# A case report of Sato's Hill, a tsunami evacuation site utilized in the 2011 Great East Japan Earthquake, and a literature review on its effectiveness

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## Abstract

In Great East Japan Earthquake, the damage caused by the tsunami was extensive, especially in the coastal lowlands. We report a case of Sato's Hill, a private tsunami shelter that saved residents of Higashi-Matsushima. According to an internet archive search and Mr. Yoshifumi Sato, the hill provided shelter to 70 people. A literature search reveals that the tsunami height reached up to about 17 m in coastal areas and 40 m inland. Google Maps and inundation record data verified the safety of Sato's Hill at that time. This report is useful in the development of future tsunami countermeasures.

Keywords : tsunami evacuation shelter, Great East Japan Earthquake, Sato's Hill

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### 1. Introduction

On March 11, 2011, a magnitude 9.0 earthquake struck off the coast of eastern Japan. Approximately 20,000 lives were lost, mostly due to the tsunami(1,2), and the casualties were particular heavy in the coastal lowlands. In addition to the human cost, the damage from the earthquake is estimated to be about 16–25 trillion JPY.

Given the distribution of causalities, evacuation plans for low coastal areas are considered particularly important now and in the future. Before 2011, some local governments in coastal areas constructed high-rise buildings as a countermeasure against tsunamis(3,4). However, these buildings were insufficient to provide shelter to all evacuees during the tsunami disaster following the Great East Japan Earthquake. Even worse, the leadership of the town of Otsuchi in Iwate Prefecture was lost in the aftermath of the tsunami(5,6). Despite this, there were some successful cases of evacuation, such as the Kamaishi case(3), in which an eight-floor tsunami evacuation facility provided shelter to residents. Here, we report another successful case: Sato's Hill, a private evacuation site near the coast of Higashi-Matsushima in Miyagi Prefecture, where many lives were lost in the tsunami(7)(Figs. 1 and 2). Sato's Hill provided shelter to 70 tsunami evacuees after the Great East Japan Earthquake(8). In this work, we evaluate the validity of Sato's Hill as a tsunami evacuation building.

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Fig 1: Map of Japan. The blue arrowhead shows the location of Higashi-Matsushima(Fig 2).Source: Google Maps



Fig 2: Map of Higashi–Matsushima and the surrounding area. The blue arrowhead shows the location of Sato's Hill(Fig 7).Source: Google Maps

### 2. Methods

#### Literature search

Mr. Yoshifumi Sato, who built the shelter at Sato's Hill, provided an account of the events of the day the Great East Japan Earthquake struck (8). We also performed an internet search of the word "Satoyama" by using Google Search. If a URL could not be reached, we retrieved a cached copy of the page from Internet Archive(https:// archive.org/). For Japanese articles, we searched J-STAGE using the keywords "tsunami," "evacuation facility," and "height" in Japanese and selected papers we considered as related from their title. For English articles, we searched ProQuest using the keywords "tsunami," "evacuation," height," and "shelter" and selected the resulting papers from their titles, examined their contents, and decided which to reference.

### Tsunami height evaluation around Sato's Hill

We determined the inundation situation around Sato's Hill at the time of the earthquake and evaluated its safety by using Google Maps and inundation record data (http://www.jsgi-map.org/ tsunami/)(9).

# 3. Results

Figure 3 is a statement from Mr. Yoshifumi Sato about his shelter and the events of March 11, 2011(8). According to Mr. Sato, this facility provided shelter to 70 people after the Great East Japan Earthquake. He also reported that approximately 70 % of those who took shelter were local residents, and the others were passersby. Mr. Sato and his colleagues evacuated to the hill 30 min. after the earthquake struck. He saw the tsunami approaching just as they arrived. He found about 40 people seeking refuge on the hill. Shortly after that, other passersby evacuated to the hill. The shelter contained supplies such as food and blankets, which kept the evacuees warm and prevented hypothermia.

Figures 4, 5, and 6 show photographs of Sato's Hill. Our literature search produced eight Japanese media articles related to Sato's Hill(8,10-16). The following summarizes the results of our literature search.

Sato's Hill is about 700 m from the coast and about 30 m above sea level(8,10-14). Steps are maintained so that foot traffic can reach the hill's summit(Fig. 4). Sato's Hill is currently participating in a fieldwork program with a disaster education facility based in a closed elementary school(KIBOTCHA)(14, 15).

The academic literature search returned 180 articles on J-STAGE and 374 articles on Pro-Quest with details of the tsunami height and evacuation shelter height. Examining the article titles and contents related to the tsunami height in the area around Sato's Hill, we found no articles on J-STAGE and one on ProQuest, which indicated that the tsunami height reached about 17 m in the coastal area and about 40 m in the inland area(17). The height of the tsunami differed with time, so it is difficult to accurately determine. The maximum tsunami height planned for in tsunami evacuation guidelines is the expected tsunami height plus a safety margin of 2 stories(about 6 m); in this way, the maximum height was estimated as 23 m in coastal areas and 46 m in inland areas(17, 18). We used Google Maps to extract a map around Sato's Hill from inundation data and created a schematic regional map describing a straight line passing from the coast to Sato's Hill(Fig. 7 and Table 1). The tsunami height around Sato's Hill was about 6-7 m, and the maximum height was about 13 m, which is less than that of Sato's Hill.

In my career, my business was protecting human lives. Because of that, I wanted to do something to save people from disaster. In 1999, when I was 65 years of my age, I entrusted my business to my son and began building a shelter. The shelter was located about 700 meters inland from Nobiru Beach in Higashi-Matsushima, on the Pacific Ocean, on a small hill. The hill was about 30 meters high was merely 50 meters away from the original Nobiru Station at the time of disaster.

At 14:46 on March 11,2011, an extremely long and powerful earthquake struck East Japan, lasting over 200 seconds. Then the massive tsunami arrived. In a blink of an eye, the tsunami devoured many lives and properties. Oku-Matsushima, known for its beautiful sceneries of green pine trees and pristine white sand beaches, also suffered tremendous damage.

Under such circumstances, over 70 people evacuated to my shelter, and everyone survived, including no loses to hypothermia.

It was believed that the area was not affected by historic tsunamis from Meiji and Showa eras and the Chile earthquake. The city officials and scholars did not think large tsunami would ever hit.

However, the massive tsunami did arrive.

We cannot tell when or where earthquakes will occur. There is no guarantee that any place is safe from tsunami just because there is no previous record of one occurring.

Let us not forget the tragedy of March 11, 2011 and humbly learn and think about the cycles of this beautiful planet. We learn from our experiences of what a natural disaster can bring, and how to build effective shelters that saves lives. We should pass that knowledge to future generations regardless of the national boundaries and ethnicities.

# Yoshifumi Sato March 10, 2016

Fig 3: A report from Mr. Yoshifumi Sato, who built Sato's Hill as a privately operated tsunami evacuation facility located 700 m from the coast on a natural rocky hill at an elevation of about 30 m.



Fig 4: A photograph of stairs maintained to allow climbing to the top of the hill.



Fig 5: A photograph of Sato's Hill in April. Seasonal flowers and cherry trees are planted around hill, where it is also possible to host seasonal events.



Fig 6: A photograph of the shelter at the top of the hill, which includes structures to keep out rain and wind and to stockpile evacuation supplies.



Fig 7: Tsunami inundation data superimposed on Google Maps data for the vicinity of Sato's Hill. The area recorded inundations of 6-7m, but Sato's Hill, which is more than 30 m above sea level, was not submerged.

	Latitude	Longitude	Height	Distance from
	(°N)	(°E)	(m)	coast (m)
1 Seashore 1	38.2217	141.1004	1	0
2 Seashore 2	38.2219	141.0958	4	195
3 Hill 1	38.2228	141.0947	21	527
4 Sato's Hill	38.2234	141.0942	24	731
5 Hill 2	38.2245	141.0931	44	1171
6 Hill 3	38.2251	141.0921	23	1481

Table 1: Location data around Sato's Hill from Google Maps and corresponding tsunami inundation data.

#### Discussion

We compiled a record of Sato's Hill, a private tsunami shelter that saved many lives in the Great East Japan Earthquake. Sato's Hill is located 700 m from the coast and is built on a natural rocky hill at a height of about 30 m. Sato's Hill provided shelter to 70 people, including local residents and passersby, after the Great East Japan Earthquake. Sato's Hill is currently participating in a fieldwork program with a disaster education facility. Our literature search revealed that the estimated tsunami height was from 23 m at the coast to about 46 m inland. This article presented the difficulty of adequately estimating tsunami heights. Google Maps and an inundation database showed the safety of Sato's Hill in the Great East Japan Earthquake.

If there are no nearby elevated locations in coastal lowland areas, or if it takes too long to evacuate to higher ground specified in an evacuation plan, it is necessary to prepare tsunami shelters with adequate height and practical evacuation plans. Tsunami evacuation shelters were prepared in many municipalities(3, 4, 8, 9, 19, 20), but their performance depends on factors such as tower height, building strength, equipment, space, and stockpiling of supplies(18).

There are some standards for the design of tsunami evacuation shelters, such as coefficients for height and distance from coastal areas and obstacles(18). However, tsunami heights vary by region and time. For example, a tsunami height of 10 m is predicted for the Pacific coast in Shizuoka Prefecture(21,22)based on evaluations of historical records for hazard maps by specialists. However, tsunami height evaluations vary between reports(21, 22, 23). Previous studies did not fully verify tsunami heights, and thus the experience of Otsuchi, Iwate Prefecture, where the city hall and shelter heights were insufficient, was not reflected. Therefore, further research on tsunami height is still needed. This problem may be solved if a floating facility can be built, but it is difficult to draw concrete conclusions regarding the problem of cost effectiveness(24).

Sato's Hill is located near the coast, and verification by Google Maps showed that its elevation of about 30 m places it in a safe area. However, there is a possibility of an unprecedented earthquake or that tsunami height forecasts do not apply to all areas. It is practically difficult to prepare tsunami evacuation facilities with elevations of about 50 m in all locations. Although there are regional indicators such as elevations of 17 m or more in coastal areas and 40 m or more in inland areas, simulations for the specific topology of each area are indispensable. In other words, the specific height and location of Sato's Hill is not a universal standard for tsunami shelters.

Considering records in the literature from the viewpoint of shelter maintenance, it has been reported that many Japanese shrines were built on high ground(25). Before World War II, shrines and temples were the center of local communities, so it is possible that a system was created in which the command center of the local community managed high–elevation evacuation centers (25). Maintenance of evacuation shelters may be difficult in some government–managed facilities(8,19). Stockpiles need replenishment or replacement, and shelters require annual budgets or regular use.

In the Tohoku region of Japan, a traditional teaching called *tendenko* has been reported to save many lives when faithfully put into practice(26), although it has also been argued that *tendenko* should be just one of multiple strategies(27). Sato's Hill has begun to collaborate with disaster education facilities in order to raise awareness among local residents through disaster preparedness events(14,15), which might lead to more effective tsunami evacuations.

After 2011, many local governments rebuilt their municipalities to be more resilient against earthquakes and tsunamis. Higashi-Matsushima is one such city, where residential blocks were rebuilt on higher ground(7). In addition, numerous public and private tsunami shelters have been constructed in Japan since 2011(19, 20, 28). This movement is also spreading overseas(3, 29). Our research on the height and maintenance of tsunami shelters should aid future tsunami shelter planning.

# Conclusions

Sato's Hill is 700 m from the coast and was constructed on a natural hill at a height of about 30 m. Sato's Hill provided shelter to 70 people after the Great East Japan Earthquake. The safety of Sato's Hill was confirmed by a tsunami inundation database. Factors affecting evacuation facilities include topographic elevation or tower height, building strength, equipment, space, stockpiling of supplies, budget, and local residents' disaster preparedness. Although there are difficulties in planning for tsunami evacuation, local governments and residents in coastal areas at risk of tsunami should consider developing evacuation plans that include familiarizing themselves with the location of evacuation facilities or building appropriate shelters. The case of Sato's Hill suggests a possible direction for supporting future disaster evacuation.

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#### Author contributions

M.K. and S.A. conceived the study; M.K., S.A., Y.S. and T.S. performed the research; M.K. and S.A. analyzed the data; M.K. and S.A. wrote the manuscript.

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