Planning for Earthquakes and Tsunamis: Lessons from Japan for British Columbia

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ABSTRACT: This paper re-examines the 2011 Great East Japan Earthquake at the time of its tenth anniversary and reflects on what lessons might be learned for British Columbia (BC), Canada - in terms of preparation, emergency management and long-term reconstruction. The Pacific coast of BC (and Vancouver) is vulnerable to a catastrophic magnitude 9 earthquake and tsunami resulting from the rupture of the Cascadia Subduction Zone fault, which lies just 50 kms or so west from Vancouver Island, Washington and Oregon. The likely damage to both humans and buildings would be extensive, both from the earth shaking and the tsunami event. Compared to Japan, BC lacks a history of major seismic events close to population centres and so has little direct experience of a large earthquake and tsunami along the coastline. International comparisons of disasters provide one way of addressing the absence of first-hand knowledge of this type of calamity. In this regard, Japan has long been considered the `gold standard' for earthquake preparation and it has used the lessons from responding to the Great East Japan Earthquake to revise its own emergency response, as well as to change community and individual behavior by instilling a strong culture of disaster prevention. Based on extensive interviews in the Tōhoku region of Japan as well as in BC, my analysis scrutinizes Japanese experience in 2011 and subsequent years in terms of the four pillars of disaster management: (1) the mitigation of risk, (2) disaster preparedness, (2) the emergency response; and (4) recovery. The results indicate practical lessons for emergency management in BC as well as the need to take personal responsibility for preparing for earthquakes and tsunamis.

KEYWORDS: Disaster management, earthquakes, tsunamis, Tōhoku region, British Columbia

1. Introduction

"According to a Japanese folktale, a venerable grandfather who owned a rice field at the top of a hill felt the sharp jolt of an Earth tremor one day just before the harvest. From his hilltop vantage point, he saw the sea pull back from the shore. Curious villagers rushed out to explore the exposed tidal flats and to collect shellfish. From experience, the old man knew of the grave danger to his neighbors. With his grandson by his side, he dashed about his fields, setting fire to his crop. The villagers saw the smoke, and hurried up the hill to aid their neighbor. As they beat out the flames, they saw the old man scurrying ahead, setting new fires near the hill's crest. Hoping to prevent him from destroying all of his crops, they rushed up the hill to stop him. Moments later, the villagers saw a tremendous wall of water surging onshore, flooding the flat fields where they had just been standing – and they understood that the old man had sacrificed his harvest to save their lives" (adapted from the original story `A Living God' by Lafcadio Hearn, which was written three months after the 1896 Sanriku tsunami and included in his book "Gleanings in Buddha-Fields: Studies of Hand and Soul in the Far East', published in September 1897 by Houghton Mifflin Company of Boston & New York).

This research paper addresses important lessons in planning for future earthquakes and tsunamis in British Columbia (BC) that can be learned from the experience of disaster management at the time of the Great East Japan Earthquake experience in March 2011.[1] The 2011 earthquake reached a moment magnitude (Mw) of 9.0, the highest recorded in Japanese history. In the aftermath of the quake a powerful tsunami washed ashore along the Pacific coastline of the Tōhoku region, carrying away cars and boats, uprooting wooden houses, crippling infrastructure, causing fires, and killing or wounding thousands as it swept away everything in its path for several kilometers inland. The official casualty toll included more than 15,800 immediate deaths, 2,900 subsequent disaster-related deaths, 6,150 injured, and 2,640 people missing. About 700,000 people lost their homes and some 120,000 buildings were destroyed. The overall cost of the disaster was estimated between US$200 billion and US$300 (Ranghieri and Ishiwatari, 2014). Adding to the misery was the radiation spewing from the Fukushima Dai-ichi nuclear power plant after its cooling systems were disabled by the tsunami. Until the commencement of the Covid-9 pandemic in early 2020, the 2011 earthquake, tsunami and nuclear power plant disaster was the biggest crisis faced by Japan since World War II ended in 1945. A similar earthquake and tsunami along the Cascadia coastline of the American northwest would certainly be the biggest calamity faced by British Columbia and Canada. Shock waves from a mega-thrust earthquake would shake the major cities of Victoria and Vancouver, and the tsunami waves from such an earthquake would attack the beaches and coastal settlements of Vancouver Island destroying almost everything in its path.[2]

I argue that looking at how the Japan disaster management system prepared and responded to this cataclysm – pointing out both their successful actions as well as their major challenges and shortcomings – can help understand the nature of the forthcoming catastrophe in British Columbia (BC), Canada. It can also yield insights and advice that could be used as part of BC emergency planning for earthquakes and tsunami, as well as rescue, relief and recovery operations. Of course, no country anywhere could possibly be prepared adequately for the complex and cascading disasters that occurred in Tōhoku in 2011, but understanding how Japan struggled to manage this event carries widespread implications here in British Columbia. In large part this is because nowhere else is as experienced or prepared to deal with such disaster. Indeed, the Tōhoku region of Japan has had a recurring experience of both earthquake and tsunami events recorded in the past century or so. Throughout Japanese history stone monuments and shrines have been erected after each disaster as reminders to future generations (Suppasri et al., 2013). In sum, the story of its emergency response and community resiliency has many lessons for us in British Columbia.

Figure 1 displays the Pacific coastlines of both Tōhoku, Japan, and southern British Columbia, albeit at different scales. The map of Tōhoku shows the inundation of the 2011 tsunami and indicates that the affected area has two very distinct characteristics in terms of terrain and coastal structures. These have to be carefully considered in order to understand the characteristics of the tsunami disaster, as well as local differences in the perception of risk, disaster planning and post-disaster recovery. For instance, the northern coastline of Miyagi and Iwate prefectures has a ragged Ria coastline – called the Sanriku coast - where the shore soon rises to inland hills and mountains.[3] Here, coastal towns are far from the larger regional cities of Sendai (Miyagi prefecture) and Morioka (further north in Iwate prefecture). The combination of powerful Pacific Ocean quakes and the `sawtooth' coastline shape produced tsunami waves of massive height and reach, up to 40.5 meters in Miyako, Iwate prefecture. Before 2011, the worst tsunami event in modern Japanese history – the 1896 Meiji Sanriku Mw7.2 earthquake – occurred along this stretch of the Sanriku coastline leaving around 27,000 dead or missing, and infamously dubbing this region as the country's `tsunami coast' (Suppasri et al., 2012, 2013). As a result of this, and other previous events, much of this coast was lined by ugly protective concrete sea walls, built over the past 75 years or so and around 6-7 meters in height with metal gates for access to the sea (Edgington, 2017).

By contrast, the southern section of the Tōhoku coastline shown in Figure 1 focuses on the Sendai coastal Plain area, made up of sandy beaches giving way to very flat plains used mostly for rice growing. Here, the 2011 tsunami swept in for up to 10 kms inland, unimpeded across paddy fields and rural villages. Compared to the Sanriku coast, this southern area has lacked a history of multiple tsunami events. Consequently, fewer seawalls were installed other than at a number of small ports, and sea defences consisted mainly of coastal dikes constructed with the purpose of protecting against storm waves.

(FIGURE ONE ABOUT HERE)

Figure 1 also shows southwest British Columbia and identifies local cities and settlements, together with the Cascadia Subduction Zone (also known as the Cascadia Fault) lying between 50 km to 150 kms from the coast of Vancouver Island. The Cascadia Subduction Zone (CSZ) is a geological fault line approximately 1,100 km long that parallels the coasts of western North America from the northern tip of Vancouver Island to northern California (Thompson, 2011).

While earthquakes are commonplace in southwest BC, most are minor in terms of their energy release, or are situated so remotely off-shore that their effects on populated areas are typically unnoticed (Clague et al., 2006). In the Cascadia Fault region, the outer portions of the Juan de Fuca Plate are constantly subducting underneath the North American Plate, on which Vancouver Island rests. However, it appears that it is locked in place along its length for several hundred years at a time. The Cascadia Subduction Zone it not the only fault line in southwest BC that has the potential to cause damaging earthquake. Nevertheless, it does represent a large proportion of the risk, especially in terms of the scale of a likely future quake. It is from this area that the so-called `Really Big One' will occur, a mega-thrust earthquake of up to Mw 9 magnitude when the pressure builds up to break the locked plates (Clague, et al., 2006; Schulz, 2015).

In actual fact, the Cascadia Fault is virtually identical to the offshore fault that occurred in the oceanic Japan Trench off northeast Japan and which devastated the Pacific coast of the Tōhoku region in 2011. It is almost the same length, the same width and with the same tectonic forces at work. Both Tōhoku, Japan, and the Cascadia region of the Pacific Northwest (including the Pacific seaboard of Washington, Oregon and north California) sit above zones that dip at a low angle beneath the land. One might consider the Cascadia Fault and the Japan Trench as mirror images across the Pacific Rim of Fire, the horse-shoe shaped zone that circles the Pacific Ocean associated with a nearly continuous series of ocean trenches, volcanic arcs and seismic tectonic plate movements (Rinard Hinga, 2015). Geological research indicates that megathrust earthquakes occur along the Cascadia Fault on an average of every 500 years. However, some have been as close together as 200 years, and some as far apart as 700 years. As the last megathrust earthquake in this area took place in 1700, it is possible that another could occur along the extent of the Fault at any time (Atwater et al., 2005). Geologists such as Goldfinger argue that there is a 10 per cent chance of a full rupture in the next 30 years or so, and a 30 per cent possibility in the same time period of a smaller Mw8.0. earthquake somewhere along the fault line (Oregon State University, 2010). In British Columbia, the greatest risk from a future Cascadia subduction earthquake – both from the temblor itself as well as a subsequent tsunami – is to small communities along the Pacific coast of Vancouver Island involving a combined population of around 20,000 (for instance the towns of Tofino, Uclulet and Port Alberni). Moreover, a mega-thrust earthquake generated from the Cascadia Fault would almost certainly impact the metropolitan areas of Victoria and Vancouver, affecting a much larger population of approximately 2.8 million (Clague et al., 2006).

2. International Comparisons of Disaster Management Outcomes and Research Methodology

Disaster management scholars have long argued that international comparisons enable a better understanding of how `best practice’ emerges among disaster management and emergency response policies and programs (McEntire and Mathis, 2007). Nonetheless, while seismologists, geologists and building engineers may share a common lexicon in their specialist fields across diverse locations, this is not necessarily the case for disaster managers and emergency planners. In part, this is due to widely varying legislation frameworks, diverse protocols and institutional history, as well as contrasting access to necessary resources in different countries and regions. Consequently, studies dealing with the international comparison of disaster planning are remain relatively uncommon (but see Britton, 2006; McEntire, 2007, 2012; Miller and Rivera, 2011). Even so it is recognized that evidence from disasters occurring elsewhere can be the catalyst for issue mobilization and policy-making activity across jurisdictions. This has been found in various policy domains, such as flood management and earthquake protection (e.g. Olson, et al., 1998). There are a number of reasons.

First, the international comparison of major disasters has the ability to galvanize attention on local disaster management procedures, and whether they are adequate, through inviting the question of `What if it were to happen here?’ It is well known that thinking about disaster policy among politicians, bureaucrats and the general public suffers from what is called the `issue-attention cycle’ (Downs, 1972), whereby dramatic events, such as natural disasters, suddenly rise in public awareness and alarm, often due to sensational media reporting. However, after some time there is an inevitable decline of intense interest as other issues exert more novel and thus more powerful claims upon public attention. In a similar vein, Sylves (2015) argues that among the many challenges in crafting politics and programs in response to potential disasters, the infrequency of major disasters makes it difficult for elected leaders to justify pre-disaster expenditures in view of seemingly more pressing, ongoing needs and issues. Undeniably, the significance of a likely disaster `close to home’ is more sharply brought into focus through news of a catastrophic event elsewhere. So much so that political scientists, such as Birkland (1998), contend that truly destructive disasters fall within the signifier of `focusing events’. These are sudden, striking incidents that can act as `triggering mechanisms’ which concentrate public and political attention on a particular issue. For this reason, studies of international disasters can often raise public awareness of the need for preparation in similarly vulnerable communities.

Second, a cross-national perspective may improve emergency management research and practice in more concrete terms. New concepts and ways of looking at disasters may be generated by examining experience in different contexts, and there are likely useful ideas that can be adapted for local use. Comparison also improves the practice of emergency management as it permits learning from the mistakes and successes of others. Headway in disaster planning and emergency management is likely to be achieved when governments can emulate the positive achievement of their counterparts overseas. Indeed, there are many positive examples that can be gleaned from this type of international disaster study. For example, the Dutch can provide a great deal of advice and expertise on managing flood hazards (Zevenbergen et al., 2013). Australia offers an important model for engaging volunteers in all types off emergency management activities (McLennan et al., 2016). Yet another instance is the history of dealing with severe and wide-ranging forest fires in the US, which led to the development of the Incident Command System (ICS), a standardized approach to the command, control, and coordination of emergency response providing a common hierarchy within which responders from multiple agencies can be effective. This model has now been reproduced in disaster management systems across North America (Chang, 2017).

Be that as it may, a focusing event is an opportunity only and does not automatically result in either policy changes or even a heightened awareness of a particular issue. Moreover, international comparisons by themselves may not necessarily lead to transferable `best practice’. This is because there are also problems of directly translating and interpreting policy across borders, often making it difficult to draw important lessons from either the positive and negative experiences of disaster management in other domains. Indeed, a popular adage in the disaster management literature is that `at the end of the day all disasters are local’, signaling the importance of fully understanding local contexts in understanding both disaster outcomes as well as policy responses (Pena et al., 2014). Indeed, all crises are different, playing out over different periods of time, in different political, cultural and economic contexts, and with different stakeholders and competing interest groups. This particular corrective to the enthusiasm of scrutinizing catastrophes around the world suggests that a careful nuanced view of disasters is necessary in order to make sense of how useful international comparisons might be. The potential for disaster is growing everywhere, but the types of events experienced are based undoubtedly on each country’s geography and culture, their use of technology and institutions, and many other factors. Thus, Stallings (2006) reminds us that disasters affect all nations but in very different ways, so overseas experience must be used with caution.

Having stated these qualifications, Japanese social and economic institutions have long been used as a mirror for western nations (Vogel, 1979) and Japanese emergency practice and disaster preparedness provide a particularly illuminating model for other countries to follow. Indeed, Japanese disaster planning is often perceived as the `international gold standard’ and Japan is arguably the global leader in earthquake resilience (Rauhala, 2011; Lufkin, 2015). In truth, building retrofits in Japan are now standard, state-of-the-art shock-absorbing foundations for high-rise towers (using seismic base isolation technology) are routine, and these initiatives are complemented by public education campaigns and sophisticated warning systems. One explanation for these extensive Japanese programs is the large number of disasters that occur there. Japan has been repeatedly struck not just by earthquakes and tsunami, but also by typhoons, floods, landslides, heavy snow and volcanic eruptions For example, Japan makes up only 0.25 per cent of the world’s land but experiences a disproportionate share of the world’s earthquakes of magnitude Mw6.0 or greater at 20.5 per cent, and also the world’s volcanoes at 7.0 per cent (Nishikawa, 2011).

Since ancient times, Japanese have kept records of disaster that befell them and have amassed knowledge and technologies to cope with the severity of their geographical conditions. Japan has had a national disaster management system in place since the Disaster Relief Act of 1947 and has long used evidence and analysis from its own local disasters to continuously improve this system. Deep-seated cultural memories of large disasters based on personal as well as historic experiences have led to many innovations in disaster risk reduction. These include: (a) strict building codes and enforcement as well as retrofitting programs for vulnerable structures; (b) extensive public education programs, comprising drills for students from kindergarten to university, preparing the general population and local communities for all kinds of disasters, special research centres, disaster memorial parks, and community radio; (c) a culture of preparedness for disasters, including sophisticated early warning systems involving hundreds of sensors around the Japanese archipelago (both on land and on the seabed), earthquake, flood, storm and landslide observation systems, urban and regional vulnerability analysis and hazard mapping, together with real-time warning systems that sound alarms to warn people of imminent approaching dangers; and (d) construction of special defences, such as flood control basins, sea walls, reservoirs, erosion control dams, retaining walls against landslides, amounting in total to about 8 per cent of gross domestic product (GDP) (Ranghieri and Ishiwatari, 2004; Shaw, 2014; Singer et al., 2016). However, even though it may be difficult to imagine a country better prepared for the Great East Japan Earthquake and tsunami, Tossani (2012) argues that the large-scale, and for the most part unexpected, death and destruction in 2011 (including the Fukushima Dai-ichi nuclear power plant meltdown) may have eroded the public's confidence in its government's ability to properly anticipate and react to this type of calamity.

In order to examine the events of 11 March, 2011, and to facilitate an insightful comparison of disaster management practice between Japan and BC, I use the four phases of comprehensive disaster management that form the basis for an all-hazards approach to emergency management (Gallant, 2008; Coppola, 2011). The four phases are mitigation, preparation, response, and recovery (see Figure 2).

(FIGURE TWO ABOUT HERE)

Mitigation involves long-term programs aimed at reducing or eliminating consequences of a hazard (e.g. building codes, disaster insurance, land-use management) or by the assessment of threats to a community, including the likelihoods of a disaster taking place by risk mapping. Preparedness involves equipping people who may be impacted by a disaster, or who may be able to help those impacted, with the tools to increase their chance of survival and to minimize their financial and other losses. It includes the planning, resource allocation and training of individuals. This phase also involves disaster response exercises that help people practice what to do if a disaster occurs, as well as developing operational capabilities for responding to an emergency (e.g. emergency operation centres, emergency communications networks, emergency public information, mutual aid agreements and resource management plans, as well as practice drills for emergency personnel). Response activities are taken directly after an emergency to save lives, minimize property damage, or improve recovery (e.g. emergency plan activation, emergency instructions to the public, emergency medical assistance, manning operations centres, reception and care, shelter and evacuation, and search and rescue). Relief, a term commonly used in international disaster management, is one component of response. Response also includes public donations, incident management, coordination, search and rescue, damage assessments, and the handling of fatalities. Recovery involves returning victims' lives back to a normal state following the impact of disaster consequences. The recovery phase generally begins after the immediate response has ended, and can persist for months or years thereafter. Recovery involves the cleaning up of debris, the reconstruction of public services, the rebuilding of public infrastructure, housing and local businesses, and all that is necessary to help restore civic life, including disaster assistance and crisis counseling. Together, all these activities and more comprise the four phases of Comprehensive Emergency Management and they formulate the basis for an all-hazards approach to emergency management (Gallant, 2008).

The research for the empirical portions of this paper, which now follow, was informed by my semi-structured interviews with first-responders (e.g. military, police, local and national government officials) as well as disaster managers in both Japan and British Columbia during the past 10 years or so. The focus of the interviews was to capture Japanese policies and programs at the time of the 2011 disaster (including the assessment of mega-earthquake and associated tsunami risks, as well as preparation activities and post-disaster programs). In British Columbia the `really big one' has not yet happened, but preparations are underway and my research focus was to ascertain the current state of planning.

3. Mitigation: Risk Analysis, Prediction and Building Standards.

3.1. The Japanese Experience: The Failure of Adequate Prediction

Mitigation programs comprise efforts to prevent large-scale disasters, and include programs to minimize loss or harm as well as assessing threats to a community. In terms of understanding the hazards facing the Tōhoku coastal region, the 2011 Great East Japan Earthquake and tsunami completely surprised the country's forecasters who were caught off-guard by its savage power. Indeed, many of the assumptions behind the preparations for a Tōhoku region earthquake and tsunami – measures that I address in the following section – can be traced to an under-estimation of the likely danger together with the resulting consequences of the quake, especially the size of the tsunami that came afterwards.

Earthquake preparedness in Tōhoku prior to March 2011 focussed largely on addressing the recurrent Miyagi off-shore temblor (*Miyagi-ken-oki jishin*) and associated tsunami. This periodic event had consistently been used as the basis for local hazard mapping as well as in the determination of design specifications for sea walls and other structural defences against tsunami along the coast. The Miyagi off-shore quake regularly produced a temblor around magnitude Mw7.5 (between Mw7.2 and Mw8.2), and this had occurred seven times since 1793 (1793, 1835, 1861, 1897, 1936, and 1978, as well as during 2005) in an source area off the Oshika Peninsular, part of Ishinomaki city, Miyagi prefecture (Wu et al., 2008). The epicentre location was roughly in the same area as the March 11 mega-earthquake. In sum, all of these powerful off-shore earthquakes prior to 2011 produced destructive three meter tsunami waves that killed more people than the quakes themselves, largely along the northern Sanriku coastline (Satake, 2015). However, despite disaster projections and preparations aimed at mitigating the destructive impacts of this recurring pattern of earthquakes the Sanriku coast had in the past experienced even stronger quakes and even more destructive tsunamis, both in 868 (the Mw8.6 Jogan earthquake) and in 1611 (the Mw8.3 1611

Sanriku earthquake). These two events caused large tsunami inundation areas not only along the Sanriku coast but also in the southern Sendai plain area of Miyagi prefecture (Namegaya and Satake, 2014).

Following the 1995 Hanshin-Awaji earthquake (centred on Kobe in western Japan) wider technical investigation was carried out in Japan to define the characteristics of expected earthquakes, including those anticipated along the Japan Trench. For the northeast Tōhoku region, eight off-shore earthquake scenarios were examined resulting in a series of forecast probabilities of occurrence. A version of Japan's seismic hazard map incorporating these scenarios was released by the National Research Institute for Earth Science and Disaster Prevention in 2009, just two years before the Great East Japan Earthquake occurred (National Research Institute for Earth Science and Disaster Prevention [NIED], 2009). This divided the offshore areas of northeast Japan into five distinct seismic zones. Each scenario was assigned a probability of likely future earthquakes based on the area's historical record. Analysis of these eight hypothetical events formed the basis of hazard assessment of Japan Trench earthquakes and associated tsunamis until early 2011. Unfortunately, no consideration was given to the possibility of a far more devastating rupture of multiple segments of the Japan Trench all at once - as actually occurred with shocking results on March 11.

Perhaps not surprisingly, the National Research Institute for Earth Science and Disaster Prevention predicted an extremely high 99 per cent probability in the subsequent 30 years of a Mw8.0 earthquake in the northern Sanriku coastline of Miyagi prefecture, based on the past 400 years patterns of the Miyagi off-shore temblor. Indeed, the probability that another off-shore earthquake in this area having a similar magnitude was ranked as the very highest likely future event that could be predicted in Japan, prior to 2011. By contrast, earthquakes emanating from the Japan Trench fault line lying offshore from the southern Sanriku offshore region, which included the Sendai Plain area, were given a lower probability; only a 30 to 40 per cent change of rupturing in the following 10 years, and a 60 to 70 per cent chance in the following 20 years. Even more important for disaster planning this southern section of the Trench was expected to unleash an earthquake of around Mw7.7. This was about as large as any in the historical record of the area over the previous 400 years, but clearly lower in intensity than the more powerful Mw9 earthquake that took place in 2011. Moreover, based on historical records known at that time the Sendai Plain itself was considered to have a lower tsunami risk compared with the Sanriku coast. For instance, in the northern coastal areas the maximum run-up height from the 1896 Sanriku tsunami was recorded at 38.2 meters in the bay alongside Ōfunato town, Iwate prefecture; but the same seismic event produced a tsunami less than five meters along the coast of Sendai city. For the separate fault segment offshore from the Fukushima Dai-ichi nuclear power plant, around 100 kms further south, the same foresting approach postulated only a magnitude Mw7.4 earthquake, with a less than two per cent chance of occurring over the next 100 years and less than 10 per cent chance over the next 50 years (NIED, 2009).

In sum, prior to 2011 the Miyagi off-shore quakes were selected as scenario events for disaster management planning because they were thought to be the most likely quakes in the future. "They were high probability `100 year events'" and their estimated impacts, including tsunami events and expected inundation along the coast, were used to prepare local hazard maps, coastal sea wall protection and the location of disaster evacuation refuges" (interview with Mr. Takeshi Koizumi, Senior Coordinator for International Earthquake and Tsunami Information, Earthquake and Tsunami Observation Division, Seismological and Volcanological Department, Japan Metereological Agency, Tokyo, 5th April, 2012). With hazard maps built on the assumption of off-shore earthquakes in the magnitude Mw7.5 to Mw8.0 range, residents and disaster planning in Tōhoku coastal communities during early 2011 would have anticipated a maximum tsunami of around four to five meters in height. However, as intimated earlier, what the hazard maps did not allow for was the coupling of individual segments that allowed the rupture of the Japan Trench to propagate for some 500 kilometers, unleashing an earthquake of magnitude Mw9.0 that could produce tsunami waves more than 10 meters in height.

Surprisingly, the much larger seismic occurrence associated with the earlier 869 Jogan earthquake (estimated at least a Mw8.4 magnitude temblor) and its resulting tsunami, which caused widespread inundation not only of the Sanriku coast but also along the Sendai plain, apparently did not inform preparedness activities prior to 2011.[4] Despite scientific demonstration that its inundation extended more than four kilometers inland across the Sendai Plain (roughly similar to the inundation extent on March 11, 2011) this extreme event was not included in hazard modeling and mapping, due to it being perceived at that time as an seismic outlier, one that occurred over 1,000 years ago and having a low probability of recurrence (Fraser, et al., 2012). Perhaps also, this judgement was due to a lack of knowledge (at least in early 2011) regarding the potential source area and the absence of tsunami deposit data on the inundation of other sections of the Tōhoku coast (Sugawara et al., 2013). While many commentators point out this apparent prediction failure (Bernas, 2019), it should also be noted that that the 2011 Great East Japan Earthquake and tsunami resulted from an even larger Mw.9.0 temblor compared to the Jogan earthquake (releasing 33 times more energy than a magnitude Mw.8.0 event). The 2011 temblor was the most powerful earthquake recorded in Japan since 1900 when seismic recording devices were first used, and the fourth most powerful ever detected worldwide. Regrettably, scientific research on tectonics in the Japan Trench was insufficiently advanced to provide wide-spread scientific support among seismologists of an imminent risk from a Mw9.0 earthquake. In the face of this failure of prediction, the 2011 earthquake and tsunami as well as the Fukushima Dai-ichi nuclear power meltdown were deemed afterward by government as a unique and unforeseeable events, something `beyond imagination' (the Japanese word is *soteigai*).

3.2. The Japanese Experience: Strict Building Codes and Seismic Upgrading Programs

Other aspects of disaster mitigation programs in Japan, particularly the country's strict building codes, operated successfully to decrease damage by the earthquake. By way of example, only one per cent of total casualties were attributed to building collapse caused by the quake (Zaré and Ghaychi Afrouz, 2012). Indeed, if the mega-earthquake had been the sole hazard, then Japan could have claimed for itself a momentous triumph in planning for the impact of a major subduction fault temblor. Unfortunately, for the communities of the Tōhoku region the overwhelming cause of the substantial damage and loss of lives was the large-scale tsunami, which as we have seen produced much higher waves than what was assumed in designing sea wall coastal defences.

In addition, building on experience in the devastating Hanshin-Awaji Earthquake in 1995 Japanese regulators addressed the many construction quality issues inherent in the large-scale collapse and fires that spread among older wooden buildings in Kobe at that time. The damage in Kobe triggered an improvement of building quality assurance mechanisms in Japan and the promotion of large-scale seismic retrofitting work (World Bank, 2018). When a disaster occurs in Japan, civic facilities buildings, such as school gymnasiums, are usually utilized as evacuation facilities and shelters. For this reason, seismic retrofitting for public buildings has been a priority and has served as an entry point for increasing the country's overall seismic resistance rate and resilience under the 1995 Act for Promotion of Earthquake Proof Retrofit of Buildings. Thus, by 2015 around 100 per cent of schools and 90 per cent of public important buildings had met the approved seismic resistance grade with funding provided by the Ministry of Education, Culture, Sports, Science and Technology (MEXT). Local governments also set their own targets for retrofitting buildings. For instance, in 2008 Sendai city began offering home seismic resistance diagnostic services and subsidies for seismic retrofitting (World Bank, 2018).

3.3. Earthquake and Tsunami Mitigation Strategies in British Columbia

When set alongside Japanese experience, British Columbia mitigation strategies against the possibility of lalrge earthquakes has been mixed. On the one hand, both scientists and policy makers have well understood the risk posed by the Cascadia Fault since the late-1980s, in part due to increasing use of paleoseismology to examine patterns of seismic activity in the sea bed and tsunami events on the coast of Vancouver Island and the Northwest American Pacific seaboard (Atwater et al., 2014).[5] Emergency Management BC (EMBC) is the designated provincial agency tasked with assisting local municipalities and First Nations communities in British Columbia prepare for natural disasters. However, when compared to its focus on generating earthquake scenarios for metropolitan Vancouver and Victoria, EMBC to date has not yet developed or published a well-researched disaster scenario for a Mw9.0 earthquake and resultant tsunami generated by a rupture of the Cascadia Subduction Zone (unlike the scenario EMBC produced for a less powerful yet more immediate crustal-type earthquake affecting metropolitan Vancouver) (Province of British Columbia, 2015).

While the exact timing of the next big temblor in BC cannot be accurately determined, seismologists estimate that if the Cascadia Subduction Zone slips, the resulting quake will be between magnitude Mw8.7 and Mw9.2 (Atwater et al., 2005). Previous Cascadia Subduction Zone earthquakes of varying intensities have occurred 41 times in the previous 10,000 years (Oregon Office of Emergency, Oregon State Government, 2020). Dividing the time span by the number of quakes results in 243 years, which is the crude average time interval between these mega-quakes. Currently, the southwest of British Columbia (and the coastline of Washington, Oregon and northern California) is now more than 320 years into a Cascadia Subduction Zone earthquake cycle, and by this reckoning such an event is currently overdue. Of course, estimating seismic interval rates is not an exact science. Nevertheless, the odds that a full-fault release or rupture – the Really Big One – are about one in ten in the next 50 years (Goldfinger et al., 2012). Thus, the odds off it happening in the near future are still quite low. Yet this catastrophic event is accepted by BC disaster managers as a real possibility (interview with John Oakley, BC province's emergency manager with responsibility for the Vancouver area, March 2012).

To prepare for this eventuality, EMBC carried out an earthquake and tsunami response drill in 2016, hosted by the city of Port Alberni on Vancouver Island. This exercise, named Exercise Coastal Response, was province’s first full-scale earthquake and tsunami planning exercise that brought together stakeholders from all levels of government (as well as the Canadian Armed Forces, First Nations communities, critical infrastructure operators and non-government organizations), to simulate how they would collaboratively work to respond to the impacts of an earthquake and tsunami catastrophe along coastal British Columbia. Its purpose was to test the procedures set out in the BC Earthquake Immediate Response Plan and to promote inter-agency co-operation among internal and external agencies that support emergency response (Province of British Columbia, 2016). A follow-up exercise by the BC province is planned for 2022 focused on addressing a scenario based around a powerful crustal earthquake striking metropolitan Vancouver (Province of British Columbia, 2021).

Local cities and communities on Vancouver Island have also started to plan for a forthcoming mega-quake, usually through commissioning their own risk analysis studies and converting expected tsunami wave heights to hazard maps that are made available to the general public (see for example, the Capital Region Coastal Flood Inundation Mapping Project Summary [Capital Region District, 2020] which was prepared for the City of Victoria and adjacent municipalities). In this regard, the Tofino District Council on Vancouver Island received funding from EMBC in 2019 to analyze its tsunami risk, with the final report indicating a harsh finding. Specifically, if a large tsunami generated from a Cascadia Fault mega-earthquake struck during the day-time in the summer tourist season, roughly 30 per cent of Tofino’s estimated 4,500 summer population would not be able to escape to higher ground in time. At night-time, the estimated figure rose to 75 per cent of Tofino’s summer population (Northwest Hydraulic Consultants, 2019; see also Cheff et al., 2019). In response to this warning, the District council published a `Tsunami Smart Road Map’ in 2020, indicating both short-term and longer-term projects it intended to pursue aimed at mitigating the risk of a large tsunami (District of Tofino, 2020).

In terms of reducing earthquake vulnerability of older buildings and infrastructure, retrofitting progress in coastal British Columbia has been slow over the past 30 years or so. A major problem is the large number of older structures at risk, especially those located in the cities of Vancouver and Victoria. Current building regulations for new structures in BC are on a par with those in California and other jurisdictions that are exposed to earthquake risk. However, there are estimated to be thousands of buildings in Vancouver and Victoria built prior to the development of earthquake building codes put in place in the early 1970s. In the absence of any large-scale public funding programs for mandating seismic retrofitting, local governments have had little incentive to require mandatory upgrades of older buildings other than for essential public structures, such as schools and bridges. For instance, in 2004 the Province of British Columbia announced a 10-15 year, $1.5 billion seismic retrofit program for the province's 750 at-risk public schools (Ventura, et al., 2012).

For the many private buildings that are vulnerable to earthquake shaking, key challenges include the high cost to building owners of seismic retrofitting as well as the potential loss of affordable housing if an older generation of apartment buildings have to be demolished. In the case of metropolitan Victoria, it was estimated that around 4,000 buildings were at risk of complete damage from a major earthquake due both to the age of these structures as well as to unstable soils.

A study report on this issue determined that there was over five per cent probability that 30 per cent of the Victoria's buildings would suffer so much damage in an earthquake during the next 50 years that they would collapse or have to be demolished. The City of Victoria's response was to provide 10-year tax breaks as well as grants for private owners to retrofit recognized heritage buildings, but progress has been slow at only around three upgraded buildings per year (Hoekstra, 2017). In Vancouver, the city government has moved ahead with identifying the risk to the many thousands of commercial and residential apartment buildings constructed prior to the introduction of seismic standards in building controls, especially the risks to multi—storey brick apartments that provide rooms to the city's poorest living in the Downtown Eastside neighborhood (Hoekstra, 2019). Other clusters of pre-1973 buildings at risk include those located in the Vancouver downtown, the city's West End, the east side along the Kingsway and Broadway thoroughfares, together with the industrial and commercial areas of south Vancouver along the Fraser River. Nonetheless, to date there has been no formal program to mandate seismic retrofit of older private buildings. Even so. , some buildings in Vancouver have received seismic upgrades when changes-of-use or major renovations have triggered municipal by-law requirements regarding seismic safety.

4. Preparation: Early Warning Systems and Evacuation to Higher Ground

Having identified local hazards and their likely risks, how can disaster planners protect local communities? No matter what the risk, disaster warning systems can prepare for and mitigate the damage caused by earthquakes and tsunamis. However, implementing appropriate countermeasures, such as encouraging evacuation of residents to higher ground after a tsunami warning, depends on grasping the right information and disseminating it to the public in a timely manner. Warning systems must therefore be designed to take into account both the hazard and likely community responses (Committee on the Future of Emergency Alert and Warning Systems: Research Directions, 2018).

4.1. Japanese Earthquake and Tsunami Warning Systems

Japan has the world's most sophisticated earthquake early-warning system, born out of a combination of necessity and high-tech know-how. In the wake of the Great Hanshin-Awaji Earthquake, the Japanese Diet first passed the 1995 Earthquake Disaster Management Special Measures Act to promote comprehensive measurements for earthquake disaster management, and then established a high-density seismic monitoring network (Suganama, 2006). While several countries have introduced early warning systems for major earthquakes, with most focused on a particular quake-prone area, Japan's system is unique in its breadth of coverage, as it occurs across the entire country with around a thousand individual observation points (Ito, 2018).

This system is operated by the Japan Meteorological Agency (JMA) and is designed to alert the general public whenever an earthquake creates shaking at or above level 5 on Japan's energy intensity scale, which is severe enough to crack walls.[6] Based on a seismic reading taken a few seconds after an earthquake beings, the system was introduced in 2007 and provides up to tens of second of warning before the major shaking commences.[7] The overall aim is to mitigate damage by providing sufficient lead time to slow down trains, stop elevators, and give the affected population a small amount of time to take protective measures, such as `drop, cover and hold on', before the shaking starts (Japan Meteorological Agency, 2007). The JMA first estimates the distribution of strong ground tremors and then issues a warning to government officials, factories and schools, as well as to radio and television companies. In addition to this type of warning, the Japanese Government's Fire and Disaster Management launched `J-Alert' in 2007, an early warning system that transmits warnings to the public directly through residents' phones by SMS (short message systems) and text alerts (Centre for Public Impact, 2016).

Compared to earthquakes, tsunami warnings are more challenging to forecast precisely and this has severely tested the JMA's twin goals of speed and accuracy (Japan Meteorological Agency, 2013). The Agency first established a tsunami warning unit for the Sanriku coast in 1941 and expanded this into a nationwide service in 1952. Following a devastating tsunami to the Japanese coast from the large 1960 Chilean earthquake the system also commenced forecasting long-distance tsunamis originating from seismic events across the Pacific Rim of Fire. Over the years the JMA improved its tsunami alert system and began issuing estimated tsunami heights in 1999. The JMA's current policy is to announce the characteristics of all major quakes – including any tsunami warnings – within three minutes of commencement. The reasoning is that, depending on the temblor's location, a near-coast tsunami could conceivably arrive within 15 minutes, and so the Agency's aim has been to give people in the tsunami's path at least 10 minutes warning. At the time of the 2011 Great East Japan Earthquake the contents of any tsunami warning were classified into the following three categories according to the estimation of tsunami height: `Major tsunami (estimated at more than 3 meters), `Tsunami' (estimated at 1or 2 meters) and `Tsunami advisory' (0.5 meters or less). At that time it was believed that the JMA tsunami warning system used the most advanced technology in the world (Ranghieri and Ishiwatari, 2014).

On 11 March, 2011, the JMA system successfully delivered an alert to the national media and the government of a powerful earthquake impacting the Tōhoku region, and beyond, between six and 40 seconds before the first major jolt. While local governments in coastal areas close to the mega-quake epicenter received the Agency's warnings, the greater Tokyo region (where many areas experienced strong level-6 shaking) received no advance notice. Furthermore, for many residents closest to the epicenter, such as those living in the coastal city of Ishinomaki and those in Sendai, the Agency's early warning came too late for any effective personal preventative reaction, as it was issued almost simultaneously as the first tremors from the quake struck these areas (Fraser et al., 2012).

On the other hand, the rapid *shinkansen* trains together with nuclear reactors in Tōhoku, both of which had their own automatic warning systems, shut down promptly as designed (the Fukushima Dai-ichi nuclear power plant suffered a loss of power and cooling functions in the subsequent tsunami). In addition, all Japanese households serviced by urban gas in 2011 were equipped with microchip-controlled gas meters that automatically shut off the gas flow when an earthquake stronger than JMA level 5 was detected. During the March 11 earthquake, these meters immediately stopped the gas to each household, and the Sendai City Gas Bureau shut off its supply of gas. Thus, Sendai was spared from the large-spread off fires that ravaged Kobe in the 1995 Hanshin-Awaji earthquake. In sum, Japan's earthquake warning systems were able to reduce economic damage and loss of life, signalling their utility as a key tool of disaster management (Tosani, 2012).

On the basis of the preliminary data available, earthquake monitoring computers on March 11, 2011, measured (incorrectly) the quake as a magnitude Mj (JMA magnitude) 7.9, one which had occurred at a depth of 10 kilometers. After confirming this information the data was then fed into the Agency's tsunami simulation, which identified the pre-programmed quake scenario closest to the seismic events being detected and then generated tsunami warnings for Japan's entire eastern coast. These were announced on national media and sent to local governments along with the estimated magnitude, epicenter and depth of the quake. Less than three minutes passed since the quake began, and so the Agency's first important goal had been met (Cordkil, 2011). When the quake was over - after a full five minutes of continuous shaking - it then became possible to calculate more precisely just how big it had been, and at 4pm on March 11, 2011, earthquake monitoring officials upgraded the temblor to magnitude Mw8.4. This reading was subsequently revised to Mw 9.0 by mid-day March 13th., more than 12 times larger than originally thought in terms of energy released. The problem with the initial estimate of the quake's intensity was that the system of calculations assumed a `point source' for an earthquake, and in this case the initial point source led to the initial estimate of a magnitude Mw7.2 quake. In fact, however, the Japan Trench ruptured along hundreds of kilometers of fault line parallel to the coast, and this more extensive source area unleashed much more destructive energy. Indeed, the accuracy of the JMA forecast system in 2011 appeared to break down at around a magnitude 8-quake or above (Cyranoski, 2011).

In terms of the subsequent tsunami warning, the JMA issued the first alert at 2.49pm, three minutes after the earthquake, and so it again met its goal regarding the speed of warning. Yet, because of the unprecedented size and complexity of the seismic event, leading to its initial underestimation, the JMA at first broadcast a `Major' tsunami warning to the coasts of Iwate, Miyagi and Fukushima prefectures with height estimates of 3 meters, 6 meters and 3 meters, respectively. However, these estimates were well below the actual recorded tsunami heights that peaked at over 8.5 meters along the coast of the city of Miyako, Iwate prefecture, at over 8.0 meters in the city of Ōfunato, Iwate prefecture, and also at over 9.3 meters in the city of Sōma, Fukushima prefecture. Indeed, after the strength of the tsunami was measured in real-time, through the records reported by offshore tsunami buoys, the JMA revised the contents of its tsunami warning over the following 30 minutes, with estimates of 3 meters, 6 meters, over 10 meters, 6 meters, 4 meters and 4 meters to the coasts of Aomori, Iwate, Miyagi, Fukushima, Ibaraki and Chiba prefectures, respectively (Corkil, 2011; Ranghieri and Ishiwatari, 2014).

4.2. Escape Routes to Higher Ground

Ultimately, the success of any earthquake and tsunami early warning system is measured by what actions people take and their willingness and ability to escape to higher ground. Municipal governments in Japan have had the major responsibility for developing evacuation procedures and are responsible for issuing evacuation orders to the public on receipt of a warning from the JMA or national government. This type of public announcement warning people to escape to higher ground is achieved via roof-top or street-based loud speakers and indoor receivers in public buildings. In addition, community-based volunteer fire corps personnel, trained in disaster management, use various tools such as hand-held speakers, fire bells, sirens and fire engine loud speakers to warn communities in the affected areas of the impending tsunami (Ranghieri and Ishiwatari, 2014).

How effective was this system on March 11, 2011? According to interview surveys by the Japanese government, almost half of the population received no tsunami information or evacuation orders in the affected areas; and around 60-70 per cent did not receive the revised information issued by the JMA about increased expected tsunami heights. Despite this, Fraser et al. (2012) records that there was an overall 96 per cent survival rate of those living in the inundated areas of the Tōhoku region, with substantial differences along the affected coasts of Iwate, Miyagi and Fukushima prefectures. Specifically, post-disaster evaluations indicated that people who lived along the Sanriku coast had a higher tendency to make a timely evacuation, in large part because these communities had more experience of this type of disaster than those who lived on the Sendai plain or in Fukushima prefecture. As intimated earlier, when compared with the Sanriku coast prior to 2011 the Sendai Plain was considered to be a relatively low-hazard area for tsunami events. Indeed, historical records showed there had been no large tsunami occurrence in the Sendai plain area since the 1611 Keicho-Sanriku tsunami, whereas the Sanriku coast was affected by great tsunamis in 1896 and 1933, and also by the 1960 Chile earthquake tsunami. As noted already, a particular concern for the northern Ria coast was its remarkable tsunami-amplification property because of its narrow, V-shaped topography, a situation very difference than the southern flat plain coast. Moreover, because of the location of the 1896 and 1933 earthquake's epicentre off the Sanriku coast, the Sendai plain was protected from the subsequent tsunamis because of its more southern location, which is also somewhat sheltered by the Oshika peninsula lying just north of the Sendai Bay.

The occurrence of two prior huge tsunamis just 37 years apart (the 1896 Meiji tsunami and the 1933 tsunami) taught the residents of the Sanriku coast about the very real dangers of tsunamis, which was reinforced by local disaster preparations led by municipal officials or local neighborhood associations (*jichikai*)). For example, around 93 percent of survivors in Kamaishi city, Iwate prefecture recorded that they evacuated quickly, with 60 per cent of them starting their evacuation less than 10 minutes after the earthquake. By contrast, only 60 per cent of the people in Natori city, Miyagi prefecture (located on the Sendai plain) evacuated quickly, with just 30 per cent of them starting their evacuation within 30 min of the earthquake. Indeed, as a result of inadequate or non-existing evacuation drills, communities in the coastal community of Yuriage, Natori city, suffered a fatality rate of 11-12 per cent if they lived close to the fishing harbor and an astonishingly high 22 per cent fatality rate in more inland residential areas (Ranghieri and Ishiwatari, 2014).[8]

Despite these geographical differences - leading to very different attitudes to tsunami risk as well as evacuation practices and drills in local communities - there were many cases documented of people in all Tōhoku's coastal communities who delayed evacuation until it was too late – often as a result of social or parental responsibility - or who quickly evacuated to a safe place but then went back to their houses, for many reasons, and who ultimately became casualties (Yun and Hamada, 2015). In addition, the original (lower and erroneous) tsunami height estimates may have caused some people to delay their evacuation, possibly leading to increased casualties. Indeed, some survivors claimed that they felt safe based on the original JMA estimate of 3 meters height for Iwate and Fukushima. Many people did not seriously consider the dangers of a forecast tsunami height of just 3 meters, as this was lower than numerous sea walls and dykes constructed along the Sanriku coast. By way of example, in the Tarō's coastal community, Iwate prefecture (part of Miyako city), a substantial sea wall had been constructed up to 10 meters in height. While the tsunami height estimates were later revised in several communities, the local radio or speaker system malfunctioned following the earthquake due to power failure and consequently many residents in Tarō were unable to take action based on the revised higher tsunami heights (Matanle, et al., 2019).

Yet another contribution towards local fatalities was the inundation of supposedly `safe evacuation zones' or shelters identified by local municipalities and marked in community hazard maps. Local governments designate sites for evacuation from tsunami and quakes, and typically these comprise public structures, such as elementary and junior high schools, local assembly buildings, as well as shrines and temples. Some are upland parks or vacant lots. Unfortunately, in 2011 there were many designated evacuation buildings and shelters that failed to protect lives because of the unexpected tsunami heights and runup. For instance, a community gym designated as an evacuation shelter in the flat region of Rikuzentakata city was overcome by the tsunami and many people lost their lives. In the entire Tōhoku region the three worst designated evacuation shelter locations inundated by the tsunami were those for Rikuzentakata, Iwate prefecture (35 out of 68 places), Onagawa (12 out of 25 places) and Minami-Sanriku, both in Miyagi prefecture (31 out of 78 places). Tragically, these mishaps contributed to the relatively higher number of overall fatalities recorded at tsunami inundation areas in these three locations: 11.8 per cent, 11.2 per cent, and 6.3 per cent, respectively (Suppasri et al., 2013). For areas where high ground was too far away, some municipalities had designated vertical evacuation refuges that could be used to shelter in the face of an oncoming tsunami, some comprising existing high-rise office buildings and car parks, as well as especially-built structures (Fraser, et al., 2012).

Surveys of where people lost their lives in the March 2011 tsunami also indicated that approximately two-thirds of people escaped the inundation using their cars – particularly so in the Sendai Plain communities, where about one-third of survivors attested to being entangled in traffic congestion or poor road conditions immediately following the earthquake. Indeed, between 10 to 15 per cent of all deaths from the tsunami occurred in cars (Fraser et al., 2012). There also were problems in the evacuation of the elderly and disabled who would have been less mobile, less able to hear the warnings via phones, television and through local sirens, and less able to evacuate easily to higher ground. All told, victims of the disaster aged 60 or older accounted for 65.2% of the deaths, with 2 per cent of total victims being in their 70s (Nakahara and Ichikawa, 2013).

4.3. Japanese Lessons

What lessons can be taken from these case studies and the Japanese experience as a whole? First, tsunami warnings can inform people that they are in danger, but by themselves they cannot guarantee people's safety. No matter how advanced early warning technology becomes, a guiding principle is that residents should take initiative to escape from a tsunami on their own as soon as they feel a strong quake. Indeed, the most important lesson is that one should not wait to act until official information arrives, the strong ground shaking from a subduction zone quake itself is the first alert to take action and evacuate. Second, it is very clear that prior experience and memory of past tsunami disasters, together with recent evacuation drills helped to reduce the tsunami fatality ratio in coastal areas along the Ria coasts of the Miyagi and Iwate prefectures, as people living along the Sanriku coast had higher tsunami awareness and evacuation recognition. This finding indicates the importance of experience education for disaster prevention.[8] Delays in evacuation are likely to cause many deaths in a local tsunami event, and education programs should be put in place specifically to reduce this potential issue.Third, the basis of disaster prevention ought to be `self-reliance', by which each individual acts on their own judgement to protect themselves (*tendenko* in Japanese). However, this presents a challenge in how to address those people in a community that have difficulty with self-reliance, such as the disabled.[9]

All told, Japan's investment in disaster preparation programs over the years had been wide ranging, covering seismic and tsunami detection, early-warning systems and multi-channel distribution channels. However, a final lesson from Japan's early warning system was its limitation in responding to a `near-field' or `local' extreme magnitude earthquake. While official warning systems appeared to work well when tsunamis were generated by distant earthquakes they proved far less effective during near-shore mega-earthquake events.

4.4. British Columbia Preparation Experience

In British Columbia, the provincial government commissioned an earthquake warning system in 2016 that would provide alerts of a megathrust earthquake along the Cascadia Subduction Zone. Sensors were placed on the sea bed as close to the fault line in order to give up to 90 seconds warning before the destructive shock waves arrived. When fully operational it would provide advanced alerts warning to the public through their phones, and other early warning systems could be alerted. For instance, if a major earthquake was detected then major transportation systems, such as the metro Vancouver Skytrain, could be stopped and city gas supplies could be shut down. While this earthquake warning system has merit, there is currently no program in place to warn residents of a local or near-field tsunami that would be generated in the case of a Cascadia subduction mega-quake. The earthquake itself would be the natural warning for coastal communities to seek refuge immediately away from the coast on high ground (CBC News British Columbia, 2018).

In the case of tsunamis generated from `distant' quakes, warnings are currently disseminated through official channels comprising the US National Tsunami Warning Center, Natural Resources Canada, and the US Geographical Survey. In January 2018 these alert systems were put to the test when a Mw7.9 earthquake was detected just after midnight in the Gulf of Alaska having the potential to trigger a tsunami affecting communities along the western BC coast (US Geological Survey, 2018). The tsunami disaster never came, but this event allowed evaluation of official warning systems, including the efficacy of phone-based alerts, local community warning sirens and other forms of mass notification, such as fire trucks roaming streets with loud speaker alarms. Although many people were woken and evacuated, several specific challenges were identified following a fairly successful `trial run' of the warning system. For instance, in Port Alberni, one post-event survey found that 93 per cent of participants evacuated, or had begun evacuation their homes by the time the evacuation order was lifted after some hours. Most sought shelter in the homes of family or friends outside the designated evacuation zone. However, a heavy reliance on vehicle transportation led to traffic congestion, and a small number indicated that they were unable to evacuate due to illness or disability in their homes. Others reported confusion about whether their homes were located inside or outside the evacuation zone marked on official hazard maps (Tanner and Reynolds, 2020). In the district of Tofino, a large number of evacuations took place by around 600 residents who fled after siren warnings to the Tofino community's 300-person community centre seeking refuge. However, some residents never heard the district's beach sirens, and the district's phone notification systems malfunctioned and never warned subscribers to evacuate. This problem also occurred in metropolitan Victoria (Global News, 2018). Although the expected tsunami never eventuated, one benefit of the `false alarm' in 2018 was that many survey participants indicated an understanding of the risks they faced and were willing to sign up to warning signal applications on their phones, as well as to update their personal and family emergency response plans. In addition, municipal officials identified ways that critical information could be better communicated to residents in future emergencies though web sites and social media.

As already noted, there has been no attempt to arrange any official tsunami warning for `local' tsunamis caused by a full rupture of the Cascadia Subduction Zone as the travel time of a tsunami to coastal areas - approximately 20 minutes to communities such as Tofino and Ucluelet - would be too short to initiate any formal alert. Thus, if a local earthquake were to occur, its shaking would be the only effective warning. Indeed, this is indicated in most official documents provided by the provincial and local governments (e.g. the BC Government Tsunami Preparedness and Response warning, [BC Government 2020a]), which is encouraging when measured against the reported experiences after March 11, 2011, in the Tōhoku coastal region of Japan. However, it is known that there is pubic misunderstanding whether or not official warnings in BC communities, including local sirens, would cover tsunami generated by local sources (interview with Keith Orchiston, Emergency Program Coordinator, District of Tofino, 11 August, 2016). This is an ongoing issue for public awareness and preparedness. Emergency Preparedness BC works with local communities to encourage people living on the coast to learn about tsunami risk, the need for immediate evacuation should a Cascadia subduction earthquake occur, and to engage in `High Ground Hikes' that identify escape routes residents would need to follow to safety (BC Government 2020b). The BC government also arranges an annual `Shake Out' earthquake drill for large employers and their staff every October, while a similar event focusing on `Tsunami Preparedness' takes place in the all coastal communities in the second full week of April (BC Government 2019). While much of the Vancouver Island coastline is fortunate to have high ground close by, the low-lying tourist beaches of Tofino and associated accommodation are far from any high ground locations and the local official evacuation goal to escape an incoming tsunami of `20 minutes to reach 20 meters in height', cannot be achieved for all beach-side accommodations due to the topography of the near-by land. Consequently, Tofino's `Tsunami Smart Road Map' includes plans for a tsunami vertical evacuation tower close to the low-lying Chesterman Beach. However, this project has been accorded a low implementation priority due to cost considerations (Zomerman, 2020).

5. Emergency Response: Search, Rescue and Relief Operations

No amount of planning and preparation can prevent catastrophic disasters. Consequently, well-trained search and rescue teams are an essential part of disaster management. `First-responders' are trained persons who respond to an emergency or crisis call. They may be police officers, fire fighters, or emergency medical technicians. After a major earthquake and tsunami their role is to search for and to rescue survivors either trapped in crushed buildings or under rubble or washed out to sea, to offer medical help and then transport them to a safe place. The response phase of this and other types of emergency may commence with search and rescue, but in all cases the focus will quickly turn to fulfilling the basic humanitarian needs of the affected population (food, water, medicine and so on) (Harris, 2018).

5.1. The Role of First Responders in Japan

In Japan, local municipalities and prefectural governments play a leading role in planning for and responding to disasters. Normally, immediate rescue and relief operations after local earthquakes, floods or monsoon damage would be dealt with by local police, fire fighters and the coast guard (Edgington, 2014). Local government offices typically were expected to assume the role of command posts for both search and rescue and relief efforts, such as setting up evacuation centres and requisitioning emergency supplies of food and other supplies. However, because of the magnitude of the March 11, 2011, earthquake and the unexpected scale of the tsunami, many additional resources were required for effective rescue of survivors. Moreover, due to the widespread nature of the disaster there was a need to support large numbers of residents, many of whom had lost their housing. Consequently, local governments were unable to respond by themselves. Indeed, some municipalities, such as Rikuzentakata, Minamisanriku and Ōtsuchi along the Sanriku coast, lost their town halls and in some cases they lost their mayor and senior officials to the tsunami. In addition, many hospitals that would normally deal with the emergency care of persons injured by the disaster were either swept away or unable to perform their functions. As a result, a major feature of the emergency response stage of the Great East Japan Earthquake was the vast number of rescue forces and medical personnel brought in to assist from outside the local Tōhoku area.

The Japanese disaster management system had made many improvements to its emergency response operations since the Hanshin-Awaji (Kobe) earthquake in 1995. For example, a national government crisis unit was on duty 24 hours a day with a stand-by emergency team. On March 11, 2011, the Japanese government took action just four minutes after the earthquake, and an Emergency Disaster Response Headquarters, headed by the prime minister, was organized within 30 minutes. A national emergency was declared and the first teams of both active and reserved troops from the Self Defense Forces (SDF, or *jietai*) were deployed and reached the affected area within hours. On the first day, SDF liaison personnel were dispatched to prefectural offices in Miyagi (located in Sendai), Iwate (in Morioka) and Fukushima (Fukushima city). In contrast to the damage incurred in coastal communities, the prefectural command centres were located inland and could assist rescue and relief missions. Within the first week this involved about half of Japan's military forces, around 107,000 personnel, fully equipped with 540 aircraft and 60 vessels. Using helicopters to conduct rescue operations in isolated settlements they rescued over 19,000 disasters victims during the first 72 hours following a disaster, a critical window for saving and treating survivors, and this accounted for almost 70 per cent of all people rescued in the disaster. In addition, the Japanese government requested help from the US forces stationed in Japan to help with the relief work and provide logistical support, such as transportation of relief supplies, in `Operation Tomodachi' (Operation Friend). The US forces assisted with search and rescue missions, and restored transportation facilities, including Sendai Airport – a vital air hub for the region (Terada, 2012).

In light of lessons learned from past disasters in Japan, many other national agencies, as well as prefectures and municipalities outside the affected region, had formed a variety of specialized teams for use in disasters and these were quickly deployed to the Tōhoku coastal region. For example, Disaster Medical Assistance Teams (DMATs) were dispatched from around Japan. These comprised teams of medical doctors, nurses and coordinators trained to conduct emergency operations, transport patients, and to support local hospitals provide care for people with chronic illnesses. Other national disaster agencies were also quickly deployed to the disaster area, such as the Japanese Red Cross Society and emergency fire response teams from the Fire and Disaster Management Agency, as well as police and firefighting units from various prefectures. Aid was supplied from other local governments, in the form of food, water, medicine and helpers. Municipal and prefectural councils of social welfare recruited and received disaster volunteers to damaged areas, conducting activities such as removal of disaster waste and mud around houses, recovering mementos, being companions to the elderly, and supplying hot food (Suzuki and Kaneko, 2013).

While a growing crisis at the Fukushima Dai-ichi nuclear power plant greatly impaired the capacity of the national government to focus on recovery in Tōhoku, the first week after the event the rapid deployment of many first responders. Major challenges in this immediate period included securing road access to remote tsunami-affected areas. SDF personnel commenced their full deployment and operations on March 12th, , 2021, but their route to the damaged coasts was slowed by blocked roads (see Figure 3). In contrast, the major north-south Tōhoku Expressway/Joban Expressway (national routes E4/E6) together with National Route 4, two of the artery highways in the region, suffered no structural damage from the earthquake as a result of pre-disaster seismic retrofitting, and this allowed emergency vehicles to access the city of Sendai in Miyagi prefecture and Morioka in Iwate prefecture. However, the narrow local roads along the Pacific coast (National Routes 6 and 45) were destroyed in certain sections by the earthquake, as well as being inundated or swept away by the coastal tsunami and covered with debris, making them impassible. Similarly, the mountainous east-west roads leading to the Pacific coast were obstructed by debris and affected by landslides. Accordingly, first priority was given to the herculean task of quickly recoving east-west roads to enable rescue and relief teams to reach the tsunami-stricken areas. On March 11, the Tōhoku Regional Bureau of the MLIT decided to implement `Operation Comb Teeth' for the rapid strategic clearance of these east-west roads across the vast disaster area. With the combined support of the Self-Defense Forces, prefectural governments and local construction companies, the operation was completed by March 18. The operation consisted of three steps: (1) Clearing the Tōhoku Expressway and National Route 4 in one day to secure the inland south-north axis; (2) Clearing the national routes eastwards from the inland axis routes to reach the Pacific coastal communities in four days; (3). Clearing and repairing the coastal National Routes 6 and 45 within a week from the earthquake, and to make 97 per cent of Route 45 passable, thereby securing south-north access along the Pacific coast (Ranghieri and Ishiwatari, 2014).

(FIGURE THREE ABOUT HERE)

The success of Operation Comb Teeth contributed significantly to subsequent rescue and relief activities. Thanks to the work of the SDF, local government staff, prior agreements with private construction companies, and advance financial arrangements from the national government, the roads leading to towns on the affected coast were cleared in less than a week. Furthermore, by March 15, all 14 ports along the stricken coast were either entirely or partially usable and began accepting vessels delivering emergency supplies and fuel. Water supply services were resumed for about 90 per cent of residents within a month, while electric power was 90 per cent restored within a week (Ranghieri and Ishiwatari, 2014).

Apart from the challenges imposed by the troublesome access to coastal communities, communications with affected parts of Tōhoku were very difficult. Because the earthquake had caused problems with power outages, communication infrastructure was also damaged and this frustrated initial efforts to assess damage and determine relief needs. Access to satellite telephones were at first largely restricted to military units. Helicopters from the military and prefecture governments were dispatched to carry out aerial surveys of affected areas, and later to deliver food and water to stranded survivors. Still, as access to the devastated areas improved, especially with the removal of debris, and as roads, air runways and coastal harbors were reopened, the search for victims gradually widened to more remote areas. In the first week after the quake, fuel shortages hampered the delivery of relief supplies to shelters where survivors took shelter, and also limited the use of heavy machinery and heaters. In some cases no help from outside came for several days (Joint Research Group on Resilience of Kyoto University and NTT, 2012).

With the multiplicity of organizations providing support, and in the absence of prior practice through wide-area disaster response exercises in the region, coordination among first-responders was difficult. In the immediate emergency period each rescue force was largely in charge of its own operations. Therefore, how was collaboration arranged after that to improve longer-term relief coordination? First, `three-party meetings' (*sansha kaigi*) were arranged at each municipal level, involving SDF forces, local government officials and non-government/non-profit representatives (NGO/NPO) representatives. They prepared list to share information about who was working at which shelter locations, and based on this NGO/NPOs were allocated according to their capacity to provide assistance, such as hot meals. Second, local governments also coordinated among themselves. While fire-fighting units in Japan frequently engaged in mutual support agreements with those in neighboring jurisdictions, local government made special agreements with each other for help in the wake of a disaster often involving wider mutual assistance that covered a broader range of activities. Specifically, any loss of municipal capacity after a disaster is counterbalanced by support from other municipalities under the Basic Disaster Act, 1947. In March 2011, prefectural governments in the Tōhoku region tried to gather resources and personnel and coordinate those provided by other local governments under formal and informal mutual aid agreements. For instance, in the Kansai region (western Japan), prefectures belonging to the Union of Kansai Governments established in 2010 decided to provide support by choosing counterparts in the Tōhoku disaster area.[8] Third, private companies that produced food, bottled water, and daily commodities, together with those who specialized in delivery services operating at the national or regional level became important resources to support survivors and to distribute supplies from warehouses to evacuation shelters. Nonetheless, it was reportedly difficult to match supplies with local needs in all cases (Sakamoto, 2014).

Twinning arrangements between localities in disaster-affected areas and their counterparts in unaffected areas also proved to be effective in the subsequent period. As already noted, local governments in areas affected by the Great East Japan Earthquake and tsunami faced difficulties in responding to the disaster and thereafter functioning adequately, suffering serious damage to their office facilities, data services essential for the provision of municipal services, as well as the loss of public officials. To compensate, many prefectures and municipalities outside the Tōhoku region took the initiative to quickly send their own staff to help the localities deal with longer-term post-disaster relief activities and recovery operations. About 79,000 local government officials were dispatched from all over Japan to the affected prefectures and municipalities by the end of 2011, in capacities ranging from civil engineering and urban planning to social work and finance. Some of these arrangements were based on formal agreements brokered by the national government that clarified the necessary legal backing and cost-sharing arrangements - while others were based on goodwill (Ranghieri and Ishiwatari, 2014).

Thanks to many efforts the living environment in evacuation shelters along the devastated Tōhoku coast improved in the weeks that followed the earthquake. Partition walls were installed by NGOs, tents were set up for women to change clothes or to nurse infants. There were corners established for children to play in and outdoor bathing sets were installed. As time elapsed from the date of the earthquake, the SDF shifted their priority from rescue and relief activities to the search for missing persons. The SDF found and retrieved approximately 9,500 bodies, amounting to around 60 per cent of the total. By the middle of April, 2011, many coastal communities had their rubble cleared into temporary stock piles and the mass-search for missing persons declared finished. By early July, 2011, medical team assistance from other prefectures had ended, and most local medical facilities were managing on their own. All hospitals in the damaged region that were not destroyed had returned to their normal operations (Edgington, 2014).

5.2. Emergency Response in British Columbia

As in the Tōhoku coastal region during 2011, a coastal mega-earthquake and tsunami in British Columbia would similarly overwhelm the capacity of local municipalities to provide an effective response, including rescue of and care for survivors. Where would outside assistance come from and how soon could it arrive?

The BC provincial government has had considerable experience with emergency response associated with annual summer wild fire events in remote communities, often requiring mass evacuation of local residents (Cornwell, 2020). Typically, severe wild fires require the declaration of a Provincial State of Emergency and fire fighting forces are brought in to assist from across Canada, as well as from the US and overseas. Evacuation of communities are organized by the regional command offices of Emergency BC and carried out with the help of local police. Reception centres and short-term accommodation for displaced persons who are either evacuated or who have lost houses to wild fires are managed by the Red Cross and volunteer organizations. Each local municipality has established Emergency Support Services (ESS). The ESS system involves a team of trained volunteers who provide short-term basic support to people impacted by disasters, normally up to 72 hours (BC Government, 2020c). Clearly, a catastrophic earthquake and coastal tsunami would require a very different type of response than this, both in scale and in duration. It would assuredly require the assistance of rescue and medical teams from outside the province.

As already noted, as part of its preparations for a major coastal earthquake, British Columbia has issued an Earthquake Response Plan dealing with the responsibilities of various government agencies (Province of British Columbia, 2015). An underlying assumption is that full-time and part-time military forces in BC would be able to assist in search and rescue operations. Practically, that would mean part-time reservists, estimated to be around 5,000 to 6,000 personnel. However, many of these are first responders in their civilian jobs as fire and police officers, and lack adequate transportation and emergency rescue supplies (Cain, 2017). For longer-term relief operations the Canadian Armed Forces are prepared to deploy thousands of their forces, helicopters, ships and other forms of assistance under the federal government Operation Panorama plan (Joint Task Force, 2014). Despite that, one major issue is that it could take several days for the military to bring materials and personnel to the coast from Edmonton, Alberta (more than 1,400 kms from Vancouver Island), and from elsewhere. Because of the wide-area consequences of any rupture to the Cascadia Faultline, it is extremely unlikely that military assistance from the US could be expected. Severe earthquake damage to Seattle and Portland, together with tsunami destruction to coastal Washington and Oregon would require the full support of the armed forces of the United States.

While unable to muster the same number of first responders as were provided in Japan, British Columbia faces similar difficulties as those found in the Tōhoku region. In particular, the race to access the rugged coastline of Vancouver Island to rescue survivors in remote communities would present a serious challenge. Figure 4 indicates the air, road and marine staging areas and transport nodes envisaged by the BC Earthquake Response Plan. One problem gaining access to the BC coast is that a catastrophic earthquake would likely wreck airports, harbors, bridges and access roads, crippling any possible emergency response and effectively cutting off Vancouver Island and even parts of metropolitan Vancouver. In this regard, just one major road provides the critical transport link with Tofino, Uclulet and Port Alberni (Provincial Route Number 4, the Alberni Highway/Pacific Rim Highway). However, this essential roadway washes away at times in winter because of severe weather and is also blocked by accidents, Thus a problem of broken roads similar to that experienced in Tōhoku is likely to impede the arrival of first responders and the delivery of relief supplies after a mega-earthquake, cutting off delivery of food, medicine and other supplies (Zomerman, 2020).

(FIGURE FOUR ABOUT HERE)

6. Reconstruction: Finding a Place to Live

Transition shelter plays a crucial role in housing reconstruction following a catastrophic disaster. Reconstruction of permanent housing in disaster-stricken communities cannot move forward until complex issues are settled, such as the removal of debris and plans for the rebuilding. Even after recovery programs are agreed on and reconstruction projects launched, it may take several years for permanent housing to be completed and receive displaced persons. In this context, affected communities may have to rely on temporary housing programs for extended periods of time. The characteristics of these will have a significant effect on not only on survivors' housing, but also their overall recovery (Lizarralde et al., 2009). Accordingly, the final example of how lessons for British Columbia might be drawn from the events following the Great East Japan Earthquake reflects on the implementation of temporary housing in the Tōhoku region during the past 10 years.

6.1. Temporary Housing Programs in Japan

Japan's organization of post-disaster temporary housing is among the most highly-developed in the world (Bris and Bendito, 2019). Prefectural governments are responsible for providing temporary housing under the Disaster Relief Act, 1947, with funds allocated from the national government. Municipal governments coordinate with prefectures for the selection of sites, the allocation of affected people, and the maintenance of specially constructed housing units. In 2011, the earthquake and tsunami led to the total collapse or destruction of some 108,000 houses, and an additional

117,000 houses suffered damage making them uninhabitable. As a result, more than 450,000 people had to be evacuated to emergency shelters, typically public school gymnasiums. In the event, around 75 per cent of emergency shelters had closed within four months of the disaster as people were moved gradually to temporary housing, although some stayed open until February, 2012. By that time, the massive quantity of debris left by the tsunami had been gathered up and stored at temporary sites in the majority of devastated coastal communities (Hongo, 2012).

Since the disaster of the Great Niigata Fire, 1955, temporary accommodation in Japan had been provided mainly in the form of industrialized prefabricated housing installed in barrack-like complexes (Bris and Bendito, 2019). Typically, prefabricated units provided around 30 square meters of floor area – including two 4.5-tatami-mat living/sleeping rooms, a small kitchen, one bathroom, and no dedicated storage area - suitable for two or three people. This standard plan offered the advantages of high production capacity, uniform building quality, and the possibilities of quick and easy installation, disassembly and portability. All Japanese prefectures in Tōhoku had prior supply agreements with the Japan Prefabricated Construction Suppliers and Manufacturers Association (JPA). However, given the magnitude of the 2011 catastrophe, other companies were also contracted, including members of the Home Production Organizations and the Japan Wooden Housing Industry Association, who supplied traditional wooden housing units (Bris and Bendito, 2019).

That being said, the type of temporary housing used in 2011 was influenced by geographical considerations. Thus, in the Sendai Plain area, undamaged privately-owned rental apartment buildings were available for survivors in urban areas such as Sendai City. About 66,000 units were secured, with 80 per cent of rental costs paid for by the national government. Further north along the Sanriku coast rental accommodation was not a viable option for areas that suffered extensive destruction of housing. The towns in Fukushima were affected by the quake and the tsunami, and some presented a unique challenges for survivors due to the nuclear accident and radiation hazards. Accordingly, around 80,000 Fukushima residents had to be relocated from the emergency evacuation zone for an uncertain length of time. Overall, in Iwate and in northern Miyagi almost only prefabricated housing units were installed to support survivors while they waited for their long-term housing situation to be resolved, while in the rest of Miyagi and in Fukushima mostly private rental apartments were used with public housing accounting for another 18,000 units allocated to survivors and evacuees (Ranghieri and Ishiwatari, 2014).

Each type of temporary housing has their own characteristics, advantages and disadvantages. The strength of using existing rental apartments included a faster exit by survivors living in shelters. Their main weakness was that evacuees often became geographically separated from their original communities on the coast causing local municipalities greater difficulty in visiting citizens and in providing necessary information and support. By contrast, prefabricated temporary housing construction (or mass-produced wooden housing) could be arranged in complexes ranging from 50 to 250 units laid out in rows of six or seven housing units that local governments could more easily supervise and provide services to. This type could also be produced relatively speedily in a matter of months because of the national government's pre-arranged Memorandum of Understanding with prefabricated home manufacturers based upon a standard design. However, many delays occurred in implementing temporary housing complexes along the Sanriku coast due primarily to the difficulty of finding appropriate space for sufficient housing units on high ground away from the devastated coast. Indeed, government policy required land for temporary housing to be on public property as well as being outside the tsunami inundation zone, safe from future disasters (EERI Special Earthquake Report, 2011).

Japanese local governments had learned many lessons about temporary housing management from past experiences with disaster recovery. In Kobe, for example, large tracts of temporary housing were built too far away from the city either in outer suburban locations in the mountains, or even more distant in other municipalities (Edgington, 2011). In the aftermath of the 1995 Hanshin-Awaji earthquake there was an acute shortage of temporary housing and newly built units were allocated through a lottery system. This often created hardship for residents, especially elderly people who lived alone and who found themselves far from their original neighborhood, friends and support systems. Moreover, the shortage of any common spaces, green areas, and adequate living facilities in temporary housing complexes had an adverse impact on the mental health of survivors. These conditions also impeded building a sense of local community and exacerbated the feeling of loss for affected people. At worst, there were many cases of `solitary deaths' (*kodukushi*) of elderly people living by themselves in temporary housing units who could not drive. Indeed, some temporary housing units remained unoccupied as prospective residents in evacuation centres found them inconvenient, uncomfortable and much smaller than their original houses (Edgington, 2016).

Learning from these policy missteps, many municipalities along the Sanriku coast tried to promote the relocation of survivors out of emergency shelters into temporary housing in groups, or initiated other types of programs to improve social networks and to avoid isolation. However, the difficulty of finding land in hilly terrain meant that the supply of temporary housing often fell far short of the demand so that a lottery system was started to determine who was eligible to move into available housing units as they became available, similar to Kobe. While this may have seemed fair, it created considerable anxiety among people who had lived their entire lives in small fishing hamlets that remain the basic units of rural Japanese society in the Tōhoku region. Many elderly survivors were afraid of experiencing loneliness in temporary housing units and the necessity of becoming dependent on other people to drive them to doctors or to shopping. They often preferred to stay in evacuation shelters until all the people of their particular village could be resettled together (Shiozaki, 2013).

Yet another quandry concerned the plight of children in temporary housing. Due to the remote location of many complexes children often had to be bussed to schools, and back again, and consequently had little or no chance to play with each other after school. School playgrounds themselves were often used for transitional housing, and many city parks were swept away by the tsunami (interview with Kuriya Katsuyoshi, NGO worker, Minami Sanriku, 20th June, 2015).

Overall, Japanese temporary housing units had undergone very little variation in design, either in construction or in layout during the previous 25 years. The pattern of temporary housing complexes encouraged residents' independence and self-sufficiency, but contributed to isolation and a lifestyle that made it harder to assist the most vulnerable residents. Moreover, the bare-minimum standards necessary to meet the tight deadlines for assembly were not suited to the cold climate of the Tōhoku region. Problems included gaps between walls and roofs encouraging drafts, the absence of noise or thermal insulation, and the lack of shelves of storage areas. In summer months the temporary housing units became humid and damp, encouraging mold on the inside walls. Outside, the units were assembled with no awnings or enclosures around them making it hazardous for small children and the elderly. As relocation into temporary housing proceeded several innovations were introduced, including physical upgrades to improve daily living comfort (such as outside benches and fences). The Japanese Red Cross provided the so-called `six treasures' for each unit – a TV, refrigerator, microwave oven, washing machine, rice cooker and an electric water jug – using funds collected from donations (Japanese Red Cross Society, 2020).

To counteract the problems associated with social isolation, local governments, volunteers and non-governmental organizations (NGOs) arrangedd patrols to check on temporary housing residents and to assist with physical and mental health issues. Special community centres were built with the aim of promoting communication among residents by organizing various events. Some of the larger temporary housing complexes provided temporary convenience stores, hairdressers and postal services. Smaller complexes were often connected to shops by bus, and in some cases visiting trucks from the shops came to temporary housing locations with food and fresh vegetables. Even so, Bris and Bendito (2019) reported that initiating these activities and services was not enough to prevent *kodokushi*, which reached levels on par with Kobe.

Over time, municipalities along the Sanriku coast engaged in land development projects to create new housing lots to for disaster-affected communities (Edgington, 2017). In this regard, survivors were not expected to stay in transitional accommodation for more than two years under the provisions of the Disaster Relief Act, 1947. However, due to the slow progress and delays in the work to prepare land for new buildings that would be safe in the event of another tsunami, municipalities were forced to grant one-year extensions to allow evacuees to stay in temporary housing complexes. In fact, it took longer to relocate all residents from various forms of temporary accommodation to permanent housing than even five years after the Great Awaji-Hanshin Earthquake. For example, as the sixth anniversary off the disaster arrived in 2017 more than 35,000 people were still living in makeshift 2-room apartments (Brasor and Tsubuku, 2017). Even by 2018 there were still more than 5,600 people recorded living in temporary housing in Iwate, Miyagi and Fukushima, most comprising retired seniors who had no opportunity to enter the private housing market and who were reliant on the construction of public housing by either the prefecture or municipal governments. In temporary housing compounds where many residents had already moved away, those remaining had fewer interactions with other people and needed continuous support (Bris and Bendito, 2019).

6.2. Transitional Housing Programs in British Columbia

British Columbia has not yet experienced a catastrophic earthquake and tsunami leaving large numbers without housing. Summer wild fires and spring floods in BC often gives rise to an evacuation of residential areas. In such circumstances the BC government funds volunteers to assist the evacuees under the Emergency Services Support (ESS) program, which was discussed earlier. During the period immediately following a fire or flood emergency, ESS volunteers help evacuees to connect with emergency lodging or long-term housing providers. The ESS program itself is designed to provide short-term assistance only for up to 72 hours. During this time, lodging and food services are provided through commercial facilities, such as hotels, restaurants and other local merchants. The BC Ministry of Housing supports municipalities who receive evacuees by coordinating emergency demands for lodging. Thus, if large numbers of people forced from their homes cannot find motel or hotels then BC Housing (the operational organization of the Ministry of Housing) provides temporary supplies, such as bed cots and blankets, for short—term group accommodation, often arranged in community halls (interview with S. Bibby, Director, Security and Emergency Services at BC Housing, September, 2015). For longer-term accommodation required when a person's house is either burnt or otherwise damaged, the expectation is that evacuees would use their own resources to pursue recovery housing options, such as funds released through insurance claims. Standard home and business insurance in BC typically provides coverage for living expenses elsewhere for the period that evacuees are unable to return to their residence (Emergency Management BC, 2010).

In the event of a catastrophic emergency following a Cascadia subduction earthquake that displaces hundreds or thousands of residents from their homes, either in Vancouver Island or in the Vancouver region, it will become necessary to construct immediate emergency shelters as well as long-term replacement houses for lost structures. Immediate emergency shelters for large-numbers of displaced persons would likely include tents, trailers, and camper vans. These would be required for the first few weeks or months following a disaster. After this period, transitional housing solutions would be necessary (interview with S. Bibby, op.cit.).

What then are the lessons from Japanese experience for local municipalities in BC should such a mass-accommodation program need to be activated? First, residents in temporary housing may have to live in transition housing for 5 years or possibly longer before their original houses destroyed in the quake or tsunami could be rebuilt. Consequently, there are many benefits to be realized if municipalities engage in `pre-emptive recovery' planning, especially preparing for post-disaster temporary housing before a disaster occurs. Where land is scarce, say in the already built-up areas of Victoria and Vancouver or in coastal towns that are likely to suffer high levels of damage, the preparation of a `land bank' should be a critical component of pre-disaster contingency plans. A land bank program would identify preselected areas that could be quickly converted for temporary housing, or even more permanent relocation over 10 to 20 years. Second, community cohesiveness of evacuees could be encouraged by providing well-thought out timing and site options for the provision of temporary housing.

In this regard, BC Housing has already examined the likely need for modular and manufactured housing solutions to long-term dislodgment of communities from devastated areas. Accordingly, in 2019 it developed a `tool kit' for municipalities and First Nations governments, based on best-practice design principles for modular housing complexes (BC Housing, 2019). The approach behind this policy initiative is to develop well-designed temporary housing units as a step towards providing permanent housing. In other words, by providing modular housing of high standard that meet BC building code requirements and which has a building life expectancy of several years, local communities could contribute to more permanent housing expectations. The `tool kit' also encourages communities to reserve potential sites for transitional housing in advance. From a local municipality's perspective, high-standard modular housing built as part of a post-disaster reconstruction phase could be treated as community public rental accommodation for survivors while they establish their own personal recovery. To that end, there would also be a need for local governments in BC to assume the role of managing large numbers of rental units.

7. Conclusions

This paper has argued that The Great East Japan Earthquake and tsunami was a `focal event' - its destruction along the coast of Tōhoku on the same scale as the disaster that will someday occur in in coastal British Columbia. It is also one of the rare disasters that occur at low frequency but which have pernicious impacts that challenge public policy response everywhere. Accordingly, it behooves policy makers in BC to draw lessons from the Japanese experience in 2011. Table 1 suggests implications for British Columbia from the Japanese post-disaster findings examined in this paper, grouped under the four pillars of disaster management.

(TABLE ONE ABOUT HERE)

Other aspects of Japanese post-disaster practice not covered in this study also warrant a fuller examination through future research, including how the disposal of huge volumes of post-disaster debris were organized in the Tōhoku region and best-practices in the management of the many evacuation shelters that were required immediately after the tsunami struck. In addition, the efficacy of various longer-term land-use and economic reconstruction programs carried out since 2011 in the affected communities should be considered. Of course, the traditional adage highlighted earlier in this paper that `all disasters are local' applies in this case, requiring a nuanced understanding of applicability of Japanese post-disaster policy to BC. By way of illustration, Japanese structural and engineering programs against tsunamis, such as constructing high sea walls, are unlikely to find wide-spread approval in British Columbia.

No country can prevent large-scale natural disasters or even plan for them adequately, as we cannot predict when and where they will happen. We can only prepare for them by learning as much as possible about the risks and consequences of devastating events, and also by making informed decisions to manage both. Both Japan and British Columbia have Japan well-resourced agencies responsible for disaster management. But in regard to coping with low-probability high-impact catastrophes, Japan has the comparative advantage in terms of its `culture of disaster preparedness' based upon its long experience in coping with a multitude of natural hazards (Lee and Preston, 2012). The Great East Japan Earthquake was the first disaster in Japan's modern history that exceeded all expectations and predictions, and its dimensions were almost beyond imagination. Nonetheless, the relatively high rate of survival in Tōhoku can be attributed to high awareness of the tsunami hazard and subsequent effective evacuation, especially along the Sanriku coast, as well as seismic reinforcement that reduced the number of casualties and damage from the mega-earthquake. Officials in British Columbia have known about the Cascadia Fault hazard for more than 30 years but the lack of regular earthquakes and experience with coastal tsunamis in BC means that governments have to make every effort to raise public awareness as well as accelerating the implementation of contingency plans.

Japan was able to learn from the policy missteps made at the time of the 1995 Hanshin-Awaji earthquake. It has also revised and improved its own disaster management system since 2011. For example, the JMA has expanded its seismic and tsunami monitoring network to provide quicker and more accurate estimations of earthquakes and tsunami (Japan Meteorological Agency, 2013); Suppasri et al., 2015). Local municipalities have been involved in hazard mapping along the Tōhoku coastline and rebuilding towns that relocate housing areas away from the coast on higher ground, and which incorporate new road layouts that signal well-defined escape routes and well-located evacuation centres (Edgington, 2017). Elsewhere in Japan, governments are preparing for the high probability of a large Mw8-Mw9 earthquake occurring along the Nankai, Tonankai and Tokai fault rupture areas off the Pacific coast of southwest Japan, as well as a Mw7 Tokyo inland earthquake (Edgington, 2019). Evacuation plans implemented during the 2020 summer typhoon season in southern Japan suggest implications for disaster management at a time of Covid-19. The protocols adopted in this case involve extreme sanitary precautions in evacuation shelters, restrictions on numbers accepted at each centre, social distancing and the use of hotels to avoid problems associated with `the three Cs' of confined spaces, crowded places and close contact. Some municipalities in Kyushu showed crowding levels and capacity levels on their web site in real time. Others tried to distribute evacuees by arranging their transportation to other cities in preparation for oncoming typhoon damage comprising high winds and driving rain (Osumi, 2020, Reynolds, 2020; The Japan Times (2020; The Mainichi, 2020).

Footnotes

1. The earthquake, which occurred off the Pacific coast of the Tōhoku region at approximately 2.46pm on March 11, 2011, was named the `2011 Tōhoku region Pacific offshore earthquake' by the Japan Meteorological Agency but is more commonly known as the Great East Japan Earthquake among the general public and academia (Iokibe, 2020).

2. A mega-thrust earthquake is categorized as a great earthquake with the magnitude more than 8 Mw in seismological classification (Natural Resources Canada, 2020).

3. Ria coastlines are distinctive geographical features, somewhat similar to the Norwegian fjords. They result in an indented coastline of deep V-shaped bays where land rises rapidly from the sea to the mountains. Because of the nature of the seabed the rugged Ria coastline in Miyagi and Iwate prefectures caused the 2011 tsunami energy to focus and amplify, with waves running up steep coastal valleys and striking up to 30 meters in height (Satake, 2005).

4. In the 1990s, Japanese geophysicists began studying a fault model of the 869 Jogan Earthquake, now considered similar to the March 2011 earthquake. Research papers were published in 2007 to 2010 estimating that the Jogan quake was a M 8.4 earthquake in a large source off-shore zone measuring 200 kms by 100 kms (reported in Sawai et al., 2012). However, even this assessment of the Jogan quake's force was much smaller than the magnitude Mw9.0 scale the 2011 Great East Japan Earthquake. In 2009, seismologists with the Japanese National Institute of Advanced Industrial Science and Technology (AIST) concluded that because of the uncertain re-occurrence of this type of quake, the risk of such an infrequent event was accepted as the probability was low, and the costs incurred in mitigation (say through higher sea walls or relocation of buildings and settlements), were considered undesirable. There was no knowledge of when it might re-occur (reported in Birmingham and McNeill, 2012).

5. Paleoseismography refers to the study of past earthquakes (`paleo' means old, and `seismology' is the study of earthquakes). A fundamental assumption that paleoseismologists use is that what happens in the past will most likely transpire in the future (McCalpin and Nelson, 2009).

6. The Japanese earthquake seismic meters measures in *shindo*, which is the actual degree to which the ground at a particular location is shaking (Japan Meteorological Agency, 2020).

7. There are no known means to reliably predict earthquakes. However, seismic instruments can rapidly detect an earthquake as it begins to unfold and communicate a warning before shaking arrives. Earthquakes release energy that travels through the Earth as seismic waves. Primary or `P' waves travel faster than the damaging `S' (or secondary) waves that are the cause of severe ground shaking. It is the ability to detect the first `P-waves' that enables early warning systems to provide rapid estimates of the location and magnitude of an earthquake as it occurs, and the arrival time and intensity of ground-shaking at specific locations across a region, allowing protective actions to take place before any shaking hits. For the Japan Meteorological Agency's early warning to be effective it must be issued before the S-waves arrive at an affected location. As every second counts the entire process is automated (Cordkil, 2011).

8. In an attempt to further account for why evacuation behavior varied among Tōhoku communities, Suppasri et al. (2012) analyzed the role of previous tsunami events, particularly the maximum runup height of tsunami waves. For instance, in Ōfunato, Iwate prefecture, maximum runup heights of 38.2 meters and 28.7 meters were recorded for the 1896 Meiji and 1933 Showa tsunamis, respectively, due to the funnelling effect of the Ria V-shaped bays, which amplified the tsunami damage. However, for these same two tsunamis, a much smaller maximum runup height was recorded in the Sendai plain of less than 5 meters and 3.9 meters, respectively. The tsunami in 1960 that was generated by an immense earthquake in Chile also concentrated in, and mainly damaged, the Sanriku coastal towns. However, as noted above, the 2011 tsunami was generated by a much larger earthquake and its 500 km rupture covered the whole area of the Tōhoku region. Although the tsunami was higher along the Sanriku coast and more perilous due to the Ria coastline, prior experience and awareness encouraged local residents to evacuate rapidly. On the other hand, people in the Sendai plain area and in Fukushima had less tsunami experience and so were slower to evacuate, yet the tsunami height was lower and the devastation was less. These factors may explain why count of fatalities in the two areas were similar.

9. The experience of two schools illustrates the importance of continual disaster education and personal responsibility. In the Unosumai area of Kamaishi city a successful school evacuation is often called the "Miracle of Kamaishi" because all 580 students and teachers from two schools survived the tsunami even though their school buildings were destroyed by the tsunami. Although their schools were located outside the expected tsunami inundation area, on the basis of historical records, the students decided to leave their schools and evacuate to higher ground, and all of them survived. A school evacuation drill was performed on 3rd March (the memorial day of the Showa-Sanriku tsunami), about one week before the tsunami (Ranghieri and M. Ishiwatari, 2014). `*Tsunami tendenko*' is a phrase in the dialect of the Sanriku region that is used to encourage people to evacuate from the tsunami alone without taking any belongings or waiting for other family members. This phrase can be translated as "you should protect your life by yourself". Therefore, it is acceptable not to blame people who did not help others. The "Miracle of Kamaishi" was a very good example of the practical use of *Tsunami tendenko* because the children started their evacuation by themselves, and all were saved. By contrast, the example of Okawa primary school, located near the mouth of the Kitakawa River within Ishinomaki City indicates the high cost of unpreparedness. The 2011 tsunami claimed 74 out of a total of 108 children and 10 staff. Most of the children that survived climbed up a small mountain behind the school in order to escape. Others went to a nearby river bridge where they were struck by the tsunami. The school had not conducted evacuation drills and had no tsunami plans before the 2011 event (Parry, 2017). The fine line between life and death after a major tsunami appears to be successful preparation (Koshimura and Shuto, 2015).

10. An interesting example of support in the relief stage concerns the city of Tono (population around 26,000 in 2010) which lies roughly 25 kms inland from the coast. Annual exercises since 2007 focused on how Tono could provide swift support to coastal cities and towns if they were affected by a tsunami. Despite damage to several public buildings in Tono, life-saving supplies were provided to several tsunami-affected cities through to mid-April, including 140,000 ready-to-eat rice balls, 125,000 blankets and clothes, 38,000 kilograms of rice and 63,000 litres of fuel. A total off 4,106 city employees and citizens, together with 2,649 volunteers were mobilized to provide support (World Health Organization, West Pacific Region, 2012).

Table 1. Lessons from Japan for British Columbia Arising from the Great East Japan Earthquake and Tsunami.

Disaster Management Pillars	**Lessons from Japan**	**Implications for British Columbia**
1. Mitigation	-do not underestimate the worse scenario earthquake or tsunami. -the benefits of seismic retrofitting of vulnerable building structures and critical infrastructure.	-conduct impact scenarios for a full rupture of the Cascadia Faultline. -implement mandatory seismic upgrading of pre-1970 building stock and critical infrastructure in Vancouver, Victoria and elsewhere in Southwest BC.
2. Preparedness	-understand the limitations of early warning systems and explain these to affected communities. -expand drills and training to prepare for mass evacuation at the time of a mega-earthquake. -many evacuation centres were poorly located.	-continue with the coastal earthquake early warning system in BC; but understand and explain to local communities its limitations in the case of providing warnings `local' tsunamis generated by Cascadia Fault earthquake. -prepare coastal communities on a routine basis to evacuate independently to higher ground, or to vertical evacuation structures, as soon as a large earthquake occurs; identify safe refuge locations.
3. Response	-the necessity of assembling large numbers of first responders from outside the damaged areas to assist in search and rescue, as well as relief operations. -plan for military and commercial assistance to clear roads quickly to stricken coastal communities.	-conduct frequent joint-military and civilian drills in advance of the Cascadia Faultline mega-earthquake and tsunami. -develop mutual aid agreements (MOAs) with federal agencies, provincial agencies and local municipalities outside of the `at risk' areas of coastal BC. -develop mutual aid agreements with private sector road construction operators to quickly gain access to coastal communities.

4. Recovery	-the inevitability of large-scale post-disaster displacement and the need for rapid large-scale transitional housing programs. -the likelihood of survivors requiring temporary housing for 5 years or more.	-develop pre-disaster MOAs with modular building companies for the construction of well-designed temporary housing. -conduct pre-disaster recovery contingency plans that identify land for modular housing complexes for local survivors.

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List of Figures

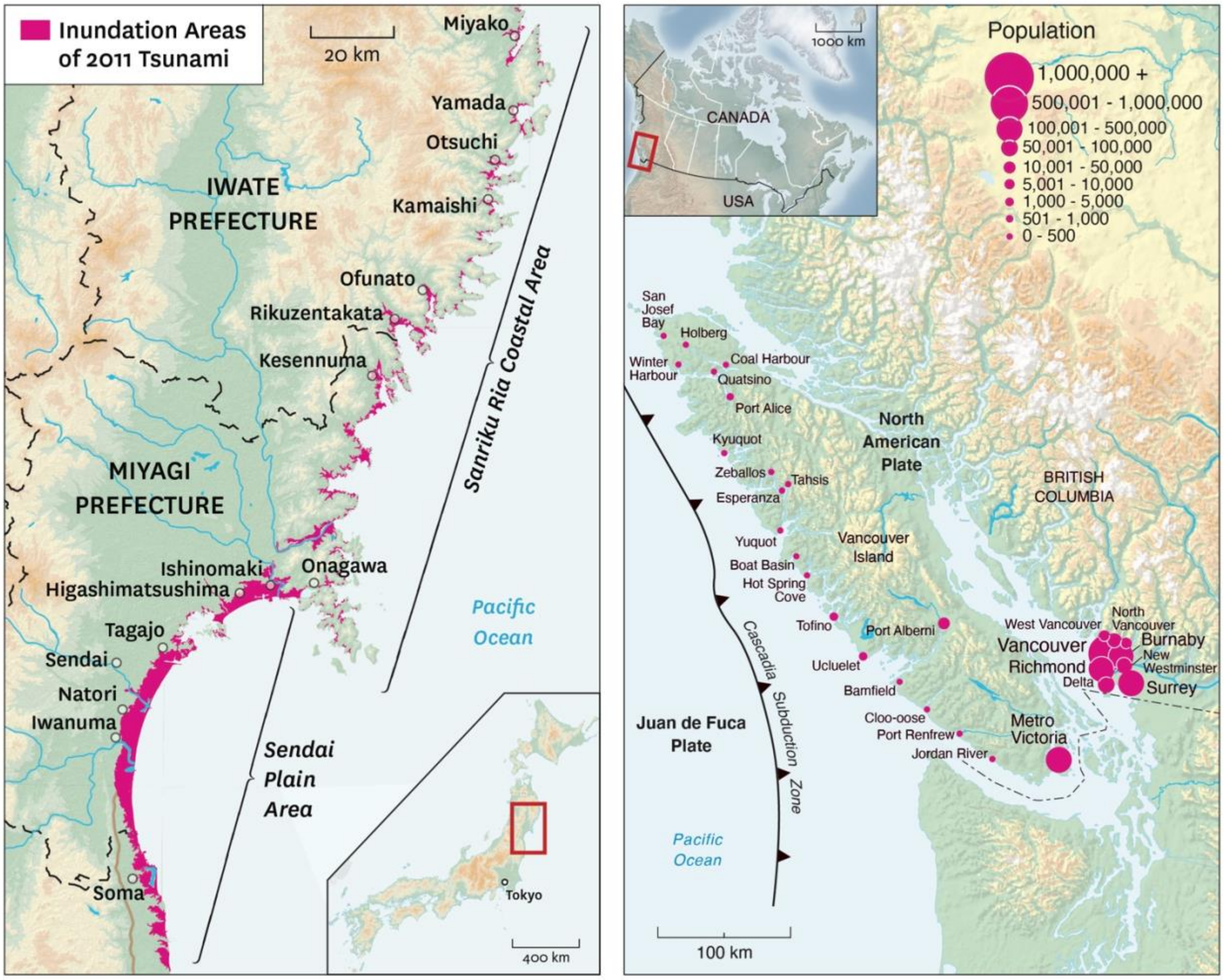

Figure 1. The coastlines of Tōhoku Japan and Southwest British Columbia

Figure 2. The Four Pillars of Disaster Management (based on material in Gallant, 2008).

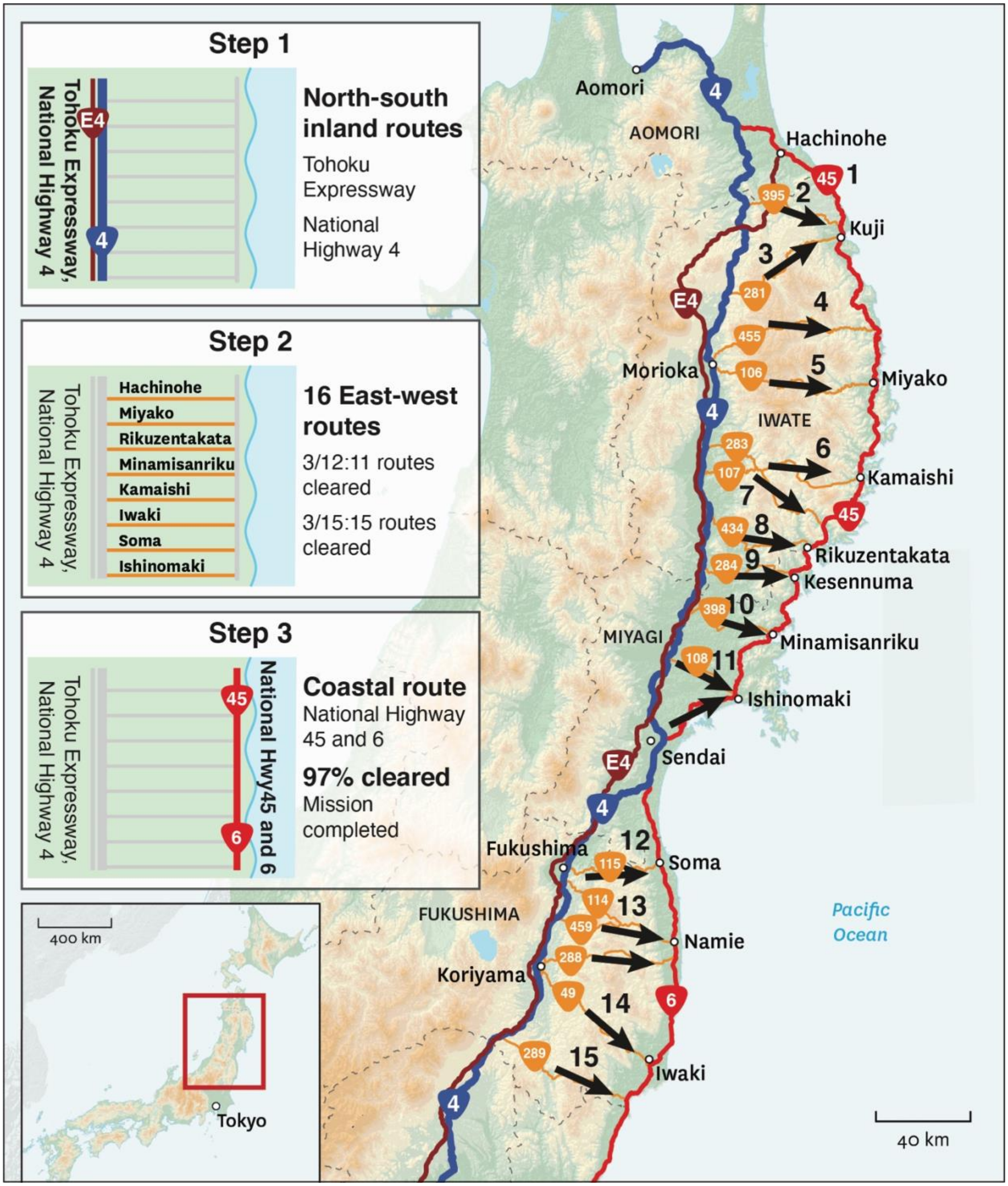

Figure 3. Map of Operation Comb Teeth, March 2011.
Source: base on information in Ranghieri and M. Ishiwatari (2014)

Figure 4. Staging Areas and Transport Nodes at the Time of a Coastal Earthquake in British Columbia.
Source: based on material contained in Province of British Columbia (2015)