Offshore evacuation of fishing boats - Lessons from the 2011 Great East Japan tsunami and its future challenge-

Anawat Suppasri[1], David Nguyen, Yoshi Abe, Mari Yasuda, Yo Fukutani, Fumihiko Imamura and Nobuo Shuto

Abstract

Offshore evacuation, a behavior by the fishermen to save their boats from incoming tsunami, has gained more attention in the wake of the 2011 Great East Japan Earthquake (GEJE). This tradition had been practiced in tsunami-prone fishermen communities, including those along Sanriku Coast in Northern Tohoku. By boats heading offshore prior to the tsunami's arrival, the boats are considered to be saved with smaller tsunami size in the deeper ocean. With many fishermen practicing this evacuation during the GEJE, this effort has been regained attention for protecting fishermen's crucial asset, the boat, and various guidelines and maps to evacuate offshore have developed and revised across Japan since then. Relevant evacuation procedure is also considered and practiced in the US, revealing the importance of this procedure beyond Japan. Nevertheless, detailed study on offshore evacuation to understand its most appropriate procedure for a survival has been limited. This paper summarize the results of in-depth interviews on fishermen's evacuation response during the GEJE, and explains its relationship to geography confirmed on site. The result suggests that fishermen experienced tsunami in rias coast had better chance of evacuating boats offshore while those in coastal plains or inner bay had not. This was due the decision of fishermen on their proximity to the coast against time of tsunami's arrival. Correctly understanding topographic conditions of each fishing ports and revising guidelines with explicit procedures are therefore indispensible.

1. Offshore evacuation and research objectives

1.1 Offshore evacuation by the fishermen

Fishing boats are the single most important asset for fishermen as their livelihoods depend entirely on their ability to operate from a boat (Suppasri et al., 2013). Previous study found that damage probability of fishing boats was significantly increased when the tsunami height was more than 2 m or when the flow velocity was more than 1 m/s (Suppasri, et al., 2014). In times of tsunami, extreme anxiousness on their boats make many fishermen go to the coast to confirm its condition or strengthen mooring before evacuating to higher ground. Some fishermen even decide heading to the ocean with their boat. This is called "*Oki-Dashi*" or "Offshore evacuation", a Japanese tradition that has been practiced among fishermen to protect their boats from tsunami. Fishermen can save their boats by going offshore rather than leaving them moored at fishing ports, because tsunami size decreases with sea depth. However, this action could be life threatening and needs a well experience for a right decision whether to evacuate into the ocean or to higher ground. Even if decided for an offshore evacuation, the boats need to be well-controlled, and encounters many additional difficulties while evacuating in the ocean. This type of evacuation,

[1] International Research Institute of Disaster Science (IRIDeS), Tohoku University.

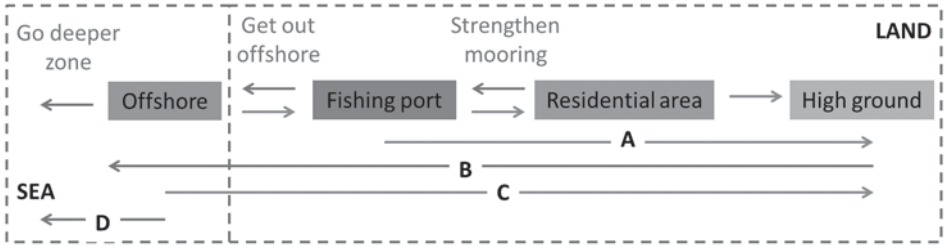

Fig. 1 Evacuation flow chart of fishermen during an earthquake and tsunami

therefore, was not officially recommended by the national government prior to the GEJE and the guideline has since been revised.

Theoretically, four types of fishermen's behavior can be observed after an earthquake:

A: Fishermen feel an earthquake inland and evacuate to a higher ground
B: Fishermen feel an earthquake inland and evacuate offshore with their boats
C: Fishermen feel an earthquake offshore and return inland to evacuate higher ground
D: Fishermen feel an earthquake offshore and go to the deeper sea with their boats

For type A, fishermen "inland" includes those who feel an earthquake at home and leave to strenthen boat's mooring prior to evacuating higher ground.

According to the Kahoku Shinpo (2013a), at least 1,100 boats evacuated offshore and at least 26 had failed. The primary reason for the failure was said to be the shortage of time, compared to the needed time for the access to port from inland, evacuate to the deepest part of the bay, and to further sail into the open ocean. In some cases, boats can catch a fire from floating debris.

The tsunami generated from the 2011 Great East Japan Earthquake destroyed multiple ports in the Tohoku Region. The reconstruction of fishing ports depend on a variety of factors such as the height of new seawalls and residential areas, influencing the amount of time needed. If seawalls are too high, they will affect the landscape of the ports and residences will have more difficulty in observing the initial tsunami wave condition before it's arrival. Moving residential areas to high ground will help to save lives and reduce housing damage in the long term but it will cause difficulty for fishermen especially in terms of access to aquacultural work, requiring more time reaching their boats to go offshore.

1.2 Research Objectives

This study explores the decisions of fishermen regarding the offshore evacuation and its corresponse results in the wake of the 2011 GEJE. Questions are addressed along the offshore evacuation procedure, including: i) how decisions on evacuation, to higher grounds or offshore, are made; ii) how far did boats evacuated offshore; and iii) what are the problems encontered in the ocean during the evacuation. Newly developed activities after the 2011 tsunami in other regions weree also introduced to demonstrate present attempts to mitigate problems related to offshore evacuation. By doing so, futher recommendation for research practice in the area, such as fishing port management, can be developed. The results of this study can be an input for the fishermen's evacution procedure for the future tusnamis as well as general problems occuring during the reconstruction of fishing ports. This is because it is important not only to save lives during a tsunami event, but also to prepare for a period of hardship that may follow after the disaster.

2. Offshore evacuation

Offshore evacuation has never been officially recommended as an emergency response procedure for the fishing ports by the national government. Although such practice has a great potential to save the boats, but risk losing fishermen's lives without a technique and a right timing decision. Nevertheless, this evacuation has been commonly performed by the fishermen in areas experiencing frequent tsunami, and more attention are being paid after the 2011 GEJE. This type of evacuation is also regulated in the coastal areas of the US, which explains the importance of further attention. Coastal states affected by the tsunami from the GEJE has also begun to revise their rules based on their experience. However, scientific research on this topic is minimally available.

2.1 Japanese experience and its transformation

2.1.1 Response against major earthquake events before the 2011 tsunami

Developed from generations of experience, retreating offshore is a common practice for Japanese fishermen to reduce the risk of damage from tsunamis. As the height of tsunamis are generally smaller in the deep sea (50 meters or deeper), boats will be safer than simply mooring their boat at port. Thus, instead of evacuating to higher ground, fishermen will attempt to move their boat to the deep sea as soon as possible after the event of a large earthquake. An example can be seen from a legend originating in Enoshima Island's Onagawa Town. The legend states that boats will be safe if they are located in a sea where its depth is three times the expected height of an incoming tsunami (Hodaka, 2012).

Japan's Fisheries Agency (2006) mentioned in their guideline that boats should be at 50 meters or deeper in the case of a major tsunami. The guideline provides information on which minimum sea depth boats should go to are based on specific earthquake magnitude and tsunami arrival time. However, this suggestion is not officially recommended by the government as driving a boat towards a tsunami is considered too dangerous and complicated. Boat operating experiences and even a bit of luck can influence the outcome of a deep sea evacuation process. Those who fail to do this will not only lose their boats but risk losing their lives.

Scientific researches related to safe off−shore evacuation are limited, but minimally available. Ohashi et al. (2007) used a tsunami numerical simulation to create an offshore hazard map as supporting tool for offshore evacuation of fishing boat in Kesennuma city. The hazard map was created by basing the questionnaire survey results asking the time for preparation and evacuation for all possible scenarios, similar to the Fig. 1.

Torii et al. (2010), inspired by the great loss of the 2004 Indian Ocean tsunami, has been working on a development of a tsunami early alert and evacuation support system for fishing boats. They examined a possibility of using the Area Mail service as an application to the smart phone as support system for the offshore evacuation. During the drill in Iwate prefecture, they asked small boat using the Area Mail service to return back to the port and medium boat to evacuate to 100 m deep sea. Both boat types spent 6−7 min to reach their target points.

Prior to this study, Katada et al (2012) investigated the offshore evacuation using fishing boat against the 2011 tsunami. They examined offshore evacuation behavior of fishermen in Nemuro city, Hokkaido using a questionnaire to approximately 200 fishermen as reconsideration of future evacuation plan. They found that among half of fishermen evacuated offshore before the estimated tsunami arrival time, only one−third of them could reach the safe zone (50 m sea depth) and one−fourth of them returned back to the port after the major tsunami warning were cancelled.

2.1.2 Responses against major earthquake events after the 2011 tsunami

Since the 2011 tsunami there were three earthquakes that generated tsunami advisory warning in Miyagi Prefecture:

7/12/2012 Miyagi−Oki (M7.3): A tsunami warning was issued in Miyagi Prefecture and a tsunami advisory was issued in most prefectures along the east coast of Japan. A maximum tsunami of 1.0 meter (JMA, 2012) was observed in Ayukawa but no major damage was reported (Kahoku Newspaper, 2012). However, a fisherman in the north of Iwate Prefecture (observed tsunami height was only 0.20 m) who was evacuating offshore 10 min after the earthquake, went missing. Japanese Coast Guard reported that his boat was found on the same night and his body six days later (Mainichi Newspaper, 2012).

26/10/2013 Fukushima−Oki (M7.1): At tsunami advisory was issued in Iwate, Miyagi and Fukushima prefectures resulting the maximum tsunami height of 0.20−0.30 meter (JMA, 2013). There was no damage or report about offshore evacuations but movement towards the sea could be observed during a live broadcast by the authors.

1/4/2014 Chile (M8.2): Tsunami advisory was issued along the east coast of Japan 18 hours after the great earthquake in the north of Chile. Maximum tsunami height of 0.60 m and 0.20−0.30 m in average were observed (JMA, 2014) but no damage was reported in Japan (Kahoku Shinpo Newspaper, 2014). In Aomori prefecture, there were some fishermen that evacuated offshore (47 News, 2014) but some decided not to do because of strong wave current during the tsunami advisory period (ABA News, 2014).

In brief, observed tsunami heights from these three near−field and far−field tsunami events were miniscule (1 m or less) compared to the 2011 tsunami. Consequently, most of fishermen decided not to evacuate offshore due to lessons from the 2011 tsunami, however those who did evacuate offshore might have thought that they would be fine because of the different tsunami size.

2.1.3 Rules for offshore tsunami evacuation and the drill after the 2011 tsunami

Tohoku Region

Aomori Prefecture proposed rules for offshore evacuation: 1) In the case of a 5 meter tsunami warning, the required sea depth and evacuation time is 50 meters and 40 min respectively and 2) The required sea depth in case of a 10 meter tsunami warning is 150 meters in sea depth. However as at least 60 minutes is required to evacuate, leading the prefecture to consider deep sea evacuations as too risky (NHK News, 2014). In addition, at night, offshore evacuation is not allowed for boats that have no lights as they cannot see the tsunami height. In local fishery cooperation in Aomori Prefecture, they decided two rules for no evacuations offshore" 1) in case tsunami arrive earlier than 100 minutes and 2) in the case of a tsunami warning (ABA News, 2014).

In 2013, Sekinehama village, in Mutsu city of Aomori Prefecture, organized an offshore evacuation drill for fishing boats. The tsunami scenario was 5 meters which arrived within 30 min. Fishermen were advised to reach their target distance for evacuation, which was about 4 km offshore. In fact, the drill was conducted a few hours after the magnitude 7.1 Fukushimaken−Oki earthquake mentioned previously. Although they could leave the port within 1−2 minutes, due to the 10 m/s strong winds, they spent 22−35 min to reach the target evacuation area which was longer than the expected of 15−20 min (Kahoku Shimpo News, 2013b).

Hokkaido Region

In preparation of the evacuation of fishing boats, drills are performed every year since 2012 in Toyokoro Town in the Nakagawa district and Urahoro town in the Tokachi district of Hokkaido (Tokachi Mainichi Newspaper, 2012 and 2013). Every year, about 20−30 boats attended the drill which had an objective to evacuate the boats to a sea that was 20 meters in sea depth rand about 3 km from the port. They found that the boats took about 15−20 min to the specified point. In addition, it took 10−20 min from the port to a safe high ground by walking. Even fishermen in these two areas know the required time for evacuating offshore but if the great earthquake had occurred, they still have difficulty in deciding whether to spend 15−20 min to save their boats offshore or 10−20 to run to high ground.

Shikoku Region

Tokushima Prefecture is an example of a region that affected by the 2011 tsunami that was 1 meter or larger in height. During that time, about 25 fishing boats evacuated offshore to an area 25 meters of sea depth. All 25 boats were reported to be safe (NHK, 2014). However, a tsunami greater than 10 meters which could arrive within 10 minutes is expected in this region (Cabinet office, 2012). Several fishery cooperatives in this prefecture decided that for such a large tsunami, the target sea depth is not 25 meters but at least 50 meters. They prepared offshore evacuation maps showing evacuation needed areas against specific estimated tsunami height. For example, at least 70 meters for tsunami with the height of 4 meters and 110 meters for a 6 meter tsunami (NHK, 2014).

2.1.4 Adaptation after the 2011 tsunami

Evacuation responses to other tsunami warnings and disaster countermeasures related to activities after the 2011 tsunami are introduced in the previous sections. There were no tsunamis that caused significant damages four years after the event in 2011. Most fishermen prefer not to evacuate offshore because of the last experience but some of them still prefer to evacuate after understanding that other tsunamis were not as large or comparable to the 2011 tsunami. For those fishermen who are still willing to evacuate offshore, they should keep in mind that tsunami sizes can still be large even if the earthquake magnitude is small, likewise a tsunami might can also be larger than the 2011 event if an earthquake of a similar magnitude were to again occur. Hence, local governments in many regions all around the country have placed considerable effort in improving countermeasures that support offshore evacuation. such as criteria if the offshore evacuation can be allowed, revising the required sea depth for each expected tsunami height, offshore evacuation drill and revising or creating new offshore evacuation map using numerical simulation and advanced information technology. Using the actual fishing boat damage data in case of the 2011 tsunami might be able to help considering the suitable sea depth rather than only using theoretical analysis of the damage. Fishermen seem having higher awareness and cooperating to disaster−related activities organized by the local governments. Nevertheless, the challenge is how to remain this high level of awareness so that offshore evacuation drill and other activities will keep continuing until the next great event. Lessons and activities in Tohoku region should be more actively applied to the west of Japan against the Nankai trough tsunami which large tsunami might reach coastal communities within 5−10 min after the earthquake.

2.2 Beyond Japan

2.2.1 Experience in the US

While Japan experienced the brunt of the tsunami, damages caused by waves were recorded as far west as Hawaii and California in the United States. In Oregon, tsunami surges hit Brookings

Harbor and entered both the basin for sporting vessels and the basin for commercial vessels. Ships that were tied to the ports were damaged and sea walls collapsed. The damage was amplified by blockage of the Chetco River which shares a common drainage with the harbor. As river water was running high with winter runoff, the surge had nowhere to go but into the two basins. According to Curry County, ten to twelve boats were missing or destroyed and 60 percent of the docks were damaged (Manning, 2011)

The State of Oregon provides a tsunami awareness manual for boaters and fishermen developed by NOAA, Sea Grant Oregon, and Oregon State University. The procedures for boat owners vary depending whether the tsunami was generated from a distant earthquake or a local one. In the case of a distant earthquake such as the 2011 Great East Japan Earthquake, the manual suggests boat operators to judge how much time has passed from the tsunami and for those out in sea to head to an area where the water is 90 m or deeper and to follow the radio. Those whose boats are still in port are advised to either move their boat and anchor up−river, cross the bar and go out to sea, or to moor the boat and evacuate the inundation zone (Oregon Sea Grant, 2007).

In Hawaii, the tsunami surges contributed to $30 USD in damages. 15 boats were sunk while hundreds were damaged while moored at port. The damages affected multiple harbors across the islands including Keehi Boat Harbor in Honolulu which lost over 140 ships, and Maalaea Harbor in Maui which lost two boats. The US Naval base at Pearl Harbor, located near Keehi Boat Harbor, did not evacuate their ships as the small and narrow inlet reduces the risk of surges. In 2013, based upon the experiences of the 2011 Great East Japan Tsunami, the US Coast Guard created safety zones within the commercial harbors of the main Hawaiian Islands that will require evacuation if a tsunami warning is issued. In the tsunami warnings post−2011, the Coast Guard had urged vessels to leave their harbors and not to return until an all clear sign was given (CBS 2012).

The State of Hawaii's Department of Land and Natural Resource's Division of Boating and Ocean Recreation (DOBOR), advises owners to take their boat on a trailer and leave the evacuation zone. In the event that it cannot be trailered, the manual suggests operators to move the vessel offshore to waters 300+ feet in depth as soon as a tsunami warning is declared, and to maintain adequate supplies of food, water, fuel as well as ensuring the ability to receive communication on harbor conditions. Boats should not return to harbor unless an official "All Clear" announcement has been made for a given harbor. In the case of a local earthquake, like Oregon, DOBOR suggests immediate evacuation to higher ground or vertically beyond the fourth floor in the nearest reinforced concrete building with four or more floors.

2.2.2 Differences between the Japanese and US scenarios

As the Great East Japan Tsunami was generated from an earthquake with an epicenter near Sendai, the cities in the Pacific and North America had sufficient timing to issue a tsunami alert and prepare for incoming waves. While coastal cities in the Tohoku Region of Japan had approximately thirty minutes (60 minutes in the coastal plains) from the first tremor to the arrival of the first surge, the tsunami waves would not arrive to Hawaii until eight hours after the earthquake whereas California and Oregon waited eleven hours. The Pacific Tsunami Warning Center issued a tsunami warning at 07:30 UTC, or roughly two hours after the earthquake, giving Hawaii and the western coast of the US Mainland, at least six hours to prepare.

In comparison to Japan, cities in the United States, including some of those in earthquake risk areas such as Hawaii and US West Coast,

do not experience the same frequency of powerful earthquake and tsunami occurrences. For example, prior to the 2011 Great East Japan Tsunami, the most devastating tsunamis in Hawaii are limited to the 1946 Tsunami that killed 173 people, primarily in Hilo on Hawaii Island, and another that occurred in 1813−4 that is not widely known among locals. The lack of powerful tsunamis, distance from major earthquake occurring regions, and isolation that allows for ample preparation time, contributes to a reduced sense of urgency in comparison to their Japanese counterparts. Indeed, in both Hawaii and in the US West Coast, spectators arrived to areas under warning in order to witness the event.

The lack of this sense of urgency in Oahu, which did not suffer as much as Hilo in the 1946 tsunami, and in the US West Coast, may have perhaps contributed to the lack of reaction among boat owners to evacuate to the deep sea. As a response, boat owners were more responsive in subsequent tsunami warnings in Hawaii. However concerns over spectators continue to persist as the recent 2014 Chilean Earthquake led to another tsunami warning, but again, swimmers and surfers were spotted, ignoring calls to evacuate to safer areas.

Physical factors such as topography and evacuation zones also influenced the damages experienced by boats in both states. The topography of the inlets also played a significant factor in damages as the narrow inlet of Pearl Harbor significantly reduces the risk of tsunami surges, while in contrast, Brookings Harbor's proximity to river drainage, created additional tsunami risks, leading to a build−up of the surging water. In addition, the lack of areas to secure ships upstream in Oregon, led to the inability of some ships to escape as there was nowhere to dock.

3. Research Methods

The methodology used by this study includes (1) personal interviews with fishermen in the prefecture as lessons from the 2011 tsunami and (2) secondary sources, primarily from Japanese news agencies as newly developed activities after the 2011 tsunami in other regions such as offshore evacuation drills and offshore tsunami evacuation maps. A background of each fishing port is provided to confirm field surveys conducted during the interview. We mainly focused on the fishermen that experienced the 2011 tsunami and continues to rely on fishing as done for generations. Our interviews with the fishermen spanned approximately eight months, covering the Sanriku Ria coast, the Sendai Plains and Matsushima Bay coastal regions in Miyagi prefecture. Details of the surveys including location, date, and number of interviewed fishermen are shown in Table 1. Open−ended semi−structured interviews started by asking if they evacuated offshore or not. If not, we then asked (1) the reason why they did not evacuated offshore, (2) if the disaster dissemination systems that led them to high−ground evacuation worked properly and (3) which evacuations helter they chose. On the other hand, if they evacuated offshore, we then asked (1) the situation during the earthquake such as their location and mooring method, (2) the experiences related to time during the earthquake to their evacuation offshore, their time spent away from their original location, problems encountered during evacuating offshore, and reasons that made led them to return back to the port.

4. Interview results

4.1 Response of fishermen in Sanriku Ria coast

Kesennuma city: There are some fishermen in Tadakoshi village who succeeded in evacuating offshore and very likely to continue to do so in

Table 1 Details of fishermen interview survey in Miyagi prefecture

Location	Date	No. Interviewed
Kesennuma city, Karakuwa town, Tadakoshi area	20 June 2013	4
Kesennuma city, Hajikami area	5 April 2013	3
Motoyoshi district, Minamisanriku town, Utatsu, Niranohama area	6 July 2013	8
Motoyoshi district, Minamisanriku town, Shizugawa, Sodehama area	14 September 2013	2
Ishinomaki city, Yagawahama area	29 June 2013	4
Miyagi district, Matsushima town	3 November 2013	1
Shiogama city and	18 May 2013	1
Katsura Island	18 May 2013	1
Sendai city	1 June 2013	1

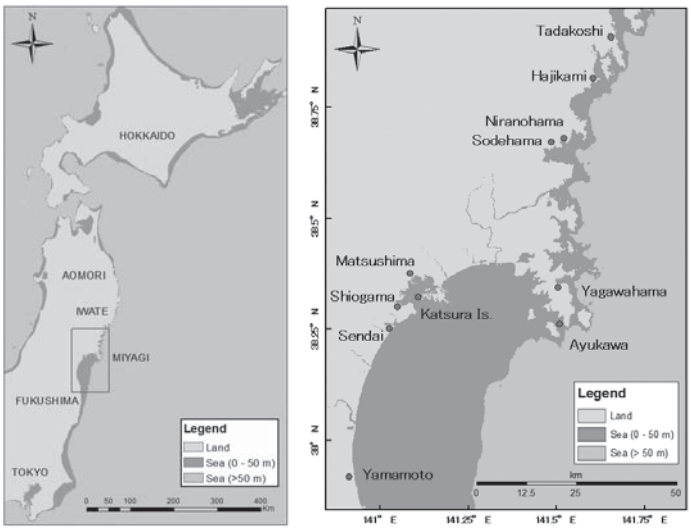

Fig. 2 Map of the east Japan and Miyagi prefecture displaying depth of the sea

the event of another tsunami. During the 2011 tsunami, the fishermen brought food provisions with them to sea but experienced communication difficulties as they were unable to retrieve information on the situations the condition of their ports and towns. They did not evacuate offshore for the 2012 tsunami event as the fishermen resided in a village that differed from the location of where their ports were moored. The fishermen stated that they are not worried and will continue their current practice of offshore evacuations in the event of future tsunamis. The fishermen attributed their confidence to the robust knowledge and experiences inherited from their ancestors after similar powerful tsunamis affected the region in 1896, 1993 and 1960.

In Hajikami, some of the fishermen interviewed also served as volunteer fire fighters. Despite concerns over the safety of their boats, the fishermen prioritized their duties first. One interviewee went to manually close the seawalls and another operated a patrol car to evacuate

residents. As they were unable to find time to evacuate their boats, their boats were destroyed. However the interviewees were glad they survived the tsunami.

Minami−Sanriku town: Tsunami awareness may be different even in the same affected area. A fisherman in Utazu, Minamisanriku town travelled somewhere inland outside of the village at the time of the earthquake and did not directly experience the 2011 tsunami, drove his boat offshore during the tsunami warning event on the 7th December 2012. The tsunami was small but the village expressed disappointment towards his action. Thus, even though he resided in a village that was devastated by the tsunami, the lack of directly experiencing the tsunami led him to his decision to evacuate while most of villagers still remember the awful experience of the 2011 event.

In Niranohama, most fishermen immediately evacuated to high ground after strengthening the mooring ropes to their boats. They said this might because of tsunami evacuation drill that was organized at the end of 2010 or few months before the tsunami. Therefore, local residences still had very high awareness of the tsunami evacuation. In Sodehama, we met a fishing family that built their house on high ground tens of years ago. They said this is because their ancestors experienced the great tsunamis in this region, i.e. 1896 and 1933 and they decided to move to the present location since then.

Ishinomaki city: In Yagawahama, we interviewed both fishermen who immediately evacuated to high ground and those who succeeded in evacuating offshore. The first group stated that while they worried about their boats, their lives are more important. They finally went to their boats; strengthened the ropes before evacuating to high ground. The second group said they were out at sea during the time of earthquake. They decided move to a deeper sea location and survivled while witnessing the destruction of other boats failed to evacuate. The fishermen stated that although they survived this tsunami, they may not re−consider the same deep sea evacuation in a future tsunami event.

4.2 Response of fishermen in Sendai plain coast region

Unlike the Sanriku region, fishermen in this region need more time (at least one hour) to reach the deep sea. A fisherman we met in Sendai immediately evacuated to high ground as she believed that she might have no time evacuate to the deep sea. However, she stated that one of her friend survived by evacuating offshore near Sendai port.

All of the interviewed fishermen did not evacuate offshore but evacuated to high ground instead. Especially in areas inside a bay such as Matsushima and Shiogama, because the city located in the deepest side of the Shiogama bay far from the bay's entrance, about 30−60 min is required for fishing boats to evacuate to a deep sea of at least 50 meters. Although fishing boats are very important to the respondents, most of their boats were relatively small and comparatively cheaper, leading towards less incentive to prioritize the safety of their boats over their lives. These conditions led our respondents in deciding to evacuate to high ground. A fisherman told our group that while a warning announcement was disseminated via wireless speakers and vehicle navigation radios, he felt that it was not so successful as it failed to convince people to start evacuations. In general Shigama residents were not as knowledgeable on tsunami evacuations and held less tsunami experiences than their counterparts in the Sanriku area. The respondent felt that education was the most important and that evacuating to higher ground should be prioritized over a large sea wall as a sea wall cannot fully guarantee survival but proper evacuation and knowledge can..

In Katsura, a small remote island off the coast of Shiogama city, response and support might

not arrive in time which is why they had set up their own emergency team. The fishermen that we interviewed also served as fire fighters for the island. The team comprised of 20 members from a total population of 200 residents. Just about 5−10 min after the earthquake, they met together and agreed that this event might be greater than the 1960 Chilean tsunami. The respondents launched patrol cars for disseminating warning using siren as the wireless speakers were not working and at the same time cleared evacuation routes from the collapsing debris. Also they called fishermen who were in the sea to come back and evacuate to a school or shrine located at higher elevations. All residents of the island survived the tsunami.

4.3 Problems and difficulties after getting out offshore

Based on the surveys, we found common problems fishermen experienced after evacuating offshore which are as follows:

(1) Coldness: Small fishing boat generally lack roofs that could protect fishermen from strong wind, rain or snow. For example, snow continued to fall into the evening during the 2011 tsunami.

(2) Loss of connectivity: We found that during the 2011 event mobile phone networks were down. Some of portable radios inside the fishing boat worked but only provided information on big cities and were devoid of local circumstances. Thus, fishermen had no idea what happened to their village and when they could return.

(3) Starvation: Only a few of the respondents carried canned food and water with them during the evacuation. Most of the respondents starved until they could return to land.

(4) Debris obstruction: The tsunami destroyed everything in the port whose remains would become debris. This floating debris hampered navigation between offshore and the port. In the 2011 event, most of fishermen experienced difficulties returning home due to debris obstruction, leading to 1−3 days of travel.

5. Conclusions and recommendations

5.1 Inland or offshore evacuation

For those fishermen who decided to evacuate offshore, most of them could not go as far as they expected and felt they were lucky to survive and save their boats, despite experiencing various troubles encountered during their overnight stay in the sea. However, what made different is how fast they perform offshore evacuation and how the level of knowledge of tsunami behavior due to the bathymetry of their port as discussed in the following section. Fishermen in Sanriku area felt very strong shaking as they were near epicenter of the earthquake, leading them to take prompt action. Many of them also had experienced the tsunami from 1960 Chilean Earthquake. Fishermen in other areas may need more than 5−10 min to check warning information before making their decision. This gap can make the difference between life and death. Many of the fishermen that decided not to evacuate offshore but evacuated to high ground felt remorse over the loss of their boats but were satisfied with their decision to prioritize their life first. Most of these fishing boats are insured, thus if insurance companies can ensure that fishermen will get paid and be able to buy new boats soon after a tsunami, fishermen may not risk evacuating offshore and without a doubt, evacuate to higher ground. Based on the experiences of fishermen who survived the 2011 Japanese Tsunami, one can conclude that although the historical tsunami background is different between Sanriku area and others, there is a strong determination to evacuate offshore in comparison to areas beyond Sanriku with less tsunami experiences.

5.2 Understanding the topography for better decision making

Knowing about the tsunami characteristics of

a fishing port is also important. For example, a tsunami arrived at a peninsula in the Sanriku areas as fast as 30 min or less because the areas are located in the deep sea and close to earthquake epicenter. However due to the influence of the deep sea, boats can reach a safety zone of 50 meters or deeper within a short period of time. On the other hand, for a plains area such as the Sendai plains, boats would have to traverse 30 km or more to reach the 50 meter sea depth. In other words, with the maximum speed of fishing boat at 20 knots (36 km/h), the boats will need almost one hour or more in evacuating offshore to survive. In other words, although the tsunami may arrive later in the Sendai plains (about one hour after the earthquake) the boats should immediately evacuate. This example shows that the required time for evacuating offshore can differ. Relocation to high ground will definitely affect the evacuation culture of some fishermen who still prefer to save their boats from tsunamis because they should perform the evacuation faster. This action will be more difficult and risky for future tsunamis. Hence, education for fishermen based on localized situations is vital in ensuring survival.

5.3 Research Implications

Although there is still no clear answer in regards to the best offshore evacuation solution, some important key future research has been identified.

(1) Offshore tsunami evacuation map: By compiling simulated tsunami height and velocity from probabilistic tsunami hazard assessment and damage estimation of fishing boats using fragility curves, offshore tsunami evacuation maps can be created providing information on successful probability of the offshore evacuation at each point from the shoreline. The map can be developed for application for smart phones or tablet computers making use of GPS technology as real time decision support.

(2) The influence of high−ground relocation: Most of the fishing villages will be relocated to higher grounds after the 2011 tsunami. This strategy was implemented after the two great tsunamis in 1896 and 1933. In the case of 1933 tsunami, most villages decided to relocate to a distance no more than 400 meters from their original location and an altitude lower than 15 m (Suppasri et al., 2014). However, it is clear that after the 2011, many villages have planned to move to areas where the altitude difference is higher than 30 m and a distance further than 400 m from their original location; such relocation to ensure that all villages will be safe from future tsunamis because their destination point will be 40−50 m higher than the sea level. Relocation to high ground will definitely affect the evacuation culture of some fishermen who still prefer to save their boats from tsunamis because they should conduct their evacuations more promptly. This action will be more difficult and risky for future tsunamis. Nevertheless, similar to the past experiences, many of villagers returned to the coastal area. Therefore, long−term study of the influence of high−ground relocation is needed.

(3) Education activities: As mentioned in the previous section, activities such as increasing disaster awareness, improving understanding of topography of the coastal area, and offshore evacuation drills are necessary to optimize the response against the future events.

Acknowledgment

We greatly appreciate the assistance of Mr. Susumu Tsuboi together with other six fishermen in Tadakoshi, Mr. Yasuhiro Sato and together with other eight fishermen in Niranohama and

Mr. Yoshietsu Atsumi together with other three fishermen in Yagawa for their time and kind cooperation of the interview. Valuable comments from Dr. Kanako Iuchi are highly appreciated. We express our deep appreciation to the special research funding from the Government of Japan and Tokio Marine & Nichido Fire Insurance Co., Ltd. and through the International Research Institute of Disaster Science (IRIDeS) at Tohoku University.

References

47 News (2014)
http://www.47news.jp/localnews/aomori/2014/04/post_20140404100241.html (in Japanese) (Accessed: 3 April 2014)

ABA News (2014)
http://www.aba-net.com/news/news011.html (in Japanese) (Accessed: 3 April 2014)

Cabinet office, Government of Japan (2012)
http://www.bousai.go.jp/jishin/nankai/model/ (in Japanese) (Accessed: 29 August 2012)

CBS (2012)
http://www.cbsnews.com/news/tsunami-warning-in-hawaii-downgraded-to-advisory/

Fisheries Agency (2006) Guideline for disaster resilient fishing community development, 165 pp.

Hodaka, K. (2012)
http://www.hodaka-kenich.com/3.11-coverage/2012/05/12125933.php (in Japanese) (Accessed: 12 May 2012)

JMA (2012)
http://www.jma.go.jp/jma/press/1212/07b/201212072000.html

JMA (2013)
http://www.jma.go.jp/jma/press/1310/26a/201310260410.html

Kahoku Shinpo Newspaper (2012)
http://www.kahoku.co.jp/news/2012/12/20121208t73037.htm (in Japanese) (Accessed: 8 December 2012)

JMA (2014)
http://www.jma.go.jp/jma/press/1404/03c/201404031810.html (in Japanese) (Accessed: 3 April 2014)

Kahoku Shinpo Newspaper (2014)
http://www.kahoku.co.jp/tohokunews/201404/20140405_73019.html (in Japanese) (Accessed: 3 April 2014)

Kahoku Shinpo Newspaper (2013a)
http://www.kahoku.co.jp/news/2013/11/20131124t73014.htm (in Japanese) (Accessed: 24 November 2013)

Kahoku Shinpo Newspaper (2013b)
http://www.kahoku.co.jp/news/2013/10/20131027t21006.htm (in Japanese) (Accessed: 27 October 2013)

Katada, T., Murasawa, N. and Kanai, M. (2012) Inspection of the rule development effect about Fishing-Boat Evacuation against Tsunami － Example of Correspondence of fishermen belonging to Ochiishi fishery cooperative in Nemuro City in 2011 Tohoku earthquake and tsunami －, Disaster information, 10, 103-112 (In Japanese with English abstract)

Mainichi Newspaper (2012)
http://mainichi.jp/select/news/20121208k0000e040155000c.html (in Japanese) (Accessed: 14 December 2012)

Manning, Jeff (2011)
http://www.oregonlive.com/pacific-northwest-news/index.ssf/2011/03/post_18.html

NHK (2014)
http://www3.nhk.or.jp/news/web_tokushu/2014_0311.html (in Japanese) (Accessed: 11 March 2014)

Ohashi, T., Koshimura, S. and Imamura, F. (2007) Design of a tsunami hazard map on the sea to reduce fishing boat user's damage, In proceeding of the coastal engineering conference (JSCE), 54, 1351-1355. (In Japanese with English abstract)

Oregon Sea Grant (2007)
http://seagrant.oregonstate.edu/sgpubs/

onlinepubs/g07004.pdf

Tokachi Mainichi Newspaper (2012) http://www.tokachi.co.jp/news/201205/20120518−0012597.php (in Japanese) (Accessed: 18 May 2012)

Tokachi Mainichi Newspaper (2013) http://www.tokachimail.com/urahoro/backnumber2013.php?d=20130523 (in Japanese) (Accessed: 16 May 2013)

Torii, H., Sawamoto, J., Segawa, N., Sugino, E. and Nomura, Y. (2010) Tsunami early warning and evacuation support system for fishery workers by mobile phones, In proceedings of the 2010 IEEE 24th International Conference on Advanced Information Networking and Applications Workshops, Perth, WA, 20−23 April 2010, page 704−709.

Suppasri, A., Muhari, A., Futami, T., Imamura, F. and Shuto, N. (2013) Loss functions of small marine vessels based on surveyed data and numerical simulation of the 2011 Great East Japan tsunami, Journal of Waterway, Port, Coastal and Ocean Engineering−ASCE (published online)

Suppasri, A., Muhari, A., Futami, T., Imamura, F., and Shuto, N. (2013) Loss functions of small marine vessels based on surveyed data and numerical simulation of the 2011 Great East Japan tsunami, Journal of waterway, Port, Coastal and Ocean Engineering, 140 (5), 04014018.

Suppasri, A., Yasuda, M., Abe, Y., Fukutani, Y., Imamura, F. and Shuto, N. (2014) Relocation after tsunamis in the Sanriku area and the condition of fishing villages two years after the 2011 Great East Japan tsunami, Post tsunami hazard reconstruction and restoration, Springer Monograph (in print)

United States Coast Guard (2013) http://www.uscgnews.com/go/doc/4007/1930237/Tsunami−evacuation−rule−established−for−Hawaiian−Islands−commercial−harbors#sthash.zFsT0U2d.dpuf