

The June 15, 1896 Meiji Sanriku Earthquake occurred at 7:32pm on the fifth day of the fifth month in the old lunar calendar. Villages in the area had been celebrating the Boys' Festival, and military organizations were celebrating Japan's recent victory over China. Gentle ground motion and the absence of seawalls exacerbated the disaster. The tsunami struck about 35 minutes after the earthquake. Three main waves of the tsunami swept over the landscape, and many villages lost the majority of their inhabitants. The total death toll was 21,959, over 10,000 structures were washed away, and over 7,000 boats and ships were destroyed or damaged.[14]

At 2:31 in the morning of March 2, 1933, the magnitude 8.1 Sanriku Earthquake (sometimes called the Shōwa Sanriku Earthquake) shook residents awake. Originating near the location of the 1896 event, the 1933 earthquake was the result of the rupture of an intra-plate fault. Although geologically different from its 1896 predecessor, the 1933 earthquake was functionally similar in that it threw off a large tsunami. The maximum wave height at Ryōri Bay was 28.7 meters. The Sanriku Earthquake and tsunami resulted in slightly more than 3,000 deaths and over 1000 injuries. The shaking, waves, and fire combined destroyed over 6,000 houses, and local residents endured 77 aftershocks of M6 or higher for six months following the main shock.[15]

It should be clear from this overview that large tsunamigenic earthquakes have occurred repeatedly in precisely the areas devastated by the March 11, 2011 event. Writing in approximately 2006, Okada Yoshimitsu pointed out that:

> In the Tōhoku region, there is a stronger tendency for large earthquakes and the tsunamis that accompany them to occur offshore, owing to plate subduction. In the years to come, there is an extremely high likelihood of a large earthquake originating beneath the sea floor along the Japan Trench.[16]

Moreover, hazard maps in the front matter of Okada's book list the area offshore from Sendai as having a 99% chance of experiencing a magnitude 7.5 or greater earthquake during the next 30 years. The earthquake and tsunami of March 11, 2011 was the event which Okada anticipated, reflecting a broad consensus of the seismological community. In this sense, the earthquake was an expected event, at least among a small group of experts.

I should emphasize that current knowledge and technology is unable to predict earthquakes with any degree of precision that would be of practical use in, for example, allowing for orderly evacuations of dangerous areas. To say that the recent earthquake was an expected event means that knowledge of the relevant geological mechanisms and historical experience indicated that moderately large tsunamis are likely to occur in the area every few decades, and extremely large and destructive events are likely to occur every few centuries. With this knowledge in mind, it would probably be prudent to build critical, and potentially dangerous, infrastructure such as nuclear power plants in light of worst-case scenarios to withstand M9-class shaking and tsunami heights on a par with those of 1896 or 2011, plus an additional safety margin.[17] The 2011 event did moderately exceed expectations in terms of the sheer quantity of energy released by the earthquake (magnitude), but the 1896 event still holds the record for tsunami height, if only by an insignificant few centimeters. Had people heeded the warnings on still-extant stone monuments from 1896 not to build below the point of the monument, their houses would have been safe from the recent tsunami.[18]

Update: According to a news report on June 12, 2011, the March 11 tsunami reached a maximum height of 40.5 meters, thus exceeding 1896 levels. It is therefore possible that some locations that would have been safe in 1896 would not have been safe in 2011.

The Case of Osaka

Before taking a closer look at the Tōhoku situation, the case of Osaka provides useful comparison. Two massive tsunamigenic earthquakes shook Osaka and large areas along the coast in 1707 and 1854. Until March 11, 2011, many historical seismologists regarded the 1707 Hōei Earthquake as the most powerful known earthquake to have shaken Japan. It generated tsunami waves that washed through the coast of Honshū from Suruga Bay southward, through much of Shikoku, and parts of northern Kyūshū. Like Hōei, the December 24, 1854 Ansei Nankai Earthquake (M8.4) was an offshore subduction zone earthquake that generated a destructive tsunami. Both the Hōei and Ansei Nankai earthquakes were geologically similar to the 2011 Tōhoku Earthquake.

The Hōei Earthquake and tsunami caused coastal villages to develop evacuation plans that usually involved the entire community assembling at a temple, shrine, or other suitable location on high ground. Anticipating the need occasionally to spend a night or two at such locations, some villages constructed simple shelters at the evacuation area. Throughout the area within range of the 1707 tsunami, generations of rural coastal residents fled to high ground when the earth shook. Sometimes the move proved unnecessary, but the Hōei devastation loomed large in historical memory. A writer living in the Kii Peninsula, for example, explained that “fearing a tsunami, people set up lean-to shelters in the mountains,” and letters, diary entries, and other documents dealing with rural areas regularly describe lowland villages in terms such as “Owing to tsunamis, everyone had set up huts in the mountains, and not a single person was dwelling” in the lowland village.[19] Not all accounts, however speak of an effective response. “There is a saying that complacency is the greatest enemy (*yudan-taiteki*),” began a short essay that went on to criticize people of the present for ignoring the lessons of the 1707 Hōei Earthquake and tsunami “as if it were an ancient tale” and not currently relevant knowledge.[20] The writer was referring to Osaka.

Although the Hōei tsunami damaged Osaka, between 1707 and 1854, there had been a substantial turnover in the city’s population, including an influx of people from inland areas. Historical memory of the type needed to preserve effective tsunami evacuation practices was weak or absent. As early as the 1662 Kanbun Earthquake, many residents of Osaka fled to boats moored in the city’s rivers and remained there for several days or even weeks to escape the nerve-wracking shaking from aftershocks that usually followed major earthquakes. An order by Osaka’s Machibugyō in 1854 prohibiting onboard drinking parties clearly indicates that the city authorities regarded fleeing to boats as a perfectly viable option, provided people remain sober.[21] Inland earthquakes such as Kanbun were more common than offshore tsunamigenic events, and by 1854, the Hōei Earthquake would indeed have seemed like “an ancient tale” to the few people in Osaka who even knew about it. Much more relevant would have been the magnitude 7.25 Iga-Ueno Earthquake of July 9, 1854, approximately six months prior to Ansei Nankai. As many people as possible rode out the many Iga-Ueno aftershocks in the relative comfort of boats in the rivers. Moreover, the Ansei Tōkai earthquake of the December 23 caused some shaking in Osaka but no tsunami. The result of the mass flight to boats on the 24th was tragic and dramatic. The massive tsunami waves that swept up the rivers crushed nearly all of the boats, resulting in perhaps 800 deaths.[22]

The case of Osaka in 1854 serves as a preview. Some of the basic conditions of modern life such as the relatively easy movement of people and a weakening of traditions in local communities contributed to the fatal lack of historical memory. Similar forces have been at work in the Tōhoku region and elsewhere since the 1890s.

A Closer Look at 1896 and 1933

Returning to the Tōhoku region, I examine the tsunamis of 1896 and 1933 in detail, particularly the short term and longer-term responses to these events. The scope of the disaster in 1896 was overwhelming at first. Without warning, mud and sand buried about 70 coastal communities, bodies mixing in with debris from smashed houses. In Iwate Prefecture, where about 20,000 died, 125 women died for every 100 men. The main reason was that men often set out in the evening for night fishing. In one village, for example, about 40 fishermen in five or six boats went out the evening of the tsunami. At sea, they experienced nothing unusual and were shocked to see their demolished village as they approached shore. Many such returning fishermen heard voices calling out for help in the dark as they returned. Local lore regarded voices in the water as those of ghosts. Moreover, answering the calls of such ghosts would result in their pulling the responder into the water. This situation resulted in delays in the fishing boats mounting rescue operations.[23]

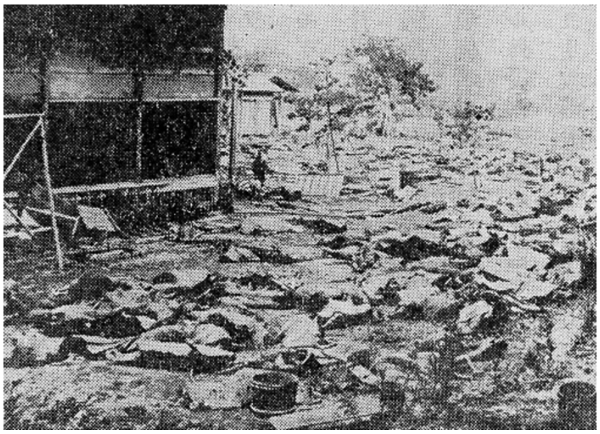


Figure 1. Bodies line the ground outside a local temple in Kama'ishi, 1896. From Yamashita Fumio, *Shashin to e de miru Meiji Sanriku ōtsunami* (1995), p. 20

In the hardest hit villages, the tsunami killed the majority of residents. Tarō Village, for example, lost 83% of its residents. Only 36 of its population of 2,000 survived. The waves washed away all public infrastructure plus 285 of 336 houses, and because the village faced the Pacific Ocean directly, the water swept most bodies out to sea. In the days following the tsunami, a large number of these bodies washed up on shore.[24] Owing to warm summer conditions, a lack of people, and a lack of infrastructure, disposal and identification of the many bodies was a major problem. Sometimes debris became a funeral pyre for unclaimed bodies. Hirota Village used fishing nets to recover bodies at sea. As many as 50 came up in one sweep, so many that only half could be brought to shore at a time.

Figure 2. Drawing of the recovery of bodies at Hirota, 1896. From Yamashita Fumio, *Shashin to e de miru Meiji Sanriku ōtsunami* (1995), p. 21

Bodies in the ocean soon became encrusted with sea creatures, and starving dogs set upon corpses on land, sometimes biting people who tried to restrain them. Bodies from one village often floated to other areas, further complicating identification. In Iwate Prefecture, 10,200 of the 18,158 bodies recovered were disposed of in mass graves.[25] This gruesome aftermath would have made a strong impression on survivors and people entering the area.

The total monetary cost of the 1896 disaster was between 7,100,000 and 8,700,000 yen, approximately 10% of the national budget for that year. The total cost of the 1995 Kobe Earthquake was also just over 10% of the national budget, so the financial impact of both events was roughly comparable.[26]

Hattori Kazumi, governor of Iwate Prefecture, issued general instructions published on June 20 in the local newspaper, the *Iwate kōhō*:

> The present tsunami that struck 60 *ri* off the Tōhoku coast is an unprecedented (*zendai-mimon*) catastrophe, and it is essential to

> be alert to maintain hygiene in the affected areas to the best of our ability. Especially after a disaster, fearsome outbreaks of epidemic and contagious disease occur. . . . It is especially necessary for us to attend to steps such as setting up evacuation centers, treating the wounded and sick, properly disposing of corpses, potable water, and cleaning up the debris widely strewn about the disaster area.[27]

This concern with "hygiene" (*eisei*) appears frequently in documents related to this earthquake, and it was typical of the times.[28] Governor Hattori's general directive became a detailed set of instructions for cleansing, burning, disinfecting, and taking other measures thought to prevent the spread of disease. For example, "Periodically open the windows and light a fire to maintain dryness in houses. In particular, this should be done before sleeping."[29]

Other steps in dealing with the immediate aftermath of the tsunami included dispatching medical personnel and gangs of laborers to the area, measures to control theft and looting (sometimes at the hands of the gangs of laborers), and attempts to control hoarding and price gouging. In one case, the police investigated a rice dealer in Miyako-chō claiming his shelves were empty and found that he had enough rice in stock for 20 days. They lectured him on the evils of price gouging during this unprecedented (*mizō*) emergency and forced him to sell his stock at a moderate price.[30] Although the details were different in 1896, the general problem of hoarding necessities appeared in 2011, even in areas not directly affected by the disaster.

The central government dispatched specialists to the disaster area, and interior minister Itagaki Taisuke left Tokyo for a tour of the region on June 22nd. Each of the affected prefectures established relief centers. Miyagi Prefecture, for example, created the Temporary Tsunami Bureau (Kaishō rinjibu). It operated for 67 days from June 20 to August 25. People from Iwate, Miyagi, and Aomori prefectures living in Tokyo established an agency to coordinate the solicitation, collection and shipping of aid to the afflicted regions.[31]

Figure 3. The seawall at Tarō, sometimes called "The Great Wall" by local residents. From Yamashita Fumio, *Shashin to e de miru Meiji Sanriku ōtsunami* (1995), p. 41.

Of particular interest is the longer-term recovery and rebuilding effort. Let us first consider the specific case of Tarō, the village that lost 83% of its population. Following the 1896 disaster, the remnants of Tarō and some newcomers attempted to move to a safer location at the base of a mountain but ultimately failed to do so. The 1933 tsunami once again wiped out most of the village. Instead of relocating, the remnants of Tarō began constructing a 10-meter high seawall, the full length of which was completed soon after the war. Postwar Tarō Town thrived in the shadow of this fortress-like seawall, and not always behind it.

On a recent visit to Tarō, Itō Kazuaki was surprised to see houses and shops on the seaward side of the wall.[32] A recent internet search using the term "田老町" (Tarō-chō) reveals photos of the seawall and surrounding areas, memorials to the 1896 and 1933 disasters, a tsunami evacuation direction sign, and sadly, the twisted wreckage of the town after March 11, 2011.[33]

The destruction of the "Model City" of Tarō

In 2003, on the 70th anniversary of the 1933 disaster, the town formally issued a "Declaration of a tsunami defense town" (*Tsunami bōsai no machi sengen*) in honor of those who died and styled itself as a "Disaster defense town" (*Bōsai no machi*, also the title of a booklet published by the local board of education).[34]

Figure 4. Tarō in the wake of the March 11, 2011 disaster. The great seawall was not tall enough to hold back the tsunami. Source (accessed 5-13-2011)

Tarō boldly standing up to the fury of the sea is, of course, a tragic testament to overconfidence. It is hardly unique in this regard. In examining all of the communities that made plans to relocate after the 1896 disaster, a majority were either unable to put their plan into action or gradually moved back to low-lying areas. Communities that relocated to higher ground and remained there usually suffered little or no damage in 1933. Some specific examples illustrate the range of possibilities. Funakoshi in Iwate relocated to higher ground by extending a road up a mountain and building houses on either side of it. Tanohama, which had been wiped out, planned to merge with Funakoshi and re-distributed land at the same location. New Tanohama residents, however, unaware of the danger, gradually relocated closer to the coast. In 1933, Tanohama was destroyed again, but Funakoshi escaped with no damage. Yoshihama escaped damage in 1933 by similarly extending a lowland road up a mountain and relocating there. Ryōri moved several residences to high ground, but over the years, they returned to the original location. The village was devastated again in 1933. Hashikami in Miyagi entirely relocated to high ground, assisted by the prefecture building a new road. Damage in 1933 was light.[35] Notice the key role of infrastructure in the form of roads to support communities that successfully relocated.

It is significant that the trend to return to original locations, or otherwise to abandon safe venues and move lower and closer to the coast, greatly accelerated after the passing of 10 years. It is as if historical memory, or at least the sense of danger, greatly diminished after the passing of a tsunami-free decade. Other reasons for remaining in or returning to low-lying areas included convenience for those in the fishing industry, a lack of potable water after moving, inconvenient road networks, the main part of the community remaining where it had been, attachment to ancestral land, a tendency gradually to make temporary huts used for work into permanent dwellings, and an influx of people into the area without knowledge or experience of tsunamis.[36] Many similar issues are likely to play a role in the future of the region.

Looking Ahead

"*Tsunami tendenko*" is a well-known expression in the Tōhoku region. It means that when a tsunami is on the way, run for dear life and pay no attention to anything or anyone else. The expression highlights the sense of urgency that became so clear to people around the world watching videos of the sea's deadly advance on March 11, 2011. Although a variety of lessons are prominent now, in the immediate aftermath of the disaster, this study suggests that historical memory and an acute sense of danger will fade fairly rapidly. Individuals and society as a whole obviously face a major challenge moving forward in the region, particularly with respect to rebuilding. Demographics may be a factor in favor of longer-term safety. With the population of the area already declining, rebuilding in safer locations may be slightly more practical than a generation ago. Yet this may be weighed against factors that make the original location desirable.

The recent disaster revealed both strong and weak points in Japan's earthquake and tsunami preparedness. Earthquake-resistant buildings in the Tokyo area generally performed as expected, as did other systems such as emergency shut-down mechanisms in trains. The shortage of food and fuel in Tokyo, despite receiving only a glancing blow, suggest much greater distribution problems in store should a large urban area be hit with a major earthquake. The issue of nuclear power plant safety, of course, is a relatively new and vexing problem in a country with few energy options.

Ideally, the recent Tōhoku disaster should work against complacency in other areas of Japan vulnerable to large earthquake and tsunami combinations. The Tokyo areas is vulnerable both to an ocean trench earthquake like the Great Kantō Earthquake of 1923 and to the rupture of faults under the city itself such as occurred in the Ansei Edo Earthquake of 1855 (no tsunami). Strain has been accumulating behind the Nankai Trench such that areas from the Kii Peninsula to northern Kyūshū could at any time suffer a Tōkai or Nankai earthquake (or both, as in 1707 and 1854), which would almost certainly generate massive tsunamis. All of these possibilities involve major urban areas.

Finally, the 2011 Tōhoku Earthquake is directly relevant to the Pacific northwest coast of the United States and southern Canada. In this region precisely the same type of M9-class seismic events have happened approximately every 500 years for the same reason, subduction of the Pacific Plate. The most recent such event took place on January 26, 1700. Estimates of the earthquake's magnitude range from 8.7-9.2. Extensive Japanese records of an "orphan tsunami" (*minashigo Genroku tsunami*) led investigators to discover that an earthquake and tsunami had devastated coastal areas of the Pacific Northwest, even submerging entire forests. Tsunami evacuation signs are now common in coastal areas of Oregon and Washington State, and researchers have discovered extensive evidence in the myths and legends of native peoples of massive earthquakes and tsunamis in the past.[37] Outside of Native American lore, however, today's Pacific Northwest possesses no collective memory of disastrous seismic events and is in many other ways less prepared for the possibility of a disaster than its cross-plate neighbors in the Tōhoku region of Japan.

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recently completed a book-length study of earthquake culture in early-modern Japan"

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Notes

[1] Okada Yoshimitsu, Saishin Nihon no jishin chizu (Tōkyō shoseki, 2006), p. 52.

[2] Itō Kazuaki, *Jishin to funka no Nihonshi* (Iwanami shoten, 2002), pp. 106-7.

[3] Koshimura Shun'ichi and Shutō Nobuo, "Meiji Sanriku jishin tsunami," in Chūō bōsai kaigi, *1896 Meiji Sanriku jishin tsunami hōkokusho*, 2005, pp. 15-17.

[4] Koshimura and Shutō, "Meiji Sanriku jishin tsunami," pp. 15, 17-20. See diagram 2-9 for three possible models for this process. Most reference books do not distinguish between magnitudes for the earthquake versus the tsunami and typically state a magnitude of 8.5 for the entire event.

[5] See, for example, Jay Alabaster, "Tsunami-hit towns forgot warnings from ancestors." Associated Press, April 6, 2011. Alabaster mentions the "tightly knit community of Aneyoshi," part of Miyako City, as a place that fared relative well in the recent disaster.

[6] For details of the complexities of tsunami height calculations and the conclusion that a 38 meter height at Ryōri is a reasonable estimate, see Koshimura and Shutō, "Meiji Sanriku jishin tsunami," pp. 25-30.

[7] Shinsai yobō chōsakai, eds., *Dai-Nihon jishin shiryō*, vol 1 (kō), pp. 38-39, Itō, *Jihin to funka*, p. 107, and Koshimura Shun'ichi, "Sanriku chihō no tsunami saigai gaiyō," in Chūō bōsai kaigi, *1896 Meiji Sanriku jishin tsunami hōkokusho*, 2005, p. 3.

[8] Koshimura, "Sanriku chihō," pp. 3-4, and Itō, *Jishin to funka*, 107. For an example of a detailed account of the event describing the precise reach of the water, see Tōkyō daigaku jishin kenkyūjo, ed., *Shinshū Nihon jishin shiryō*, ho (supplement), p. 98.

[9] "Higashi Nihon daishinsai: senjin wa shitteita 'rekishi gaidō' shinsui sezu," in *Mainichi shinbun*, April 19, 2011, link.

[10] Koshimura, "Sanriku chihō," p. 4.

[11] "Namazu ga ugoku to kanarazu jishin ga okoru," in *Yomiuri shinbun*, April 1, 1932, morning edition, p. 7. See also excerpts of a presentation Hatai gave on his research, "Namazu no ugoki de jishin o yochi," in *Yomiuri shinbun*, October 14, 1932, morning edition, p. 4.

[12] "Ika toresugi wa dai-jishin no zenchō? . . . senmonka mo kyōmi," in *Yomiuri Online*, May 1, 2011, link.

[13] Koshimura, "Sanriku chihō," p. 5.

[14] Itō, *Jishin to funka no Nihonshi*, pp. 107-113, and Okada, *Jishin chizu*, p. 58.

[15] Okada, *Jishin chizu*, p. 59, and Itō, *Jishin to funka no Nihonshi*, p. 117. For photos of Ryōri Bay before and after the 1933 tsunami, see this site.

[16] Okada *Jishin chizu*, p 50.

[17] As Rodney C. Ewing and Jeroen Ritsema point out, "In the case of the Fukushima Daiichi power station, the magnitude of the earthquake (9.0 on the Richter scale, or M9) and subsequent tsunami (with a reported wave height of 14 meters) exceeded the credible event on which the nuclear power plant's design was based." See "Underestimating nuclear accident risks: Why are rare events so

common?" *Bulletin of the Atomic Scientists*, May 3, 2011, link.

[18] Regarding these stone monuments, see the widely reproduced article by Martin Fackler, "Tsunami Warnings for the Ages, Carved in Stone," *New York Times*, April 20, 2011, A6.

[19] "Zoku jishin zassan," in Shinsai yobō chōsakai, *Dai-Nihon jishin shiryō*, pp. 420, 423. For more examples of villagers fleeing to high ground in advance of tsunamis, see, pp. 419, 462, 467, 469-471, 482-483.

[20] "Jishin nikki," in Shinsai yobō chōsakai, *Dai-Nihon jishin shiryō*, vol. 2 (otsu), p. 488.

[21] Nishiyama Shōjin, "Ansei nankai jishin ni okeru Ōsaka de no shinsai taiō," in Chūō bōsai kaigi, *1854 Ansei tōkai jishin, Ansei nankai jishin hōkokusho*, p. 51. The decree was issued one day after the main shock of the Tōkai earthquake, just before the Nankai earthquake and its tsunami struck.

[22] Nishiyama, "Ōsaka de no shinsai taiō," pp. 51, 55-59, 62. For an image of the carnage, from the popular press, see this address(upper left image).

[23] Shutō Nobuo and Koshimura Shun'ichi, "Meiji Sanriku jishin tsunami ni yoru higai," in Chūō bōsai kaigi, *1896 Meiji Sanriku jishin tsunami hōkokusho*, 2005, pp. 22-25.

[24] Itō, *Jishin to funka*, p. 113 and Kudō and Koshimura, "Higai," p. 38.

[25] Shutō and Koshimura "Higai," pp. 38-41.

[26] Shutō and Koshimura, "Higai," pp. 45-46.

[27] For a thorough discussion of the emerging concept of hygiene, including in Meiji Japan, see Ruth Rogaski, *Hygienic Modernity: Meanings of Health and Disease in Treaty-Port China* (Berkeley: University of California Press, 2004).

[28] Quoted in Shutō Nobuo and Koshimura Shun'ichi, "Gyōsei no ōkyū taiō," in Chūō bōsai kaigi, *1896 Meiji Sanriku jishin tsunami hōkokusho*, 2005, p. 47.

[29] Shutō and Koshimura, "Gyōsei," p. 48.

[30] Shutō and Koshimura, "Gyōsei," pp. 49-50.

[31] Shutō and Koshimura, "Gyōsei," pp. 51-59.

[32] Itō, *Jishin to funka*, p. 118 and Shutō Nobuo and Koshimura Shun'ichi, "Meiji sanriku tsunami saigai kara no fukkō," in Chūō bōsai kaigi, *1896 Meiji Sanriku jishin tsunami hōkokusho*, 2005, p. 91.

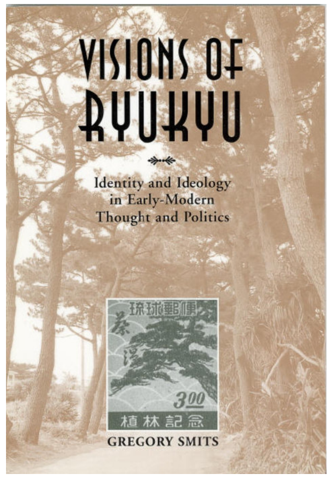
[33] See also "Bōsai no machi mo kaimetsu . . . Tarō no higeki." Link.

[34] For the text of the declaration, photos, and details of the 1933 disaster and subsequent seawall, see Yamashita Fumio, "Sanriku Kaigan Tarō-chō ni okeru 'tsunami bōsai no machi sengen' to dai-bōchōtei no ryakushi," in *Rekishi jishin*, no. 19 (2003), pp. 165-171, link.

[35] Shutō and Koshimura, "Fukkō," pp. 91-92.

[36] Shutō and Koshimura, "Fukkō," pp. 92-93.

[37] For a detailed analysis of the orphan tsunami see Brian F. Atwater, et al., *The Orphan Tsunami of 1700 (Minashigo Genroku tsunami): Japanese clues to a parent earthquake in North America (Oya-jishin wa Hokubei seikaigan ni ita)* (Reston, VA: United States Geological Survey, distributed by University of Washington Press, 2005). This book is also available in digital form to the public here. Regarding myths and legends as clues to past seismic events, see R.S. Ludwin and G. J. Smits, "Folklore and earthquakes: Native American oral traditions from Cascadia compared with written traditions from Japan," in L. Piccardi and W. B. Masse, eds. *Myth and Geology* (London: The Geological Society, 2007), 67-78, 86-91.



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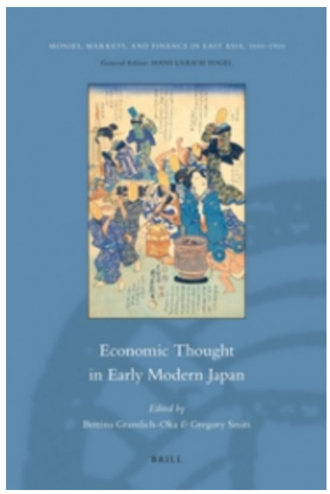

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