Advances in Natural and Technological Hazards Research

Vicente Santiago-Fandiño
Shinji Sato
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Kanako Iuchi *Editors*

The 2011 Japan Earthquake and Tsunami: Reconstruction and Restoration

Insights and Assessment after 5 Years

Springer

Advances in Natural and Technological Hazards Research

Volume 47

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ISSN 1878-9897 ISSN 2213-6959 (electronic)
Advances in Natural and Technological Hazards Research
ISBN 978-3-319-58690-8 ISBN 978-3-319-58691-5 (eBook)
DOI 10.1007/978-3-319-58691-5

Library of Congress Control Number: 2017944442

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer International Publishing AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Onagawa Port in Miyagi Prefecture. This composite picture shows below the enormous destruction suffered by the port due to the 15 m high tsunami waves which destroyed more than 70% of the buildings and produced a large number of casualties. The *top image* gives a view of the extent of its reconstruction by August 2015 initiated by the local private sector and the community soon after the tsunami occurred; the ongoing large landscaping and over 4 m high ground rising to relocate commercial and industrial facilities can be easily seen (photos by V. Santiago-Fandiño)

Foreword

A tsunami is one of the rare, naturally occurring, low-frequency disasters that have an enormous impact and can be extremely devastating. In the past 100 years, more than 260,000 people perished in 58 separate tsunamis. At an average of 4600 deaths per disaster, the casualty toll has surpassed that of any other natural hazard. Tsunamis know no bounds, making international cooperation a key factor in developing deeper political and public understanding of risk reduction measures. As a result, the UN General Assembly declared the 5th of November as World Tsunami Awareness Day, as of 2016.

The devastation caused by the earthquake and tsunami in Japan in 2011 included approximately 20,000 casualties (dead and missing people). The tsunami levelled 130,000 houses and severely damaged 260,000 more. Around 270 railway lines ceased operation immediately after the disaster, and 15 expressways, 69 national highways and 638 prefectural and municipal roads were closed. About 24,000 ha of agricultural land was flooded and severely damaged, and aquaculture facilities were completely destroyed. In addition, the tsunami triggered a nuclear accident at the Fukushima Daiichi Nuclear Power Plant, which compelled the government to establish evacuation zones and to order approximately 154,000 people to be displaced for their own protection.

Five years have passed since the tragedy in 2011. In fact, the overall reconstruction and revitalization period was well underway at this time then. Shortly after the March 2011 events, the Japanese government had presented budgets, modified laws and ordinances and eventually established a “Reconstruction Agency” in 2012. A reconstruction time frame of 10 years was specified: the first 5 years (2011–2015), the “Concentrated Reconstruction Period”, was allocated 25 trillion Japanese Yen (approximately $250 billion), while the latter 5 years (2016–2020), the “Reconstruction and Revitalization Period”, have been allocated 6.5 trillion Japanese Yen (approximately $65 billion).

In accordance with this national strategy, a huge number of engineering, environmental, social, economic and policy projects have been implemented or are still underway since March 2011. Since the first 5-year period ended in March 2016, progress and outcomes are likely to be evaluated by the Reconstruction Agency to ascertain their efficacy, achievements and challenges. A publication is planned, probably by the end of 2017, compiling the findings, experiences and lessons learned in the selected case studies; the scientific and academic community will be invited to contribute, as will the decision makers and planners.

This book could be seen as the precursor of this planned publication. Selected case studies document the significance of the 2011 disaster and its environmental and social impacts, as well as the recovery and reconstruction process. It complements previous publications, albeit covering a larger time span, summarizing experiences and lessons learned in various aspects of the process, as well as issues that remain as yet unresolved.

This book is a unique collection of papers written by experts and researchers in a number of fields, focusing on the tsunami impacts and the restoration and reconstruction process after the 2011 catastrophe. By incorporating the major lessons learned in this analysis, we expect to enhance the future resilience and sustainability of the damaged areas.

We have no intention of repeating the tragedy of the 2011 Tohoku earthquake and tsunami. However, it is difficult to prevent, reduce and mitigate a low-frequency disaster. It is absolutely mandatory that a careful analysis should be made of the 2011 catastrophe since a new disaster or combination of them may occur again, but we have to keep in mind that even then it might be difficult to use the accumulated experiences and knowledge due to changes that may have taken place in the society in the meantime.

We believe that it is important to share our experience so that other countries can better protect themselves from major disasters by adopting—or adapting to, as required—some of the measures taken by Japan to deal with the enormous challenge of restoring and reconstructing the damaged areas and also learn about the strengths and weaknesses of the response to the 2011 Tohoku earthquake and tsunami for their own benefit. It is my belief that due to the nature, focus, analyses and time span covered by this book, a broad range of professionals, scholars, decision makers and others, whether directly involved or merely interested in the restoration and reconstruction process after the March 2011 events, will also greatly benefit from its content, insights, analyses and lessons learned.

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Fumihiko Imamura

Preface

This book was conceived as a result of witnessing and/or directly participating in the enormous effort of the people along the Tohoku coastline in the north-east of Japan to restore and reconstruct the destruction left by the devastating earthquake and tsunami in March 2011. During the more than 5 years since then, the national and prefectural governments, local authorities and residents, the private sector, scholars and the academia as well as research institutions, NGOs and the general public—either as volunteers, in local associations or through their own personal efforts—have been ceaselessly trying to restore and/or rebuild the affected areas, social structures and lives. Likewise, there has been no lack of effort in trying to better understand the causes and impacts of the earthquake and the tsunami along the coastline and in developing preventive measures, scientific and technological approaches, engineering and construction, laws and policies to be better prepared for any forthcoming similar unavoidable events in Tohoku or in other coastal areas in Japan.

This publication has been an enormous challenge, both technically and work-wise. The idea of compiling a number of studies to provide an overview of what has been done in the various fields of restoration and reconstruction work in Tohoku in the 5 years since the March 11, 2011 events originated in mid-2015 and only came to fruition in early 2017, with the publication of this book.

Although this book is not intended to be an exhaustive compilation, it is the culmination of several years' experience and the comprehensive knowledge of experts in the restoration and reconstruction process, which could certainly be of interest to scholars, researchers and stakeholders alike.

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Kyoto, Japan — Norio Maki
Sendai, Miyagi, Japan — Kanako Iuchi

Acknowledgements

The editors wholeheartedly express their gratitude to the principal authors and co-authors since without their kind and committed collaboration, the present book would not have become a reality. Likewise, the same is expressed to the peer reviewers for their most helpful comments and advice. Last but not least, the editors also express their appreciation to those who directly or indirectly participated in the production of this book including also Springer International Publishing AG for the support and flexibility shown throughout its production.

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Part I
Planning, Policy and Governance

Chapter 1
Complexities and Difficulties Behind the Implementation of Reconstruction Plans After the Great East Japan Earthquake and Tsunami of March 2011

Yasuaki Onoda, Haruka Tsukuda, and Sachi Suzuki

Abstract The damage resulting from the Great East Japan Earthquake (GEJE) and subsequent tsunami necessitated a re-evaluation of the way land is used in the affected areas. Despite receiving various reconstruction subsidies, many disaster-affected municipalities have struggled in their rebuilding efforts under various difficulties: scarce resources, a sharp increase in construction costs, a shortage of expertise, and the strict application of the new tsunami mitigation rule (Two-Two Rule). However, it has been difficult to track these continuous challenges and struggles. Most reconstruction decisions are made at the municipal level, and the information is not widely shared.

The author has participated in many reconstruction projects as an architectural planner and a reconstruction advisor. Based on the outcome of recent studies and the author's own practical experiences, this article aims to show the actual status and challenges of reconstruction works after the GEJE.

Keywords Great East Japan Earthquake (GEJE) • Two-Two Rule • Build Back Better • Public housing • Relocation • Community

1.1 Introduction

On March 11, 2011, a magnitude 9 earthquake hit northeast Japan. It caused a huge tsunami, which devastated five hundred km of the coast. 15,891 people were killed, and more than 2500 people are still missing (National Police Agency 2016). This

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V. Santiago-Fandiño et al. (eds.), *The 2011 Japan Earthquake and Tsunami: Reconstruction and Restoration*, Advances in Natural and Technological Hazards Research 47, DOI 10.1007/978-3-319-58691-5_1

great loss of life and property reflects the serious impact that low-frequency, large-scale disasters like tsunamis can have on our society.

The responsibility for reconstruction after the Great East Japan Earthquake (GEJE) lay with Japan's governmental bodies. The central government established the laws and put together a budget for reconstruction; offices of prefectural governments supported municipalities and took on the main role of planning hazard mitigation; and the individual municipalities played a direct role in the planning and implementation of the reconstruction work. With urban infrastructure taken care of by the local governments, residents of affected areas worked on restoring their homes and livelihoods.

Under this division of responsibility, each municipality has large influence on the outcome of its own reconstruction (Ubaura 2015; Iuchi et al. 2014). Depending on available resources and the socio-economic conditions of the area and residents, each municipality took a different approach to reconstruction, with varying degrees of success. Many municipalities faced great challenges, and few managed to achieve Build Back Better (BBB).[1]

As an external expert, the main author of this chapter has been assisting several municipalities in the planning and implementation of their reconstruction work. Focusing on efforts at the municipal level, this article introduces the constraints and unique strategies taken to tackle those challenges, and explores issues of hazard-protection design and planning strategies, the implementation process, and public housing construction.

1.2 Hazard-Protection Designs and Planning Strategies

1.2.1 Level-One Tsunami and Level-Two Tsunami

For affected municipalities, the first step of planning is to identify future disaster risks and put together a strategy for protection. After the GEJE, the government's Central Disaster Prevention Council decided to establish the Development of Areas Resilient to Tsunami Disasters Act, which designates two levels of tsunamis that municipalities have to consider when creating protection plans (Maki 2015).

A "Level-One tsunami" is caused by a magnitude 8 earthquake and is estimated to occur once within a hundred years, while a "Level-Two tsunami" is caused by a magnitude 9 earthquake and is estimated to occur once every 500 to a thousand years. The council then decided that reconstruction policies should include the building of sea embankments along the coastline to protect lives and properties against a Level- One tsunami, and to assure more time for evacuation in a Level-Two tsunami.

[1] The United Nations Office for Disaster Risk Reduction (UNISDR) released the Sendai Framework for Disaster Risk Reduction in March 2015 (UNISDR 2015b). The Build Back Better (BBB) principle is one of the four priorities stated in the framework.

The prefectural office set the height of each sea embankment based on the results of a computer simulation. In order to estimate each tsunami wave as precisely as possible, the Ministry of Land, Infrastructure and Transport (MLIT) developed a computer-simulation program that is operated by the prefectural office to support reconstruction planning. The tsunami-affected municipalities organize their reconstruction plans based on the results of the simulations.

Facing tough emergency conditions, as well as stress on time and resources, prefectural governments had to simplify the response to simulation results in order to push through their reconstruction plans as quickly as possible. For example, even though the 500-km coastline is made up of diverse topographies, it was roughly divided into several "regional coasts." There are 24 regional coasts in Iwate prefecture, 22 in Miyagi prefecture and 14 in Fukushima prefecture. It was decided that, for the sake of simplicity, embankments within each regional coast would be built to the same height. However, this decision proved inefficient, as it did not take into account each area's population and the density of buildings that need to be protected behind the embankments. It also failed to address the fact that the estimated height of a tsunami at the mouth of a bay is actually much lower than that at the inner part of a bay.[2]

1.2.2 Two-Two Rule and Regional Development

The interval between two successive Level-Two tsunamis is estimated at about 500 to a thousand years. But, for the victims, the impact is traumatic and a lot more recent. Many find it hard to accept a policy in which the central government merely encourages them to evacuate and take refuge, without building physical protection. In response to public criticism, the central government changed its policy for a Level-Two tsunami, to include setting up a disaster-hazard area. It tasked the local governments with estimating the risks in their areas and drawing up boundaries showing where the biggest risks are.

Research showed that the rate of destruction caused by a tsunami is influenced by the inundation depth, and that its inflection point is about 2 m deep (MLIT 2011). Using this result, the government announced that any area that is vulnerable to more than 2 m depth of inundation from a Level-Two tsunami would be considered a high-risk zone. This concept of protecting cities against a 2-m inundation caused by a Level Two tsunami is hence called the Two-Two Rule. It's widely known among reconstruction practitioners.

Because it is convenient to set boundaries based on computer simulations done by the prefectural office, many disaster-affected municipalities used these boundaries to create their own reconstruction plans. As a starting point to developing their

[2] An exception is the Kesennuma area, where the bay mouth and inner harbor are categorized in the same "regional coast" (*see:* http://www.thr.mlit.go.jp/Bumon/B00097/K00360/taiheiyouoki-jishinn/kaigann/kaigann2.pdf).

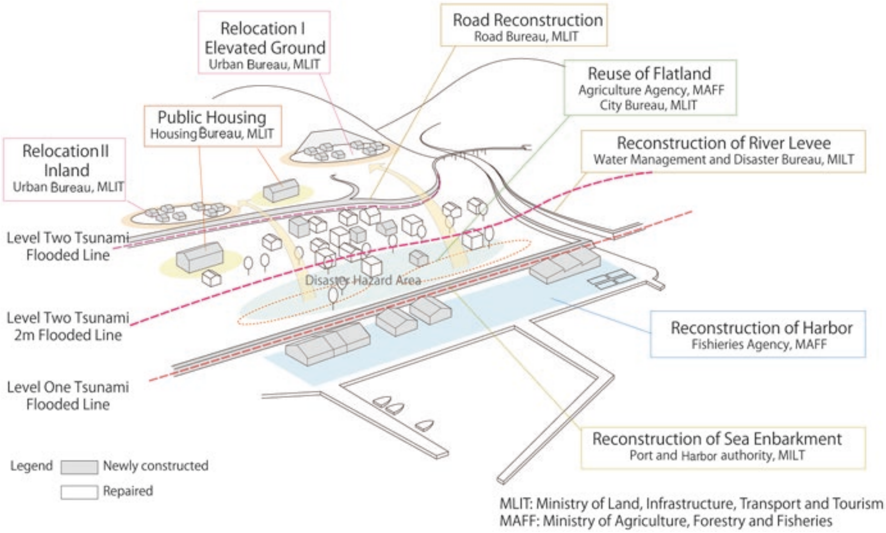

Fig. 1.1 Schema of reconstruction project from GEJE (Y.Onoda)

reconstruction plans, all municipalities had to identify their "Two-Two boundaries" so as to determine the appropriate tsunami protection and land-use restrictions. However, results of the computer simulation are interconnected with the design of hazard protections such as sea embankments, bay-mouth breakwaters, mounds etc. (Fig. 1.1). So testing several combinations or modifying designs based on simulation results required asking the prefectural government to do multiple simulations for accuracy. Unfortunately, only a few municipalities took this multi-cycle approach in their planning.

1.2.3 Reconstruction Strategies

After the municipalities finalized their recovery plans, they had to negotiate with the national reconstruction agency to get enough funding through the Great East Japan Earthquake Subsidy. The agency—a unit established by the central government as an authority for post-disaster reconstruction after the GEJE—prepared a set of various project schemes and subsidies from which municipalities can select. These include building hazard protections, land adjustment, public housing construction etc. Each municipality had its own strategy for choosing its project, and these strategies differed widely.

Following Two-Two Rule, some affected municipalities constructed new sea embankment to protect themselves against Level One tsunamis, and have their ground levels raised as protection against Level Two tsunamis. This strategy usually requires large-scale, long-term construction work, which can cause a strain.

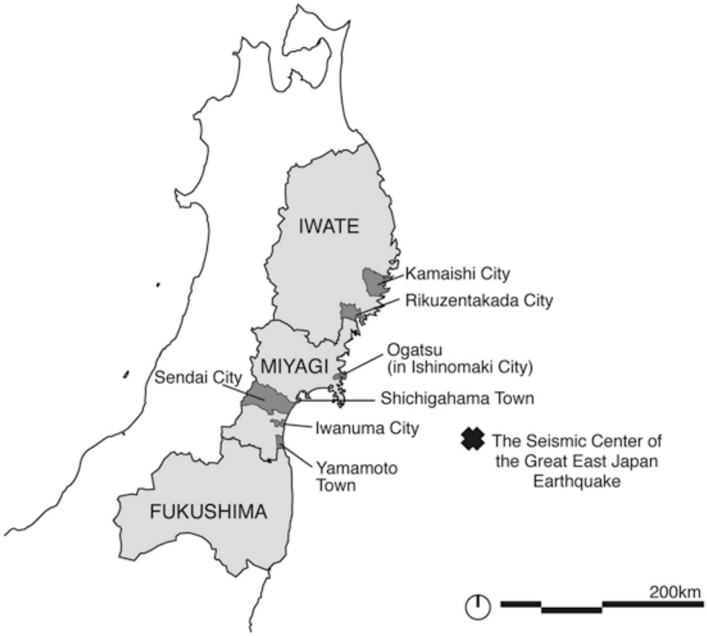

Fig. 1.2 Map of three heavily affected prefectures (Y. Onoda)

Rikuzentakata City[3] (Fig. 1.2) is one example where the impact was quite severe. The municipality applied for large-scale rebuilding (Fig. 1.3a) and ground raising, which was deemed necessary. But the construction work lasted many years, causing a population outflow.

The situation was even more drastic in Ogatsu, in Ishinomaki City. The municipality decided to construct a large sea embankment to protect against a Level One tsunami. However, with the Two-Two Rule, there was insufficient land in the safe zones to move the residents to. So, residential land had to be created by cutting through the hard rock of a hillside (Fig. 1.4). The construction work was elaborate, time consuming and produced very limited results. Consequently, many residents decided to move out of Ogatsu, causing the population there to drop significantly.

There are, however, successful cases, such as Kamaishi,[4] which avoided huge projects involving ground construction, and instead combined (1) several hazard protections with (2) hierarchical disaster-risk zones. Kamaishi's hazard protections consisted of repairing a bay-mouth breakwater, building a new sea embankment against an L1 tsunami and having an artificial mound, all of which work together to greatly reduce the impact of a tsunami (Fig. 1.3b).

Hierarchical disaster-risk zones are designed to contain several classes of restrictions: a safe area allows general construction, while higher risk areas allow the

[3] Population of Rikuzentakata City is 19,472 (October 2016) and the area is 231.94 km^2.

[4] Population of Kamaishi City is 36,372 (October 2016) and the area is 440.34 km^2.

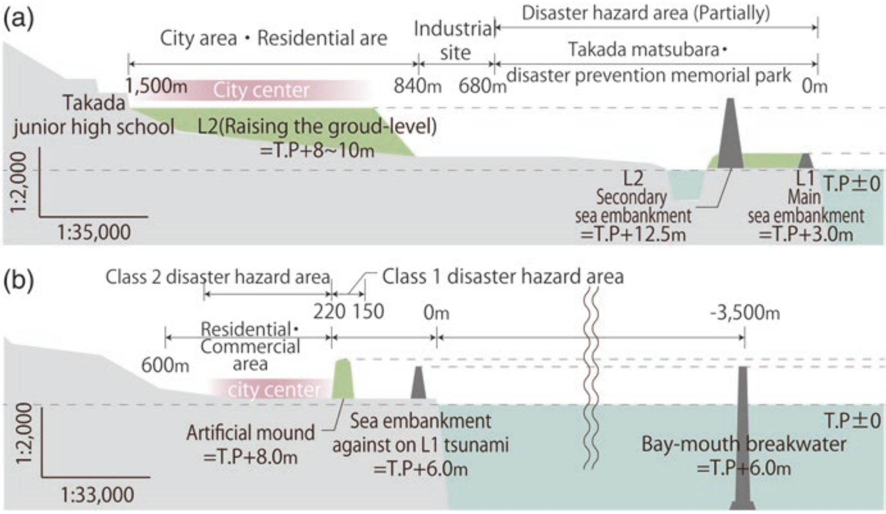

Fig. 1.3 Section of tsunami-hazard protections and city center. (**a**) Rikuzentakata City and (**b**) Kamaishi City (Onoda and Tsukuda 2016)

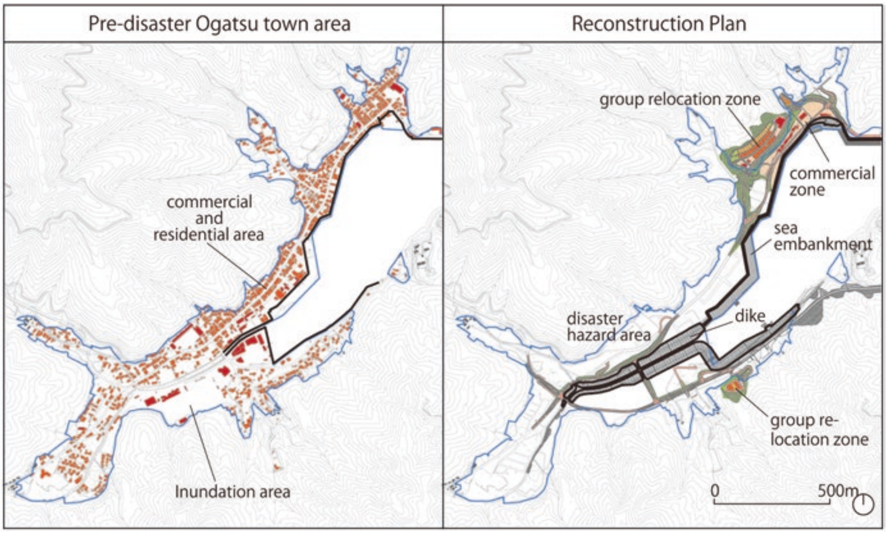

Fig. 1.4 Comparison map of Ogatsu before the disaster and after reconstruction (A.Toki)

construction of buildings, but stipulate that the first floor should not be used for residential purposes (Class 2). The highest risk areas prohibit any construction of houses at all (Class 1). Doing (1) and (2) in combination, shortens the construction period and enables quicker reconstruction of the city center in situ, without ground elevation.

1.2.4 Summary

Municipalities continue to face various difficulties in their reconstruction efforts.

Many are struggling with a shortage of resources—trying to balance necessary reconstruction projects with demands from the public and central government to provide more protection against L1 and L2 tsunamis. Sea embankments, one of the proposed protection strategies against an L1 tsunami, are big and expensive and believed by some to have adverse effects on the area's fisheries. Consequently, sea embankments have been a controversial issue, with many coastal residents questioning their necessity and effectiveness.

While it did not garner as much media attention as the sea embankments, the Two-Two Rule also led to some challenges. The rule's strict restrictions meant that many municipalities found it difficult to develop new land use. It also limited their ability to take into account each municipality's unique geographical conditions, as well as the cultural traditions of the local communities.

1.3 Implementation Process

Amidst the difficult situations mentioned above, the municipalities have been struggling to conduct their own reconstruction plans. This chapter looks at the implementation process through a categorization of affected municipalities based on their strategies, and explains the characteristic issues and responses, with some examples.

1.3.1 Key Phase of Project Implementation

As the majority of the reconstruction projects are related to the revitalization of the town's living environment and housing, and as the selection of which method to use for those projects is unique in each city, we look at these basic strategies for reconstruction with regards to housing projects. According to a previous study (Onoda et al. (2015)), the tsunami affected 15 municipalities in Miyagi prefecture. They are divided into five categories based on principal component analysis.[5]

The five categories are:

1. Land rearrangement oriented—municipalities with heavily damaged downtown areas that require big land rearrangement projects.

[5] Indicators for the analysis were (1) budget for urban-planning projects, (2) rate of budget for urban-planning projects to total budget of surface-construction projects (includes all projects towards revitalization of the town's living environment and housing, except public-housing projects) and (3) number of damaged and destroyed residences.

2. Group relocation oriented—municipalities with some damaged fishing villages that require small relocation projects.
3. Complex—municipalities that fall between the first two types.
4. Public housing oriented—municipalities that require minimal rearrangement and relocation, and some public housing projects;
5. Large city—municipalities with big urban areas that have comparatively affluent resources and can afford large reconstruction projects.

By the end of 2011, municipalities in every category had issued their own reconstruction plans and even started some projects. But after that, the implementation process became quite diverse.

One of the most important phases of any implementation process is the one between the issuing of the reconstruction plan and the start of the first project. During that period, the local governments sent out questionnaires to their communities to find out if the victims intended to remain in the area or leave. Results of the survey determined the amount of reconstruction needed (Onoda 2014a). This is especially important for the "group relocation-oriented" municipalities, and the survey results there tend to be more precise because they are usually based on face-to-face interviews.

In the case of Shichigahama Town,[6] which belongs to the "group relocation oriented" category, the municipality communicated carefully with residents and encouraged many victims to remain. This enabled officials to put together a more accurate reconstruction plan for public housing.

For the victims who own the land in disaster hazard areas where the government had indicated that they would buy them out, the survey results were more varied. Some victims made their decision on whether to leave or remain depending on the price they were offered for their land.

1.3.2 Organizational Structure

An implementation strategy can have different characteristics depending on the amount of reconstruction work and the municipality's resources. Figure 1.5 shows the relationship between the percentage of budget for reconstruction projects for living environment to pre-disaster annual revenue, and the number of staff in each municipality.

It has become clear that "land rearrangement oriented" is the group facing the biggest challenges, as they have to implement large projects with a small staff. Municipalities in this category also have to carry out complicated land rearrangement or re-zoning projects that require professional and skilled manpower.

[6] Population of Shichgahama Town is 18,571 (October 2016) and the area is 13.19 km^2

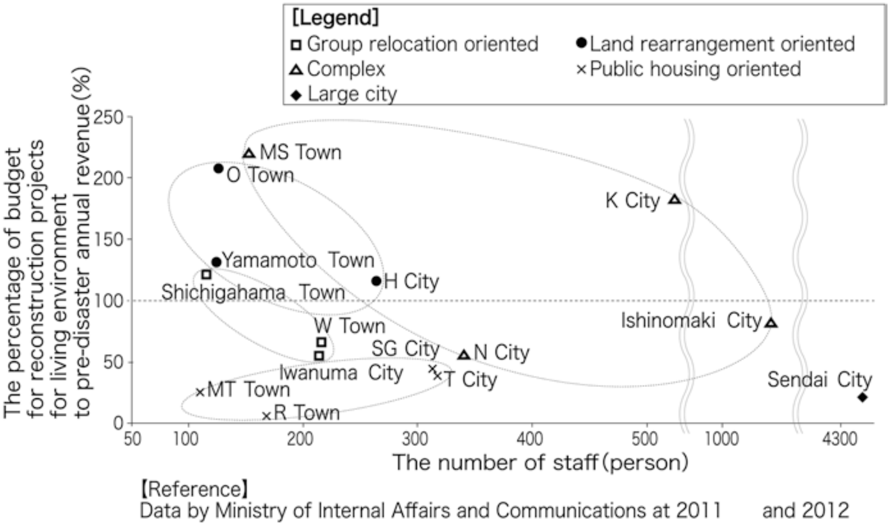

Fig. 1.5 Scatter graph depicting the number of staff and the percentage of budget for reconstruction projects for living environment to pre-disaster annual revenue (Onoda et al. 2015)

Yamamoto Town, which belongs to this "land rearrangement oriented" category, received temporary staff from non-disaster-affected municipalities. The town reorganized the government's single "reconstruction division" into four functional divisions to accommodate the bigger and more specialized group preparing for the implementation phase (Fig. 1.6).

This change in division structure adversely affected the way the projects were managed. Meetings in Yamamoto Town became little more than information-sharing sessions. Each sub-section promoted its own project, but the town as a whole had difficulty integrating the projects into a collective vision. The case of Yamamoto Town is in contrast with that of Shichigahama Town, a municipality in a similar situation due to its proximity on the scatter graph. Shichigahama Town had only one "reconstruction division" that shared not only basic information but also the direction of the projects. This led to the successful integration of the different projects and a smoother reconstruction process.

1.3.3 Summary

The affected municipalities can be segmented into different categories based on the combination of reconstruction projects, which can be considered as basic strategies. Some of these strategies influenced the structure of the reconstruction division in certain municipality offices.

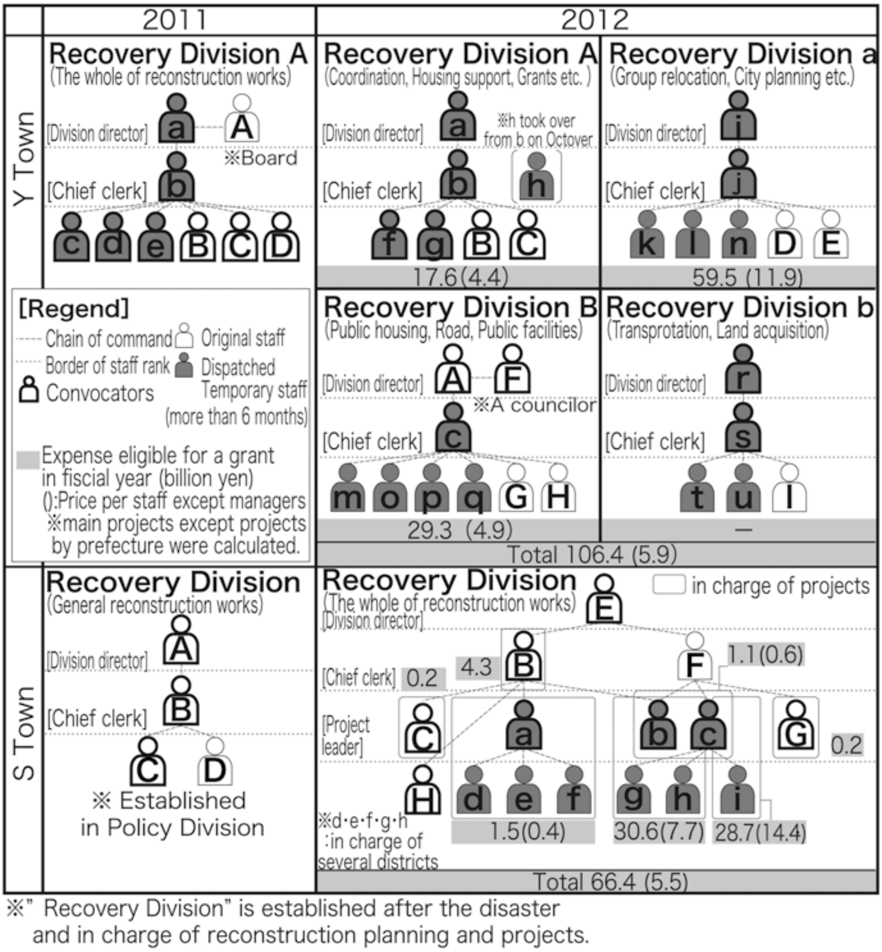

Fig. 1.6 Organization chart of the Department of Reconstruction (Onoda et al. 2015)

In order to achieve efficiency in the reconstruction process, it is important for officials to share not only basic information but also the specific details and the full vision for the town among themselves and with the public.

The immediate provision of specific information to victims influenced the municipalities positively: It helped to increase the number of victims who chose to rebuild their homes with their own resources instead of living in public housing. Inter-sectional information sharing, especially the collective vision, also helped local governments to effectively arrange many complicated projects within segmented sections.

1.4 Housing Reconstruction

1.4.1 Lessons from the Great Hanshin Earthquake (1995)

Municipalities are responsible for providing land and public housing for the victims. Considering previous disaster experiences—including the Great Hanshin Earthquake in 1995—the sudden change in living arrangements of the victims is a critical issue of the reconstruction process.

Many victims feel uncertain, lonely and vulnerable after moving from temporary housing—which provided had a sense of community—into new settlements. In the case of the Great Hanshin Earthquake, there were numerous reports of suicides and people who died alone after moving into public housing (Tanaka et al. 2009). It was obvious to researchers that the existing public-housing schema was not conducive to recreating the sense of community that the victims needed.

After the GEJE, public housing was once again a priority, especially with the scale of destruction caused by the tsunami. Because a large number of public housing construction projects had to be implemented within in a short period, building quality was not a major consideration. However, there were attempts to create better quality of housing for the residents in the new developments, including the application of a front-access plan (Fig. 1.7).

1.4.2 Successful Cases of Good Quality Development

Each municipality devised a way to advance the quality of housing projects. Three successful cases are featured in this section.

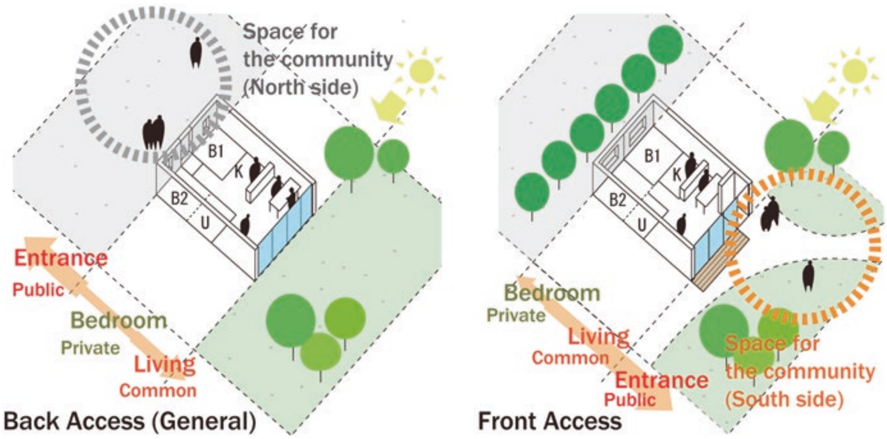

Fig. 1.7 Front-access plan: a schema for community-friendly housing (Onoda 2014b)

In Shichigahama Town and Iwanuma City, reconstruction was quick, and the architecture is of good quality. The way they achieved such success is now known as the "Shichigahama-Iwanuma Method." The local governments selected architects capable of designing community–friendly public housing through a proposal competition, and the prefectural government then supported the competition process through to the completion of the construction drawings.

In the case of Kamaishi City, they organized all their reconstruction projects comprehensively. They adjusted their hazard-protection design and kept the downtown area in its original location (as seen in Chap. 1). They also devoted resources to improving the quality of the housing projects, which in turn led to the creation of an attractive downtown area.

1.4.2.1 Management of the Total Process of Public-Housing Reconstruction (Shichigahama Town)

Shichigahama Town is the smallest municipality in the disaster-affected area. Much of its reconstruction success can be attributed to smooth communication between the municipal government and the residents.

From the first phase of reconstruction, the communities worked positively together on issues such as building consensus, the self-dependency or independence of each community and establishing good collaboration with professionals.

In the following, the key points are explained along with the implementation process:

1. It was important that officials presented a clear reconstruction vision and shared adequate information with the victims. In the early phase of the reconstruction, the town published the estimated purchase price of private lands that had incurred damage from the disaster. That encouraged the victims to consider building their own homes because they could channel the money from the sale of their land into rehabilitation and reconstruction. The local government also conducted a survey to find out if the victims intended to remain in the town or leave it. They held face-to-face interviews with the victims and provided information about available public support. This operation contributed to an increase in the number of residents willing to rebuild their houses themselves, and thus, reduced the number of public-housing units that the government had to build for them.
2. Public-housing blocks were built in existing residential areas. New housing projects were embedded within existing community units, called "hama" or old fishing village. It helped to create a sustainable situation.
3. Community-friendly building plans for public housing, e.g. a front-access plan, were needed to encourage communication between residents. Architects for the projects were selected based on the requirements drawn up by a team of reconstruction advisors (including Onoda Y and others). All public housing units in Shichigahama were completed with the goal of deterring suicide and avoiding solitary deaths. Therefore, the team stressed a rational approach towards

Fig. 1.8 Shobutahama post-disaster public housing, design by Atelier Hitoshi Abe (Atelier Hitoshi Abe)

community-friendly planning and tasked the architects with developing various front-access-plan designs (Fig. 1.8).

4. Selecting a capable and appropriate architect to handle difficult planning projects was crucial, as was getting public-procurement support from the prefectural office to bid competitively for a skilled contractor.

For the planning of the resettlement area, the city adopted a participatory process and involved the residents with support from some professionals. In the following, the key points are explained along with the implementation process:

1. The planning committee of the resettlement area in Tamaura Nishi was organized in June 2012. Members of the committee were selected from the residents of the six villages. Each village recommended three types of candidates: a representative, a female member and a young member. They also invited three

Fig. 1.9 Tamaura Nishi Resettlement Area (Chuo University Ishikawa Lab)

specialists—Mikiko Ishikawa as the landscape architect, Yasuaki Onoda as the architectural planner and Yoshihide Sanbe as the expert of housing policy—to share their expertise. Formal committee meetings were held 28 times. There were also many informal meetings in which issues and concerns were discussed and addressed.

2. During the discussions, it was decided that community members from each village would move together into the same area of the resettlement site. Members also proposed integrating two village communities into one cluster and assigning a small park with a community house to each cluster. These parks would be connected, through a greenway, to a large park with landscaping, a reservoir and a shopping market at the west end. Public housing for the people of the village would be distributed among these clusters, with each site connected to each cluster as part of a community. A separate space for public housing that had existed before the disaster would be installed at the east end beside the large park (Fig. 1.9).
3. The basic public housing units are made of wood, built as semi-detached and designed to be community-friendly. Four architectural firms were selected based on the proposal-type-competition organized with the assistance of the reconstruction advisors. About 210 units were completed by the end of 2013.
4. A rational-management approach was necessary to complete the housing projects. This included selecting a capable and appropriate architect to handle the difficult planning works and designating some construction work to local contractors. Getting public-procurement support from the prefectural office to bid competitively for a skilled contractor was also important.

1.4.2.2 Design-Proposals to Create a Future for the City (Kamaishi City)

Kamaishi City has been paying attention to the quality of its reconstruction from the early phase. The plan of the city has taken shape and is looking quite attractive.

At the beginning of its reconstruction planning, various opinions were considered, including relocating the main city center from the coast to an inland suburban area. The city organized public workshops with the residents in June 2011 (with emotions still raw from the disaster 3 months earlier) to build a consensus. They were supervised by the reconstruction directors—architect Toyo Ito, architectural planner Yasuaki Onoda and town planner Arata Endo.

Through these workshops and other related activities, the local government kept up continuous communication with the people. They decided to bring intense development to the existing central part of the city and offered attractive options and sustainable solutions to people who were able to rebuild their own livelihoods themselves.

To achieve all its goals, the local government started the Kamaishi Future City Project (KFCP) in 2012, with the following three concepts:

1. Identifying professionals that can offer useful and creative ideas for future development
2. Connecting residents with specialists and entrepreneurs to encourage the projects
3. Developing business partnerships and collaborations between the local government and external companies towards the common goal.

In the following, the key points are explained along with the implementation process:

1. Rational reconstruction approach with multi-layer hazard intervention was introduced. The reconstruction schema of Kamaishi is balanced between safety and the quality of the environment. The local government not only invested in huge hazard interventions, but also in the projects that can contribute to the revitalization of the city, e.g., public housing. The installation of multi-layer protection (Fig. 1.3b) was key to saving money and time and helped to improve the living environment of the city center.
2. Intensive reconstruction of public architecture led to the creation of a compact city center. The local government purchased a site in the downtown area for the purpose of building public housing and requested that the architects connect the housing with a walkway network (Fig. 1.10).
3. Clustered development of community-friendly public housing took place in the downtown area. According to the KFCP, the local government organized seven design competitions to select appropriate architectural firms. Public housing projects occupy an important place in Kamaishi City, and the selected architects worked closely with the contractors to create a good development.
4. A public-procurement system was developed for the implementation of the project. Since the start of full-scale reconstruction work, the construction costs have been rising drastically. In this situation, deliberative designs by capable architects could suddenly become a bundle of risks and high costs for a contractor. This discouraged cost-sensitive contractors from participating in the competitive bid. There was an inevitable conflict between achieving deliberate designs for

Fig. 1.10 Public housing in downtown Kamaishi designed by Chiba Manabu Architects and Daiwa House Industry

the betterment of the residents and managing the projects on time and within budget. As a compromise, the local government adopted a design-build proposal method to select a team comprising a designer and contractor.

Additionally, many architects who worked on KFCP took part in a workshop for reconstruction run by Archi Aid, a volunteer network of architects working on reconstruction after the GEJE. This experience gave many non-local experts the opportunity to understand the complicated situation in the disaster-affected areas and also the need for careful and thoughtful cooperation with local governments and communities (Archi Aid 2016).

1.4.3 Summary

Among the reconstruction projects that began after the 2011 tsunami, many had limited capacity to consider the post-construction quality of the environment. The municipalities that achieved a good environment did so through careful management of each implementation phase. First, it is important to select capable architects and contractors who can provide good designs under difficult situations. Second, community-friendly planning is crucial in order to keep or build community ties. Third, coordination with the private market is necessary to overcome scarce resources caused by the disaster.

1.5 Conclusion and Discussion

From the issues and case studies highlighted in the previous chapters, we extract five key lessons in order to achieve good-quality reconstruction. They are:

1. Quality versus Risk: Generally speaking, the Two-Two Rule is a compromised concept to satisfy the community's desire for safety, as well as the government's need to complete the reconstruction projects quickly and without controversy. However, application of the Two-Two Rule has led to unexpected challenges. These include an insufficiency of land that meets the safety requirements for building houses in some municipalities. To avoid unexpected problems, it is important that the reconstruction plan is carefully thought out and discussed with all relevant and affected groups before implementation.
2. Utilization of Existing Social Resources: In the case of Shichigahama and Iwanuma, the municipalities utilized community units that had existed before the disaster to facilitate consensus building and to create opportunities for the towns' future. Inserting new public housing into existing residential areas also helped community members build and maintain good relations with each other.
3. Collaboration with Specialists: Reconstruction is a complicated combination of specialized projects. To achieve a proper perspective, it is useful to have adequate advice from, and collaboration with, specialists and experts. By adjusting the framework of public procurement, Shichigahama Town, Iwanuma City and Kamaishi City created the opportunity to collaborate with specialists. There are many variables in the reconstruction process that can make achieving Build Back Better difficult. Involvement of a high-performance specialist can greatly contribute to the quality of reconstruction projects.
4. Use of Private Sector for Implementation: The huge reconstruction projects led to a shortage of labor and materials, which then brought about a sharp rise in building costs. In these situations, the local governments had to develop a unique method for using resources from the private sector to secure the quality of the projects, as shown in the case of Kamaishi City.
5. Shape of Organization for Integration: Most of the municipalities affected by GEJE had already been struggling with aging populations and declining birthrates before the 2011 disaster. The local governments had to integrate various reconstruction projects into a wider vision for the future growth of their region. As in the case of Shichigahama, the organization of the local government is important to ensure that all aspects of the region's well-being are considered.

Acknowledgements The authors would like to thank Prof. Mikiko Ishikawa, Prof. Hitoshi Abe and Assistant Prof. Ayano Toki for providing figures. We would also like to thank Prof. Michio Ubaura, Prof. Katsuya Hirano from IRIDeS and Prof. Yoshimitsu Shiozaki from Ritsumeikan University for their general support as colleagues of the research group. We greatly appreciate officials in Shichigahama Town, Yamamoto Town, Iwanuma City, Ishinomaki City and Kamaishi City for sharing information. The study is supported by Japan Society for Promotion of Science (JSPS) KAKENHI Grant Number 25303023. Last but not least thanks for Ms. Melissa Heng for proof reading.

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Chapter 2
The Problems of Plan-Making: Reconstruction Plans After the Great East Japan Earthquake

Fukuo Akimoto

Abstract Time is a scarce resource in disaster restoration. However, reconstruction plan-making itself, if not properly undertaken, can bring the risk of delaying the reconstruction processes. This paper provides an overview of some of the main problems and issues related to the planning process and policies towards the reconstruction efforts undertaken during the first months after the Great East Japan Earthquake and Tsunami of 2011 and some related issues thereafter. The study concludes that the Statutory Planning System in Japan lacks the terms meaning the "planning" and the "planning process", hence plans sometimes are being prepared without a clear idea of "planning" or "planning process", even today.

After World War II, the national, prefectural and municipal governments began to prepare reconstruction plans respectively, while "*machi-zukuri*" or community planning efforts initiated by local residents were emphasized after the Great Hansin-Awaji Earthquake. This brought some important planning and decision-making problems about how and when administrative bodies at each layer and the community residents should interact and decide about important issues under conditions of precious time and scarce resources. After the Great East Japan Earthquake of 2011, the national government issued a concrete reconstruction vision, *takadai-iten*, for disaster areas, albeit without explaining how it would be done; it also conducted a survey, without a clear idea of the planning process, to be developed and followed at the municipal level. Prefectural governments constructed tsunami-protection barriers, such as coastal dikes and levees, without previously consulting with the local community, so this sparked considerable controversies with local residents, while most municipal governments focused upon relocation of homes from low-lying areas to a newer, safer locations on higher grounds, rather than pursuing infill development in and around existing residential districts or villages.

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V. Santiago-Fandiño et al. (eds.), *The 2011 Japan Earthquake and Tsunami: Reconstruction and Restoration*, Advances in Natural and Technological Hazards Research 47, DOI 10.1007/978-3-319-58691-5_2

From the lessons learned after the 2011 earthquake and tsunami, there is a need for the national government to promptly develop and provide financial assistance and human administrative capabilities for the affected local governments, while keeping fiscal discipline at the national and local levels, and encouraging prefectural governments to coordinate infrastructure planning with adjacent local community plans, and mandating municipal governments to prepare community plans in accordance with local conditions. Last but not least, there is a need to develop programs and provide financial assistance to the affected communities whereby supporting their *machi-zukuri,* which will enhance their readiness and resilience against future catastrophic events such as the expected Nankai Trough earthquake and tsunami.

Keywords Planning • Plan-making • Reconstruction plan • Decentralization • Community

2.1 Introduction

It is crucial for national, prefectural and local governments to prepare workable reconstruction plans effectively and implement them quickly after the disaster, since time is a scarce resource in disaster restoration. However, reconstruction plan-making itself might ironically involve the risk of delaying the reconstruction process, particularly since the governmental system has been decentralized and made more complicated after World War II and the planning problems of disaster reconstruction became more complex.

This paper examines the ideas of planning as the basis of the study and clarifies the fundamental problems of reconstruction planning after World War II by briefly looking at the case of the Great Hanshin-Awaji Earthquake, as well as analyzes the problems of the reconstruction efforts after the Great East Japan Earthquake of 2011. Particular emphasis is placed on the period from March to December 2011 because, from this critical period, the reconstruction process has developed.

2.2 The Fundamental Problem of the Statutory Urban Planning System: "Plan-Making" Without "Planning"

The term "town planning" appeared in England in the early twentieth century. Patrick Abercrombie defined "planning" as "the accommodation of several units to make a complete but harmonious whole" (Abercrombie 1959), while the term "planning process" was assumed to be a process with "a simple sequence derived from Patrick Geddes: survey-analysis-plan" in which "*The existing situation would* *be surveyed; analysis of the survey would show the remedial actions that needed to be taken; the fixed plan would embody these actions*" (Hall 2002).

In 1913 "town planning" was translated as "*toshi-keikaku*" in Japan by H. Seki (Watanabe 1993), while the "*Toshi-Keikaku*" Act was enacted in 1919. However, the term "*toshi-keikaku*" in the Act only meant "authorized maps of planned public facilities or zoning", and the Act did not have any Japanese term meaning "planning" or "planning process". Thereafter, "*toshi-keikaku*" have often been prepared without any clear idea of "planning" or a "planning process", while "plan-making" does not necessarily mean "planning" in Japan.

The term "*fukkou-keikaku"* (reconstruction plan) appeared in Japan just after the Great Kanto Earthquake in 1923. The Imperial Capital Reconstruction Plan Bill drafted in December provided in the provision of Article 1 that "*fukkou-keikaku* (reconstruction plan) for the imperial capital herein shall mean '*toshi-keikaku'* of Tokyo and Yokohama". Although the bill was revised and passed as the Special "*Toshi-Keikaku*" Act and "reconstruction plan for the imperial capital", then term in Article 1 was rewritten as special "*toshi-keikaku*", thereafter a reconstruction plan generally meant "*toshi-keikaku*" and had no connotation of "planning". The lack of a Japanese term meaning "planning" or "planning process" has been the fundamental problem of the statutory reconstruction-planning system as well, as of the statutory urban-planning system in Japan until today.

2.3 Problems of Division of Roles Among National and Local Governments in the Disaster-Reconstruction Process

Another problem lay in the "*Toshi-Keikaku*" Act. The term "*toshi*" in the Act means not a local government but a geographical area, while the act enabled the Interior Minister to designate a "*Toshi-Keikaku*" Area corresponding to an urban area and to set up a "*Toshi-Keikau"* Commission as a national agency for the area. A "*Toshi-Keikau"* Commission provided plans for the area, while the Interior Minister authorized the plans, and not the "*Toshi-Keikaku"* Commission or the national government but local agencies had to execute these plans. The Act divided the power of decision making and the responsibility for execution. In relation to the existing situation at the time, Beard (1923) wrote:

> The law makers evidently shrink.... They do not trust the city government or they wish to keep all important powers in their hands of the central government. In their dilemma they have fallen between two stools. ... They divide the power and render the central and local agencies alike incompetent to handle the great task of city planning. Hence it must be said that if American experience is any guide, it will not be wise to expect very much ... The law divides authority and responsibility. The commission is not an instrument of action...

This author also hinted that "*toshi-keikaku*" would be caught up in the bureaucratic turf battles that made comprehensive city planning difficult for local governments, stating that there were many conflicting authorities and agencies in Tokyo. Some departments of the central government and a number of private utility corporations holding privileged positions granted by high-level authorities exercised their power over the city authorities, the situation allowed for independent decision-making and plan development by these entities without prior consultations with the local authorities.

After the Great Kanto Earthquake, the Government Cabinet meeting approved a document titled "The scale of the budget and cost, and the policy of Reconstruction Projects for the imperial Capital" (October 24, 1923). This divided the authority and responsibilities by having the Imperial Capital Reconstruction Agency of the national government control the design standards of the reconstruction plans, while the projects would be operated under the local autonomy.

Beginning soon after World War II, decentralization of government power has progressed. Prefectural governors and mayors are now chosen by popular vote in direct elections, since the Constitution of Japan and the Local Autonomy Law were enacted in 1947. Most of the powers of "*toshi-keikaku*" were transferred from the national government to prefectural and municipal governments by the New Toshi-Keikaku Act in 1968, while most of those powers have been assigned from prefectures to municipalities by the Omnibus Decentralization Act in 2000. However, in this decentralized three-layer administrative system, a new planning problem in the disaster-reconstruction process has arisen: how and when administrative bodies at each layer should decide about what issues, while time is a precious resource in a disaster-restoration process.

This problem rose to the surface after the Great Hanshin-Awaji Earthquake in 1995, which struck Hyogo, Osaka and Kyoto Prefecture killing more than 6000 people. Recollecting reconstruction efforts after this earthquake, A. Koshizawa (1996) stated at the time that still there was a problem regarding the appropriate division of roles and coordination of initiatives in the reconstruction process among the central, prefectural and local authorities and the public and private sectors. In light of this, the need to have three clear levels of reconstruction was crucial, i.e.: *"(1) infrastructure restoration at regional level, (2)"toshi-keikaku" at city level, and (3)"machi-zukuri" at district and community level. Reconstruction issues at each level vary in timing to fix its policy, in method to build consensus, and in size of its impacts on reconstruction process."*

In this reconstruction process, "*machi-zukuri*" was emphasized in the late 1990s, while the term "*machi-zukuri*" itself appeared first in the 1940s (Watanabe 2011). Kobayashi (2004), a community planner in Kobe, proposed that "*we should begin not from "toshi-keikaku" at city level, but from "machi-zukuri*" at community level and then move up to the city level", and Kobayashi (2005) defined "*machi-zukuri*" as "*a continuous efforts to improve community by self-governing people*". He further stressed the fact that the local people in "*machi-zukuri"* need money to hire planning consultants, while he highlighted that a similar approach to that of the Community Development Block Grant (CDBG) existing in America could be considered as an example for the purpose, particularly since it is a flexible federal program that provides communities with resources to address a wide range of unique community development needs at the discretion of local governments.

2.4 Problems of Reconstruction Plan-Making After the Great East Japan Earthquake

2.4.1 A Failure to Define the Appropriate Division of Roles

On March 11, 2011, the Great East Japan Earthquake M_w9 0, the strongest earthquake recorded in Japan, struck an extremely large area on the Pacific Coast of the Tohoku and some parts in the Kanto, with 15,894 killed and 2557 missing, mostly due to a tsunami as of September 9, 2016 (Asahi Shimbun 2016e), and also caused the worst accident in the history of atomic-power plants in the country.

At the time, the central government of Japan failed to define the appropriate division of roles and coordination of initiatives among national, prefectural and local governments, in handling this large-scale, complex disaster. The national government should have provided financial and human assistance to local governments, while local governments should have prepared reconstruction plans best suited for their geographical conditions. However, on the contrary, the government presented a single concrete reconstruction vision for devastated areas without showing the means to achieve it. On April 1, the Prime Minister, who headed the Democratic Party of Japan (DPJ), proposed "*takadai-iten* (relocation of homes from low-lying areas to safe locations on higher grounds)" at a news conference (Kan 2011).

Unfortunately, as highlighted, this type of relocation project is not necessarily best suited to the elderly; furthermore, it will also require high maintenance costs that become a financial burden for local governments. In some cases, a better option would have been to build compact residential areas around existing residential districts or villages (Iwate Nippou 2011; Nakai 2012; Sawada 2011; Satou 2012). However, the prime minister's message, by emphasizing *"takadai-iten",* limited the reconstruction-policy options at the local level, while it led to delays in this resurgent process because the government did not reveal any financial-assistance program for "*takadai-iten*", even though a number of cities, towns and villages in the damaged areas were small in size and lacked human and financial resources, as well as expertise in disaster reconstruction.

One month after the earthquake, the central government set up a 16-member Reconstruction Design Council, a large blue-ribbon commission reporting to the Prime Minister, as well as the 19-member Council's Study Group. Unfortunately, no guidelines for the Reconstruction Design Council were provided, while no experts in disaster reconstruction joined the Council or its Study Group. Hence, it took a long time for the council members to understand the existing situation (Mikuriya 2011; Yomiuri Shimbun 2011a).

On May 1, the Prime Minister informed the Diet that he would wait until the end of June when the Reconstruction Design Council would submit the proposal, and thereafter he would begin to compile the second supplementary budget for the fiscal year 2011 that was to consider full-scale financial support for the reconstruction projects on the basis of the Council's proposal (Asahi Shimbun 2011d). Analyzing this policy now, it appears that it was developed by first considering the aims and then the means to achieve the ends, which contradicts the principle stating that the "means and ends should be simultaneously chosen" (Lindblom 1959).

Immediately after the quake, a special team of the Diet members of the ruling Democratic Party of Japan was already drafting a basic law and 17 complementary laws focusing on the reconstruction projects, expecting the Cabinet Office to approve them as bills in mid-April (Asahi Shimbun 2011e, 2012c). Also, the Ministry of Public Management, Home Affairs, Posts and Telecommunications was considering establishing "a new special district system for reconstruction to relax government regulations" (Mainichi Shinbum 2011a). But, they both were delayed due to the above mentioned decision.

In another instance, some local governments in the disaster area, including Minami Sanriku Town, Higashi Masushima City and Ishinomaki City began to launch "*takadai-iten*" or collective relocation projects prescribed in the Act on Special Financial Support for Promoting Collective Relocation for Disaster Mitigation, but they could not act on them because financial assistance from the central government was unclear (Asahi Shimbun 2011f, 2012c). It became clear that it was impossible for small towns with small annual budgets to implement "*takadai-iten*" projects which will cost tens of billions of Japanese Yen without financial support from the central government (Asahi Shimbun 2011f; Yomiuri Shimbun 2011b).

On June 25, 2 months after its establishment, the Reconstruction Design Council delivered a proposal titled "Towards Reconstruction: Hope beyond the Disaster". It proposed "*takadai-iten*" and emphasized "municipality-led reconstruction", but it did not include any concrete financial and human resources assistance programs for local governments. Instead it only gave an estimated cost of the losses due to the disaster, reaching about 16.9 trillion Japanese yen (The Reconstruction Design Council in response to the Great East Japan Earthquake 2011). Furthermore, it emphasized the necessity of a tax increase (Reconstruction Design Council in response to the Great East Japan Earthquake 2011).

Oddly, 1 day before the Council's proposal, the Prime Minister established the Reconstruction Headquarters in response to the Great East Japan Earthquake within the Cabinet Office, while, 1 month after its establishment, the Headquarters announced "Basic Guidelines for Reconstruction", also emphasizing that "the main administrative actors accountable for the reconstruction shall be municipalities" (Reconstruction Headquarters in response to the Great East Japan Earthquake 2011). Again, it did not describe any concrete assistance programs for local governments. Rather, it stipulated that "temporary taxation measures" will be examined as financial resources (Reconstruction Headquarters in response to the Great East Japan Earthquake 2011) and announced, for the first time, the estimate of the scale of reconstruction budgets during the first 5 years after the disaster ('the intensive reconstruction period'), which totaled at least approximately 19 trillion Japanese yen, while estimating at least 23 trillion yen for period of 10 years ('the reconstruction period') (Reconstruction Headquarters in response to the Great East Japan Earthquake 2011).

It is important to emphasize that both the Reconstruction Design Council's proposal and the Reconstruction Headquarters' guidelines referred to "*fukkou-keikaku*", while the Reconstruction Agency often mentioned “land use plan”. However, they never specifically defined and detailed the contents of the “*fukko-keikaku*” or land use plan, nor the methods intended to prepare them.

Meanwhile, in May 2011, in order to support local governments, the Ministry of Land, Infrastructure and Transport (MLTI) began a survey of the tsunami-devastated areas with a 7.1 billion yen budget, which consisted of a tsunami-damage survey and analysis, a study of possible reconstruction patterns and a study of reconstruction methods for towns and villages. However, the survey lacked the idea of a “planning process” at local level. The MLIT could not define the method and procedure of how local governments could prepare what kind of reconstruction plans on the basis of this survey, and how to coordinate three levels of reconstruction issues: (1) infrastructure restoration at the regional level, (2) “*toshi-keikaku*” at the city level, and (3) “*machi-zukuri*” at the district and community levels.

A new Prime Minister of the Democratic Party of Japan was elected on September of the same year, and the new cabinet endorsed the third supplementary budget bill (October 21). At the time, local governments in the affected areas began to complete their reconstruction plans and, by the end of the year, among the 43 municipalities in the coastal tsunami-hit area in Tohoku, 33 had already completed their reconstruction plans, while 41 were scheduled to complete plans within the then current fiscal year, according to a survey by the MLIT (Reconstruction Headquarters in Response to the Great East Japan Earthquake 2012). It is most important to highlight the fact that many completed reconstruction plans were nothing more than a list of projects prepared for budgetary requests to the national government.

Since the national government did not provide financial assistance programs, most plans remained as basic visions and basic plans and lacked appropriate measures to implement them. For example, most plans proposed building restrictions in tsunami-damaged areas and relocating people in the lower areas to higher grounds, but did not contain any financial scheme including the purchase price of the land in the tsunami-hit area, which elicited some strong comments by the local community members. One resident said “to be honest, there is no way to comment on it because the plan is short on specifics” (Kahoku Shimpo 2011).

By the end of 2011, the new administration secured the financial resources for reconstruction projects. The Financial Resources for Reconstruction Securing Act, promulgated on December 2, enacted the Reconstruction Special Tax, which is covered by adding 2.1% to national income, residents, and corporate tax rates in the 25-year period starting in 2013. The tax was expected to produce 10.5 trillion Japanese yen. The government also established financial assistance programs for local governments, i.e., the Great East Japan Earthquake Reconstruction Special District Act promulgated on December 14 set up a new reconstruction grant system of about 2 trillion Japanese yen effective from fiscal 2011 to 2015.

Ironically, the outlines of the Financial Resources for Reconstruction Securing Act and the Reconstruction Special District Act were basically the same as the draft bills that the original DPJ’s special team had prepared earlier, at the end of March in the same year, but some precious time was lost (Asahi Shimbun 2012c).

2.4.2 Problem of Reconstruction Grants: A Collection of Categorical Grants

The new reconstruction grant is not a block grant like CDBG in the USA, as Kobayashi had emphasized as a must for "machi-zukuri" after the Great Hanshin-Awaji Earthquake. However, at first, the DPJ had proposed a reconstruction block grant.

Early in March, the special team of the DPJ Diet members drafted the Basic Law for Reconstruction, which included "a block-grant" for local governments (Asahi Shimbun 2011b). In June, the Kan Administration announced an ambitious plan to establish a reconstruction grant that local governments could discretionally spend for reconstruction (Asahi Shimbun 2011g), while the Reconstruction Design Council's "Towards Reconstruction" of June 25 and the Reconstruction Headquarters' "Basic Guidelines for Reconstruction" of July 29 emphasized establishing "an easy-to-use and highly flexible grant system" for local governments (Reconstruction Design Council in response to the Great East Japan Earthquake 2011; Reconstruction Headquarters in response to the Great East Japan Earthquake 2011).

However, the reconstruction grant that the new Cabinet established in the Reconstruction Special District Act is not a block grant, but a collection of categorical grants that are made for specific purposes and are administered by the central government's vertically divided ministries and agencies in Tokyo. The Act limited eligible projects for the reconstruction grants to the five ministries' 40 projects, including public housing projects for victims, group relocation projects, land readjustment programs and other related projects (Asahi Shimbun 2012a, b, d; Mainichi Shimbun 2014). The reconstruction grant is not "an easy-to-use and highly flexible grant".

2.4.3 Problem of Reconstruction Budget: Erosion of Fiscal Discipline

Immediately after the quake, the special team of the DPJ Diet members proposed to raise the government's share of reconstruction works spending (Asahi Shimbun 2011a). In April, the MLIT established a policy to raise the portion of disaster recovery projects funded by the state coffers from up to 80 to 99% (Asahi Shimbun 2011c). However, on October 6, the new Prime Minister of the DPJ at the time conveyed, at the special committee of the House of Councilors, that the central government would entirely cover the cost of reconstruction projects with no burdens on local governments (Yomiuri Shimbun 2011c). As a result, the new administration raised the portion of the costs of reconstruction projects funded by the national government up to 100%.

This decision brought some controversy because it was felt that there was a need for the local administration to bear some of the costs according to their economic strength to enhance their sense of responsibility (I-Io 2016; I-Okibe 2016; Okamoto 2016a, b).

The new administration under Prime Minister Shinzo Abe of the Liberal Democratic Party of Japan expanded the budgetary scale of reconstruction measures and projects to be effected within 5 years of the disaster's occurrence ('the intensive reconstruction period') from 19 trillion Japanese yen to 25 trillion Japanese yen (January 29, 2013), and to 26.3 trillion Japanese yen (January 14, 2015), while the administration informed local governments in May 12, 2015 that they should also bear some of the costs for the reconstruction projects beginning in the fiscal year 2016, i.e., after the end of 'the intensive reconstruction period'(Asahi Shimbun 2015).

2.4.4 *Lack of Coordination Between Coastal-Levee Plans and "machi-zukuri"*

Soon after the tsunami took place in 2011, the Reconstruction Design Council's proposal emphasized that "the recent tsunami transformed existing concepts relating to natural disasters. …If we base our efforts on a concept of 'disaster reduction,' we must certainly focus on people-oriented measures that move away from an exclusive reliance on waterside defensive structures. ... future countermeasures against tsunami will have to be transformed from 'lines' of defense, such as coastal dikes and tide barriers, to 'multiple defenses' that are 'area-based,' encompassing rivers, roads and urban planning. … and tsunami breakwaters, coastal dikes and tide barriers should be rebuilt, in view of the protection they provide to inland areas against relatively frequent tsunami, and storm surges and waves caused by typhoons" (Reconstruction Design Council in response to the Great East Japan Earthquake 2011.

In this respect, it was important for local governments to coordinate tsunami-defense designs with nearby community plans (Nakai 2012; Ubaura 2013); however, the Design Council could not spread the idea of "disaster reduction" and "multiple defenses" policy to other governmental ministries and agencies (I-Io 2016). The Directors General of relevant ministries and agencies of national government sent a notice to the Coast Administrators on July 11, 2011 suggesting to design tsunami breakwaters, coastal dikes and tide barriers so as to protect inland areas against relatively frequent tsunamis (MLIT et al. 2011), but this notice did not mention at all about "disaster reduction" and "multiple defenses" policy emphasized in the Design Council's proposal.

Thereafter, ministers, prefectural governors and mayors of local governments serving also as Coastal Administrators speeded up the repair, reconstruction and building of coastal structures in order to complete their projects by the end of fiscal 2015 (whereby finalizing the end of 'the intensive reconstruction period'). Soon after the notice was issued, within 2 or 3 months, they specified heights of the sea dikes or levees (Mainichi Shinbun 2011b; Asahi Shinbum 2013b). This was done before the local coastal people began to prepare adjacent community plans (Asahi Shinbum 2016c), because sea-levee rebuilding projects are one of the disaster recovery projects based on National Government Defrayment Act for Reconstruction of Disaster Stricken Public Facilities, which, quite different from ordinary public works, emphasizes the quick repair of broken infrastructure and does not require cost-and-benefit analysis (including maintenance and operation cost), environmental impact assessments and consensus from the local people (Asahi Shimbun 2014).

As soon as the prefectures announced the new heights of sea dikes or levees, discontent that “sea levees are too high” was growing among neighborhood residents on the coast, on the grounds that (1) nothing worth protecting would be left on the level ground near the sea because people would move up to higher places by relocation projects, (2) high sea dikes and levees would impair the views of ocean and scenery, particularly at the sightseeing areas, and would blanket sandy shores at the bathing beaches, and (3) people had failed to escape from the tsunami because of sea dikes or levees (Asahi Shimbun 2011h, 2012e; Yomiuri Shimbun 2011d; Mainichi Shimbun 2013). Supporting these viewpoints, the Prime Minister wife called for upon rethinking the construction of sea dikes or levees in December 2013 by expressing concerns about the fact that opposing opinions by the public had not reached the mayors, while also stating that unnecessary structures or their heights might spoil the view, alter ecosystems and hurt the fishing industry (Asahi Shimbun 2013a, b). At the end of this year, the Cabinet decided to extend the deadline of the disaster-recovery projects to be financed by the Reconstruction Budget from fiscal 2015 to after fiscal 2015, so that prefectural governments would have enough time to discuss this issue with local residents (Asahi Shimbun 2013c).

In the autumn 2014, the Japan Society of Civil Engineers set up a Disaster Reduction Assessment Committee to study the way to decide on the height of sea dikes or levees, while considering the costs and benefits (including disaster-reduction effects and negative effects on scenery and fishing industries) with the participation of local residents starting from the planning stage. The Committee expects to publish a proposal in fall 2017 (Asahi Shimbun 2016b), but as of January 2016, while 594 sea levees are to be built in Iwate, Miyagi, and Fukushima Prefectures, Miyagi Prefecture lowered the heights of 133 locations among 359, and Iwate Prefecture 23 among 136, at the request of local residents (Mainichi Shimbun 2016b). However, the discussions between the prefectural governments and local people are still going on in Karakuwa Town and Otani Kaigain in Kesennuma City, Ogatsu in Ishinomaki City and Fujinokawa in Miyako City (Mainichi Shimbun 2016a, b; Asahi Shimbun 2016a; Yomiuri Shimbun 2016). On May 5, 2016, the Chair of the Subcommittee of Seawall of the Central Disaster Prevention Council regretted that “civil engineers tend to design coastal levee without considering adjacent community plans” and that a system in which the Central Disaster Prevention Council reviews and checks the coastal levee plans proposed by national and prefectural governments should have been established (Asahi Shimbun 2016d).

2.4.5 Plan-Making of Takadai-Iten Projects Without a Planning Process

As noted earlier, the Prime Minister and the Reconstruction Design Council proposed "*takadai-iten*" to tsunami-devastated areas in 2011, while the subsequent administration in 2012 raised the share of the national subsidy of this project to 100%, while the Special District Act included "*takadai-iten* or "Projects for Promoting Collective Relocation" in the list of reconstruction grants, but did not infill development in and around existing residential districts or villages. Most cities, towns and villages naturally designed and implemented *"takadai-iten"* projects to take full advantage of this grant system, rather than infill development that is not eligible to get grant money.

However, in February 2014, a press person from the Asahi Shimbun reported on the basis of the newspaper's own survey that the number of building lots that Iwate, Miyagi and Fukushima Prefectures planned to build by disaster collective-relocation projects, land readjustments projects and fishing village projects for disaster resilience, surprisingly dropped about 20% from 28,060 lots at the end of 2012 to 22,288 lots at the end of 2013, because people had relocated to other areas or decided to live in public housing due to the heavy financial burdens of building their own houses (Nakamura 2014). In 2014 (October), the Board of Audit Japan disclosed that 25 municipalities in Iwate, Miyagi and Fukushima Prefectures had 342 districts of collective relocation project, but the number of building lots decreased nearly 25% from 14,638, in the original plans by the same token (The Board of Audit Japan 2014), to 10,868 lots.

In spite of population aging and decline in the affected areas most local governments developed reconstruction plans without having prepared population-growth projections hence missing a fundamental requirement for land use and transportation planning. Oddly, mayors in the disaster area repeatedly stated that they could not disclose the reduction in size of residential land area due to a negative population growth (Tsuboi 2016); if made public a strong opposition by the residents would have ensued as they expected a more positive planning strategy to revert the existing population problem (Higashino 2014).

Planning experts should prepare alternative sketch plans for communities in view of population decline and aging and show the residents these plans with the prerequisites for success and what will happen if they fail before they decide on final plans (Hayashi 2011). However, most plans have been provided without going through a planning process in which alternative sketches could be evaluated and, hence, the appropriate and final plan selected. The problem has existed not only in the national and prefectural governments, but also in municipal governments.

2.5 Conclusion

After World War II, reconstruction issues have become more complex through democratization and decentralization. A new planning problem has arisen: how and when administrative bodies at each layer should decide about which issues, while time is a precious resource in a disaster restoration process. Furthermore, since the Great Hanshin-Awaji Earthquake in 1995, *machi-zukuri* has been emphasized. After the Great East Japan Earthquake in March 2011, the government issued a concrete reconstruction vision of *takadai-iten* without showing the means to achieve it in April of the same year, which delayed the reconstruction process, while at the same time it narrowed the policy options at the local level. The national government began to conduct a survey in May, but had no clear idea of the planning process in municipal governments. The core problem lies in the fact that the statutory urban-planning system in Japan has lacked the terms meaning "planning" and "planning process" until today. Planning can be defined as the accommodation of several units to make a complete but harmonious whole, while planning a process is assumed as a process with a sequence of survey–analysis–plan; however, plan-making does not necessarily mean planning. The situation is the same with *fukkou-keikaku* (reconstruction plan). The national government provided a financial assistance program in December 2011, albeit without maintaining fiscal discipline at the national and local levels, and lacked a financial assistance program for *machi-zukuri*. Prefectural governments made coastal dike and levee construction plans without consulting with adjacent local communities, and municipal governments worked on relocation of homes from low-lying areas to safer location on higher grounds, rather than creating new compact residential areas built around existing villages and districts.

The lessons learned from the first months after the events that occurred in 2011, and thereafter until 2016, have proven to be most valuable for the country, particularly in the face of the highly-probable forthcoming earthquake and tsunami along the Nankai Trough, which may prove to be as devastating in magnitude and impact as the ones in 2011. This will include the need for the national government to promptly develop and provide financial assistance and human administrative capabilities for the affected local governments, while keeping fiscal discipline at the national and local levels. Moreover, prefectural and local governments will need to coordinate infrastructure planning with the affected local communities and also consider their plans and views throughout the planning process in accordance with local conditions and needs, while also developing and providing financial assistance programs for the affected communities and residents to support their *machi-zukuri*.

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Chapter 3
Building Back a Better Tohoku After the March 2011 Tsunami: Contradicting Evidence

Shingo Nagamatsu

Abstract Disaster recovery is regarded as a great opportunity to mitigate future losses from possible hazards. This idea has led the Japanese government to introduce a series of recovery programs, composed of relocation, land readjustment, and the provision of public housing; in fact, many reconstruction projects have already been undertaken under these programs. In spite of the massive reconstruction efforts for 'building back better', the recovery of the population has stagnated. Although part of the reason is the trend of population decrease in the area, the existing research and media reports have indicated that the length of time devoted to reconstruction works and the cost to local residents discourages them to the extent that they do not participate in the programs. The purpose of this study is to identify quantitatively whether such a paradoxical impact has existed during the recovery process from the 2011 disaster in Tohoku (Japan) by using panel analysis of 27 affected municipalities from 2009 to 2015. Once the analysis had been completed, a 'reconstruction paradox' was found indicating that the larger number of population emigrates from the affected area if the municipality devotes itself to the larger recovery project with heavy reconstruction projects. It was also found that the reconstruction paradox is evident in the municipalities in the high-fatality group, while those in the low-fatality group do not exhibit the significant impact of recovery programs both on in- and out-migration. Based on the results of the study, large-scale reconstruction projects are not recommended to ensure the safety of the residents but instead alternative approaches should be considered.

Keywords Disaster recovery • Migration • Disaster reconstruction • Relocation • Build back better

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V. Santiago-Fandiño et al. (eds.), *The 2011 Japan Earthquake and Tsunami: Reconstruction and Restoration*, Advances in Natural and Technological Hazards Research 47, DOI 10.1007/978-3-319-58691-5_3

3.1 Introduction

The 2011 Tohoku disaster, officially called the Great East Japan Earthquake disaster, was the most devastating calamity in Japanese postwar history, with over 18,000 people killed or missing and more than 300,000 households forced into homelessness. The recovery of social, economic, and cultural activities in the damaged area has been challenging because of the severity of damage, but has attracted both political and academic attention, similar to other major disasters such as 2005 Hurricane Katrina (Kates et al. 2006; Levine et al. 2007; Vigdor 2008), the 2000 Indian Ocean Tsunami (Barenstein 2013; Lyons 2009), and so on. There has been growing awareness that disaster is not only a threat but a critical opportunity for reducing future risks, looming behind those concerns for disaster recovery: the Sendai framework for disaster-risk reduction advocates the concept of 'build back better' in the recovery process as one of four top priorities (United Nations 2015).

The Japanese government has also regarded the disaster as an opportunity for creating a more resilient society, as the Reconstruction Design Council (2011) recommended. Thus, the government has been investing huge amounts of money, estimated as much as 25 trillion yen over the past 5 years, and will be adding 6.5 trillion yen in the succeeding 5 years for the Tohoku region. The disaster-recovery process, however, has not necessarily been smooth and successful, regardless of the huge amount of policy resources invested by national and local governments. Many affected people are still living in temporary houses even 5 years after the disaster, and the displaced population has not yet returned. Rather, most of the municipality has been suffering from an accelerated population decrease compared when to the pre-disaster trend (Matanle 2013).

The purpose of this study is to identify quantitatively the reasons behind the stagnated recovery process, by using panel analysis of 28 affected municipalities. Our primary conclusion is rather paradoxical: the reconstruction projects in the recovery programs applied by the government impeded the recovery process of a municipality. Robust convincing evidence has been found about the existence of the 'reconstruction paradox,' which means that the more reconstruction projects were undertaken by both national and local governments, the more people migrated out of the region and the fewer people migrated into the region.

Several existing studies have tried to identify the factors that determine the recovery process in terms of demographic changes. For example, Aldrich (2012) indicated in his study on the recovery process from the 1995 Kobe earthquake that the human ties and social capital that existed in the original community are a key determinant for the population to return during the recovery process. Chamlee-Wright and Storr (2009) observed the quick recovery of a Vietnamese-American community dispersed by the impact of Hurricane Katrina, and theoretically suggested that the provision of community services (club goods) by the community members was a key factor in motivating residents to return. Both studies put emphasis on the non-market provision of social services and networks to build resilience against disasters. Other studies in New Orleans during recovery from Hurricane

Katrina show that the population that migrated out of the city was more vulnerable than those who migrated into the city (Fussell 2015; Fussell et al. 2010; Groen and Polivka 2010). Part of the reason for it was the increased cost of housing. Vigdor (2008) explained why the population of New Orleans did not recover with a simple partial-equilibrium analysis of the housing market. This study also sought to analyze the population-recovery process, but its main purpose was to identify the policy impact on population recovery and its paradoxical result, which had not been covered by existing research.

This chapter looks at the recovery-policy framework of the disaster, reviews the existing literature that evaluates the recovery process, introduces the model and data for the study estimations, and focuses on the estimation results and related discussion.

3.2 Recovery-Policy Framework Provided by the National Government

Disaster recovery has been long recognized as an opportunity for both future disaster-risk reduction, and community vitalization and sustainable development (Berke et al. 1993, Shaw 2014b). In this view, reconstruction during the process of recovery offers affected communities an opportunity to integrate their efforts to create new structures (Jason David 2010). The recovery policy of the national government, after the 2011 disaster in Japan, was not an exception. In order to understand the quantitative analysis, a summary of the core points of the recovery-policy framework proposed by the national government, as described in the existing literature (Iuchi et al. 2013, 2015), was undertaken.

One of the very basic problems of the Tohoku recovery process was to provide permanent housing that is secure from future threats of a tsunami. The Ministry of Land, Infrastructure, and Transportation (MLIT) proposed the concept of level one (L1) and level two (L2) tsunamis on the recommendation of the Japan Civil Engineering Society, and it suggested tsunami-protection strategies differentiated to each level. A L1 tsunami is defined as an event occurring once every 10–100 years, whereas a L2 is defined as occurring once in several hundreds of years. This distinction was made to determine the standard of structural tsunami protection being planned during the reconstruction process. MLIT suggested that human lives and property should be protected against L1 tsunamis by structural measures, such as the construction of levees, whereas the protection strategy against the L2 tsunami should be with a combination of structural and non-structural measures. Since the 2011 tsunami was classified as an L2, additional protection measures, other than the construction of levees, would have been necessary to protect human lives and property against that magnitude of tsunami.

To address the potential L2 tsunami risks in Japan, the Reconstruction Agency proposed a package of recovery programs. The four key programs are as follows. The first is the *collective relocation program*, which aims to influence residents to move to a safer inland area. The second is the *land readjustment and raising program*, which aims to reallocate land parcels to elevated areas that are higher than tsunamis that might overtop the levees. The third key program is the *special tsunami recovery-zone act* that funds the redevelopment of the basic urban system in devastated localities. Finally, the public-housing program for disaster victims is intended to provide housing for tsunami survivors, who do not have the financial capacity to reconstruct their houses in the relocated or raised land. In this chapter, those programs are simply included in 'recovery programs.'

Three of these recovery programs, other than the *special tsunami-recovery zone act,* are not newly established programs: they existed before the disaster. A combination of these existing programs would have caused the recovery process to be faster and less uncertain than expecting new legislations and the most financially beneficial way for the survivors and affected local governments to construct a newly tsunami-resistant city. Many local governments, therefore, proposed recovery plans that took advantage of these programs by rebuilding residential areas through the collective relocation of communities to artificially raised land or inland areas with high elevations (Iuchi et al. 2013). According to the Reconstruction Agency, the number of households that applied for the collective relocation program was 8,840, which was as much as 4.8 times the previous total number of applications since the commencement of the program. Moreover, the land-readjustment-and-raising program was applied to huge areas in 50 districts, which was more than twice the number and ten times the area compared with the recovery process after the 1995 Kobe earthquake (Reconstruction Agency 2015). Cho (2014) pointed out that these programs were virtually the only options for the local government, due to the lack of sufficient funding sources.

3.3 Does Reconstruction Hinder Recovery?

Relocation is a costly option for residents. Therefore, even though the communities agree with the recovery plan for relocation, many people are reluctant to participate in it, and hence decide to leave their community. Their original lands are compensated by the government under the land readjustment program, but the amount is not enough to gain new land for houses (Ueda and Shaw 2015). The execution of the recovery plans, over the last several years, has revealed unexpected difficulties. Due to the concentration of massive reconstruction works in certain areas and the time needed for the projects, the shortages of manpower and reconstruction materials have become significant and have pushed up the reconstruction cost, leading to a delay in the overall reconstruction process (The Japan Times 2016). Furthermore, partly due to the delay in the reconstruction work, some of the displaced population could not wait until its completion, and already acquired land lots in other areas, in

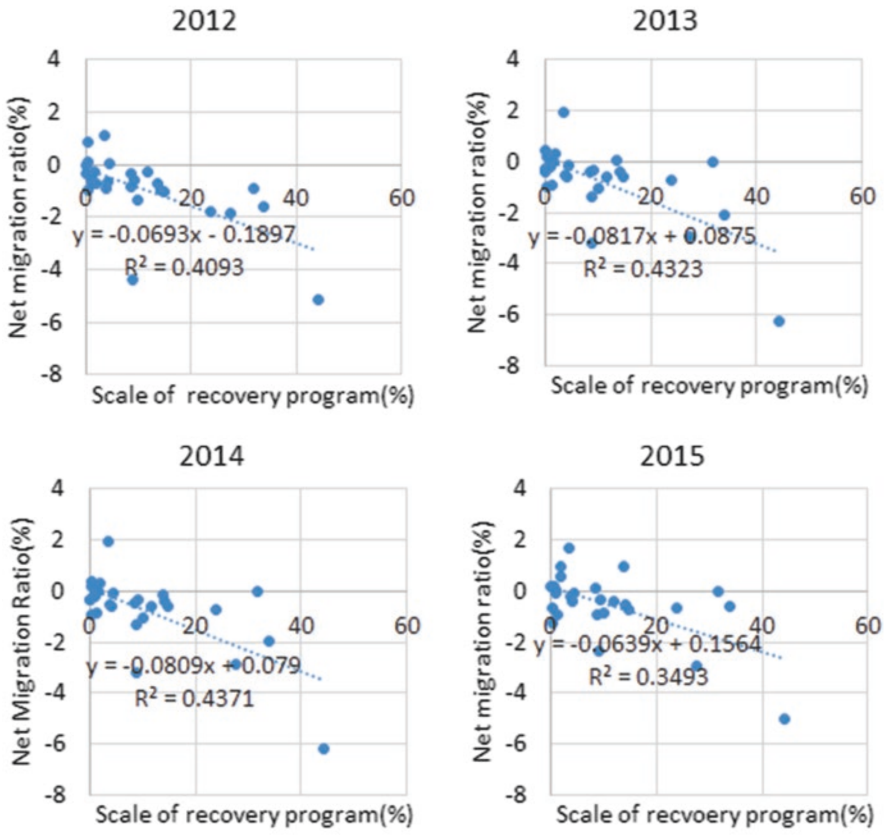

Fig. 3.1 Annual population net migration ratio and the scale of recovery programs by municipalities

spite of having agreed to the proposed recovery plan (The Mainichi 2016). The situation described here is the paradoxical result of recovery: the reconstruction accompanying the recovery projects hinders the actual recovery of the community.

In fact, the population-recovery process seems to have a strong relation with the scale of the reconstruction program, rather than with the damages suffered. Figure 3.1 shows the correlation between the annual net-migration rate (vertical axis) and the scale of the reconstruction program (horizontal axis) for the each single year from 2011 to 2015. Since the earthquake and tsunami disaster happened in March 2011, we can assume that all figures were free from the direct impact of the disaster. These figures show the negative relationship between the scale of recovery programs and the population-increase ratio. The trend shown here is very ironic: the larger the scale of recovery programs, the larger the decrease in population. Moreover, the explanatory power of this relationship is increasing from 2012 to 2014 where R-squared values of simple regression increase from 0.409 in 2011 to 0.437 in 2014.

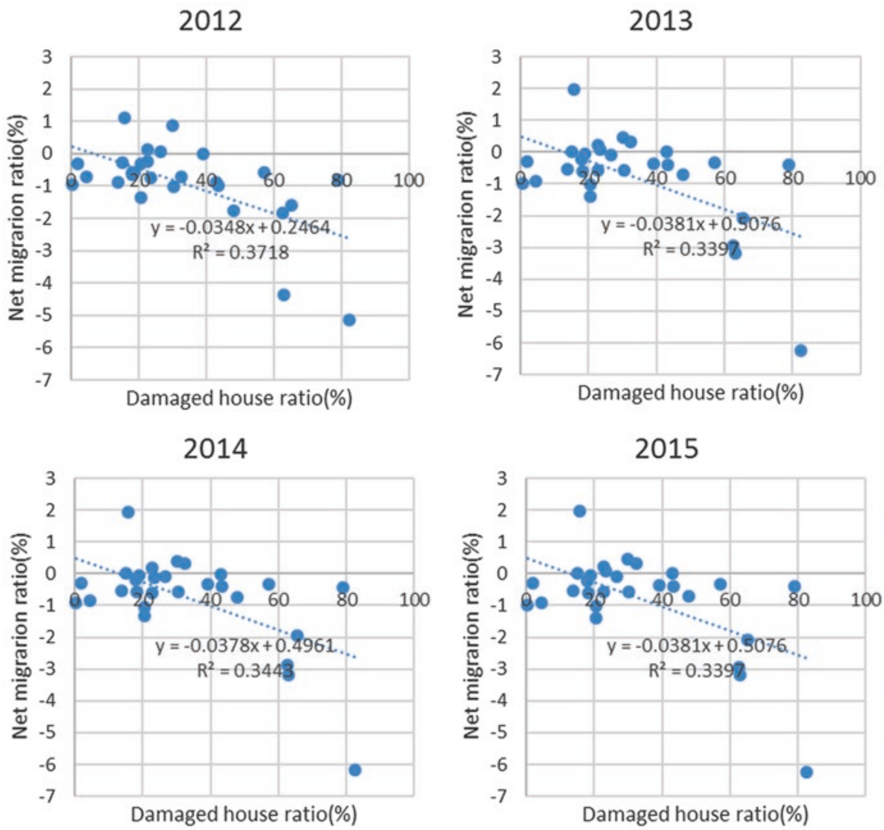

Fig. 3.2 Annual net migration ratio and the housing-damage ratio by municipalities

For the sake of comparison, the relationship between the net migration ratio and the housing damages is depicted in Fig. 3.2. There is a negative relationship between them, but not as evident as the one between the net migration ratio and the scale of recovery programs. The R-squared values were 0.371, 0.339, 0.344, and 0.349 in 2012, 2013, 2014, and 2015, respectively, which are lower than that of the regressions by scale of recovery programs shown in Fig. 3.1.

Table 3.1 provides the descriptive statics of the data used for this study.

Table 3.1 Descriptive statistics of data

Variables	Mean	Median	Max.	Min.	Std. Dev.	N
Net migration (%)	−0.90	−0.54	1.98	−10.67	1.77	196
In-migration (%)	3.93	2.78	89.84	0.39	6.54	196
Out-migration (%)	4.93	3.50	109.52	2.10	7.93	196
Scale of recovery programs (%)	5.82	0.25	44.13	0.00	10.13	196
Damaged housing ratio (%)	23.45	18.84	82.43	0.00	23.85	196
Inundated housing ratio (%)	32.07	27.14	116.16	0.00	31.49	196
Dummy for year 2011	0.14	0.00	1.00	0.00	0.35	196
Average income per taxpayer (Million Yen)	2.58	2.53	3.37	2.08	0.26	196
Average number of persons per a household	2.60	2.60	3.26	2.00	0.27	196
Newly constructed housing ratio (%)	2.48	1.63	12.76	0.00	2.32	196
Percentage of population over 65 (%)	28.39	29.26	39.80	17.51	5.14	196
Distance from a hub city (km)	50.57	61.65	93.70	0.00	29.55	196
Net migration trend	−0.42	−0.45	1.70	−1.29	0.50	196
In-migration trend	5.80	3.38	46.10	2.04	8.19	196
Out-migration trend	6.60	3.54	56.11	2.36	9.91	196

3.4 Reconstruction and Recovery-from-the-Disaster Process

3.4.1 Application of the Recovery Program and Its Decision-Making Process

The actual application of the recovery program varies depending on the individual municipal governments. Relocation is a very costly and time-consuming option. It was anticipated that a great deal of time would be needed to find a suitable and safer place to relocate, because the tsunami-affected areas were so mountainous that there is very little habitable land. Inland relocation, in many cases, required the development of new habitable land in the mountains. On the other hand, the artificial raising of inundated land, up to a maximum of 12 m in Rikuzentakata city, for example, required a vast amount of soil, reconstruction of the water and sewage system, and faced a new risk from the subsidence of raised land.

The decision-making process was not necessarily straightforward, and there had been negotiations between the residents and local governments to decide the actual recovery plan for each community (Iuchi et al. 2015; Shaw 2014a; Ueda and Shaw 2015). The conflicting opinions of the residents toward the recovery plans were revealed during these negotiation processes. As a result, some municipalities were reluctant to apply the recovery programs. For example, Tagajyo city in Miyagi prefecture, in which approximately one-third of the city area was inundated and 188

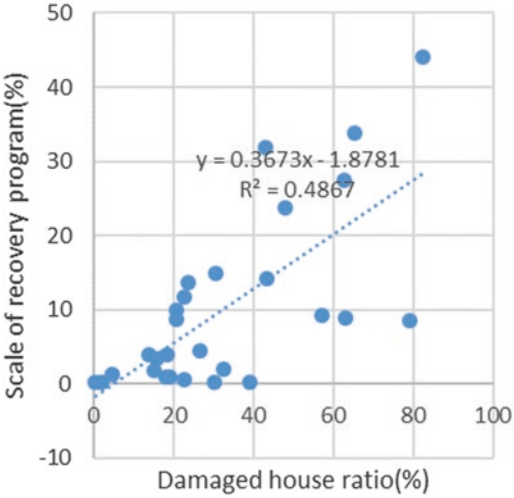

Fig. 3.3 Correlation between the scale of recovery program and housing damages by municipalities

people had died, announced that the city did not apply the recovery programs because of the residents' preference.

In fact, the scale of the recovery programs in each municipality was not necessarily adequate to the extent of the damage caused by the disaster. The vertical axis of the scattered plot shown in Fig. 3.3 denotes the ratio of the scale of the recovery program (reconstructed houses over the total number household before the disaster) and housing damages by municipalities**,** and the horizontal axis denotes the damaged house ratio (totally or partially destroyed households). It is evident that there is a significant gap in the scale of recovery programs at the same level of damage to housing.

What was behind the motivation of the local governments to apply these recovery programs? Figure 3.4 shows the correlation between the scale of recovery programs and the fatality rate among municipalities. It is obvious that the scale of the recovery program better explains the fatality rate than the damage on housing, as shown in Fig. 3.3. In other words, the municipality that suffered more casualties is more inclined to apply the recovery programs. It is very plausible that the local residents who had lost many human lives among their community might put high priority on safety and easily accept relocation.

3.5 Model and Data

The causal observation shown in Figs. 3.1 and 3.2 is not enough to identify the causal relationship between the recovery programs and the population. In order to test the hypothesis of the reconstruction paradox, the effect of other variables that affect the migration of population, especially disaster damages on each municipality, have to be controlled.

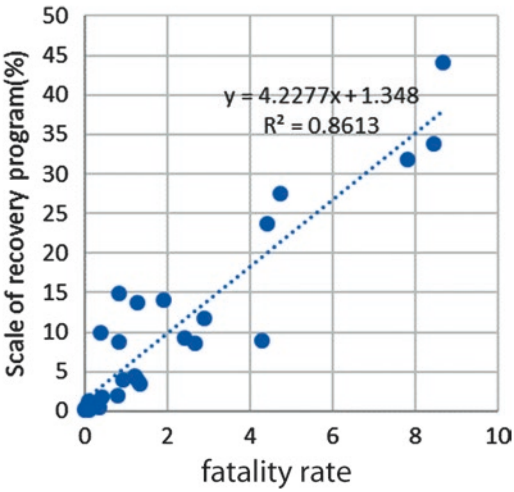

Fig. 3.4 Correlation between the scale of recovery program and fatality rate by municipality

For that purpose, the following equation was developed:

$$Migration_{i,t} = \alpha_0 + \alpha_1 Scale_{i,t} + \alpha_2 Damage_{i,t} + \alpha_3 Damage_{i,t}{}^{*} Dummy2011_t + \beta X_{i,t} + \gamma Trend_i + u_{it}.$$

Migration denotes population movement, which is the net in-migration and out-migration from the municipal area. *Scale* denotes the scale of the recovery programs applied by each municipal government. *Damage* denotes the total of physical damages in each municipality. *Dummy2011* denotes the dummy variable that takes the value of one if t = 2011. Please note that the migration in 2011 is highly contaminated by the direct shock of the disaster since the earthquake and tsunami occurred in March of that year.

Control variables in the model denoted as *X* have been included. *Trend* denotes the trend of migration before the disaster. The last term, *u* denotes the error term. Subscripts *i* and *t* denote the municipality and the year, respectively. Thereafter α, β, and γ were defined as parameters. Note that one cannot estimate the fixed effect model due to the use of time-independent variables such as *Trend*.

The data used for this analysis relate to the 28 municipalities that were damaged by the tsunami in Iwate, Miyagi, and Fukushima prefectures[1] (i = 1,...,28) from 2009, two years before disaster, to 2015, four years after the disaster (t = 2009, …, 2015). The municipalities that were affected by the mandatory evacuation order due to the radiation exposure caused by the Fukushima Daiichi nuclear power plant were

[1] The municipalities included in the dataset are Miyako, Ofunato, Kuji, Rikuzentakata, Kamaishi, Otsuchi, Yamada, Iwaizumi, Tanohata, Noda, and Hirono from Iwate Prefecture; Sendai, Ishinomaki, Shiogama, Kesennuma, Natori, Tagajo, Iwanuma, Higashimatsuhima, Watari, Yamamoto, Matsushima, Hichigahama, Onagawa, and Minamisanriku from Miyagi prefecture; Iwaki, Soma, and Shinchi from Fukushima prefecture.

excluded from the data. Therefore, our dataset consists of 196 observations for each variable.

The scale of reconstruction is defined as the percentage of housing units being provided under the recovery programs over the total number of households. The value of the numerator was derived from the National Reconstruction Agency (2015). Note that the variable takes on the value of zero when t <2012, the years when the recovery project was not planned nor implemented.

Migration data are derived from the population estimates from January 1 to December 31 each year. Note that, since both in-migration and out-migration are shown as positive numbers, subtracting out-migration from in-migration yields net migration. In this estimation, we denominate them by the estimated population as of October 1 each year. The damage data, damaged- and inundated-housing ratios, are derived from the Statistics Bureau (2013), and denominated by the total number of households as of October 2010. The fatality rate from the damage variables was excluded because, as previously seen, it has such strong correlation with the scale of reconstruction that a multicollinearity problem could not be avoided. For the same reason, one cannot include both the damaged and inundated housing ratios in a single model. Note that damage variables take the value of zero before the disaster (t <2011).

In regard to control variables, *Dummy2011* is a variable that takes the value of one when t = 2011, and zero otherwise. The average income per person is derived from taxable-income data from the Ministry of Internal Affairs and Communications, denominated by the population as of October 1, 2010. The variable can be regarded as an earning opportunity for in-migration, and an opportunity cost for out-migration. The number of constructed houses is derived from construction statistics provided by the MLIT. This variable was set to control the private housing supply out of the recovery program. The percentage of population over the age of 65 and the average number of persons per household are derived from the Basic Residents Register. The distance from the hub city is the shortest distance from either Morioka, Sendai, Koriyama, or Iwaki city, which are designated as central or large cities by the government of Japan. The migration trend is the average migration rate from 2009 to 2010, which is expected to control the inherit effect of each municipality on migration.

Some readers may be skeptical about the endogeneity of the scale variable. If governments are to decide their own scale of reconstruction programs considering the net-migration level, the scale and net migration is simultaneously decided, so that the estimated results can be contaminated by endogeneity bias. However, it was not true in the actual policy process. Most of the local governments have decided their recovery plans by the end of the year 2011, and they decided the scale of the recovery program based on the plan, and which was before each municipal government realized the extent of migration from its jurisdiction. Because of this policy-formation process, it is possible to assert that there is no endogeneity problem.

3.6 Estimation Results

Four regression models were estimated depending on the damage variable and estimation methods that are used in the estimation. Regression results are shown in Table 3.2. Both regressions 1 and 2 used the damaged housing ratio as the damage variable. While the former used pooled OLS technique, the latter used the GLS technique, assuming that cross-section heteroscedasticity existed. Regressions 3 and 4 used the inundated-housing ratio as the damage variable, the former used pooled OLS technique and the latter used the GLS technique. A Breusch-Pegan test for existence of cross-section random effects was conducted for regressions 1 and 3, but the null hypothesis was rejected for both of them. Therefore, the GLS estimations for the following analysis were employed. For reference, regressions 5 and 6 were estimated by using a cross-section fixed-effect model for the house-damage ratio and the inundated-house ratio, respectively.

In all the estimations from regression 1 to 4, the coefficient of scale of reconstruction is negative, with 1% statistical significance. On the other hand, the coefficient of damage variable does not show any statistical significance. All the coefficients of the cross-term between damage and dummy2011 are negative and significant at the 1% level. These estimation results make sense if the reconstruction paradox truly exists. However, the coefficient-of-damage variable in estimation 3 and 4 is positive, even though they are not significant. Since this is contrary to our assumption, the existence of multicollinearity should be doubted.

It should be noted that, in the fixed effect model (regression 5 and 6), coefficients for scale of recovery were estimated as significantly positive for both equation, which is contradictive to our expectation. However, the overall result of the fixed-effect model does not seem to explain the migration rate adequately. For example, the coefficients for the average number of persons per household and percentage of population over 65 are positive in both regressions, and those in regression 6 are significant, which are contrary to our expectation and not plausible. Thus, we could conclude that the fixed-effect model is not appropriate for this analysis and avoid it for succeeding analysis.

A doubt about the correlation between the scale of reconstruction and net migration should be considered. As seen in Figs. 3.3 and 3.4, the fatality rate can have a strong correlation with the scale of reconstruction. Therefore, even though the true explanatory variable is fatality rate, for example, one can obtain the statistically significant correlation shown in Fig. 3.4**.** Moreover, it is likely that if the high fatality rate destroyed community ties in the municipalities and hampered population recovery, because the fatality rate negatively affects social capital, then it negatively affects migration as well.

To avoid these deficiencies in the analysis, a separation of the sample into two groups was done: one considering the high-fatality group that is a selection of municipalities, whose fatality rates are over 1%, and the low-fatality group where the fatality rates are equal to or less than 1%. The results are shown in Table 3.3. In

Table 3.2 Regression result by using all samples

	1	2	3	4	5	6
Dependent variables	Net migration	Net migration	Net migration	Net migration	Net migration	Net migration
Damage variable	Damaged house rate	Damaged house rate	Inundated house rate	Inundated house rate	Damaged house rate	Inundated house rate
Period	2009–2015	2009–2015	2009–2015	2009–2015	2009–2015	2009–2015
Number of cross sections	28	28	28	28	28	28
Number of observations	196	196	196	196	196	196
Cross section effect	None	None	None	None	Fixed	Fixed
Estimation method	OLS	Cross section weighted GLS	OLS	Cross section weighted GLS	Cross section weighted GLS	Cross section weighted GLS
Constant	3.86 (2.6)	0.38 (1.09)	2.29 (3.4)	−0.24 (1.4)	−27.86 (3.23)	−42.81 (7.59) ***
Scale of recovery programs	−0.05 (0.02) ***	−0.05 (0.01) ***	−0.07 (0.02) ***	−0.05 (0.01) ***	0.02 (0.01) ***	0.05 (0.02) ***
Damage	−0.01 (0.01)	0.00 (0)	0.00 (0.01)	0.00 (0)	0.00 (0)	0.00 (0.01)
Damage*2011 dummy	−0.08 (0.01) ***	−0.08 (0.01) ***	−0.06 (0.01) ***	−0.05 (0) ***	−0.04 (0) ***	−0.02 (0.01) ***
Average income per a taxpayer	−0.44 (0.52)	0.08 (0.26)	−0.24 (0.65)	0.25 (0.3)	−0.72 (0.42)	−1.17 (1.01)
Average number of persons per household	−0.52 (0.39)	−0.19 (0.15)	−0.20 (0.51)	−0.14 (0.17)	7.21 (0.8)	11.09 (1.84) ***
Newly constructed house ratio	0.15 (0.06) ***	0.13 (0.03) ***	0.10 (0.08)	0.11 (0.03) ***	0.10 (0.03) ***	0.04 (0.06)
Percentage of population over 65	−0.05 (0.03)	−0.01 (0.01)	−0.06 (0.04)	−0.01 (0.02)	0.35 (0.04)	0.56 (0.09) ***
Distance from a hub city	0.00 (0)	0.00 (0)	0.01 (0)	0.00 (0)		
Trend	0.81 (0.14) ***	0.81 (0.1) ***	0.87 (0.17) ***	0.75 (0.12) ***		
R squared	0.684	0.775	0.567	0.769	0.870	0.625

(continued)

Table 3.2 (continued)

	1	2	3	4	5	6
Adjusted R squared	0.669	0.764	0.546	0.758	0.842	0.587
F statistics	44,739 ***	71.188 ***	27.097 ***	68.882 ***	31.605 ***	16.322 ***
Breusch-Pagan	18.005 ***		13.699 ***			

Numbers in parenthesis are cross section weighted standard errors
*, **, *** represents 10%, 5%, and 1% significance respectively

this analysis, the cross-section-weighted GLS was used to secure the generalities of the result for all estimations.

Estimations 1 and 2 are the result of high fatality groups, which employed the damaged-housing rate and inundated-housing rate as damage variables, respectively. The result that shows the existence of the reconstruction paradox was derived; the estimated coefficients of scale of reconstruction in both estimations are negative and significant. In addition, the result of estimation 3 and 4, which estimated for low fatality group, also shows reconstruction paradox significantly for each damage variables.

The estimated model seems to be more fitted and plausible for higher fatality groups. The R-squares of estimations 3 and 4 are much smaller than those of 1 and 2. With regard to control variables, estimations 1 and 2 exhibit a greater number of significant coefficients with expected signs. The low-fatality group conducted a relatively small scale of recovery programs, and hence its migration effect might have been not as evident as the higher fatality group.

Finally, the in- and out-migration effects were individually investigated. Table 3.4 shows in-migration and out-migration effect for high fatality group in estimations 1–4, and low fatality group in estimations 5–8. The estimated coefficients of control variables are omitted for the sake of space.

When looking at the high-fatality group, the coefficients of scale of recovery are not significant for in-migration (estimations 1 and 2), but are for out-migration (estimations 3 and 4). Instead, coefficients for damages are significant for in-migration (estimations 1 and 2), but are not for out-migration (estimations 3 and 4). The asymmetric effect of damage and scale of recovery on migration is plausible. The damages in the cities reduce the attractiveness for people from other cities to move in, but it is not necessarily enough reason for the affected people, who have been staying there, to move out because of their livelihood or their inherent affinity to the area. However, it is plausible that the cost of large-scale reconstruction made the affected people give up on the recovery program and pushed them to move out. As such, it was found that the reconstruction paradox is mainly due to the acceleration of outflow of the population.

On the other hand, when looking at the low-fatality group (estimations 5–8), no coefficients of scale of reconstruction are significant. Although the reconstruction paradox on net migration is seen in Table 3.2, one cannot derive a statistically

Table 3.3 Estimation results by fatality groups

	1	2	3	4
Dependent variables	Net migration	Net migration	Net migration	Net migration
Damage variable	Damaged house rate	Inundated house rate	Damaged house rate	Inundated house rate
Period	2009–2015	2009–2015	2009–2015	2009–2015
Number of cross sections	14 (fatality>1%)	14 (fatality>1%)	14 (fatality≤1%)	14 (fatality≤1%)
Number of observations	98	98	98	98
Constant	3.5243 (2.677)	4.3027 (3.42)	−0.9622 (1.95)	0.6077 (2.263)
Scale of recovery programs	−0.0393 (0.016) **	−0.0509 (0.016) ***	0.0351 (0.017) **	0.0353 (0.019) *
Damage	0.0099 (0.007)	−0.0008 (0.006)	0.0114 (0.007)	0.0034 (0.005)
Damage*2011 dummy	0.0816 (0.008) ***	0.0614 (0.006) ***	−0.0355 (0.009) ***	0.0231 (0.005) ***
Average income per a taxpayer	0.2515 (0.448)	−0.2702 (0.595)	0.4279 (0.406)	0.3661 (0.451)
Average number of persons per household	0.7380 (0.394) *	−0.6033 (0.525)	−0.1274 (0.277)	−0.1886 (0.285)
Newly constructed house ratio	0.1651 (0.04) ***	0.1700 (0.063) ***	0.0226 (0.051)	0.0663 (0.039) *
Percentage of population over 65	0.0782 (0.046) *	−0.1229 (0.063) *	−0.0030 (0.017)	−0.0032 (0.019)
Distance from a hub city	0.0197 (0.007) ***	0.0214 (0.008) ***	0.0011 (0.002)	0.0000 (0.003)
Trend	1.0250 (0.192) ***	0.8228 (0.232) ***	0.6174 (0.26) **	0.5629 (0.295) *
R squared	0.845	0.773	0.492	0.625
Adjusted R squared	0.829	0.749	0.440	0.587
F statistics	53.298 ***	33.230 ***	9.475 ***	16.322 ***

Estimation method: cross section weighted general least square
Numbers in parenthesis are cross section weighted standard errors
*, **, *** represents 10%, 5%, and 1% significance respectively

significant result for in- or out-migrations. Therefore, the evidence for the existence of reconstruction paradox is very weak for the low-fatality group.

It is worth mentioning that the coefficients of the dummy cross-term for in-migration (estimations 1, 2, 5, and 6) do not show significant values, while the estimation for out-migration (3, 4, 7, and 8) does. The effect of the earthquakes and tsunamis shock on migration only exists for out-migration.

Table 3.4 In- and out-migration effect by fatality group

	1	2	3	4
Dependent variables	In migration	In migration	Out migration	Out migration
Damage variable	Damaged house rate	Flooded house rate	Damaged house rate	Flooded house rate
Period	2009–2015	2009–2015	2009–2015	2009–2015
Number of cross sections	14 (fatality>1%)	14 (fatality>1%)	14 (fatality>1%)	14 (fatality>1%)
Number of observations	98	98	98	98
Constant	5.1545 (4.066)	5.4528 (3.431)	−3.5817 (5.106)	−2.4330 (4.544)
Seale of recovery	0.0119 (0.016)	0.0293 (0.019)	0.0504 (0.021) **	0.0754 (0.024) ***
Damage	−0.0223 (0.009) **	−0.0295 (0.009) ***	−0.0035 (0.012)	−0.0182 (0.012)
Damage*2011 dummy	0.0072 (0.01)	0.0101 (0.01)	0.0850 (0.014) ***	0.0827 (0.013) ***
R squared	0.480	0.330	0.533	0.467
Adjusted R squared	0.427	0.262	0.485	0.413
F statistics	9.032 ***	4.819 ***	11,161 ***	8.569 ***
	5	6	7	8
Dependent variables	In migration	In migration	Out migration	Out migration
Damage variable	Damaged house rate	Flooded house rate	Damaged house rate	Flooded house rate
Period	2009–2015	2009–2015	2009–2015	2009–2015
Number of cross sections	14 (fatality≤1%)	14 (fatality≤1%)	14 (fatality≤1%)	14 (fatality≤1%)
Number of observations	98	98	98	98
Constant	−3.6475 (1.891) *	−2.4183 (1.613)	−4.7357 (2.214) **	−3.1958 (2.713)
Seale of recovery	0.0283 (0.027)	0.0370 (0.036)	0.0446 (0.029)	0.0707 (0.038) *
Damage	−0.0227 (0.011) **	−0.0119 (0.008)	−0.0423 (0.011) ***	−0.0199 (0.008) **
Damage*2011 dummy	0.0184 (0.013)	0.0079 (0.008)	0.0492 (0.013) ***	0.0264 (0.009) ***
R squared	0.680	0.669	0.576	0.528
Adjusted R squared	0.647	0.635	0.533	0.479
F statistics	20.758 ***	19.773 ***	13,291 ***	10,927 ***

Estimation method: cross section weighted general least square
Numbers in parenthesis are cross section weighted standard errors
*, **, *** represents 10%, 5%, and 1% significance respectively

3.7 Discussion and Conclusions

The estimation results are generally in favor of the existence of the recovery paradox; the higher scale of recovery program boosts population decrease, by hindering in-migration and pushing more residents out from the disaster-affected municipalities. As seen, this can be interpreted as the costs incurred by the residents, and the time consumed for the completion of relocation, according to the existing literature.

The analysis of the sample divided into the low- and high-fatality groups showed that the recovery paradox could be evident in both groups. However, the breakdown analysis on in- and out-migration effects showed no statistically significant evidence of the recovery paradox for the low-fatality group due to a simple reason. The municipalities in the low-fatality group applied relatively smaller recovery programs than those of the high fatality group, and therefore, those who decided to leave the community that had applied the recovery program could have resettled within that municipality. The above-mentioned analysis cannot verify this explanation; however, it might be possible to say that the reconstruction paradox holds true at the community level. This could be a future step subsequent to the present study.

Asking what policy recommendations can be derived from this result, the first one is for Tohoku recovery. A simple answer to the question is the reduction in time and the cost of the recovery programs. One possible policy option might be to provide more subsidies for the residents who cannot afford relocation. However, that option would raise the overall cost of recovery programs by a huge margin, and be inevitably challenged in terms of efficiency and equality. With regard to efficiency, it might be possible for the community to manage future tsunami threats, equipped with evacuation facilities, which are not always discussed during the recovery process. More importantly, inter-regional justice has to be considered bearing on the question of why such a huge amount of money was invested only in the Tohoku area for future risk. Many coastal areas in Japan also face future tsunami threats, and policy resources should be devoted to these areas as per equality of national-risk distribution.

Even though the additional subsidies could be justified, time for reconstruction cannot be shortened significantly because of the lack of construction capacity. Avoiding the community participation and discussion process may shorten the time to some degree, but it would cause other conflicts between the residents and local governments, and would probably consume more time. Therefore, it is possible to conclude that recovery programs with relocation of this magnitude would inevitably fail. Alternative recovery programs that enable resettlement at the original location to secure the ties among the original community members, and investments in facilities for tsunami evacuation, early warnings, and human development that enable quick and smooth evacuation could be recommended.

Another recommendation is related to the understanding the concept of 'building back better.' We can never say that the recovery and reconstruction process that pushes people out is a better route to recovery, even though the structures became more disaster resistant. It is important to be aware that the meaning of better implies not only disaster-risk reduction but also the revitalization of community activities with diverse populations. Although each objective is often a trade-off, the reconciliation of both in an effective way can deserve to be called as an example of 'building back better.'

Acknowledgement This research is supported by Grant-in-Aid for Scientific Research (24221010). The initial work of this study owed by undergraduate research of Mr. Shumpei Kawatoko and Ms. Yumiko Matsuba at Kansai University. I am also grateful for comments from Adam Rose, Jonathern Eyer at University of Sourthern California, and Ilan Noy at Victoria University as an reviewer of this paper. All remaining errors, however, are mine.

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Chapter 4
Creating Urban Resilience Using Spatial Planning: The Case of Miyako City During the First Five Years After the Great East Japan Earthquake

Nadine Mägdefrau

Abstract When a city is struck by a disaster, it faces huge challenges which persist even after the first shock of the event is conquered. Often, large parts of the city are partially or completely destroyed, which makes the reconstruction process time- and cost-intensive. On the other hand, the massive destruction that a disaster causes also opens a window of opportunity, because it eliminates the former urban structure and reduces the opportunity costs for change. As a consequence, spatial planners are enabled to change the urban structure and design a more resilient city. Based on the experiences in Japan's Miyako City after the Great East Japan Earthquake and Tsunami, this chapter examines how the reconstruction process can be used to create urban resilience.

Keywords Great East Japan Earthquake • Miyako City • Spatial planning • Resilience • Engineering resilience • Evolutionary resilience

4.1 Introduction

Disasters put a huge burden on affected towns and cities. After the first shock is conquered, there still is a large amount of work that needs to be done before the city can return to its daily life: the continuity of important public services must be secured, people must be provided with safe shelter, debris must be removed and the city must be reconstructed. Nevertheless, the massive destruction that a disaster causes can also open a window of opportunity. This window results from the elimination of the former urban structure which reduces the opportunity costs for changes

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V. Santiago-Fandiño et al. (eds.), *The 2011 Japan Earthquake and Tsunami: Reconstruction and Restoration*, Advances in Natural and Technological Hazards Research 47, DOI 10.1007/978-3-319-58691-5_4

(Olshansky et al. 2012) and enables spatial planners to build back better by designing a more resilient city. This chapter will give examples of how the spatial planners in Miyako City in Japan used this chance to increase their city's resilience after the Great East Japan Earthquake (GEJE) and Tsunami. To specify the understanding of the broad term resilience, the following paragraphs give a short introduction to the emergence of resilience and explain its relevance for disaster risk reduction and spatial planning. Subsequently, the case of Miyako City's Taro District is introduced, and some of the measures that were taken by spatial planners are examined concerning their ability to increase the district's resilience.

4.1.1 Resilience: A Brief Introduction

C.S. Holling from the University of British Columbia differentiates between two basic types of resilience (Holling 1973): The first perception stems from physics and the engineering sciences and is termed "engineering resilience". It describes "the ability of a system to return to an equilibrium state after a temporary disturbance" (Holling 1973, p. 17). The faster a system is able to return to its former state—or to bounce back—the more resilient it is. Holling contrasts engineering with ecological resilience: Ecological resilience can be defined as "the magnitude of disturbance that can be absorbed before the system changes its structure" (Holling 1996, p. 33). In contrast to engineering resilience, ecological resilience allows systems to have more than one state of equilibrium. This means a system is able to maintain its basic functions, although it does not return to its former state of equilibrium after a disturbance. The system is concentrated on maintaining its existence rather than operating efficiently (Holling 1996). This ability of ecologically resilient systems to adjust to unforeseen circumstances becomes more and more important in a continuously changing world.

Holling's ecological understanding of resilience was discussed in various fields of science (Folke 2006; Manyena 2006); it has also been adopted in social sciences. Based on the understanding that people and their natural environment are intertwined, the term of socio-ecological resilience was formed (Folke et al. 2010) and enhanced to the term evolutionary resilience (Davoudi et al. 2012). The concept of evolutionary resilience conceives of the world as a complex entity that is constantly in a state of flux and therefore linked to a high degree of uncertainty (Davoudi et al. 2012). The evolutionary nature of resilience is based on the concept of adaptive cycles that are linked in panarchies (Holling 2001). This structure enables a system to use an accident as a window of opportunity to evolve. During this phase, the system invents and tests new and innovative approaches to adjust to its new framework conditions (Olsson et al. 2006). In this context, the reason for resilience's appeal for disaster-risk reduction becomes evident: Resilience enables "a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structures and functions" (IPCC 2012, p. 563). Resilience therefore combines measures to predict (e.g., through early-warning systems), resist (e.g., through protective infrastructure), adjust (e.g., through relocation to a safer place) and recover (e.g., through social cohesion) to handle chronic or acute stresses.

Today, the evolutionary understanding of resilience is widely acknowledged, which has resulted in a partial neglect of the benefits of engineering resilience. However, despite the obvious advantages of evolutionary systems to evolve, the benefits of engineering resilience for urban structure cannot be denied. Built structure needs a certain degree of robustness to endure. Therefore, spatial planners need to design a city that is able to "resist [and] absorb" (UNISDR 2009, p. 24) hazardous events whenever possible. For instance, this can be achieved by constructing buildings that withstand an earthquake, designing a communication system that operates during a hurricane or building a seawall to protect a city from a tsunami (UNISDR 2015b). Unfortunately, as the example of Taro District in Miyako City shows, sole reliance on engineering resilience is problematic. To prepare a city for the possible failure of structural protective measures, it is therefore essential to build in evolutionary resilience that combines political-institutional, social, economic and environmental aspects of resilience (UNISDR 2012). For instance, evolutionary resilience can be achieved through a city's in-advance preparation for a disaster (political-institutional), the creation of social cohesion (social), the preparation of plans for business continuity in case of a disaster (economic) or the conversation of ecosystem health (environmental) (UNISDR 2015b). For that reason, this chapter follows a twofold understanding of resilience: a city's built structure is bound to engineering resilience, while a city's political-institutional, social, economic and environmental elements correspond to an evolutionary understanding of resilience (Fig. 4.1).

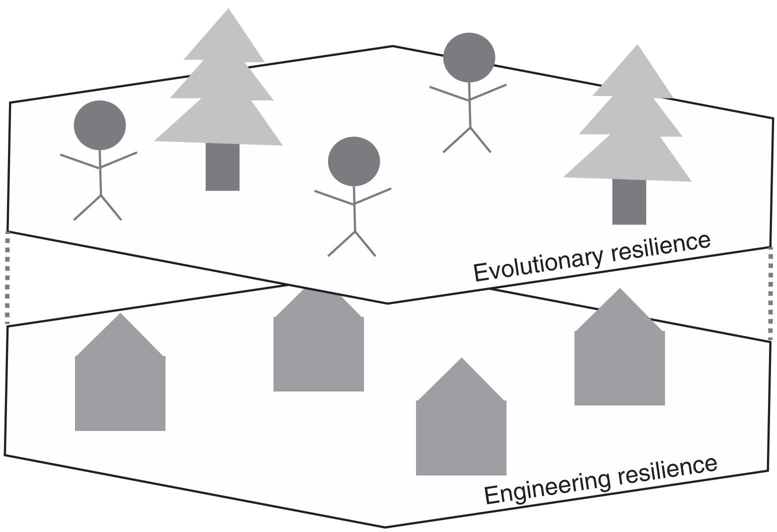

Fig. 4.1 Engineering and evolutionary resilience (Author's illustration)

4.1.2 Resilience as a Goal for Disaster Risk Reduction

By signing The Sendai Framework for Disaster Risk Reduction 2015–2020 (Sendai Framework), the UN Member States agreed on the importance of resilience for disaster risk reduction. The document mentions the term in various contexts and also highlights its importance by summarizing the document's goal as "strengthen[ing] resilience" (UNISDR 2015a). Already a couple of years earlier, when the Basic Guidelines for Reconstruction in response to the Great East Japan Earthquake were issued, the Japanese government emphasized the importance of creating "disaster resilient communities" (Reconstruction Headquarters in response to the Great East Japan Earthquake 2011). The document sets the framework for the reconstruction process in the Tohoku Region and is based on the "Basic Act on Reconstruction in response to the Great East Japan Earthquake" (Act No. 76 of 2011) issued by the Japanese government.

To determine a city's resilience and check if the goal to create resilience is met, certain indicators to measure resilience are critical. Of course, this operationalization can never completely represent reality, and some critics will always disagree with the underlying assumptions. However, for the purpose of comparability they are indispensable. One possibility to examine a city's resilience is the Disaster Resilience Scorecard for Cities. The document was induced by the United Nations Office for Disaster Risk Reduction (UNISDR) to screen the progress of building disaster resilience into cities worldwide and represents a comprehensive understanding of resilience that corresponds with the one presented above. The scorecard includes the following ten essential points that frame the measurement of disaster resilience (UNISDR 2015b):

1. Organize for Resilience
2. Identify, Understand and Use Current and Future Risk Scenarios
3. Strengthen Financial Capacity for Resilience
4. Pursue Resilient Urban Development
5. Safeguard Natural Buffers to Enhance the Protective Functions Offered by Natural Ecosystems
6. Strengthen Institutional Capacity Resilience
7. Increase Societal and Cultural Resilience
8. Increase Infrastructure Resilience
9. Ensure Effective Disaster Response
10. Expedite Recovery and Build Back Better

Each essential point is composed of various items of resilience, which cannot all be discussed here in detail. Some of these items can be influenced predominately by spatial planners (e.g., the amount of vulnerable land uses at risk), while others need the spatial planners' cooperation with other actors (e.g., the engagement of vulnerable segments of population). Furthermore, some items cannot be directly influenced by spatial planners (e.g., financial planning for disaster resilience), since they fall within the scope of other actors. This chapter can only give a small glimpse at

Table 4.1 Items of engineering and evolutionary resilience

Engineering resilience	Evolutionary resilience
Establishing and maintaining adequate protective infrastructure (e.g., levees)	Preservation and improvement of social cohesion
Reducing the amount of vulnerable land uses at risk (e.g., residential, agricultural, economic activity)	Engagement of vulnerable segments of the population

Author's illustration based on UNISDR (2015b)

spatial planners' ability to increase a city's resilience after a disaster. For this purpose, the two tabulated items (Table 4.1) for each type of resilience were selected and will be reviewed in the following section based on the experiences of the practitioners in Miyako City.

Although some authors may hold different opinions, the author strongly adheres to the UNISDR's assessment to classify the establishment and maintenance of protective infrastructure and the reduction of vulnerable land uses at risk as items to decrease resilience. The reason behind this is that spatial planning's impact on resilience is strongly related to engineering resilience, therefore limiting resilience to a system's ability to react after a disaster restricts the concept's great capabilities.

4.2 Miyako City and the Great East Japan Earthquake

Miyako City is located in Japan's Iwate prefecture, in Northern Japan. It borders the Pacific Ocean to the east, Morioka City to the west, Iwaizumi Town to the north and Tono City to the south (Miyako City 2016). The city's current area consists of the four formerly independent parts, namely, Miyako City, Taro Town, Niisato Village and Kawai Village that were merged during the great Heisei amalgamation between 2005 (Taro and Niisato) and 2010 (Kawai) (Statistics Bureau, Ministry of Internal Affairs and Communications Japan 2014, Table No. 62). Today the city spans 50 km from north to south and 64 km from west to east (Miyako City 2016).

Due to its location directly by the ocean, Miyako City has a long history of disasters. For instance, the city was struck by the Sanriku Earthquake and Tsunami in 1611, the Cascadia Tsunami in 1700 and the Sanriku Earthquake and Tsunami in 1896 and 1933. On 11 March 2011, the list of unfortunate incidents was expanded by another event when the GEJE and Tsunami hit the city and led to the loss of 407 people and 94 missing persons. The disaster damaged a total of 9088 houses (Table 4.2).

The tsunami solely affected districts along Tohoku coastline. Most affected in Miyako City were the districts Akamae, Atago/Tsukiji, the city center, Fujiwara, Kanehama, Kuwagasaki, Sokei, Takahama, Tsugarui and Taro, each with 100 or more damaged houses (Ubaura and Akiyama 2016). The following paragraphs review the efforts of Miyako City's spatial planners to increase the resilience of Taro District after the disaster. Thereby, the four above-identified items of resilience will serve as a guideline.

Table 4.2 Number of houses and type of damaged after the GEJE

Completely damaged	5968
With large-scale destruction	1335
Partially destroyed	1174
Damaged	611
Total damaged houses	9088

Author's illustration based on Miyako City Planning Division (2015)

4.3 The Reconstruction Process in Taro City

Taro District was strongly affected by the disaster. 1076 were damaged and about 84% of the entire housing stock was completely destroyed (Ubaura and Akiyama 2016). Because of the district's long history of tsunamis, the citizens of Taro had intended to relocate onto a nearby mountain at various times in the past. However, only after the 2011 tsunami the plan was realizable, before it was too costly and technically impossible (Miyako City Planning Division, Employee B 2015). Instead of relocating residential land uses onto safe land, Taro District had relied on protective infrastructure for decades, as the following paragraphs show.

4.3.1 Establishment and Maintenance of the Protective Infrastructure

After the Sanriku Earthquake and tsunami in 1933 destroyed large parts of the town (Taro District was an independent town until 2005), a system of protective levees was constructed to ensure Taro's safety against future tsunamis. The 10-m-high walls with a total length of 2433 m were completed in 1979 (Miyako City Great East Japan Earthquake and Tsunami Records Editorial Committee 2015). Unfortunately, the tsunami on 11 March 2011 was too high to be stopped by the existing seawalls. One of the walls was completely destroyed and the others were overtopped, resulting in water washing over the low-lying land behind the concrete structure (Miyako City Great East Japan Earthquake and Tsunami Records Editorial Committee 2015). This tragic incident taught an important lesson: No matter how high and strong a seawall is, it can never guarantee complete safety. It is important for people to keep this in mind and evacuate in case of a disaster, even though they might feel protected by the protective infrastructure. Still, the capabilities of protective infrastructure are undeniable, which is the reason why the Japanese government planned to establish levees along the Tohoku coastline after the GEJE.

The height of the seawalls was thereby determined based on a tsunami simulation that distinguishes between L1- and L2-tsunamis. L1-tsunamis have a probability of occurrence of every decade to several hundred years and are not as high as

Fig. 4.2 Elevation of the remaining seawall in Taro District (Miyako City) (Photo by the author, October 2015)

L2-tsunamis, while L2-tsunamis only occur every several hundred years or less frequently (Ubaura 2013). The new seawalls are designed to protect Tohoku's coast from L1-tsunamis. People who live behind them will be protected from tsunamis with this lesser height. However, extremely rarely occurring L2-tsunamis are so severe that they will overspill the levees, and the area behind them will become inundated. This means that the protective infrastructure will provide a certain degree of safety and therefore increases the city's resilience. However, an overreliance on such engineering solutions could be fatal, and additional soft measures like the installation of effective evacuation systems are urgently required to ensure the maximal safety for the citizens.

In the Taro District, the remaining seawall (Fig. 4.2) was elevated by 70 cm to compensate for the lowering of the ground caused by the GEJE (Miyako City Planning Division, Employee B 2015). In addition to this, a first line of defense with a height of 14.7 m is planned. This seawall will be located along the shore (Taro district reconstruction town planning committee 2012). This two-line defense system will be able to protect the land uses behind the second levee from future L1-tsunamis.

Keeping in mind the limits of protective infrastructure, the construction of the seawall in Taro is able to increase the district's disaster resilience against L1-tsunamis. However, the fact that structural measures can never guarantee complete safety should remain present over the years, and citizens should always follow evacuation warnings to ensure the safety of their most valuable possession—their lives.

4.3.2 Reduction of Vulnerable Land Uses at Risk

The installed seawalls can only protect Taro District in the case of a L1-tsunami. If a L2-tsunami, like the one on 11 March 2011, occurs, the low-lying area behind the two levees will be flooded (Taro district reconstruction town planning committee 2012). Most municipalities follow the rule of thumb that areas that are assumed to be subject to floods of higher than 2 m, in the case of a L2-tsunami, are restricted from residential and other vulnerable land uses. These assumptions are based on computer simulations (Ubaura 2016). This is also the case in Taro District. In the future, areas that directly neighbor the ocean will only be available for uses such as by the fishing industry. This is necessary because of the close connection between the fishing industry and the ocean. The areas between the first and the second levee are designated for additional industrial uses and parks for recreational purposes. Shops and other commercial land uses will be located behind the second levee, close to the train station. This land and the land around the elementary school will also be partially elevated, so that residents that intend to stay in this area of Taro District are able to rebuild their houses on safe ground (Taro district reconstruction town planning committee 2012).

However, the majority of Taro's citizens decided to move from the low-lying area by the sea up to nearby Otobe Hill. For this purpose, the mountain was truncated and a new district was created. This area was planned from scratch and includes space for privately owned detached houses, multi-story public houses and several smaller shops and parks (Fig. 4.3). On the lower-lying part of this newly developed area, a hospital, a fire station and other public facilities have been built (Miyako City Planning Division, Employee B 2015).

Fig. 4.3 The parcelled lots await the beginning of the construction work (Author, October 2015)

In summary, it can be stated that the land-use changes in Taro District significantly reduced the exposure of vulnerable land uses to possible future tsunamis. This mainly was achieved by the relocation of residential and other vulnerable land uses (e.g., the hospital) to higher ground. Concomitantly, the decision to only locate land uses that directly require closeness to the ocean in the area by the sea and strongly restrict land uses for the area between the first and second levee could strengthen these accomplishments. If the land-use plan is enforced continuously—even in the future—spatial planning will have served an important contribution to the enhancement of Taro's resilience.

4.3.3 Preservation and Creation of Social Cohesion

In Miyako City, spatial planners put an emphasis on community cohesion throughout the recovery process. Based on the experiences in Kobe after the Great Hanshin-Awaji Earthquake in 1995, they knew about the importance of keeping existing communities together after a disaster. Because of this, existing communities collectively moved into temporary houses that were specifically constructed for each of the city's districts (Miyako City Planning Division, Employee A 2015). Although this process was time consuming in the beginning, the efforts paid off when the affected people started to reconnect with their former friends and neighbors. For the relocation process to their final neighbourhoods, the goal was also to keep existing communities together. However, this goal could not be reached for all districts, since some communities were unable to reach a consensus on where they wanted to live. This was also the case for the Taro District. The result of this process will be that some of Taro's citizens will build their houses on the raised land near the station, and the other part will move to the newly constructed neighborhood on Otobe Hill (Ubaura and Akiyama 2016).

The co-location of existing communities in temporary housing lots also simplified the participation process for the land-use planning after the disaster, because most people of each district were living in the same place and were easier to contact. The citizens' participation in the planning process intensified the community cohesion. For this purpose, the city administration established citizen committees for each of the ten most-severely affected districts. Each committee included between 20 and 30 selected citizens and held four meetings. At the first meeting, the committee compiled and discussed their ideas about the future land uses in their district, as well as possible locations for roads and evacuation facilities. Before this meeting, the opinion of the general public was gathered with questionnaires. The second meeting enabled the committee to intensify the planning process for their district's future land uses and its transportation network, as well as the location of other important facilities. The purpose of the third meeting was to develop a draft land-use plan that was presented and discussed at briefings with the general public before it was finalized at the fourth and final meeting. After completion, the plans were publicly discussed in a second briefing and then submitted to the Mayor of

Miyako City (Ubaura and Akiyama 2016). The mutual work on the plan raised the citizens' awareness for its implementation and their acceptance of the plan. This resulted in the simplification of the purchase of land that was needed to realize the planned relocation sites (Miyako City Planning Division, Employee A 2015).

All in all, it can be said that Miyako City's focus on the preservation of existing communities helped to enhance community cohesion and likewise to increase the city's social resilience. However, this could only be achieved because the planning process enabled participation beyond legal requirements. The Japanese law only requires one public hearing and the opportunity for the public to comment on the draft plan during its display (Mägdefrau and Sprague 2016). The more comprehensive participation process in Miyako City therefore required special dedication by the spatial planners on the ground.

4.3.4 Engagement of Vulnerable Population

As aforementioned, citizen participation can play an important role to increase a community's connectedness. However, involving the public in the reconstruction process after a disaster also has additional advantages (Mägdefrau and Sprague 2016). One of these advantages is the ability to engage vulnerable population segments (e.g., children, people with disabilities or the elderly) in the planning process. The engagement of these groups is of special importance, because they tend to suffer the most in the case of a disaster (United Nations Development Programme 2014). Therefore, it is important to incorporate their needs into the plans and decrease the population's overall vulnerability.

The demographic change in Japan results in an increasing number and proportion of older citizens. This raises the necessity to meet their special needs. One example how this was done in Miyako City (although not applied in the Taro District) is the relocation of citizens, whose houses were destroyed by the tsunami, onto vacant lots in existing neighborhoods. This process can help to ensure the neighborhood's lasting viability, even if its population declines in the future. Furthermore, the established community connectedness in Miyako City's various districts increases the people's sense of responsibility for their neighborhood and causes them to offer help in the case of a disaster, which is especially important for the vulnerable population segments. By this means, the community's resilience can also be increased.

4.4 Conclusion

Based on the four items of resilience discussed in this chapter, it can be stated that Miyako's spatial planners were able to increase the city's engineering resilience as well as its evolutionary resilience. While the engineering resilience could be increased by using the classic instruments of spatial planning (e.g., land-use planning), an increase of evolutionary resilience (and especially social resilience) requires much more willpower and dedication. This is mainly because the established repertoire of spatial- planning instruments (e.g., land-use planning) does not encourage the inclusion of the general public beyond the legally required framework. Because of this, the personal commitment of individual spatial planners is essential to increase a city's resilience apart from its built structure and prepare it for future natural hazards in the best possible way.

Acknowledgements The author would like to thank the research project 'Increasing resilience of urban planning' (URBIPROOF), which was funded through the CONCERT–Japan framework by the Federal Ministry of Education and Research (BMBF), and the Japan Science and Technology Agency (JST), both of which enabled her research in Japan. The author also gives special thanks to Prof. Dr. Michio Ubaura for his most important support at all levels, and to the spatial planners of Miyako City for their insight and engagement in the reconstruction process after the Great East Japan Earthquake.

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Chapter 5
Lessons Learned in Disaster Debris Management of the 2011 Great East Japan Earthquake and Tsunami

Terri R. Norton

Abstract In the last 10 years, disasters like hurricanes Sandy and Katrina, earthquakes in Haiti and Japan and tornadoes in the Mid-Western US have caused communities to be overwhelmed with the amount of debris waste that is left behind. Debris management plans that address disasters like the aforementioned may vary by hazard type, geographical location and available infrastructure. However, with the common goal of effective recovery, there are lessons learned that may be gleamed from past events to better plan for future disasters. This paper presents a case study of debris management from the 2011 Great East Japan Earthquake and Tsunami, considering reports and updated information up to 2016. Twenty-seven million tons of earthquake and tsunami debris was generated in the three affected prefectures of Iwate, Miyagi and Fukushima. The generated debris included construction/building rubble, vegetative debris, vehicles, vessels and tsunami deposits. Management of the debris proved difficult due to the variant types and large quantities, requiring the need for multiple debris operation sites for sorting and disposal. Discussed herein is the debris management of the Tohoku region including the waste disposal and processing plans developed by the affected prefectures. The long-term goal is to improve the debris management procedures, for future events (such as a potential Nankai Trough megathrust earthquake), by learning from those who have experience and knowledge in managing disasters. Several lessons learned and improvements for the Tohoku region include: the inclusion tsunami debris provisions into the earthquake management plan, preparedness literature and education tools for all ages, increased ground elevation and evacuation shelters and taller seawalls.

Keywords Tsunami • Debris • Treatment • Recycling • Management

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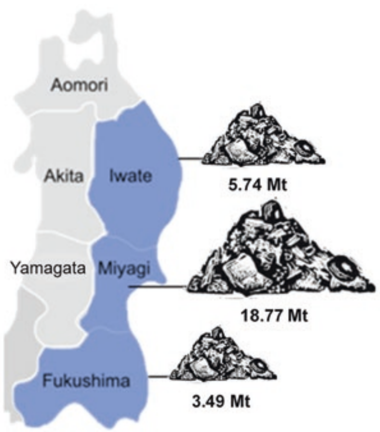
V. Santiago-Fandiño et al. (eds.), *The 2011 Japan Earthquake and Tsunami: Reconstruction and Restoration*, Advances in Natural and Technological Hazards Research 47, DOI 10.1007/978-3-319-58691-5_5

5.1 Introduction

The 2011 Great East Japan (Tohoku) Earthquake and Tsunami, commonly referred to as 03.11, had a very devastating effect on the coastal townships, industrial fishing and farming communities. On March 11, 2011 the Tohoku region of Japan was struck by a violent 9.0 magnitude earthquake and generated tsunami. Over 350,000 buildings were fully or partially collapsed causing an estimated $210 billion in total economic damage (UNEP 2012; IRP 2013). As a result of this disaster, Japan had the daunting task of managing over 27 million tons of debris. Miyagi, Iwate and Fukushima Prefectures experienced the greatest amount of damage with debris quantities estimated at 18.77 million tons, 5.74 million tons and 3.49 million tons, respectively (Hisada et al. 2015; Chang et al. 2011). Figure 5.1 presents the three affected prefectures. The amount of debris generated as a result of 03.11 accounts for approximately 14 years of general waste generated for the region. As of June 2016 the total damage cost of this disaster was estimated at 9.23 trillion JPY (Miyagi Pref. Government 2016).

5.2 General Challenges of Debris Management

Debris management begins with the removal and temporary storage on site, granting access to the self-defense force (military) for emergency response and rescue. Debris is then moved to temporary storage facilities for sorting and processing. Lifelines and supporting infrastructure are re-established during this time. The final phase of debris management happens during reconstruction, as the debris is either disposed or recycled for use during reconstruction.



Prefecture	Estimated amount of debris and tsunami deposits (Million tons)	Debris Amount (Million tons)	Tsunami Deposits (Million tons)
Iwate	5.74	4.14	1.60
Miyagi	18.77	11.21	7.56
Fukushima	3.49	1.74	1.75
Total	**28.00**	**17.09**	**10.91**

Fig. 5.1 Three prefectures within the Tohoku region affected by the 3/11 disaster and the estimated debris quantities (estimation by Ministry of the Environment 2015). *Mt* million tons

Managing large amounts of debris like that accumulated in the affected communities can be a very taxing expenditure, both in time and money. Debris generated by a tsunami can be difficult to manage as it is mixed with various types of rubble and waste. The mix may include large volumes of construction/demolition waste, marine sediments, shipping vessels, vehicles, vegetation, salt water, plastics and sludge (UNEP 2012; MOE 2011). Mixed and wood debris can present potential health and environmental hazards if not handled properly (Santiago-Fandino and Kim 2015). Therefore, effective management processes and procedures are key for a recovery process. As shown in other disasters the way in which debris is handled can impact the overall recovery duration. In 2005 Hurricane Katrina caused over $80 billion worth of damage and generated 22 mil tons of debris (excluding demolition). It took the city of New Orleans more than 5 years to deal with all the rubble and waste (Royte 2010; Adams 2013). The 2011 Joplin Tornado (EF5) destroyed over 8000 buildings and generated 4.2 mil tons (3 mil CY) of debris, having an estimated damage of $2.8 billion (Stark 2016). With the Expedited Debris Removal (EDR) initiative the city of Joplin was able to clear the area of debris within 3.5 months (Haase 2016 *per com*). In terms of debris, the Joplin Tornado is one-fifth the size of Hurricane Katrina and the Tohoku tsunami. The Tohoku region did not have an existing plan in place to deal with the huge amount of tsunami debris, however they were able to adapt/update their earthquake response plan (Environmental Bureau 2016; Kamaishi City 2016).

5.2.1 Debris Management in the Tohoku Region

The recovery process in Tohoku, Japan is projected to take up to 10 years to complete. The recovery plan is broken down into three stages – Restoration stage Fiscal Year (FY) 2011–2013, Reconstruction state FY 2014–2017, Development stage FY 2018–2020 (Miyagi Pref. Government 2016; World Bank 2015). Figure 5.2 provides the projected timeline for the disaster restoration and reconstruction work. Processing of the disaster debris began in early 2012, while the processing of the tsunami deposits did not began until 2013 (Hisada et al. 2015; MOE 2016). With a goal of completion of March 2014, this put the total time for debris management at 2 years. The processing period for the disaster debris was completed within the 3 year restoration period. The initial management of debris was handled by local municipality hired construction companies. The debris was transported first to a primary collection site. Contractors which were hired by the prefectural government then moved the debris to a secondary collection site for processing and disposal (IRP 2013; MLIT 2013).

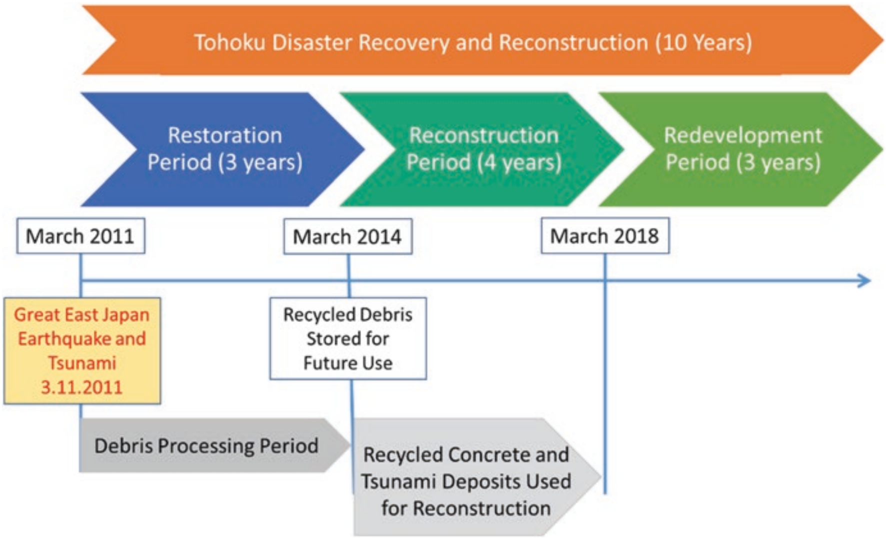


Fig. 5.2 Timeline for use of disaster debris generated by the 2011 Tohoku earthquake and tsunami

5.2.1.1 Examples of Debris Management in the Miyagi Prefecture

The debris generated in two of the most heavily affected cities in the prefecture, Ishinomaki accounted for approximately 71 years of general waste, while the debris generated in the Watari-Natori accounted for approx. 50 years of general waste (Miyagi Pref. Government 2016). The initial expectation was to process and dispose over 900,000 tons of the debris from the Miyagi Prefecture (IRP 2013). To aid the management process, the east coast of Miyagi was divided into four areas: Kesennuma area, Ishinomaki area, Sendai City and Natori area.

Within the first 6 months following the disaster, the Miyagi east block (Shiogama city, Shichigahama town, Tagajou city) had treated more than 50% of its debris and tsunami deposits (MOE 2012). However, at the onset, the speed of the waste treatment was not sufficient. The combustible and non-combustible debris required accelerated treatment. Thus the number of temporary privately owned incinerators was increased and cooperation agreements were made for debris processing in non-affected areas. In addition, public buildings were demolished to accelerate the production of recycled materials (MOE 2013).

5.2.1.2 Examples of Debris Management in the Iwate Prefecture

Similar to the Miyagi Prefecture, Iwate municipalities hired construction companies to remove and transport debris to a primary collection site. Cities like Miyako City found it difficult to deal with the huge amount of disaster debris. As a result the city

Fig. 5.3 Temporary storage of mixed debris in Noda/Kuji, Iwate Prefecture (Photo by T. Norton June 2011)

commissioned the Iwate Prefecture to perform office work related to handling the disaster debris (Miyako City 2016). In most cases the prefectural government was tasked to contract construction companies to transport the debris to a secondary collection site to be processed and disposed. Temporary storage of debris in the Iwate Prefecture is displayed in Fig. 5.3. The Iwate Prefecture expected to process 450,000 tons of its earthquake debris, making use of a cement factory in Ofunato (IRP 2013). The sorted debris was shipped to the cement plant for final processing, see Fig. 5.4.

5.3 Waste Processing Summary

The overwhelming amount of debris in 03.11 required additional steps to be added to Japan's general waste management practices. In Japan, all household waste must be sorted into various categories and placed in special bags before being collected as garbage. There is one kind of bag for household garbage and another for plastics. The garbage is then collected according to a strict schedule, and must be placed in a designated area. The procedure for processing debris waste is comprised of similar steps to traditional garage processing (i.e. sort/separation, removal, temporary storage and disposal or recycle), including the coordination between governmental entities, private contractors and local residents but on a larger scale. The debris separation process is outlined in Fig. 5.5. Separation was conducted not only at the removal or temporary storage site but also at the preliminary storage site.

Fig. 5.4 Debris sorting along the waterway in Miyako City (Photo by T. Norton June 2011)

5.3.1 Debris Processing in Miyagi Prefecture

Of the 300 temporary storage sites utilized to deal with the disaster debris and tsunami deposits, 100 were located within the Miyagi Prefecture. In the prefecture 29 temporary incinerators (+4 additional in normal operation) were operated for combustible waste, while 12 shredding and sorting facilities were used for non-combustible waste (MOE 2012). Examples of the processing facilities are presented in Figs. 5.6 and 5.7.

Sendai City's advanced action in separating the debris waste was used as a model for other affected cities. Debris was processed quickly because of the large number of workers in specialized teams and the advantage of city information and transportation networks. Figures 5.8 and 5.9 display two of the many temporary sorting sites in the Miyagi Prefecture. Sendai City utilized eight temporary waste collection sites for its citizens and three temporary storage sites: Gamou, Arahama and Ido. Their processing capabilities were 90 t/day, 300 t/day and 90 t/day, respectively. (Environmental Bureau 2016). In some areas, securing land for the temporary storage site was a challenge. Much of the Tohoku region affected by the disaster is comprised of coastal area, where the immediate need was temporary housing (World Bank 2015). In its expansive waste site on the Sendai Plain, the debris was sorted into six categories: concrete, vegetative/wood, white goods/appliances, metal, tires, hazardous goods (MOE 2011; Hisada et al. 2015).

Figure 5.10 presents the layout for the Gamou site. Under a cooperative agreement, non-affected prefectures assisted in the disposal of combustible and wood

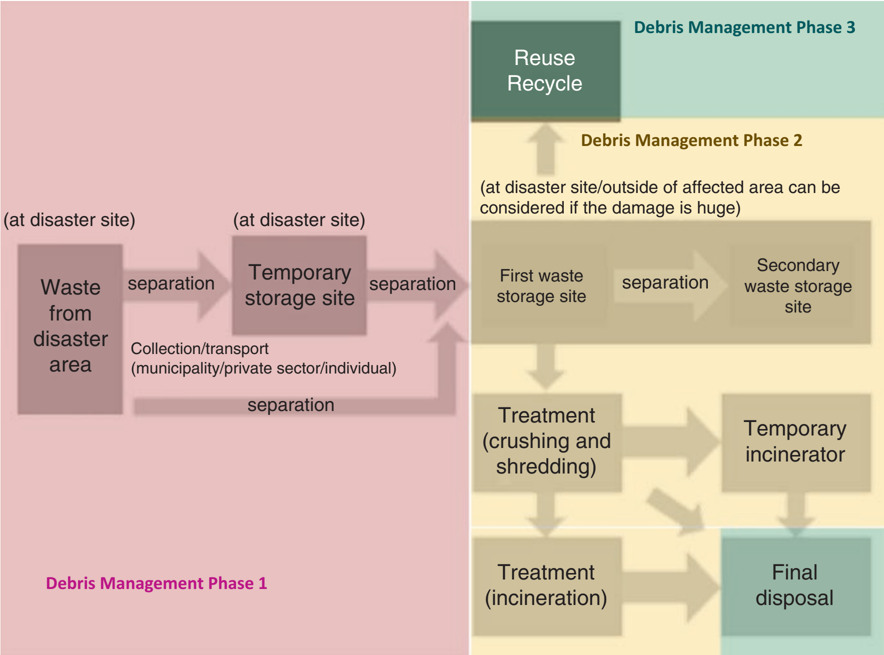


Fig. 5.5 Outline of the processes for separation and disposal of disaster waste (MOE 2014; Asari et al. 2013)

waste. Recipient prefectures of Miyagi waste include: Aomori, Yamagata, Fukushima, Ibaraki, Tochigi, Tokyo and Fukuoka (MOE 2013).

5.3.2 *Debris Processing in Iwate Prefecture*

The Iwate Prefecture utilized up to 400 temporary storage sites and the number of treatment facilities included two temporary incinerators and 11 sorting and shredding facilities (MOE 2013). By October 2012, the Iwate Prefecture had treated 25% of their debris (MOE 2012). In order to speed up the process Iwate requested the cooperation of non-affected prefectures including: Aomori, Akita, Tokyo, Shizuoka and Osaka. This cooperation planned the treatment of approximately 627,000 tons of debris which included: combustible and non-combustible debris, wood waste and fishing equipment (MOE 2012, 2014). The cooperation projects were completed in March 2013 and December 2013 for wood waste and combustible waste,

Fig. 5.6 Temporary incinerator in Kesennuma City, Miyagi (MOE 2012)

Fig. 5.7 Debris Operation site in Ishinomaki, Miyagi (IRP 2013)

Fig. 5.8 Temporary storage of damaged vehicles in Minami-Sanriku, Miyagi Prefecture (Photo by T. Norton June 2011)

Fig. 5.9 Temporary storage of concrete rubble in Natori, Miyagi Prefecture (Photo by T. Norton June 2011)

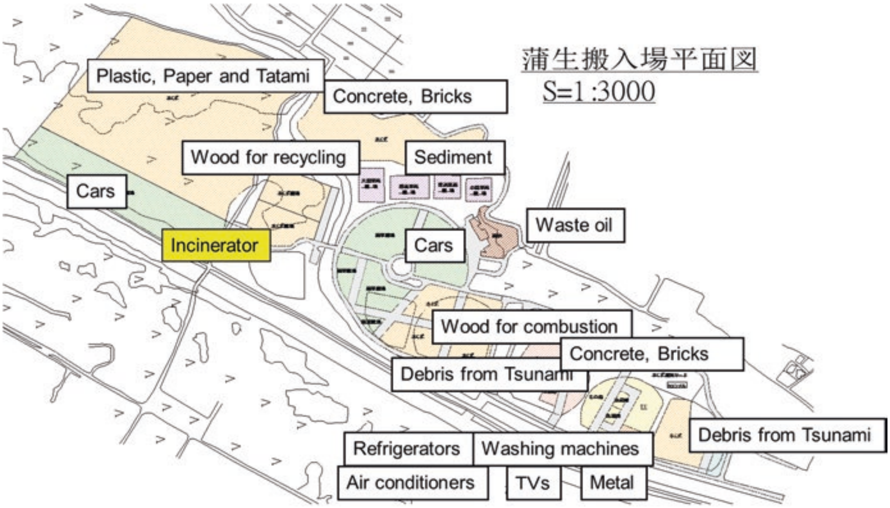


Fig. 5.10 Map for the Gamou Temporary Carry-in sites within Sendai City (Environmental Bureau 2016)

Fig. 5.11 Treatment facility for concrete debris in Yamada town, Iwate Prefecture (MOE 2012)

respectively. Concrete debris and tsunami deposits were recycled for reuse within public works projects. By promoting the use of recycled materials and providing the required properties for utilization, Iwate was able to improve its processing performance. Figures 5.11 and 5.12 present examples of debris processing for the Iwate Prefecture while Fig. 5.13 provides a site layout for the Heigawa treatment facility in Mikayo City.

Fig. 5.12 Debris sorting processing in Otsuchi district using a rotation sorting machine, Iwate Prefecture (Iwate Pref. 2015)

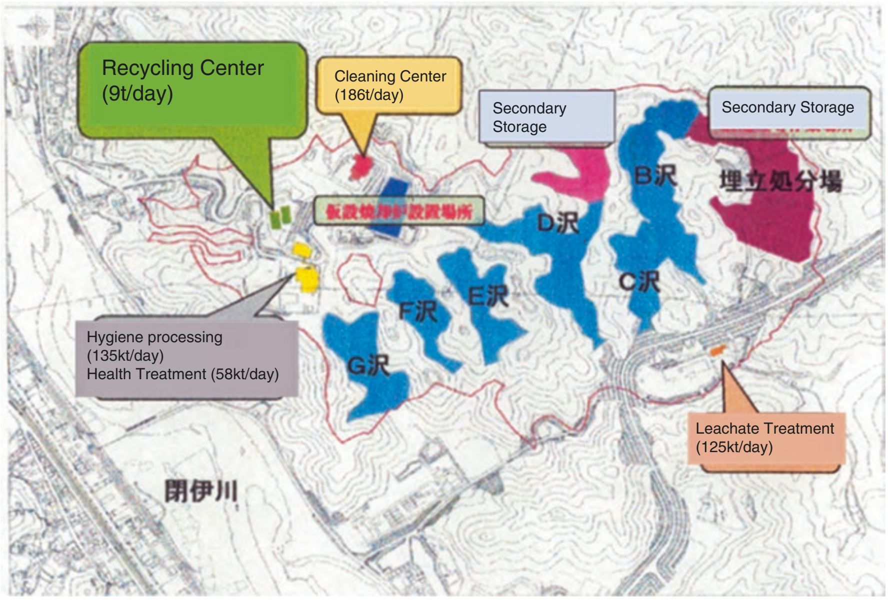


Fig. 5.13 Map for the Heigawa waste treatment in Miyako City (Miyako City 2016)

5.4 Debris Recycling

At the time of a disaster, planners must determine the quantity of waste generated, gather it in temporary storage sites, and select and arrange for appropriate disposal or recycling options (MOE 2014). The potential to recycle or reuse the debris is sometimes overlooked in order to clear affected areas quickly. Commonly, the debris is dumped in overloaded landfills which can be costly, both economically and environmentally (Esworthy et al. 2005; Murao 2014). However with large quantities, like that generated in Tohoku, it will be difficult to use a landfill for disposal, therefore it is vital to recycle as much as possible (MOE 2014; MLIT 2013).

Japan has been influential in advancing the best practices for handling disaster debris. The Japan Society of Material Cycles and Waste Management (JSMCWM) suggest that recycling should be considered in the management of debris as it helps to put resources to use in the recovery and reconstruction process. In its recommendations concrete debris is recycled for rebuilding, wood scraps can substitute for fossil fuels in power generation, scrap metal is recycled and tires are shredded to crumbs and recycled or incinerated (Asari et al. 2013). The Debris Management Guide published by FEMA includes similar recommendations. It suggests that the recycling of waste could not only aid in the reconstruction efforts, but it has the potential to speed up the recovery process (FEMA 2003, FEMA 2007, Srinivas and Nakagawa 2008).

Eighty-five percent of the recycled concrete debris and nearly all of the tsunami deposits are planned for use during the reconstruction, within public works projects (MOE 2014). These projects include the restoration of coastal embankments and levees, disaster prevention forests and national parks. The safety of the tsunami sediments was confirmed with the Ministry of the Environment before being used to build up land for public works (Environmental Bureau 2016). From July 2012, it is being used in the national coastal disaster-prevention forest and coastal levee projects. They started in late fall 2012 with embankment restoration in Natori City and national park restoration in Kesennuma city (MOE 2013). Table 5.1 presents the public works projects planned for the affected prefectures.

New technologies were needed for the reuse of contaminated concrete rubble as it would not meet the Japanese Industrial Standards (JIS) requirements for recycled aggregate. Several entities, including construction companies, universities and local government, collaborated on the development of these new technologies or recycle/reuse procedures. The results include: wave dissipating blocks filled with concrete debris, roller compacted road base made from concrete and tsunami sediment, soil stabilizing material and molded blocks as base material for levee surge barrier (Hisada et al. 2015). Recycled materials were utilized as resources for reconstruction.

Table 5.1 Major public works projects using materials recycled from debris and tsunami deposits

	Project	Recycled material	Amount (including planned use)
Miyagi prefecture	Coastal or river embankment restoration	Tsunami deposits	103
		Concrete debris	
	Coastal disaster-prevention forest restoration	Tsunami deposits	110
		Concrete debris	
	Agricultural field restoration	Tsunami deposits	15
	Park construction	Tsunami deposits	262
		Concrete debris	
	Fishing port projects	Concrete debris	29
	Construction of temporary storage sites	Tsunami deposits	89
		Concrete debris	
	Other projects	Tsunami deposits	114
		Concrete debris	
Iwate prefecture	Coastal or river embankment restoration	Tsunami deposits	30
		Concrete debris	
	Coastal disaster-prevention forest restoration	Tsunami deposits	16
		Concrete debris	
	Agricultural field restoration	Tsunami deposits	64
		Concrete debris	
	Park construction	Tsunami deposits	43
		Concrete debris	
	Fishing port projects	Concrete debris	17
	Construction of temporary storage sites	Concrete debris	48
	Other projects	Tsunami deposits	77
		Concrete debris	

(continued)

Table 5.1 (continued)

	Project	Recycled material	Amount (including planned use)
Fukushima prefecture	Coastal or river embankment restoration	Concrete debris	9
	Coastal disaster-prevention forest restoration	Concrete debris	9
	Park construction	Tsunami deposits	14
	Other projects	Concrete debris	16

MOE (2016)

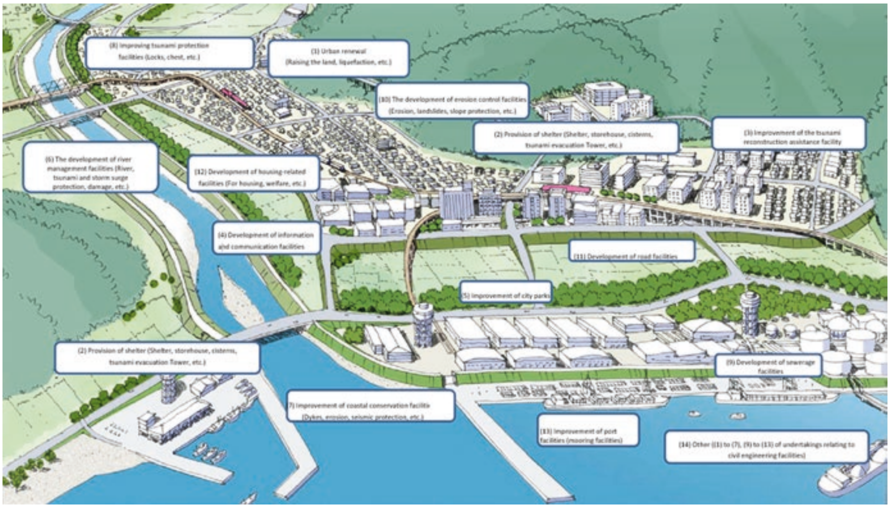


Fig. 5.14 Urban Recovery Projects at a Glance (MLIT 2013)

5.4.1 Debris Use During Reconstruction

The Tohoku region, specifically the Miyagi, Iwate and Fukushima Prefectures, will not return to the way it was before the disaster but instead will be a more hazard resilient "New Tohoku". Figure 5.14 provides a glance at the planned recovery and types of reconstruction projects. The region will be rebuilt using innovative ideas that also address challenges related to the aging population in rural and coastal communities and the relocation of younger citizens to urban cities (Masuda 2013). The New Tohoku supports accelerated construction projects for housing. Approximately 21,000 new housing is planned for new land developments that have be relocated inland or to higher ground. Another 30,000 public housing is planned for the disaster-affected areas (Reconstruction Design Council 2011). The New Tohoku also supports for tsunami protection against future events and the use of recycled debris

Fig. 5.15 Cross-section view or coastal area reconstruction and basic concept for preventing tsunami damage for the city of Sendai (Sendai City 2016)

Fig. 5.16 Ido Tsunami Evacuation Tower (Photo by T. Norton Aug. 2016)

during reconstruction. Figure 5.15 displays a cross-section view of the coastal reconstruction model for the Sendai area, demonstrating the protection measures. Residents are relocated to a safer distance from the coast, roadways are elevated, taller seawalls are constructed and elevated evacuation shelters are erected. Figure 5.16 presents a vertical evacuation tower, while Fig. 5.17 depicts a model of the planned elevated roadway. The roadway surface will be elevated to 6 m above ground level (Sendai City 2016). Similar measures are being executed throughout the region. It should be noted that many of the elevated structures (i.e. roads and evacuation hills) utilize recycled concrete and tsunami sediments as fill material.

Fig. 5.17 Model of planned elevated road near Natori City (Photo by T. Norton Aug. 2016)

Fig. 5.18 Land preparation for a housing project in the Kesennuma area (Photo by T. Norton Sept. 2015)

At present both the Miyagi and Iwate Prefectures are undergoing reconstruction. Management of the generated debris was completed in March 2014 (Hisada et al. 2015). As mentioned earlier, recycled debris is utilized in restoration, reconstruction and redevelopment projects. In the Miyagi Prefecture, the rebuilding of housing (public or private) began in 2014. Currently, land preparation for construction projects related to private housing is more than 50% complete. Sixty-three percent of disaster related public housing is also completed at this time (MLIT 2013). Figure 5.18 shows site preparation, cleared of debris and elevation raising of a proj-

Fig. 5.19 Construction billboard for Yuriage Town in Natori City (Photo by T. Norton Oct. 2015)

Fig. 5.20 Disaster waste storage piles for use in reconstruction projects (Photo by T. Norton Oct. 2015)

ect site in Kesennuma. Figure 5.19 presents a billboard on the planned construction of Yuriage Town in Natori City. Residential structures will be constructed on higher ground to protect against future tsunami hazards.

Many of the planned reconstruction projects required that the land be raised to an elevation above the tsunami inundation height. Therefore, the recycled concrete debris and tsunami deposits will play an important role in this process. Debris materials are stockpiled until time for its use. Figures 5.20 and 5.21 show

Fig. 5.21 Storage piles in Minamisanriku, Miyagi prefecture (Photo by T. Norton Oct. 2015)

Fig. 5.22 Seawall being constructed in Kesennuma area, height approximately 10 m (Photo by T. Norton Aug. 2015)

debris storage piles. In addition, several restoration projects are underway to provide coastal protection. Figures 5.22 and 5.23 below presents the construction of a coastal seawalls being constructed in Kesennuma and Kamaishi, respectively

Discussion of Challenges and Lessons Learned

Several challenges and lessons learned were observed by those dealing with the disaster debris from the 2011 Great East Japan Earthquake and Tsunami. Below is a summary of the key messages discussed with local government representatives from Miyagi and Iwate Prefectures.

Fig. 5.23 Seawall being constructed in Kamaishi City (Photo by T. Norton Aug. 2016)

5.5 Challenges

The overwhelming amount of debris and its mixed composition caused some challenges during the management process. Sendai City acknowledged that a debris management plan was in place before 2011, however the existing plan did not cover tsunami debris. Therefore it was necessary to update their management plan for earthquakes to include considerations for the tsunami hazard (Environmental Bureau 2016). In addition, many of the city offices had limited experience dealing with the huge amounts of debris (Kamaishi City 2016). Having a comprehensive debris management plan in place as well as scenario training for potential disaster events may assist with this issue. Another challenge experienced while handling the disaster debris was being able to separate out the tsunami sediments. As an example, Kamaishi City (2016) reported using the crane shake method or hose on a conveyor belt to complete this task.

5.6 Best Practices and Lessons Learned

Cross-cutting cooperation from all levels of government and with the construction industry was found to be indispensable. From the stage of developing a disaster waste management plan to frameworks, such as national, prefectural and municipal government, building a framework for collaboration that would regularly review the structure was also beneficial (Iwate Prefecture 2015). Waste processing plays a big role in the beginning stages of the recovery process. For a large disaster like 03.11, having land space available to efficiently carry-out the processing procedure was key. The secured land has generally been local government owned land or nationally owned land, because of the trouble in securing land from private land owners. Incinerators and landfills were used to dispose of debris that is not recycled. Waste containing toxic material could not be landfilled as it has the potential to pollute the environment (Santiago-Fandino and Kim 2015).

A basic stance on the treatment of the disaster waste was decided earlier on. A 3 year period was determine, with collection and transportation finishing by March 2012 and treatment being completed by March 2014. Priority was given to the area of a tsunami flood zone (Environmental Bureau 2016). Japan's disaster management system addresses all phases of disaster prevention, mitigation and preparedness, and emergency response, as well as recovery and rehabilitation. Revisions to this plan were proposed following GEJE 2011 (World Bank 2014).

Sendai's Disaster Waste Treatment system consisted of nine steps: (1) Removal of debris found during search operations for missing persons; (2) Removal of flooded household goods in Tsunami areas; (3) Removal of debris from operations in the clearing of roads; (4) Removal of vehicles damaged by the Tsunami; (5) Removal of debris from houses that were washed away by the Tsunami; (6) Removal of waste from collapsed houses; (7) Removal of bulky household waste generated by the earthquake; (8) The sorting out, crushing, and incineration of debris (waste); (9) Removal of disaster waste from Agricultural lands (Environmental Bureau 2016). This procedure and best practices for its implementation were shared with other affected cities (Sendai City 2016).

The use of recycled debris to raise the elevation of roadways and evacuation hills or embankments has proven to be a positive way to deal with the overwhelming amounts of generated disaster debris. Recycled debris enables enhanced prevention measures to combat future tsunami damage, while reducing the demand on natural resources or soil sediments. Well sorted, treated and compacted recycled concrete and tsunami sediments provide a stable sub-base or fill for the elevated structures (Sendai City 2016). The understanding of the stability for mixed uncompact debris is still in its infancy and has not been proven. More research needs to be performed in this area.

5.7 Conclusion

The 2011 Great East Japan Earthquake and Tsunami were extremely destructive to the coastal townships, particularly the industrial fishing and farming communities. Both the Miyagi and Iwate Prefectures had challenges to overcome while of managing the debris. By following the lead of Sendai City, the affected Tohoku region was able to meet the 2 year debris processing timeline imposed by the Japanese government. A thorough sort of the debris reduced the amount of debris that needed to be incinerated or disposed by landfill. A large amount of the concrete debris and tsunami deposits were recycled for use during reconstruction. New technologies were developed for the recycled debris waste and are being utilized for the public works projects. Lessons learned throughout the restoration and reconstruction of Tohoku are being used to propose revisions to the disaster management plan, for future events.

Acknowledgements The present work was possible thanks to the kind support of a Fulbright research scholar award, Council for International Exchange of Scholars (CIES) and the Japan--U.S. Educational Commission (JUSEC). The author would like to acknowledge the invaluable support of Dr. Murao and H. Sakaba of the IRIDeS International Strategy for Disaster Mitigation Laboratory, A. Takahashi and Mr. Edo of Sendai City, Miyagi Prefecture, Mr. Nagasawa and Y. Maekawa of Kamaishi City, Iwate Prefecture and the Environment Division, Miyako City, Iwate Prefecture for data collection.

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Part II
Societal and Community Recovery

Chapter 6
Revisiting Tohoku's 5-Year Recovery: Community Rebuilding Policies, Programs and Implementation

Kanako Iuchi and Robert Olshansky

Abstract With time, details of the rebuilding efforts in the Tohoku region of Japan are fading even though reconstruction is still underway. To document and analyze rebuilding efforts, this chapter longitudinally reviews 5 years of Tohoku recovery after the Great East Japan Earthquake (GEJE) with an emphasis on community rebuilding strategies, programs and their implementation status. This chapter focuses on two topics: first, the rationales for recovery planning and the coordinated reconstruction approaches at national, prefectural, and local government levels; second, the use of community rebuilding programs by local governments. Authors initiated Tohoku rebuilding research soon after the March 2011 disaster occurred, and sets of analysis in this chapter are based on numerous formal interviews and unofficial conversations held in the affected localities as well as with national and prefectural government officials. Additionally, publicly available information and data from the Reconstruction Agency were used to analyze the community rebuilding programs. Revisiting Tohoku's 5-year recovery shows that the national, prefectural, and local governments have developed rebuilding concepts and ideas, established institutions and programs to proceed with reconstruction, and made various implementation decisions to rebuild Tohoku stronger against future tsunamis. In particular, local governments have continuously been leading for the past 5 years to decide land use policies and adopt programs for stronger and safer community reconstruction. Analysis indicates that the number of districts using community rebuilding programs totals over 860, which explains why the Tohoku reconstruction itself is such a great challenge. Even with this challenge, however, we also found that local governments have extended their efforts to use community rebuilding programs in ways that best suit each of their recovery needs.

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V. Santiago-Fandiño et al. (eds.), *The 2011 Japan Earthquake and Tsunami: Reconstruction and Restoration*, Advances in Natural and Technological Hazards Research 47, DOI 10.1007/978-3-319-58691-5_6

Keywords Community rebuilding programs • Land readjustment • Collective relocation • Public housing • Tohoku recovery

6.1 Introduction

With time, information and knowledge of the recovery efforts in the Tohoku region of Japan following the 2011 Great East Japan Earthquake (GEJE) and tsunami are fading, even though rebuilding itself is only partially complete. Furthermore, it is difficult to see the larger policy picture in the midst of the minutia of implementation. Governmental officials administer rebuilding by means of everyday tasks confined to narrow administrative silos, planners are either already disengaged or minimally continuing to implement the plans they developed, and the affected population has normalized their life in temporary or resettled locations. This chapter therefore provides a broad overview of the reconstruction progress to date, including the rebuilding policies, programs, implementation, and current rebuilding status, in order to identify continuing research needs as well as lessons for future rebuilding after large-scale disasters.

The authors initiated study on Tohoku rebuilding soon after the March 11, 2011 disaster occurred. This chapter is based on information gathered from countless field visits to Tohoku coastal areas, with the first one 3 months after the disaster (EERI/ISSS 2011; Iuchi et al. 2013). Various conversations as well as interviews and consultations with government officials, planners, academics and community members are reflected in this recovery narrative. Publicly available documents and data provide information regarding current reconstruction status. Due to the complications Fukushima Prefecture continues to face regarding the nuclear power plant accident, this chapter emphasizes the efforts of Iwate and Miyagi Prefectures in rebuilding from tsunami damage, but we also briefly summarize Fukushima's current land use status.

6.2 The GEJE and 5 Years Later

6.2.1 Triple Disasters and Impacts

Tohoku confronted a triple tragedy in the wake of the Great East Japan Earthquake and tsunami (GEJE). The United States Geological Survey (USGS) records this M_w 9.0 earthquake as the world's fourth largest since 1900; the Japan Meteorological Agency (JMA) reports that the earthquake generated tsunami waves of more than 9.3 m, and Fukushima's nuclear power plant failure has been rated as level 7 – the maximum level – on the International Nuclear Event Scale (INES). Economic damage was astronomical with an estimate of 25 trillion yen (approximately USD 250 billion), making the GEJE the most expensive disaster ever in the country (Reconstruction Agency 2016c). Such negative impacts on Tohoku, already facing population and economic decline, made the country react by aiming for a resilient recovery, to be able to withstand any future tsunamis. The reconstruction and recovery policies therefore primarily emphasized raising and protecting the land by means of engineering solutions. In addition, the national government's recovery vision also underscored socio-economic enhancement (East Japan Earthquake Recovery Framework Committee 2011).

6.2.2 Reconstruction Under National Leadership

Unlike other Japanese major disasters from the recent past including the Kobe earthquake (1995) and Chuetsu earthquake (2004), the national government has played an important role in recovery from the beginning. National emergency management in the tsunami affected areas and radiation affected areas have been distinct from each other; the "emergency disaster control headquarters" was established to provide support to the tsunami affected areas, whereas the "nuclear emergency response headquarters" was created to handle radiation affected areas (Reconstruction Agency 2016a). Almost a year after the earthquake, the emergency headquarters transformed into the reconstruction agency under the "Act on establishment of the Reconstruction Agency", to speed up reconstruction processes by coordinating and simplifying recovery administrative functions by different ministries and to oversee overall reconstruction (Cabinet Office, Government of Japan 2011). This Reconstruction Agency (RA) has been given a mandate to coordinate and support local and regional governments on recovery over a term of 10 years. Of its 10-year duration, the first 5 years of Fiscal Year (FY) 2011 to FY 2015 is named the "recovery focused period" *(fukko shuchu kikan)*, considered as a period emphasizing physical reconstruction. The latter 5 years of FY 2016 to FY2020 is then called the "creative recovery period" (*fukkou sousei kikan*) that aims for additional growth and development of the affected regions (Reconstruction Agency 2016a). The RA has been given the responsibility to oversee reconstruction programs, including 40 programs for reconstruction projects completely financed by the national government. This has been a unique funding system for reconstruction in Japan, as local governments have the power to select from these national programs according to their needs.

The second phase of the 10-year recovery, the creative recovery period, has begun in FY 2016. In this phase, the RA aims to complete construction of infrastructure in communities devastated by the tsunami, and the recovery emphasis will shift to Fukushima, especially in areas where the evacuation order was recently lifted for areas affected by radiation. In the beginning of this creative recovery period, the total amount of funding for both phases of reconstruction has been revised upward to a total nearing 32 trillion yen, an increase of 3.2 trillion yen from the 28.2 trillion yen initially allocated (Reconstruction Agency 2016a).

6.2.3 Five Years of Reconstruction: Current Rebuilding Status

The RA assessed the national recovery efforts in the first 5 years as extraordinary, encompassing both strong support from the national government and remarkable reconstruction achievements by local governments. The national government urgently secured more than 25 trillion yen at the initial stage for the recovery focused phase, for which local governments are exempt from paying any costs related to rehabilitation and rebuilding (Reconstruction Agency 2015b). The concept of building back better was put up front; projects for relocating or rebuilding on higher ground proceeded by means of flexible use of national programs (Reconstruction Agency 2016a). Reconstruction progress has been good, with more than 70% of local governments completing construction using reconstruction grants by the end of FY2016. Additionally, critical public facilities and infrastructure including hospitals, educational facilities, roads and seawalls are nearing completion (Reconstruction Agency 2015b).

Rebuilding of communities, however, still has a long way to go. As of July 2016, 150,000 – or approximately 44% – of the displaced population using temporary housing assistance continue to live in a temporary status (Reconstruction Agency 2016b). Construction related to housing is still in process; only a little over 60%, or 19,000 units, of public housing planned for the disaster affected population is completed, and about 50%, or 9,000, of parcels for individual homes on higher ground have been finalized (Reconstruction Agency 2016a). By the end of FY 2016, 86% of public housing and 70% of land parcels are expected to be ready for allocation, and by the end of FY 2018, housing related construction is expected to be finally completed. The duration of this reconstruction, symbolized as structural recovery and enhancement, is expected to be a total of 9 years minimum, and more years will be required for livelihood recovery for communities.

6.3 Revisiting Rebuilding Rationales, Policies and Timeline

6.3.1 Recovery Rationales

Managing future tsunami risk was the central theme for Tohoku recovery. The idea to protect inhabitable lands from level 1 (L1) and level 2 (L2) tsunamis was introduced soon after the tsunami by the national central disaster prevention council. An L1 tsunami is defined as a “100-year event,” referring to past tsunamis that have occurred once every several decades up to a hundred years, and a L2 tsunami is defined as a low-probability “1,000-year event,” represented by the tsunami generated by the 3.11 earthquake (Central Disaster Prevention Council, Technical Investigation Committee 2011). Land areas where people live and work are protected from L1 tsunamis by constructing levees and seawalls along the coast, and from L2 tsunamis by moving residential areas to higher ground and promoting evacuation of low-lying commercial areas (Central Disaster Prevention Council, Technical Investigation Committee 2011).

Although the strategy was developed at the national level, the prefectures, which are responsible for coastline management, were in charge of calculating the required levee heights to protect inland areas from a L1 tsunami. The calculation was carried out for each bay, and then several inundation scenarios were simulated to serve as a basis for land use plans to be developed by local governments (Iuchi et al. 2013). In parallel, the national Ministry of Land, Infrastructure, Transport and Tourism (MLIT) carried out a tsunami damage survey for 62 local governments and a recovery pattern study for 43 local governments, which resulted in basic land use recommendations using damage and landscape information for 32 coastal local governments (Ministry of Land, Infrastructure, Transport and Tourism 2012b). As this initial response to the unprecedented disaster demonstrates, rebuilding better in Tohoku meant rebuilding safer and stronger to resist tsunamis.

Later in the first year, various legislative and administrative structures had begun to take shape. In December 2011, key acts and laws were enacted, including the "Basic Act on Reconstruction in Response to the Great East Japan Earthquake" (*Higashi Nihon daishinsai fukko kihon ho*) (Bill on East Japan Earthquake Basic Recovery Act 2011). It sets up basic recovery policies, including the roles of national, prefectural and local governments, as well as roles for citizens, while identifying the critical responsibilities of the national government to secure funding as well as to lead the recovery. The act also describes the way to proceed to implementation (Upper house of Japan 2011). With "the Act on Reconstruction Agency Establishment" (*Fukkocho secchi ho*) (Act on Establishment of Reconstruction Agency 2011), the Reconstruction Agency (RA) was established to administratively support the Cabinet Office, by working across various national ministries and coordinating the governments at prefectural and local levels for 10 years until March 31, 2021 (Upper house of Japan 2011). "The Law on Special Great East Japan Earthquake Reconstruction Areas" *(Higashi Nihon daishinsai fukko tokubetsu kuiki seido)* established in December 2011 and revised in 2014, also plays an important role in guiding recovery actions; 222 affected local governments were designated as "special affected areas" and were granted special administrative powers, including land use, taxation, and funding support. To benefit from this arrangement, local governments in the specially designated tsunami affected areas are required to develop various plans, including recovery promotion plans *(Fukko suishin keikaku)*, reconstruction plans (*Fukko seibi keikaku)*, and plans for reconstruction grant projects *(Fukko kofukin jigyo keikaku)* (Reconstruction Agency 2011). Developed plans are then submitted to the RA for them to review and allocate funding in an appropriate manner. This bottom-up system was innovative for nationally-funded rebuilding projects in Japan; it was appropriate because the level of damage and roadmaps to recovery varied among local governments.

The reconstruction grant project plan was the means by which local governments proceeded with reconstruction. The RA provided a menu including 40 key programs for reconstruction projects (*Kikan jigyo*) and sub-projects (*Koka sokushin jigyo*). This list of programs originate from pre-existing programs managed by five relevant national ministries: (i) Ministry of Education, Culture, Sports, Science and Technology (MEXT); (ii) Ministry of Health, Labor and Welfare (MHLW); (iii) Ministry of Agriculture and Fisheries (MAFF); (iv) Ministry of Land, Infrastructure, Transportation and Tourism (MLIT); and (v) Ministry of Environment (MOE). Local governments in the specially designated tsunami affected areas were then responsible for identifying a set of project programs that fit their reconstruction needs. To simplify the project management process, local governments prepared project plans aligned with their land use plans to submit to the RA, which coordinated with the five ministries. National ministries then evaluated the proposed projects to decide how much to allocate in reconstruction grants. The process of plan development and funding application continued until both sides agreed on the grant amounts. As of July 2016, 15 tranches of this grant allocation process had been held since June 2012 (Reconstruction Agency 2016d).

6.3.2 Process of Rebuilding by Local Governments

The Reconstruction basic act and national recovery vision specify local governments as having the primary responsibilities for recovery (Reconstruction Agency 2016a; Reconstruction Design Council 2011). Their responsibilities deepened in the second year; for example, they prepared detailed plans of land use and calculated the number of lots required for housing, thus articulating the projects needed to implement recovery. To secure needed funding for infrastructure, coordination and negotiation between the RA and prefectures also strengthened around this time.

Among the 40 key programs prepared by the RA, local governments emphasized 4 of them in particular – “community rebuilding programs” (or “programs related to securing houses” literally translated from ‘*sumai no kakuho ni kansuru jigyo*’ used in the RA’s documents) -to rebuild residential areas safely by relocating them or elevating lands (Table 6.1). MLIT manages three of the four projects. The first is the “collective relocation promoting program for disaster prevention” *(Bosai shudan iten sokushin jigyo: Boshu)* for relocating communities to safer areas, often on hillsides, from areas likely to be inundated by L2 tsunamis according to the tsunami simulation (Ministry of Land, Infrastructure, Transport and Tourism 2012a). This program allows local governments and communities to select their preferred relocation areas in exchange for the original land, which would no longer be available for residential use. It allows residential property owners to exchange their parcels in high tsunami hazard areas for new parcels on higher ground, but it does not pay for construction of new housing. This program has little flexibility, and former lands are often planned to become industrial or commercial areas. The second program is the “land readjustment program” (*Tochi kukaku seiri jigyo: Kukakuseiri*), adopted to raise land levels in areas where simulations predict inundation with a L2 tsunami. Conceptually, land parcels are reallocated to make a better use of space, by reshaping irregular parcels. Unlike the collective relocation program, this program allows mixed uses of residential, commercial, and industrial lands. However, land needs to be raised to a level where safety will be secured (Ministry of Land, Infrastructure,

Table 6.1 Description of community rebuilding programs in Tohoku recovery

Program (Japanese name)	Program description
Collective relocation promoting program for disaster prevention (*Bosai shudan iten sokushin jigyo: Boshu*)	Relocates communities to safer areas, often on hillsides, from high tsunami hazard areas. Local governments and communities can select their preferred relocation areas in exchange for the original land, which would no longer be available for residential use. Relocating households have to pay for construction of new housing on new land. The Ministry of Land, Infrastructure, Transportation and Tourism (MLIT) manages this program
Land readjustment program (*Tochi kukaku seiri jigyo: Kukakuseiri*)	Raises land levels in high tsunami hazard areas. Land parcels need to be raised to a secured level, and are reallocated to a better use of mixed land use. Property owners are responsible for building construction costs. MLIT manages this program
Public housing program for disaster victims (*Saigai koei jutaku: Koei jutaku*)	Helps local governments construct public housing that provides subsidized rental units for disaster victims who have difficulty rebuilding houses on their own. MLIT manages this program
Program on strengthening disaster risk management functions for fishing communities (*Gyoshu shuraku bosai kinoukyouka jigyo: Gyoshu*)	Holistically supports risk preventive rebuilding targeting damaged fishing communities. It covers construction of basic village infrastructure, including water and sewage systems, facilities used for disaster mitigation including evacuation roads and open spaces, and land reallocation for better preparation against future disasters. The Ministry of Agriculture, Forestry, and Fisheries (MAFF) manages this project

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Transport and Tourism 2012a). Similar to the collective relocation program, this program provides land in safer locations, but it does not pay for building construction. The third program is the "public housing program for disaster victims" (*Saigai koei jutaku: Koei jutaku*) providing subsidized rental public housing for disaster victims who have difficulty rebuilding houses on their own. MAFF manages the last of the four programs, the "program on strengthening disaster risk management functions for fishing communities" *(Gyoshu shuraku bosai kinoukyouka jigyo: Gyoshu)*. This program targets damaged fishing communities and holistically supports risk preventive rebuilding. The program allows construction of basic village infrastructure including water and sewage systems, facilities used for disaster mitigation including evacuation roads and open spaces, and land reallocation for better preparation against future disasters (Reconstruction Agency 2015a).

As of March 2016, 67 local governments were using at least 1 of the 4 community rebuilding programs, and 48 of them plan to finish ongoing projects by March 2018. Ten local governments, however, plan to finalize their tasks by March 2019, and the remaining nine will complete their work by March 2020 or later (Reconstruction Agency 2016d). For the first year of recovery, the concept of rebuilding stronger against tsunami was created; in the second year, institutional and organizational structures for plans and project implementation were consolidated; and finally in the third year, programs for community rebuilding had begun to visually take place (Iuchi et al. 2015). This third step of rebuilding has been requiring the most time, taking up to at least 8 years, until 2020 or beyond. Preparing the 40 key programs for reconstruction projects was a straight forward solution to proceed with rebuilding at once, but the actual rebuilding process has been much more complicated due to the unique recovery paths for each local government.

6.4 Adopting Community Rebuilding Programs

The speed towards completion varies by local governments. The reconstruction plans, strategies, and programs developed at the national level helped local governments to plan and initiate rebuilding processes. But local rebuilding policies and processes varied among local governments, because of different damage patterns, restrictions, and reconstruction philosophies. Initial actions for land use decisions in Iwate, Miyagi, and Fukushima Prefectures, for instance, show differences among them.

6.4.1 Land Use: Restrictions and Controls

A dichotomy of land use decisions for rebuilding by prefectures depends on whether the devastation was caused by tsunami or radiation. Iwate Prefecture and Miyagi Prefecture led in implementing land use policies for rebuilding from tsunami damage. In Fukushima Prefecture, large areas were initially unavailable for rebuilding due to radiation; contaminated soil was gradually removed to reduce radiation levels. The zones for rebuilding and exclusion are finally being decided by the end of FY2016, and reconstruction and redevelopment of designated areas will be emphasized in the latter half of the 10-year reconstruction time period (Reconstruction Agency 2016a).

The three prefectures had different initial approaches to rebuilding. In Miyagi Prefecture, a special administrative agency for building construction – an agency responsible for land use and building control – restricted private reconstruction on urban land in six local governments in April 2011 under Article 84 of the Building Standards Law. Some of this urban land was subsequently designated as affected urban areas for recovery promotion (*hisai shigaichi fukko suishin chiiki*) under the "Act on special measures concerning reconstruction of urban areas damaged by disaster" (*hisai shigaichi fukko tokubetsu sochi ho*) and which was targeted for continued building moratorium for an additional 2 years (Kahoku Newspaper 2011).

While Miyagi Prefecture imposed Article 84 to prevent sporadic redevelopment, Iwate Prefecture adopted Article 39 of the Building Standards Law and chose not to declare a moratorium (Iuchi et al. 2013). The decision to adopt Article 39 was largely due to their geographic conditions; there is minimal urban land along coastal areas, and a moratorium was less necessary. This is because it is easier to monitor and influence development in rural areas without resorting to blanket regulations.

Rather, people were inherently supportive of the idea of relocating, to be higher up on hillsides. While Iwate Prefecture did not enforce a moratorium by regulation, they asked local governments to encourage residents to voluntarily refrain from rebuilding in the tsunami-inundated areas (Ubaura 2011).

The nuclear power plant accident forced certain areas of land in Fukushima Prefecture to be restricted from living and rebuilding. The first batch of residential evacuation was ordered in the evening of March 12th, targeting areas within a 20 km radius from the Fukushima Daiichi (No. 1) nuclear power plant and a 10 km radius from the Fukushima Daini (No. 2) nuclear power plant, where the latter areas fall within the former areas ordered to evacuate. By the 15th, households within 20–30 km from the Fukushima Daiichi nuclear plant were ordered to stay inside their residences (Fukushima Prefecture 2013). By April 22nd, the government defined areas within the 20 km radius as a "high alert area" (*keikai kuiki*), and areas within 20–30 km with high radiation levels, expected to reach 20 Sieverts/year, were treated similarly to the "high alert area". Residences were then ordered to subsequently evacuate within a month. After 9 months, by late December 2011, the national emergency response headquarters for the nuclear accident (*genshiryoku saigai taisaku honbu*) published revised maps of three land use types with accompanying criteria to designate areas for evacuation orders (*hinan shiji kuiki*). These were: (i) "areas preparing for lifting evacuation" (*hinanshiji kaijyo junbi kuiki*) where radiation levels are confirmed to be less than 20 Sieverts/year, which allowed people to visit and pass through the area; (ii) "areas restricted for living" (*kyoju seigen kuiki*) where radiation levels may exceed 20 Sieverts/year, which required restrictions on continued living to protect residents' health; and (iii) "areas difficult to return" (*kikan konnan kuiki*) where radiation levels may exceed 20 Sieverts/year even after 5 years, and currently exceeding 50 Sieverts/year. Residence in this area is strictly forbidden and visits are also controlled. This rule was enforced about a year after the accident in April 2012 (Fukushima Prefecture 2013).

Evacuation orders initially affected 11 local governments located near the Fukushima Daiichi Power Plant. The area with evacuation orders totaled 1,150 km^2 with a population of 81,291 prior to March 11 (Cabinet Office, Government of Japan 2013). With progress on removal of contaminated soil, evacuation orders in some areas have been gradually relaxed after confirming the safety levels of radiation. About 70% of the total area initially designated for evacuation is expected to be inhabitable by the end of the sixth year. A total of 337 km^2 in seven local governments, however, continue to be permanently prohibited for living, and the three towns of Futaba, Namie, and Ookuma have 96%, 80%, and 62% of their territories falling into this category (Cabinet Office, Government of Japan 2013). The number of evacuees continues to be high; approximately 46% of the total population prior to the GEJE in 11 local governments continue to live in temporary housing situations, and about 30% of the original population of these local governments will be permanently pushed outside their original communities (Cabinet Office, Government of Japan 2013). Regardless of such complications faced in Fukushima, rebuilding from tsunami damage is finally being planned for places where reconstruction has been controlled due to radiation. These areas are receiving the full support of the

RA by using the 40 programs for reconstruction projects, to be accelerated so as to be completed along with other tsunami affected areas in Fukushima and other affected prefectures.

6.4.2 Implementing Rebuilding: Programs Adopted for Community Rebuilding

While devastation was unprecedented in Tohoku, reconstruction activities have also been extraordinary for their scale and complexity. For this reason, it has been difficult to comprehend the overall picture of recovery progress. To address this issue, the following sections assess the use of the "community rebuilding programs" by the hardest-hit three prefectures, and also compare features of the collective relocation program, land readjustment program, and fishing community strengthening program, jointly called programs for "land arrangement for neighborhood reconstruction."

The four community rebuilding programs have been applied in a few typical ways. First, land readjustment programs, sometimes combined with the collective relocation program, are used largely in downtown areas. These areas usually have high population densities, and projects typically involve raising land or cutting mountains. In total, six local governments in Iwate Prefecture, eight in Miyagi Prefecture, and two in Fukushima Prefecture are proceeding with redevelopment in this way. Second, collective relocation and fishing community strengthening programs are predominantly used in smaller coastal communities. These communities have few households, and relocation sites are developed mostly by cutting mountains to create level land at higher elevations. Nine and 7 local governments used the fishing community strengthening program and collective relocation, respectively, in Iwate Prefecture, 5 and 12 in Miyagi Prefecture, and 1 and 6 in Fukushima Prefecture. Third, local governments applied the public housing program in two different ways. The first way was to build collective housing in multi-story buildings, typically in more populated areas in the central parts of cities. The second way was to build single-family detached housing, typically in less populated areas, such as coastal towns and villages. This latter type of public housing can be found predominantly in sites that also used the collective relocation and fishing community strengthening programs. Twelve local governments in Iwate Prefecture, 21 in Miyagi Prefecture, and 25 in Fukushima Prefecture have used this fourth community rebuilding programs, the public housing programs.

Data compiled uses March 2016 statistics from the "Work schedule on community rebuilding" (*Sumai no fukko kotei hyo*) published by the national RA, dated May 2016. There is a caveat for this analysis, however. Our unit of analysis is the "district," a literal translation of *Chiku* as reported by the RA, which technically means a project area, consisting of a single contiguous land readjustment or collective relocation, or, sometimes, a contiguous combination of projects. A district is

Table 6.2 Number of districts using community rebuilding programs

	Districts with neighborhood reconstruction programs (some include public housing)	Public housing	Total
Iwate	121	137	258
Miyagi	205	186	391
Fukushima	53	160	213
Total	**379**	**483**	**862**

By K. Iuchi; original raw data from the Reconstruction Agency
http://www.reconstruction.go.jp/topics/main-cat1/sub-cat1-12/20160519091258.html

defined by each municipality, often relying on their local use, thus its size is not uniform – it could vary from a small neighborhood in a village with less than ten households to a downtown area with more than a thousand households. District setting and geographic formation also varies – their location could be urban or rural with different population density in flat land as in the Sendai plain or along the Rias coast in the Sanriku area.

6.4.3 Community Rebuilding Programs and Their Use

In total, 862 districts used community rebuilding programs in Iwate, Miyagi and Fukushima Prefectures (Table 6.2). Of these districts, 44% (379 districts) adopted a mix of programs related to land arrangement for neighborhood reconstruction, and the other 46% (483 districts) used only the public housing program. Among the three prefectures, Miyagi has the largest number of districts (391 districts) using community rebuilding programs, and unlike the other two prefectures, slightly more than half (205 districts, or 52%) used neighborhood reconstruction programs.

6.4.4 Neighborhood Reconstruction Programs

Among the 379 districts using the neighborhood reconstruction programs in the 3 prefectures, 350 districts or 92.3% are solely using one program per district (Table 6.3). The rest of the 29 districts (or 7.7%) have approached rebuilding by combining two programs in a district. Of the three prefectures, Miyagi Prefecture has the largest number of districts, 205, using neighborhood reconstruction programs (54.1% of the three prefectures total), and only 11 districts (5.4%) used more than one program per district. In contrast, in Iwate Prefecture 18 districts (14.9%) used two neighborhood rebuilding programs.

Out of 350 districts solely using one program, the collective relocation program was by far the most common, used by 84.3% (295 districts) of these districts (Fig. 6.1). The collective relocation program is the most common for districts in all three prefectures (Fig. 6.2).

Table 6.3 Breakdown of use on neighborhood reconstruction program by prefecture

Prefecture	Single use				Combined use				Total
	Fishing community	Land readjustment	Collective relocation	**Sub-total**	Land readjustment and collective relocation	Land readjustment and fishing community	Collective relocation and fishing community	**Sub-total**	
Iwate	22	7	74	**103**	7	3	8	**18**	**121**
Miyagi	4	16	174	**194**	11	0	0	**11**	**205**
Fukushima	0	6	47	**53**	0	0	0	**0**	**53**
Total	**26**	**29**	**295**	**350**	**18**	**3**	**8**	**29**	**379**

By K. Iuchi; original raw data from the Reconstruction Agency
http://www.reconstruction.go.jp/topics/main-cat1/sub-cat1-12/20160519091258.html

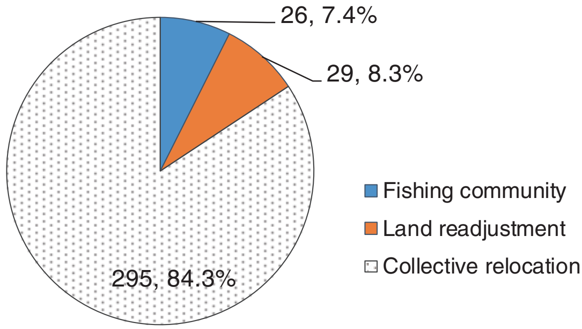

Fig. 6.1 Proportion of neighborhood reconstruction program for single use. Created by K Iuchi (Original raw data from the Reconstruction Agency (http://www.reconstruction.go.jp/topics/main-cat1/sub-cat1-12/20160519091258.html))

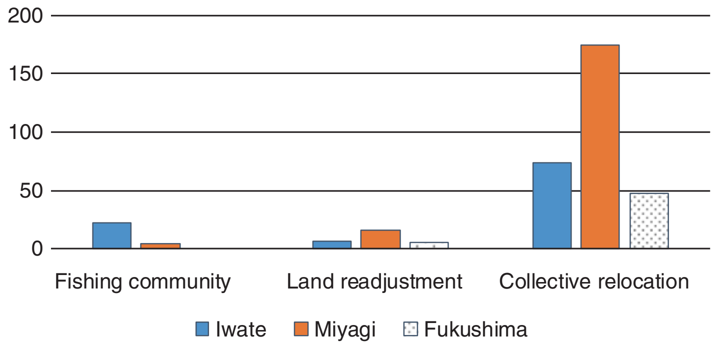

Fig. 6.2 Distribution of neighborhood reconstruction program single use by prefecture. Created by K. Iuchi (Original raw data from the Reconstruction Agency (http://www.reconstruction.go.jp/topics/main-cat1/sub-cat1-12/20160519091258.html))

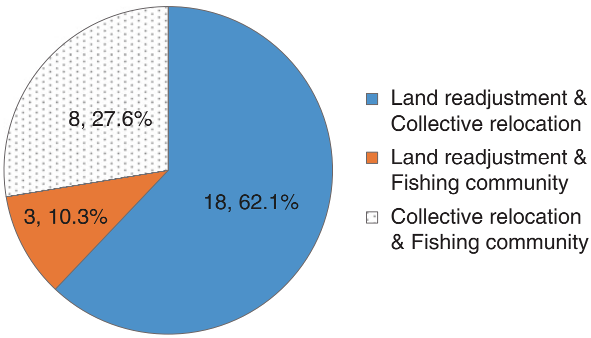

Fig. 6.3 Combined use of neighborhood reconstruction programs by number of districts. Created by K. Iuchi (Original raw data from the Reconstruction Agency (http://www.reconstruction.go.jp/topics/main-cat1/sub-cat1-12/20160519091258.html))

Among the 29 districts using two programs in neighborhood rebuilding, the combination most frequently used in a district was land readjustment and collective relocation programs. This accounted for 18 or 62.1% of the 29 multi-program districts, followed by the combination of collective relocation and fishing community programs and land readjustment and fishing community programs used by 27.6% and 10.3% respectively (Fig. 6.3). These numbers show that collective relocation

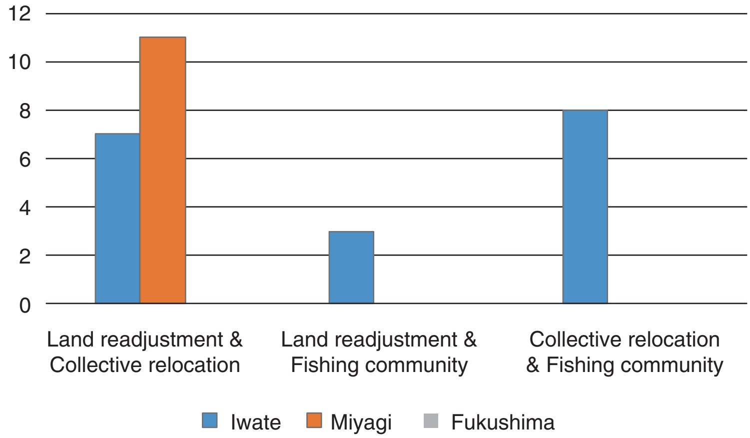

Fig. 6.4 Neighborhood reconstruction programs adopted for combined use. Created by K. Iuchi (Original raw data from the Reconstruction Agency (http://www.reconstruction.go.jp/topics/main-cat1/sub-cat1-12/20160519091258.html))

programs were also used preferably even when combined with other programs. Variations on adopted programs for combined use shows differences among the three prefectures. While Iwate Prefecture had districts that used all three types of combinations, Miyagi Prefecture only had a combination of land readjustment and collective relocation, and Fukushima Prefecture had no districts that combined programs (Fig. 6.4). These differences may derive from several reasons, including: (i) different geographical landscapes for reconstruction, (ii) knowledge and decisions of leaders and officials in local governments, and (iii) types and procedures of initial information shared on land arrangement for neighborhood reconstruction. Fukushima Prefecture, however, is still in early rebuilding stages, and community rebuilding projects are about to accelerate in areas where the evacuation orders have recently been lifted.

This analysis of neighborhood reconstruction programs shows that the three prefectures are proceeding with reconstruction by mainly adopting one program per district, often favoring the collective relocation program. In some districts, two programs of neighborhood reconstruction are combined, but to a minimum degree. Among the three prefectures, Iwate's use of programs is the most varied.

6.4.4.1 Public Housing Programs

All households that lost homes from the GEJE are eligible to live in public housing. The income cap to live in public housing was lifted with a special exemption for the GEJE recovery, although rents will reflect household income levels. As a result, demand for public housing is high, especially in shrinking regions, where families do not expect to continue to live in their hometown. Based on the data of community rebuilding programs used, about 56% of districts (483 out of 862 districts total, Table 6.2) have solely used public housing programs. Meanwhile, among 379 districts using any one of the neighborhood reconstruction programs, nearly half of them (186 districts) also used public housing programs (Fig. 6.5). This makes a total of 669 districts with public housing projects (Tables 6.4 and 6.5).

Among 186 districts with public housing programs adopted with other neighborhood reconstruction programs, 158 of them (84.9%) are with just one other program. Among the three prefectures, Miyagi Prefecture has by far the largest number of districts combining public housing and neighborhood reconstruction programs (124 districts). Building public housing in a site for collective relocation was their favored approach, as an effort to keep former communities together regardless of financial capacity among community members (Fig. 6.6).

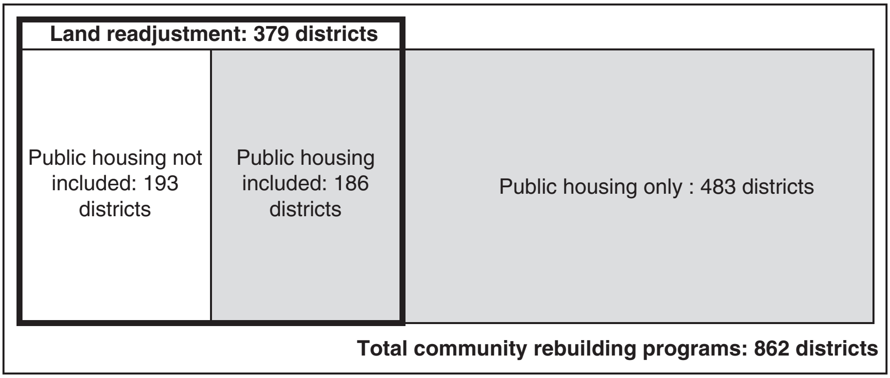

Fig. 6.5 Conceptual diagram on breakdowns of community rebuilding programs (Created by K. Iuchi)

Table 6.4 Districts using public housing program by type

Prefecture	Public housing (exclusive)	Public housing (inclusive)	Total
Iwate	137	41	178
Miyagi	186	124	310
Fukushima	160	21	181
Total	**483**	**186**	**669**

By K. Iuchi; original data from the Reconstruction Agency
http://www.reconstruction.go.jp/topics/main-cat1/sub-cat1-12/20160519091258.html

Table 6.5 Public housing and neighborhood rebuilding programs by prefecture

Prefecture	Inclusive in a program				Inclusive in two programs				
	Fishing community	Collective relocation	Land readjustment	Sub-total	Land readjustment and fishing community	Land readjustment and collective relocation	Collective relocation and land readjustment	Sub-total	Total
Iwate	8	10	5	**23**	3	7	8	**18**	**41**
Miyagi	2	101	11	**114**	0	10	0	**10**	**124**
Fukushima	2	18	1	**21**	0	0	0	**0**	**21**
Total	**12**	**129**	**17**	**158**	**3**	**17**	**8**	**28**	**186**

By K Iuchi; original data from the Reconstruction Agency
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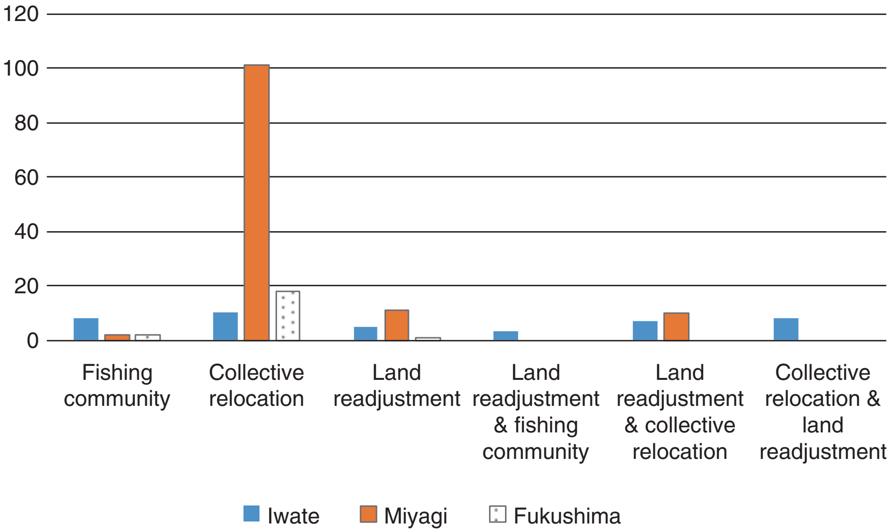

Fig. 6.6 Number of districts that combine public housing with neighborhood reconstruction programs, by prefecture. Created by K. Iuchi (Original data from the Reconstruction Agency (http://www.reconstruction.go.jp/topics/main-cat1/sub-cat1-12/20160519091258.html))

6.5 Discussion

6.5.1 On Program Use

Early in the rebuilding process, the national RA offered 40 programs for local governments to use. Four community rebuilding programs, including land readjustment, collective relocation, fishing community strengthening, and public housing programs, have been highly preferred by local governments for their neighborhood reconstruction projects. Data showed a total of 862 districts using these programs in the three most affected prefectures.

One of the key findings on community rebuilding programs is that although the Tohoku recovery has often been perceived as a top down process without any creativity, the data reveals that local governments used the four programs in different ways in order to fit their goals for land use. For instance, districts often combined different types of neighborhood reconstruction programs if that better suited their reconstruction needs. In particular, public housing projects were often combined with land readjustment, collective relocation, or fishing community projects, in order to meet the varied needs of households in a community.

Analysis also suggested clear differences between the three affected prefectures in the use of community rebuilding programs. In Iwate Prefecture, local governments have used the programs in the most flexible way, mixing fishing community strengthening, collective relocation, and land readjustment programs among and within districts. Although, of districts that used neighborhood reconstruction programs, by far the majority of districts in all three prefectures used community relocation, Miyagi and Fukushima Prefectures more strongly emphasized its use over that of the other programs. As for the use of public housing programs, local governments in Miyagi Prefecture have especially favored locating such buildings on collective relocation sites. This reveals their effort to keep pre-disaster community members together regardless of individual financial status – whether residents were able to reconstruct homes by themselves or need support from the government.

6.5.2 On Redevelopment Progress and Community

While site development and housing construction are generally proceeding toward the envisioned goals, various implementation issues have emerged, thereby extending reconstruction times and causing further hardships to dislocated homes and businesses. Site redevelopment using the land readjustment program usually takes a long time, and in Tohoku, the majority of these projects are not yet complete. Some localities do not expect to finish development of land readjustment sites until spring 2019 (Reconstruction Agency 2016c). This extended reconstruction process creates challenges, and the 5 years of reconstruction to date have already caused local businesses and residents to reestablish themselves elsewhere. Moving into the new sites 8 years after the disaster will be like starting anew.

For smaller relocation sites, whether by collective relocation program, fishing community strengthening program, public housing program, or a combination of these, the majority of developments – except some areas in Fukushima – expect to finalize construction by early 2017 (Reconstruction Agency 2016c). Houses now are being constructed in sites where lands are already allocated to residents, and public housing is nearing completion. Some residents have already moved into their new houses where construction is completed. Those who are still waiting continue living in either deteriorating temporary houses that had been constructed more than 5 years ago, or in rented units supported by public assistance.

Other issues have emerged, as households and communities continue to evolve and change over the long recovery time period. Although no published numbers are available, many homeowners are no longer able to accept public assistance to rebuild. Some have aged to an extent that they can no longer live on their own or have passed away before resettlement locations have been prepared. For others, financial circumstances have changed such that they can no longer afford to reconstruct their home. Local governments are then faced with resolving the use of vacant lots in the new reconstruction areas. For residents who have succeeded in resettling, further challenges remain. These include: creating new neighborhood associations with non-familiar members, merging into existing residents associations in new relocation sites, or rearranging community organizations with a reduced number of members in smaller communities. In the latter type of community, relocated residential areas are often isolated from urban services. In sum, those who have waited a long time are feeling left out and tired of waiting, while residents who have resettled earlier are facing new challenges to adapt to new environments.

6.6 Conclusion

The GEJE has often been called a disaster beyond expectations. In many ways, rebuilding from such devastation has also been an unprecedented effort. In the last 5 years, national, prefectural, and local governments have developed rebuilding concepts and ideas, set institutions and programs to proceed with reconstruction, and made various decisions for implementation to rebuild Tohoku stronger against future tsunamis. In particular, the national government took the lead in developing rebuilding concepts, securing funding, and establishing a national level reconstruction agency to administer rebuilding from the unprecedented devastation. Prefectural governments oversaw the reconstruction of coastal infrastructure, among many other rebuilding responsibilities.

Since the moment this earthquake and tsunami struck Tohoku, local governments have always been in the lead. They were empowered to decide on future land use and adopt programs that could reconstruct their community in a safe and strong way. National support, through recovery principles and guidelines on community recovery, have helped them decide on policies and proceed with recovery. Local governments also conducted countless negotiations and coordination with national and prefecture governments, as well as collaborated with numerous key actors in reconstruction, such as NGOs, universities, the private sector, and most importantly, their residents. Local governments also have managed details of community reconstruction, including preparation of land parcels and allocation of housing units. To gain support and understanding, local governments hosted countless meetings with residents and stakeholders.

With time, details of the rebuilding efforts are likely to fade. This chapter therefore reviewed the governmental structure of the Tohoku recovery process, recovery land use policies, and implementation of the community rebuilding programs. The number of districts using community rebuilding programs totals more than 860, which explain how the Tohoku reconstruction itself has been a challenge. Even with this challenge, however, we also found that local governments have used community rebuilding programs in ways that best suit each of their recovery needs.

Beyond physical recovery, the Tohoku recovery will continue to require further effort regarding social and economic issues, primarily because all the rebuilt communities will continue to face problems of aging, depopulation and isolation. Nor is physical reconstruction complete, particularly in radiation-affected areas of Fukushima Prefecture where rebuilding is just starting. Nevertheless, understanding the impacts on communities to date from the rebuilding policies and programs continues to be important. This can provide lessons on improving approaches and programs for future rebuilding from large-scale disasters, and identifying additional support needed by recovering communities.

Acknowledgement and Disclaimer This work was supported by JSPS Grants-in Aid Grant Number 16H03586. The Authors appreciate all those who shared their knowledge and wisdom in interviews to help prepare this chapter. The authors take sole responsibility for any inaccuracies and omissions.

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Chapter 7
Enhancing Community Resilience Through Capacity Development After GEJE: The Case of *Sendaishi-chiiki Bousai* Leaders (SBLs) in Miyagi Prefecture

Aiko Sakurai and Takeshi Sato

Abstract The *Sendaishi-chiiki Bousai* Leader (SBL) Program was launched in 2012 as a capacity development initiative in Sendai City, Miyagi Prefecture (one of the severely affected municipalities in the Tohoku region), in response to the 2011 Great East Japan Earthquake (GEJE). The Program emphasizes strengthening each community's disaster resilience by fostering locally based leaders to promote sustainable disaster risk reduction activities within existing *chonaikai* (neighborhood association) networks. Over its 4 years of implementation, 584 SBLs have been certified. The SBL Program is designed to emphasize learning from the lessons of the 2011 GEJE experience in Sendai City and conducting disaster management activities based on the community's local disaster risk. The SBL Program has helped identify a new generation of individuals who can lead community disaster risk reduction (DRR) activities. In the SBL Program, each community is placed in the driver's seat but is not left alone. After the training, the city government supports certified SBLs by providing opportunities for follow-up and SBL exchanges. The Sendai City experience indicates that developing the capacity of a community's DRR leaders in a post-disaster period can contribute to enhancing that community's disaster resilience for better community rebuilding.

Keywords Community-based disaster risk management • Capacity development • Sendai • The Great East Japan Earthquake (GEJE)

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V. Santiago-Fandiño et al. (eds.), *The 2011 Japan Earthquake and Tsunami: Reconstruction and Restoration*, Advances in Natural and Technological Hazards Research 47, DOI 10.1007/978-3-319-58691-5_7

7.1 Introduction

The word "resilience" derives from the Latin word *resalire*, to spring back (Klein et al. 2003; Manyena 2006). The concept of resilience has been discussed in various academic fields, such as psychology, ecology, organization and management science, group/team literature, and safety management. When applied to social entities, "resilience is the capacity of a social system (e.g., an organization, city, or society) to proactively adapt to and recover from disturbances that are perceived within the system to fall outside the range of normal and expected disturbance" (Comfort et al. 2010). Disaster resilience is determined by "the degree to which the social system is capable of organizing itself to increase this capacity for learning from past disasters for better future protection and to improve risk reduction measures" (UNISDR 2005). Because the roots of both risk and resilience exist within the social order itself, societies, communities, and organizations have the power to reduce risk and become more resilient (Tierney 2014). According to these definitions, increasing a community's capacity can enhance its resilience; it is a long-term process rather than an end or an outcome.

Prior to the introduction of the concept of resilience in Japan, self-help, cooperative assistance, and public assistance, called the "three types of help for disaster risk reduction (DRR)," had been a basic Japanese concept for understanding how to prepare for and respond to a disaster. This three-help concept represents who should be responsible for and capable of what kinds of disaster management activities before, during, and after a disaster. These days the concept is taught in schools following children's developmental stages and comprising steps from self-help to cooperative help to public help. In daily life, each citizen is encouraged to implement self-help activities, such as attaching furniture to a wall and preparing a family disaster preparedness plan at home, and to participate cooperatively in disaster management activities, such as taking part in a neighborhood association and community disaster drills.

In the 2011 Great East Japan Earthquake (GEJE) and tsunami disaster, due to the wide-scale catastrophe, municipal governments were severely affected and their ability to help people was paralyzed. In this situation, community residents were responsible for supporting one another to survive by evacuating from the tsunami-affected area, operating evacuation shelters, and securing food and water. Communities became first responders. Due to recognition of the limitations of public help after this calamity, the importance of self-help and cooperative help in each community has been reemphasized. Since much volunteer and international support was extended to the Japanese people, "external help" has been recognized as important in addition to the three-helps. According to the government's national poll in 2013, the Japanese citizens also recognize the importance of striking a balance among self-help, cooperative help, and public help for disaster resilience, rather than solely depending on public help (Cabinet Office 2014b). Since the 2011 disaster, accurate risk assessment by the government and experts, as well as interactive risk communication among the government, experts, and community residents, has been reemphasized to understand local disaster risks and to take appropriate action in times of emergency (Central Disaster Management Council 2011; Council for Science and Technology 2014). Based on the 2011 disaster experience and the lessons learned from it, how to effectively protect individual lives and practically respond to catastrophic situations at the local level are key issues for enhancing community resilience.

At the national level, the government revised the Disaster Countermeasures Basic Act in 2013 and introduced a new "regional disaster management plan" calling for residents to prepare their own plans and link them to that of the municipal government. The basic concept is to promote local residents' participation and sense of ownership and to localize general knowledge and information on DRR in each community. The government intends to strengthen bottom-up DRR efforts and cooperative help in addition to self-help and public help to achieve a sustainable community disaster management capacity (Cabinet Office 2014a).

What is an effective approach for the affected municipalities and communities to enhance disaster resilience by rebuilding better from their disaster experiences? To answer this question, this chapter introduces as a case study the *Sendaishi-chiiki Bousai* Leader (SBL) Program launched in 2012 in Sendai City, one of the GEJE-affected municipalities. The objective of this paper is to articulate the on-going process for enhancing Sendai City's disaster resilience by developing community leaders' capacities in the course of the disaster recovery process. The SBL Program is a localized and unique program of Sendai City, and the recently initiated Program should be further examined to assess its validly. Nevertheless, the approaches of the affected municipalities in the post-disaster phase may be useful to the understanding of the rest of the world about how to enhance communities' disaster resilience. This paper has been developed considering previous work on SBLs (Sato et al. 2010, 2015, and 2016), adding international perspectives obtained through discussion at the CERT-SBL Workshop (2016) as well as interviews with certified SBLs and a review of existing English literature on community disaster resilience.

7.2 SBL Program to Enhance the Community's DRR Capacity

7.2.1 Sendai City and the 2011 Great East Japan Earthquake and Tsunami

Sendai City is the capital of Miyagi Prefecture and the largest city in the Tohoku region, with a population of 1,084,530 individuals and 504,134 households as of August 2016 – a 1.56% increase in the number of households from 2010 (Sendai City 2016a). Sendai is located along the central Pacific coast of the Tohoku region and at the center of Miyagi Prefecture. The Nagamachi-Rifu fault lies in a northeast to southwest direction across the city, dividing the city into mountainous and hilly areas and highlands in the west and plain fields in the east. Its geographic features vary from coastal to mountain areas and are especially diversified in the east to west direction (Sendai City Disaster Management Council 2015). Miyagi Prefecture is one of the more earthquake prone regions of Japan. In 2009, the Earthquake Research Committee of the Japanese government projected the 70% probability of an earthquake off the coast of Miyagi Prefecture with a magnitude of Mj = 7.5 within 10 years, with the average occurrence interval being about 37 years.

The GEJE on March 11, 2011, resulted in 904 deaths and 26 missing in Sendai City as of January 2014. In total, 8,110 households were inundated by the tsunami (Sendai City 2016b). Agricultural, industrial, lifeline, and transportation infrastructures were severely damaged, especially in the eastern coastal area of the city. Tremors on both March 11 and April 7 caused liquefaction in coastal areas, landslides in hilly areas, and the collapse of developed lands in the western part of the city (ibid). On March 13, 2011, 105,947 people, representing over 10% of the city's total population, were living as evacuees in 288 shelters throughout Sendai. Of the 288 shelters, 197 were originally designated as evacuation places at the city's public schools. Schools inspected and identified as safe for occupation were used as evacuation shelters. The last shelters were closed on July 31, 2011 (ibid).

7.2.2 Development of Jishubo *Organizations and the Issues Faced*

In Japan, cooperative help has been promoted through activities by community-based disaster management organizations (CBDMOs) called *Jishu-bousai-soshiki* or *jishubo*. Since the 1995 Hanshin-Awaji earthquake, the government has urged the national establishment of *jishubo* based on the neighborhood associations (*chonaikai*) or residents' associations (*jichikai*) existing in each community. The 1995 revised Disaster Countermeasures Basic Act stipulated the municipal government's role in fostering community-based organizations. In the spirit of neighborhood cooperation, residents are expected to form volunteer disaster management organizations aimed at contributing to disaster prevention activities. In Kobe City, Hyogo Prefecture, one of the cities more affected by the 1995 earthquake, an original and unique CBDMO has been established. Instead of a neighborhood association *jishubo*, it is a BOKOMI ("*Bousai Fukushi Komyunithi*"), that is, a disaster prevention and welfare community (Matsuoka et al. 2012). Until now, each elementary school district has organized a BOKOMI, and 191 BOKOMI cover all households in Kobe City.

Chonaikai and *jichikai* are both volunteer-based community governance units in Japan, and the local government agencies make full use of them to transmit information and instructions to neighborhood residents (Bajek et al. 2008). Though neighborhood associations in Japan have long histories and deep roots in their communities, in the last 30 years their capacities have been weakened and they have faced a crisis of disappearing due to the urbanization of communities, diversification of people's lifestyles, and aging of the population. Thus, although the number

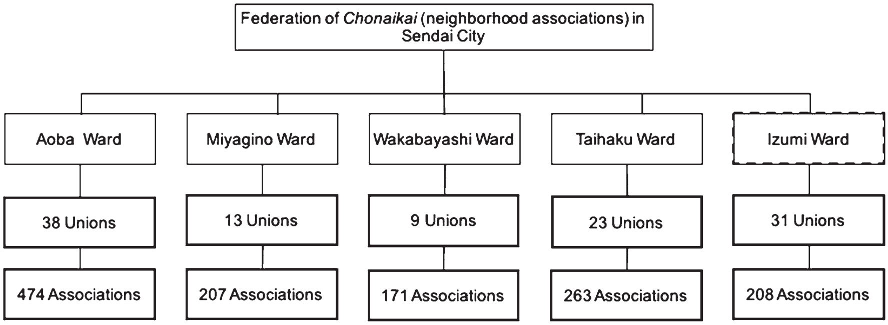

Fig. 7.1 Structure of *chonaikai* in Sendai City (Source: adapted by authors from information by Sendai City Federation of Chonaikai)

of *jishubo* to household ratio remains high, individuals are not necessarily motivated to volunteer for DRR, and the *chonaikai* leader's role rotates among its members. Moreover, members have passive attitudes and lack a proactive approach to promoting disaster preparedness in the community (Kuroda 1998). In this situation, DRR activity is an additional burden imposed on these neighborhood associations on top of their other daily activities, including neighborhood cleaning, garbage collection, and recycling, as well as organizing community activities such as athletic and cultural events.

In Sendai City, the ratio of *chonaikai* to the total number of households was 81.2% in 2015. There are 1,388 *chonaikai* units at the community level under 114 unions. Figure 7.1 shows the structure of the neighborhood associations by ward in Sendai City.

Each neighborhood association in Sendai City is encouraged to organize its *jishubo* at a unit level, and in some places, a group of *chonaikai* units organize one *jishubo* as a union. In the city, the ratio of *jishubo* to the number of households was 97.5% in 2011 and increased to 98.9% in 2014 (Sendai City 2015). Compared with the national average of 77.9% (Cabinet Office 2014b), Sendai City's ratio has been higher because the city has been promoting disaster preparedness in anticipation of another catastrophe similar to the Miyagi offshore earthquake of 1978.

7.2.3 **Jishubo***'s Emergency Response to the 2011 GEJE Disaster in Sendai*

A survey conducted in fall 2011 among all 1,358 *chonaikai* chairpersons by the fire department of Sendai City with Tohoku University revealed how the *jishubo* at each neighborhood association functioned during the 2011 disaster. The response rate was 86.2%, including 34 *chonaikai* that were adversely affected by the 2011 tsunami. Eighty-two percent of *chonaikai* were activated to respond to the disaster by either the management team or the management team and local residents. The major activities conducted by these *jishubo* were safety confirmation and information collection. Almost half of the activated *jishubo* units operated evacuation shelters (Sato et al. 2015). As previously mentioned, 288 evacuation shelters were opened throughout the City of Sendai after the March 11 earthquake. Comparing the number of shelters to the number of *chonaikai* organizations, one evacuation shelter was shared among residents of multiple *chonaikai*. In this situation, how actually were the evacuation shelters operated and by whom?

Prior to the 2011 disaster, the evacuation shelters were supposed to be operated by the municipal government officers through collaboration with evacuees, local community members, and host organization staff. However, due to the wide-scale disaster, the city government did not have enough officers dispatched to the shelters at the time of the 2011 disaster. It was reported by the media that evacuation shelter management was generally well organized through cooperative help among the schools, evacuees, local residents, and community organizations. However, school interviews conducted in 19 public schools in Sendai City revealed (despite the small sample surveyed) that, in reality, school principals and teachers in many cases served as evacuation shelters hosts and were required to take full responsibility for shelter management in addition to their main role of protecting students' safety and providing educational services to the children covered by the collaboration. Out of the 19 surveyed public schools, only one school had its evacuation shelter management led by the neighborhood associations' union in the school district (Japan Association of Safety Education 2014).

7.3 SBL and the SBL Program

The term "*Sendaishi-chiiki Bousai* leader" is translated into English as "a community leader who promotes DRR activities in Sendai City." Since Sendai City already has a high ratio of *jishubo* among households, the SBL Program focuses on increasing the DRR capacity of local community members by utilizing existing *jishubo* organizations through providing training, certifying them as SBL, and returning certified SBLs to their *jishubo* to conduct locally contextualized DRR activities. The SBL Program design has been articulated since 2010 after review of the existing DRR training program in Japan and the Community Emergency Response Team (CERT) program in the United States (Sato et al. 2016). It was finally launched in 2012 after reflection on the actual disaster experiences of and lessons learned from the GEJE.

7.3.1 Profiles of SBLs

From 2012 to 2016, 584 people attended the training and were certified as SBLs (Table 7.1). Among the participants, 439 people (75%) were recruited on the recommendation of a *chonaikai*, and 145 participants (25%) applied to the Program by

Table 7.1 Profiles of certified SBL members (2012–2016)

Participants	Male	Female
Total participants (n = 584)		
Number (%)	440 (75%)	144 (25%)
Average age	66.8 years old	60.4 years old
Participants recommended by *chonaikai* (n = 439)		
Number (%)	351 (80%)	88 (20%)
Average age	67.7 years old	61.3 years old
Self-applied participants (n = 145)		
Number (%)	89 (61%)	56 (39%)
Average age	63.0 years old	59.0 years old

Source: Modified from Sato et al. (2016 -in Japanese)

themselves. Among the participants, 75% were male and 25% were female. The self-applied participants comprised more females and younger people. Sendai City intends to increase the number of SBLs to five at each neighborhood association union.

7.3.2 *Role of the Sendai City Government*

The need to foster the community-based DRR leaders (SBL) and their roles is articulated in Sendai City's revised disaster management plan of 2015 (Sendai City Disaster Management Council 2015). During a normal period, SBLs are expected to develop a community disaster management plan based on local features and issues in their respective communities and to implement effective disaster drills and other disaster prevention activities. Additionally, SBLs are expected to become catalysts for promoting DRR collaboration with other community organizations, such as schools, medical clinics, and social welfare organizations. During an emergency period, SBLs are expected to lead the evacuation of local residents and to initiate the implementation of rescue and operate shelter management activities (ibid).

As the secretariat of the SBL Program, the Crisis Management Bureau of the Sendai City government provides free training to its citizens. It also organizes a series of information and experience exchanges as follow-up activities by certified SBLs to raise citizen awareness and improve the SBL Program. Figure 7.2 shows an example of the organizational structure of a *jishubo* incorporated into a *chonaikai* and the positioning of an SBL.

7.4 SBL Training

Training is a core component of the SBL Program. As shown in Table 7.2, the training is designed as a practical two-day, participant-centered program. An original training textbook was developed for the SBL Program by an examination

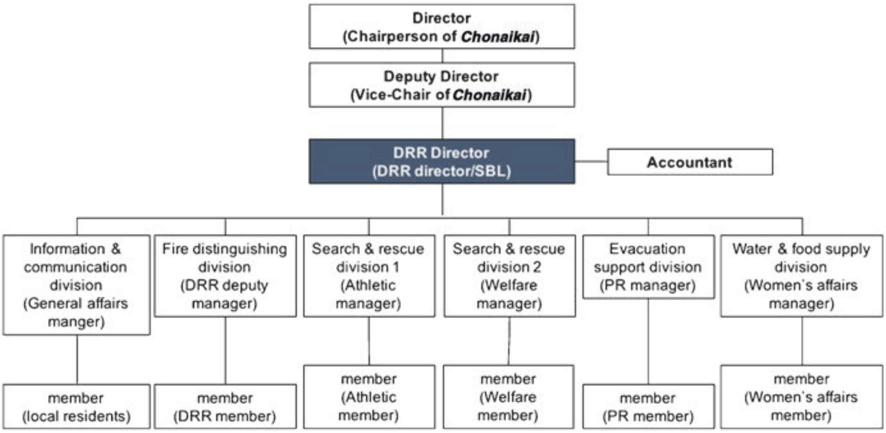

Fig. 7.2 Organizational structure of *jishubo* and example of an SBL in the structure (Source: Sato et al. 2016 *-in Japanese*)

Table 7.2 SBL training curriculum

Chapter in Text/Form	(min.)	Contents
DAY 1		
–	10	Opening
–	15	Self-introduction
Chapter 1 "Three helps on DRR"		
Lecture	15	1-1 Understanding a basic concept of self-help, mutual-help and public-help
Lecture	10	1-2 Role of Sendai-City Bosai Leader
Lecture	15	1-3 Support by the Sendai City Government to enhance the community-based disaster risk reduction activities
Lecture	10	1-4 Importance of collaboration among community-based organizations
Chapter 3 "Skills for daily disaster preparedness"		
Practice	45	3-2 How to conduct fire extinction at early stage
Practice	50	3-3 How to conduct rescue activities
Chapter 2 "Understanding local community's features"		
Lecture	30	2-1 Understanding local contexts of own community neighborhood
Lecture	15	2-2 Preparation for a disaster prevention map
Lecture/Practice/Discussion	15	2-3 Assessing community's capacity on DRR
Chapter 3 "Skills for daily disaster preparedness"		
Lecture	10	3-1 How to collect and convey information
Lecture	15	3-4 How to evacuate residents at a time of disaster
Lecture	15	3-5 How to evacuate from tsunami disaster

(continued)

Table 7.2 (continued)

Chapter in Text/Form	(min.)	Contents
Chapter 4 "Activities to enhance DRR capacity at community"		
Lecture	15	4-1 Preparing the community disaster management plan
Lecture	15	4-2 Preparing action cards for the community disaster management
Lecture and Practice	30	4-4 Disaster Imagination Game (DIG)
Lecture and Practice	40	4-5 Disaster prevention game: Crossroad game
Lecture	20	4-6 Introduction of other disaster prevention games
DAY 2		
Chapter 3 "Skills for daily disaster preparedness"		
Lecture	50	3-6 How to conduct first-aid support
Practice	40	3-6 How to conduct first-aid support
Chapter 4 "Activities to enhance DRR capacity at community"		
Lecture	30	4-3 Evacuation of vulnerable groups who require support during disaster
Chapter 5 "Learning from the 2011 Great East Japan Earthquake and Tsunami disaster"		
–	20	5-1 Watching tsunami disaster video
Lecture	20	5-2 Listening from a story-teller about life at evacuation shelter
Lecture	20	5-3 Learning from disaster experiences
Chapter 6 "Evacuation shelter management"		
Lecture	60	6-1 How to operate an evacuation shelter
Chapter 7 "Summary"		
Lecture and Discussion	20	7-1 Identifying DRR issues at your local community
Lecture and Discussion	20	7-2 Discussion on how to promote local residents' participation
Discussion	25	7-3 Discussion on DRR activities that could be conducted at your community
–	20	7-4 Self-assessment of understanding on the training
Lecture	40	7-5 Oath of commitment to leading the community's DRR activities

Source: Sato et al. (2015 -in Japanese)

committee on fostering community-based DRR leaders. Trainers come from different units of the city government, such as the fire department, the Crisis Management Bureau, the Welfare Bureau, and key players on DRR including hospitals, universities, and local nongovernmental organizations.

Based on the lessons learned from the GEJE, the training program includes lectures on evacuation shelter operation and tsunami evacuation of vulnerable groups, which reflects the latest DRR policy of the Sendai City government. The training also includes a unit called "learning from the 2011 disaster." One lesson learned from the 2011 disaster is that disaster damage caused by hazards differs depending on local geographical and socioeconomic conditions. As previously mentioned, Sendai City's earthquake damage came from various causes, including the tsunami, liquefaction, landslides, and the collapse of developed lands throughout the city. Thus, the training program focuses on supporting local residents in understanding their exposure and vulnerability to hazards in their local context, rather than providing general hazard information. In the program, participants learn how to find information by using an old topographic map, a fault map, and a landslide hazard map and are provided community files with information about demographic features, community organizations, and community events hosted by each elementary school district. The training program helps participants acquire practical knowledge and skills to prepare their respective communities' disaster management plans and to implement disaster response drills and other DRR activities.

7.4.1 Assessment of the Community's Disaster Management Capacity

The training includes an exercise to assess a community's disaster management capacity. The sheet is based on a quantification method for evaluating the regional safety factor, defined as the ratio of the emergency response potential ability (ERA) to the earthquake disaster risk (EDR) of each *chonaikai* organization (Sato et al. 2010). The sheet lists 33 questions regarding a community's emergency response ability. A community's ERA reflects a *jishubo*'s organizational potential ability to respond promptly after a disaster, which could prevent damage expansion and reduce secondary damage in the community. These 33 questions are categorized under the four elements of knowledge, skills, resources, and organizations and are divided into five levels according to the advancement of activities as presented in Table 7.3. When the 33 questions are answered, a community's disaster management capacity can be scored a maximum of 100 points.

Table 7.3 Level of DRR disaster management capacity at a DRR organization

Level	Description
Level 1	A DRR organization is established at a community and roles and responsibilities are determined among the member.
Level 2	The DRR organization takes part in DRR activities/events organized by the government
Level 3	The DRR organization assesses the community's situation and identifies its local issues on DRR
Level 4	The DRR organization progresses their activities
Level 5	The DRR organization develops a community disaster management plan proactively and monitors and reviews the plan

Source: created by the authors from Sato et al. (2010 -in Japanese)

Using the sheet for regular assessment of each community's exposure to hazards could help communities implement their activities in a plan–do–check–action cycle. This includes observing a community's progress, understanding its weak and strong points in disaster risk management, and identifying subsequent steps according to the community's hazard exposure. The assessment sheet provides a step-by-step procedure to advance community-based DRR activities and could contribute to enhancing communities' disaster risk management capacities in a sustainable manner. In addition to increasing each community's emergency response ability, countermeasures to secure safety in earthquakes, such as retrofitting building structures and attaching furniture to avoid it overturning when shaken should be arranged in each household.

7.4.2 SBLs Building Collaboration Between Community and School

Certified SBLs conduct a series of DRR activities in their own *chonaikai* units. A follow-up survey conducted by the SBL secretariat has found that the most popular activity is DRR school drills. As of August 2016, 193 schools from elementary to high school levels have been designated as official evacuation shelters in Sendai City. The city's revised local disaster management plan encourages establishing an evacuation shelter management committee in each designated shelter and preparing each community's disaster management manual. As the bodies responsible for these facilities, schools are expected to support the initial setup of the evacuation shelters if a disaster occurs when the schools are open. For schools and educational authorities, collaboration among their communities and other stakeholders is critical for resuming classes as early as possible and minimizing negative impacts on education, such as by reserving classrooms that should not be occupied by evacuees. Since 2008, the Sendai City Board of Education has promoted collaboration among schools, households, and communities to support educational activities by establishing "community headquarters to support schools." In 2012, it also advocated "disaster education in Sendai" (Sendai City Board of Education 2015) based on collaboration among schools, parents, and local community members. Responding to such educational sector initiatives, the Crisis Management Bureau of the Sendai City government provides – with each school district's permission – a list of SBLs in each district. The SBLs have started to play a coordinating role in promoting collaboration between schools and communities for localized DRR activities.

The Nanzai *chonaikai* union undertakes one of the better practices of SBL collaboration with schools. In this union, local residents actively participate in community and school activities, such as summer festivals, athletic events, and graduation ceremonies. Prior to the 2011 disaster, earthquake disaster drills had been conducted in each *chonaikai* unit in Nanzai. Having operated three evacuation shelters in its area and hosted 200 tsunami refugees from neighboring areas, the Nanzai *chonaikai* union jointly organized an elementary school district drill in collaboration with 25 *chonaikai* units and an elementary school in 2012. The school decided to conduct the drill on a Saturday (not a school day) as an official activity, with 350 pupils' participation. Since then, year by year the drill has been upgraded. In 2015, a comprehensive DRR drill was expanded to the junior high school district level, with three *chonaikai* unions, students, and teachers from three elementary schools and one junior high school, the fire and the police departments, and city government officers. Fourteen SBLs in the three *chonaikai* unions performed active coordination roles.

Such a large-scale collaboration including students and schools in the Nanzai district could not have been realized without the chairperson of the Nanzai *chonaikai* union. For example a devoted community leader who grew up in the *chonaikai* and is a certified SBL and a retired high school principal understands the school decision-making structure and annual scheduling of school activities and occupies a leadership position in the community, he can be an honest broker to serve as a bridge between the school and the community. This example indicates that, in addition to having institutional arrangements, the presence of a SBL who both understands the school organizational culture and has face-to-face relationships in the community can help develop effective collaboration between a *chonaikai* and area schools.

7.5 Discussion and Conclusion

Sendai City launched the SBL Program in 2012, 1 year after the GEJE disaster. Utilizing actual disaster experiences and the high ratio of *jishubo* organized at each *chonaikai*, the SBL Program benefits from its focus on locality, practicality and sustainability. First, the SBL Program provides a 2-day training comprising practical knowledge and skills to support SBLs in identifying local issues and priorities to enhance community disaster resilience. Second, certified SBLs are required to actually implement locally contextualized disaster management activities in their respective communities. Thus, the Program focuses mainly on training local residents who can utilize existing *chonaikai* networks. Third, the city government fully supports the SBLs and the SBL Program by offering free training; certifying the SBLs; providing opportunities for follow-up, information sharing, and awareness raising; and monitoring the progress of the Program and improvements of it. In the SBL Program, local residents and communities are placed in the driver's seat of DRR activities, but they are not left alone.

In the 4 years since the launch of the SBL Program, best practices are identified at the community level. However, they exist primarily where active community participation had already been practiced for many years prior to the 2011 disaster. A challenge is leveraging certified SBLs to activate disaster management activities in communities where *chonaikai* networks are relatively weak. Another challenge is supporting a new generation who have not been active members of *chonaikai* and/or *jishubo* organizations but are interested in DRR activities and in being certified as SBLs. This group tends to include more females and younger people than exist among active community members, and it has potential to promote a generational change from the existing senior-, male-dominant current leadership. To support the new generation, community leadership must listen to them and let them play a role in the existing organizational structure. Furthermore, certified SBLs should have opportunities to advance their skills and knowledge from disaster response to disaster risk reduction. There are many opportunities for SBLs to share their experiences with other ward levels and at the citywide level. The city government also plans to provide an advanced training course. With more certified SBLs and SBL networks, further modification of the Program is required to be truly practical and sustainable. Other municipalities and other countries that promote community-based DRR activities could consider adopting these goals of practicality, locality, and sustainability.

The Program's ultimate goal is to strengthen the community's DRR capacity. From this perspective, it is still at an initial stage. Therefore, more experiences are required to determine the Program's validity and effectiveness in terms of its actual impact on reducing disaster risks in communities. The following quotation represents the major stakeholders' consensus on disaster education and community preparedness in Japan:

> *The capacity of a society to accommodate itself of and recover from the effects of a natural disaster depends on how much each individual was able to learn from the past experience and knowledge passed down from our ancestors, and how much they were able to prepare for disaster in daily life through partnerships among households, schools, and the community. The goal of disaster education is to increase the capacities according to each individual's level.* (International Forum for Promoting Education on Disaster Resilience 2015)

As has been shown, communities' disaster resilience can be realized through a combination of self-help, cooperative help and public help. Disaster researchers and practitioners in Japan have been making efforts to convert the spirit of cooperative help to practical actions for effective disaster risk management. The 2011 disaster accelerated efforts to create more direct links to reduce the risks of disaster in each community thereby enhance each community's disaster resilience since the events occurred.

Acknowledgment This work was supported by the Grant-in-Aid for Scientific Research on Innovative Areas (No. 2651008) from Japan's Ministry of Education, Culture, Sports, Science and Technology.

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Chapter 8
Community Design in the Recovery Following the March 2011 Earthquake and Tsunami

Hideki Koizumi and Mariko Tsuji

Abstract At the beginning of this chapter, the authors illustrate the framework for discussing community issues and arguments over the situation of communities in recovery following the Great East Japan Earthquake. During the process of recovery from the earthquake, the functions of mutual support and assistance were maintained in units based on the pre-disaster territorial communities through the stage when people were moved into evacuation shelters. But when people were relocated into temporary housing, the functions collapsed in many cases. Then, it could be said that community-design practice for people affected by the disaster had become one of most important issues, and the authors outline recent efforts in community design taken by national, prefectural, and local municipal governments, and private entities such as NPOs. The support systems for community design and community development formed gradually beginning in 2012 in multiple layers of government. After that, the authors describe a case in community-design practice performed in the city of Kamaishi as one of most successful and innovative cases of community-design practices in the recovery following the Great East Japan Earthquake. As the conclusion, the authors indicate the importance of ensuring the continuity of community development and an elaborate strategy for ensuring that continuity; then they explain the necessity of creating community- design practices based on collaborative multi-actor partnerships in the process of recovery following the Great East Japan Earthquake. These practices could be useful models not only for community design in a recovery following a future disaster, but also for community design in any urban area an aging population and falling birthrates.

Keywords Community design • Machizukuri • Place making • The Great East Japan Earthquake • Tsunami

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V. Santiago-Fandiño et al. (eds.), *The 2011 Japan Earthquake and Tsunami: Reconstruction and Restoration*, Advances in Natural and Technological Hazards Research 47, DOI 10.1007/978-3-319-58691-5_8

8.1 Introduction: Framework for Discussing Community Design in the Recovery from the March 2011 Earthquake and Tsunami

To better understand the situation and for the sake of the analysis, it is necessary to outline the framework for discussing community design[1] in the context of recovery and reconstruction following the March 11 evens. There are, at the very least, four main issues in community design:

- Sustaining and regenerating territorial communities such as neighborhood associations;
- Formation of communities of interest that address challenges in the disaster-stricken area;
- Mutual collaboration between them and partnership and cooperation with public administration and private enterprises; and
- Construction of systems and mechanisms for achieving progress in the foregoing issues.

Moreover, community design in the context of recovery and reconstruction following the March 11 earthquake and tsunami must be discussed with consideration for the specific characteristics of this disaster, which include the following: (1) The damage occurred over an extensive area (500 km^2); (2) Urban areas and villages along most of the coastal region suffered the catastrophic damage when the tsunami struck; (3) The aging of the population and falling birthrates were already a more acute problem in most of the disaster-stricken areas than elsewhere in Japan; and, to make matters even worse, (4) There is the complicating factor of a nuclear disaster (Fukushima).

This paper discusses reconstruction in a disaster-stricken area in the southern part of Iwate Prefecture, with particular reference to the above-mentioned points (2) and (3).

8.2 Reconstruction and the Sustenance and Regeneration of Communities

Looking at the current state of the (non-) sustenance and regeneration of communities in the actual reconstruction process as a first step for the analysis.

[1] In this article, the authors defined community design as making the built and social environment of a community better, almost the same as the Japanese term '*machizukuri*'. The authors selectively use these two terms, community design and *machizukuri*, according to the context of the description content.

8.2.1 The Derailing and Collapse of Efforts to Sustain and Regenerate Territorial Communities When People Moved into Temporary Housing

From the March 11 events to a few months afterwards, mutual support and assistance frameworks were maintained in units based on the pre-disaster territorial communities (neighborhood association, administrative district, hamlet, etc.), through to the stage when people moved into evacuation shelters (the emergency-response stage). However, once people relocated to temporary housing, those frameworks collapsed in many cases, with the exception of a few small settlements and some municipalities, such as Miyako City.

In a small fishing village, it is easy to perceive the territory of the community and for those affected by the disaster to see each other face-to-face, so relocation into temporary housing near the existing settlement was prioritized from the time when temporary housing was being built. In contrast, where there was blanket destruction of the urban area, it was not possible to devise ways to ensure that people were moved into temporary housing complexes in units of the former neighborhoods or placed in the same or adjacent complexes alongside their former neighbors.

Since this disaster caused particularly extensive damage along the Sanriku region characterized by precipitous terrain, it was difficult to secure land for development, which in turn made it hard to make plans at an early stage for building the temporary housing required. Design and construction of each temporary housing complex began as soon as the requisite land was secured, with efforts to secure land, arrange contractors, and undertake construction work proceeding in parallel. At time that the first temporary housing complexes were completed, local governments were unable to inform disaster-stricken local citizens when they would be able to live in which complexes. Under these circumstances, fairness made it difficult to adopt a stance of prioritizing residents from a particular district or neighborhood, so the tenants for each complex were chosen by means of a lottery, in many cases.

Moreover, when temporary housing was first provided, quantity of supply had to be the priority, but, as needs were not met, the quality of the housing and the built environment of housing complexes on which it stood ended up being poor. One issue was also the adoption of a layout plan for the temporary complexes in which all units were arranged in parallel, facing south, so residents had few opportunities to stand and interact with each other, which hindered the formation of a sense of community. In addition, in many cases, only temporary housing was built, without coordinating its construction with efforts to build temporary shops or offices. As a result, while there were few problems in places where the temporary housing was in or near existing downtown areas, daily life in temporary housing was very difficult in locations where the housing was isolated from the existing downtown area or in municipalities where the downtown area and residential districts had virtually vanished as a result of the tsunami.

8.2.2 *Difficulties in Regeneration of Territorial Communities in Disaster-Stricken Urban Areas*

As described above, where there was blanket destruction of the urban area, most of the residents were assigned temporary housing by lottery without any consideration of their former territorial communities (neighborhood association, administrative district, hamlet, etc.), which in turn made a community-based approach to the reconstruction projects that followed extremely difficult.

Since residents have been dispersed across different temporary housing facilities, people are, in many cases, unable to find out where their former neighbors currently live, making it nearly impossible for them to spontaneously get together with other members of their former neighborhood. Even if the local government did attempt to arrange such gatherings, many of the victims had lost their vehicles in the disaster, so were unable to travel independently.

Furthermore, in the reconstruction projects that followed, each zone of an urban area that had suffered blanket destruction was, in many cases, designated as a single land-readjustment project unit, without any consideration to the size or scale of the area, nor to the fact that the area covered by each project unit had formerly contained many territorial communities (e.g., neighborhood associations). This kind of approach to the designation of a land-readjustment project was probably due to the desire of the project organizers to secure a large project area, because a larger area offered greater flexibility in the replotting design. Due in part to this approach to designation, examples of a finely tuned community-based consensus-building process have been few and far between.[2]

In addition, since some of the flooded areas had been designated as disaster-hazard areas, meaning that the land could no longer be used for residential purposes, residents of such areas had no choice but to relocate to higher ground (this also made the relocation of pre-disaster territorial communities difficult). In many cases, parts of the original territorial communities were excised to facilitate the move to higher ground. Furthermore, in the cases of urban areas with blanket destruction, the decision on where to relocate was left up to each victim or household affected by the disaster; since systematic mass relocation of an entire neighborhood association was judged difficult due to the large number of relocating residents and the difficulty of securing the lands suitable for large-scale developments.

[2] According to the interview carried out in September 2011 by the author with the municipal officials in the disaster-stricken municipalities in the southern part of Iwate Prefecture, it was learned that: "Rather than carrying out a carefully crafted decision making in regard to planning with professionals, we were faced with the great number of contracting works we have never experienced, and we were overloaded with the work that we needed a few dozen staff just to take care of them." On the other hand, residents expressed their hope to have experts with them to carefully review the situation and their disappointment in the municipality's way of doing things. The issue then was this great gap between the municipal government and the hopes of the residents.

8.2.3 *Creation of New Communities as Actors in Problem Solving*

8.2.3.1 Situation and Issues Noted as of September 2011

As of September 2011, 6 months after the disaster, new communities were sprouting and launching new activities. The following was the situation at the time[3]:

(a) *The birth of various community organizations, such as temporary housing-complex neighborhood associations, temporary shopping streets, machizukuri (town/community development) companies, and community-based nonprofit organizations*:

Around this time, in disaster-stricken areas, neighborhood associations were starting to be established in temporary housing complexes. At the same time, construction of temporary shops funded by the Organization for Small & Medium Enterprises and Regional Innovation was finally getting underway. In areas where shops were being constructed at a rapid pace, a new type of shopkeepers' association (different from those in existence before the disaster) were being formed by shop owners determined to reopen their shops as quickly as possible after the disaster. Furthermore, in areas such as Rikuzentakata City and Otsuchi Town, new organizations, such as nonprofits pursuing community regeneration, *machizukuri* companies born out of existing businesses, and similar bodies, were beginning to be formed.

(b) *Establishment of collaborative mechanisms among NGOs and NPOs at the prefectural level*:

One of the key characteristics of this disaster recovery process is the active role NPOs and NGOs are playing in recovery and reconstruction (in addition to continuous support offered by municipalities outside of disaster-stricken areas). Collaborative Reconstruction Centers—whose roles and issues do need to be discussed here in detail—were established at the prefectural level soon after the disaster. With the support of the relevant prefectural center, NGOs and NPOs working in each prefecture came together to study issues common to disaster-hit municipalities and are now engaging in the necessary activities. In Iwate Prefecture, for example, Tono No Magokoro Net (http://tonomagokoro.net) and other NPOs founded in the wake of the disaster were quick to provide logistic support, such as distributing goods and dispatching volunteers immediately after the disaster; 6 months down the line, they had begun to shift the core focus of their activities to support for community formation.

(c) *Issues noted as of September 2011*:

While neighborhood associations were starting to form at *some* temporary housing facilities, they were not necessarily running smoothly. In order to

[3] Some revision has been done based on Koizumi (2012a, b).

clearly understand the needs and suggestions of disaster victims, it has been essential for residents to communicate and share their interests and problems with each other. However, given that, in some cases, residents were not entrusted with the management and operation of the meeting room at the temporary housing facility or had no acquaintances or friends at the same facility, it was felt that the principal need was to support the *place of meeting w*here people could talk to each other about these matters.

Supplies needed for activities had been lost in the disaster, places that could be used for activities were difficult to find, and know-how and start-up funds were lacking. All of this meant that an array of supports was in fact necessary to bring the ideas of residents to fruition—even when they did demonstrate the willingness to take the initiative—and to enable temporary shops and *machizukuri* companies to undertake the activities, businesses, and services that they wanted to provide.

It was becoming apparent that it was difficult for prefectural-level organizations and logistic-support ones alone to address rapidly changing needs and circumstances on the ground.

8.2.3.2 Situation and Issues Noted as of November 2014

The situation as of November 2014 (3 years after the events) was as follows[4]:

(d) *Current state of the various activity groups based in disaster-hit municipalities*:

Each temporary housing-complex neighborhood association faced different issues: while some were successfully developing independent activities, others were virtually moribund or, in some cases, actually had stopped operating. These differences seemed to arise from various different factors, such as the organizational structure of the neighborhood association, the original hometown of the residents (whether many of them came from the same neighborhood, or were from different areas), and the existence of groups that support community activities. Moreover, although the residents' stay in the temporary housing complexes had been expected to be prolonged, the number of people moving out was gradually rising. As a result, maintenance of neighborhood associations and management of temporary housing were facing new difficulties.

In the meantime, community activity groups and NPOs based in disaster-stricken areas had had their labor costs for various projects paid by the Job Creation Fund Project of the Ministry of Health, Labour and Welfare. As a result, many young people in the disaster-hit areas had been able to take the opportunity to engage actively in community activities and *machizukuri* projects, and in many cases they

[4] Based on the findings at Rikuzentakata City, Kamaishi City, and Otsuchi Town, where the author is involved in the reconstruction process.

had demonstrated some level of achievement. However, the outlook for the project was gloomy (as it was being downscaled), and these organizations were faced with the need to restructure the business models for their operations and projects. On the other hand, a few of the groups from outside the disaster-stricken areas had stopped providing support after 3 years. While many still continue to provide support, some groups might not have been able to continue to do so, after Fiscal Year (FY) 2015, due to difficulties in securing funds.

(e) *Expanded support by prefectures and the national government*:

Since FY2012, community-support funds from prefectures have been augmented by an additional reconstruction quota. The Reconstruction Agency also had started providing assistance in 2013 (New Tohoku Leading Model Project) that targeted not only tangibles but also intangibles. Support for organizational management and activities that demonstrated sensitivity towards the needs of each area and group continued to be necessary.

(f) *Creation of a community-activity support system at the municipal level*:

Some municipalities were taking the lead in creating a system to provide support to various community organizations and activity groups. For example, in Rikuzentakata City, the nonprofit organization Respite House Hands, based in Ichinoseki City, got involved in the development of a temporary shopping street (Osumi Tsudoi-no-Oka Shopping Street), using one of the units there to establish the Rikuzentakata *Machizukuri* Collaboration Center.[5] This body provided the basic services offered by *machizukuri* centers and collaborative activity support centers. These services included advice about *machizukuri* activities, information about grants, PR activities for groups, seminars on the skills and knowledge that community groups needed to improve their skills, and the loan of meeting rooms, etc. They also held six meetings of the Rikuzentakata Citizens' New *Machizukuri* Conference between October 2013 and February 2014, based upon which they compiled a report with proposals covering four themes: *industry* and *tourism*, *medical care* and *welfare*, *local community* and *disaster prevention*, albeit they also included *education and child rearing*. They also operated an information portal called the *Machizukuri* Platform.

In Otsuchi Town, the municipal government and the University of Tokyo concluded a comprehensive agreement on reconstruction assistance on the 19th of March 2012. Under this agreement, the author and others were working with town officials on various community-regeneration projects, including the resumption of the Hometown Creation Partnership Grant,[6] a scheme that the town had operated

[5] See http://rtmachikyodo.jimdo.com (in Japanese; accessed December 2016)

[6] Furusatozukuri Kyoudou Suishin Gigyou Hojyokin, currently named Community Katsudou Suishin Jyoseikin, see the link http://www.town.otsuchi.iwate.jp/gyosei/docs/2014112500042 (Japanese) and https://translate.google.es/translate?hl=en&sl=ja&u=http://www.town.otsuchi.iwate.jp/gyosei/docs/2014112500042/&prev=searchaccessed (English) December 2016.

before the disaster. We helped to revive the town's Reconstruction Council, to establish similar councils in areas outside the disaster-stricken areas, and also to create a mechanism for collaboration between support organizations (NPOs and NGOs) and territorial residents' organizations (establishment of a residents' community council).

Furthermore, we were operating a community-activity grant scheme in partnership with the municipal government as part of the aforementioned New Tohoku Leading Model Project,[7] as an initiative separate from the municipal government's own projects. This grant scheme should be understood and regarded as an attempt to deploy a national-government scheme at the municipal level, using local intermediary organizations (or the like) with a deeper understanding of the needs and challenges faced by each area and groups to allocate and distribute the necessary resources.

(g) *Practicing "temporary machizukuri" aimed at community care*:

A team from two universities, the University of Tokyo (including the author) and Iwate Prefectural University (under the guidance of Professor Kanou), proposed the establishment of a "community-care-based temporary housing facility" in disaster-stricken municipalities in Iwate Prefecture that includes Tono City, which was providing logistic support. Tono City has already built temporary housing based on the proposal, while Kamaishi City took the proposal a step further by integrating it into a "temporary *machizukuri*" initiative with an emphasis on community care, which it is currently undertaking in the Heita Park district.

Moreover, it could be said that the difficulties with temporary housing are related to problems with the housing plan itself, the layout of individual housing units in the complex, the location of the complex and its spatial relationship with other facilities and existing downtown areas, the selection of residents, and the continuity of communities.

To assist in solving the problems, the "community-care-based temporary *machizukuri*" considers to (*i*) create a physical environment for the "community" that has been well thought-out from the perspective of community care; and at the same time (*ii*) set up community organizations and run them *in situm,* whereby (*iii*) they would create a situation in which members of the community care for other members within the community; and to make it possible (*iv*) various mechanisms or systems that respect the ideas and inclinations of the community are developed. In other words, this type of *machizukuri* places an emphasis on fostering both the tangible and intangible aspects of community development and mutual support. Figure 8.1 (left) shows the layout of the temporary community in Heita Park. This

[7] Reconstruction Agency of Japan.
http://www.reconstruction.go.jp/topics/main-cat1/sub-cat1-11/20131003170713.html and http://www.reconstruction.go.jp/english/) Accessed December 2016.

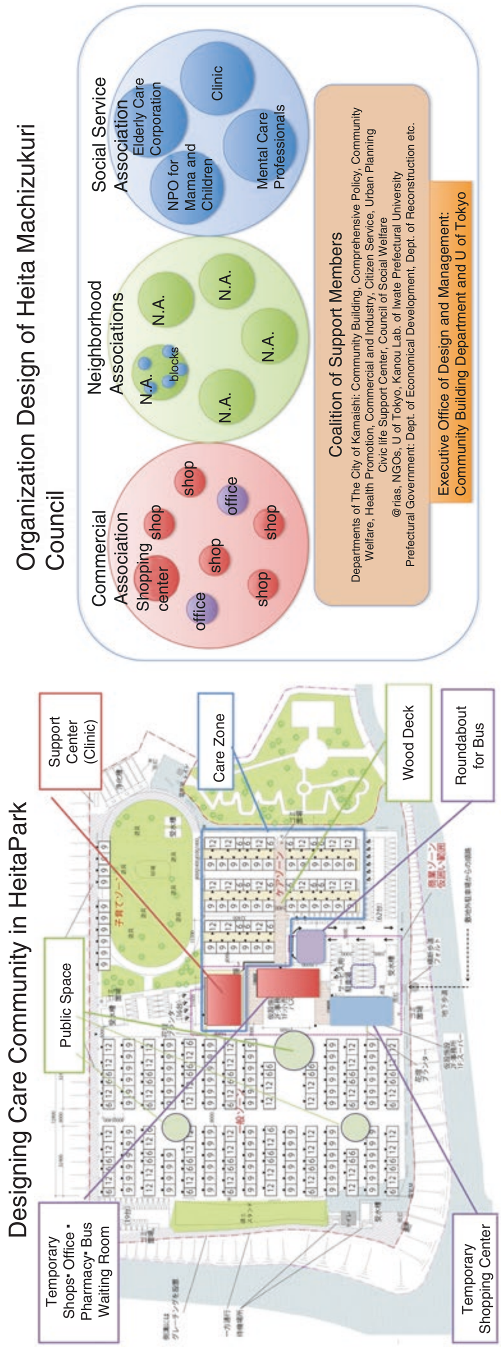

Fig. 8.1 (*Above left*) Layout of the temporary community in Haita Park, and organization of the Heita Machizukuri Council (*above right*)

Fig. 8.2 View of Heita Park Temporary Community in 2012

community is located far from the existing downtown area, and it is intended as an experimental model for relocation to higher ground.

The temporary community has a number of notable features from a spatial planning perspective, including: (a) a wooden deck has been used to create an alley, to nurture interaction among neighbors in the smallest unit of a community; (b) this alley is linked to the support center, which has a day-care service and a clinic, and to the shopping street, creating an environment where the elderly and the disabled can easily go out and be looked after by others; (c) the temporary community contains not only residential units but also medical/welfare centers, shops, and offices; and (d) to maximize these advantages, a Machizukuri Council (Fig. 8.1 (right)) has been established in addition to establishing neighborhood associations, in the hope that community activities will emerge from collaboration among the various actors. Figure 8.2 shows how the shopping street in Heita Park looked.

There is evidence that this design is functioning as expected. As far as (a) is concerned, residents bring chairs to sit on the deck and groups are formed and interact. In the case of (b), a business operator (Japan Care Service, Inc.[8]) has taken the lead in an initiative in which doctors at the clinic and staff at the Daily Life Support Center are working together to care for elderly people living alone. Regarding (d), the neighborhood association was founded in November 2011, while the shopping

[8] Japan Care Service Corporation. http://www.japan-care.com Accessed December 2016

street was established the following month, just before Christmas time. Right at the end of 2011, the Support Center held a traditional event for children with the cooperation of the neighborhood associations and the shopping street. This event was the *Machizukuri* Council's first full-fledged activity. It continues to carry out various activities to date, and a survey conducted to ascertain the psychological state of residents confirmed that activities of this kind by the *Machizukuri* Council are achieving positive results, albeit only to some extent.

This initiative is positioned as a means of creating in a temporary community a residents' organization (territorial community) that embraces residents who come from different neighborhoods. This can also be said to be an attempt to design a model for next-generation communities with an emphasis on care, which can be applied not only to the disaster-stricken areas but also elsewhere in Japan, in places that are or will be faced with a decreasing birthrate and an aging population.

8.3 Toward Community Design for Reconstruction Through Collaborative Partnerships

The lessons learned from this case study on community design could prove to be most helpful in the recovery, restoration, and reconstruction process of future disasters.

8.3.1 Ensuring the Continuity of Community Formation

One of the most important parts of community design and *machizukuri* aimed at the formation of diverse communities is ensuring continuity from the evacuation period through to the period following reconstruction. In particular, temporary housing resettlement and reconstruction projects can fail to sustain existing territorial communities in the transition from the evacuation period to the temporary *machizukuri* period, as well as failing to sustain newly formed territorial communities and communities of interest in the transition from the temporary housing period to the reconstruction period. One could say that the temporary *machizukuri* period is the most important phase for ensuring the continuity of community formation.

Disaster-stricken areas are seeing burgeoning efforts to build systems and structures to support community design during the temporary-housing period. Continuing, improving, and developing these as reconstruction projects get underway in earnest could help to lay the institutional infrastructure required to ensure that community organizations can be more active even in post-reconstruction period. As well as the development of community development centers, *machizukuri* funds, and other mechanisms for supporting reconstruction *machizukuri*, of course, this also includes the creation of new collaborative structures and hubs for industrial development along with enhancing community businesses, and the provision of medical care and welfare services.

Adopting a strategy for maintaining continuity of community formation and regeneration in this way will be vital.

8.3.2 Community Design Based on Collaborative Multi-actor Partnerships

The community design aimed at reconstruction in areas affected by the Great East Japan Earthquake and tsunami examined in this chapter could be described as "community design aimed at reconstruction through collaborative partnerships." Current initiatives aiming at dealing with future disasters, based upon community design, must adopt the mindset of building collaborative partnership structures, whereby encouraging the involvement of diverse actors that would contribute to solving problems in the post-reconstruction period.

Likewise, in urban areas, where Japan is facing a variety of issues associated with the aging population and falling birthrates, the construction of collaborative partnership structures involving diverse actors working together to resolve problems will be essential. In this regard, practices on community design such as the ones presented in this chapter, could also be taken as model in any urban area with ageing of the population and falling birthrates.

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Chapter 9
Healthy Community Resilient Against Disaster

Shinichi Egawa, Aya Murakami, and Hiroyuki Sasaki

Abstract After the Great East Japan Earthquake (GEJE) and Tsunami in 2011, the physical and mental health of the affected people showed completely different characteristics from those of earlier disasters. Despite the lower number of injured people compared to those affected by the Great Hanshin Awaji Earthquake (GHAE) in 1995, the health needs were mainly non-communicable diseases and mental health issues. Those needs far exceeded the damaged state of local health care facilities. The nationwide disaster medical system established after GHAE worked fully for the first time, but further improvements of the response system, such as implementation of a disaster medical and public health coordinator, more efficient emergency medical information systems, and the establishment of specialized health care assistance teams including psychiatry, rehabilitation, reproductive health, public health, and oral care, were found to be necessary after GEJE. Reconstruction of the damaged hospitals should be based on the safe hospital concept and the prioritized parts of community reconstruction during this era of aging and urbanization of populations.

Disaster risk reduction (DRR) is achieved by decreasing hazard exposure and vulnerability while increasing the capacity for adaptation. The Sendai Framework for DRR 2015–2030 adopted by 185 member states at the Third World Conference 2015 in Sendai, emphasizes the effects of disasters on physical and mental health. The Bangkok Principle was adopted to implement its health aspects. Now it is necessary to accumulate scientific evidence clarifying the relation between health and DRR such as the correlation between life expectancy and the disaster risk index. By incorporating health as a central target of DRR, our community can be made sustainable, healthy, and resilient against disasters.

Keywords Disaster medicine • Public health preparedness • Sendai Framework • Capacity building • Life expectancy

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V. Santiago-Fandiño et al. (eds.), *The 2011 Japan Earthquake and Tsunami: Reconstruction and Restoration*, Advances in Natural and Technological Hazards Research 47, DOI 10.1007/978-3-319-58691-5_9

9.1 Introduction

The fact that disasters affect the health of people has been so readily apparent that international frameworks (International Decade for Natural Disaster Reduction (IDNDR) 1995; UN-ISDR 2005) did not sufficiently include the word "health" until the Sendai Framework for Disaster Risk Reduction 2015–2030, which was adopted by 185 member states of the United Nations at the Third World Conference, Sendai, Mar. 14–18, 2015, and which ultimately included 34 instances of the word "health." During this era of globalization, urbanization, and aging society, and along with the increased complexity of society, disaster effects are becoming greater and more complicated. The Sendai Framework emphasizes the broader and more people-centered preventive approach to disaster risk against multiple hazards including biological and technological hazards (UN-ISDR 2015). Health, a state of complete physical, mental, and social wellbeing and fundamental human rights, should be the most important world-wide social goal (WHO 1978).

On March 11, 2011, 14:46 JST, the Great East Japan Earthquake (GEJE) M9.0 struck. Its ensuing tsunami struck eastern Japan shortly thereafter. The total length of the coast line affected by tsunami waves was more than 500 km. Many hospitals located in coastal areas were devastated. Moreover, the radiation released by an accident at the Fukushima Nuclear Power Plant (NPP) caused long-term internal displacement of affected residents. Miyagi Prefecture, the closest prefecture to the epicenter, had been periodically struck by earthquakes every 30–40 years. The last major tremor before GEJE occurred in 1978. Thereafter, homes and other structures were retrofitted with earthquake-resistant, seismic-resistant, and seismically isolated structures. Consequently, building collapse was minimal. The number of injuries was significantly lowered: 6220 compared to 43,792 in Great Hanshin-Awaji Earthquake (GHAE) in 1995 (Table 9.1). Additionally, the Japanese government officially certified GEJE related deaths of 3472 people during the subsequent five years (as of Mar. 2016, Reconstruction Agency Japan 2016).

Table 9.1 Comparison of three recent strong earthquakes in Japan

	M	Injured	Direct deaths and lost	Officially certified related deaths	Displaced
Great Hanshin-Awaji Earthquake 1995	7.3	43,792 (a)	5,502 (b)	910 (a)	320,000 (c)
Great East Japan Earthquake 2011	9.0	6,220 (d)	18,456 (d)	3,472 (e)	470,000 (f)
Kumamoto Earthquake 2016	7.3	2,173 (g)	50 (g)	25 (g)	180,000 (g)

Sources *in Japanese*: (a) Fire and Disaster Management Agency (2016), (b) National Policy Agency of Japan (1995), (c) Hyogo Prefecture (1996), (d) National Police Agency of Japan (2016), (e) Reconstruction Agency of Japan (2016), (f) Reconstruction Agency of Japan (2011) and (g) Fire Department (2016)

Very recently, starting from Apr. 14, 2016, sequential strong earthquakes with M7.3 struck Kumamoto Prefecture in Kyushu Island and killed 50 people, prompting nationwide operation of the disaster medical system again for the first time after GEJE. The Kumamoto Earthquake occurred because of active fault movement after more than 400 years of inactivity. Consequently, people were not aware of the risk of earthquake. Many houses and buildings collapsed, creating 2173 injuries (Table 9.1).

Although the figures related to each earthquake differ considerably, the health sector has accumulated a large amount of knowledge and operational improvement through coping with the response, recovery, and reconstruction phase of respective disasters.

The disaster risk is calculated using the following equation:

$$R = (H) \times (Vx) / C,$$

where R stands for risk, H signifies hazard, Vx denotes vulnerability, and C represents capacity.

The equation shows that the risk is increased by the extent of exposure to the hazard or strength of the hazard and by the vulnerability of the community, but it is decreased by the improvement of the coping capacity. This section presents a specific examination of the preparedness, response, and further improvement of the disaster medical system in Japan and on the rationale of health as the central indicator of resilience of a community against disaster.

9.2 *Building Back Better* from Disasters and the Change of Health Needs in GEJE

Figure 9.1 shows the trend of deaths caused by natural disasters in modern Japan. In the Great Kanto Earthquake of 1923, more than 100,000 people were killed, mainly by fire. Consequently, fire proof structures of buildings were promoted and the date of onset, Sept. 1, became national Disaster Drill Day. Before the Basic Act on Disaster Control Measures (Japanese Government 1961) was enforced, Japan had sustained climate and water-related hazards causing thousands of deaths. The Basic Act contributed considerably to lessen the number of victims in disasters for more than three decades, mainly by controlling water-related hazards such as early warning, land designs including dams, river banks, and sea walls. In 1995, however, 5502 people were killed by the collapse of buildings in GHAE, which prompted the creation of the nation-wide disaster medical system and the establishment of the Japanese Association of Disaster Medicine *(http://square.umin.ac.jp/jadm/)*.

The health needs in GEJE present a different spectrum in diagnoses, with temporal and spatial diversity. The cause of death was mostly drowning by tsunami, but the number of injuries was significantly lower, as shown in Table 9.1, which means

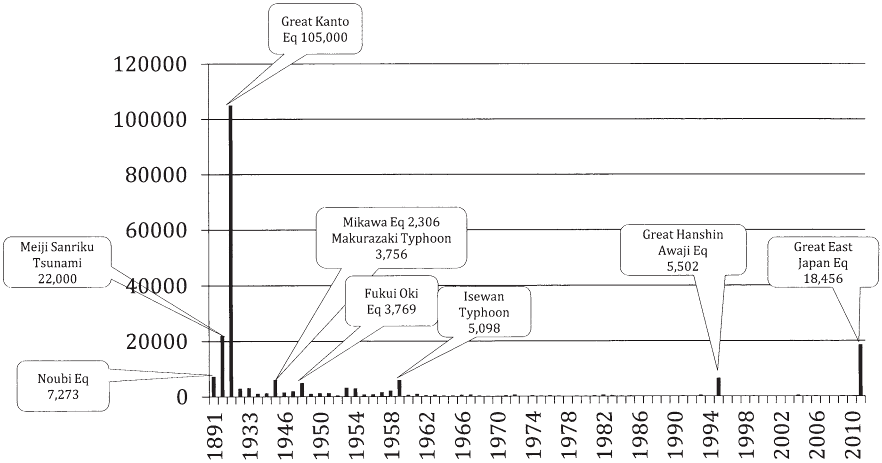

Fig. 9.1 Trend of death toll by natural disasters in Japan. The *bar* indicates the total number of deaths by all disasters in the year. Major disasters are indicated by the annotations (Source: Cabinet Office, Government of Japan (http://www.bousai.go.jp/1info/pdf/saigaipamphlet_je.pdf))

the people who were able to escape from the tsunami also escaped from injuries. People who survived the direct effects of earthquake and tsunami, however, had to face the aftermath as well.

The affected population lacked water, food, and power for heating in the winter weather, lost daily medical goods and health care supplies because of the tsunami in coastal areas and because of the paralysis of logistics in the inland areas. People were left to help themselves in difficult situations of losing their family, friends, pets, homes, and property. All hospital workers and municipal workers had to face the surge of needs and demands although they themselves are also victims of disaster. In coastal areas of Fukushima Prefecture, residents within the 30 km from the NPP were forced to evacuate to distant places with no preparation. The total number of displaced people amounted to 470,000 (Table 9.1). As a result, the designated evacuation centers were full of affected people who lost their homes and personal effects.

The immediate medical and public health needs were related to injuries. Health-related problems arose because of loss of food, water, and power for heating, cooking and communication and loss of fuel for cars. Hospitals and health facilities were damaged severely by the tsunami. Although structurally saved, the functions were greatly impaired because of a lack of lifelines and damage to non-structural components. Within 24 h, the Japan Disaster Medical Assistance Teams (J-DMAT) began to arrive in the affected areas and started to provide medical care and coordination of medical relief activities (Homma 2015).

Because local hospitals were heavily damaged by tsunami waves and the workers in the facilities were also victims of the disaster, external medical relief must incorporate consideration of the transportation of patients to the other hospitals in

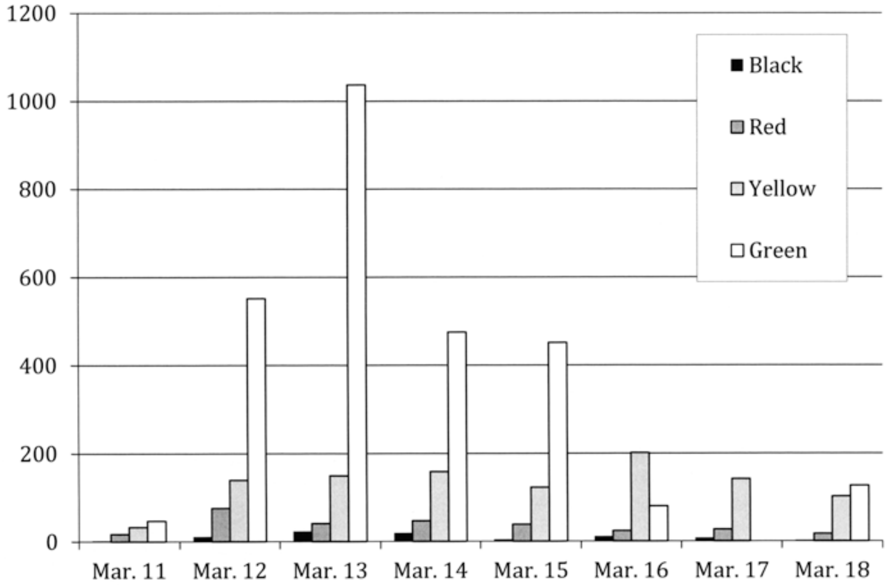

Fig. 9.2 Number of patients who visited Ishinomaki Red Cross Hospital. Triage Level: *Black*; deceased, *Red*; Critical (Data Source: Japan Red Cross Ishinomaki Hospital (*http://www.ishinomaki.jrc.or.jp/hemc/earthquake/patient/*))

adjacent municipalities to decrease the load of the surge. Miyagi Prefecture assigned disaster medical coordinators before GEJE and coordinated medical relief teams in collaboration with dispatched J-DMAT and its headquarters located in Tokyo. Two streams were applicable to medical care. One is medical care in hospitals within and outside of the affected area. The other is medical care in the evacuation centers and homes within the affected area. Inpatients were also transported to networking hospitals to the greatest extent possible to decrease the hospital load.

The Ishinomaki Red Cross Hospital accepted more than 1000 patients at various levels of triage on the second day, as presented in Fig. 9.2. A huge surge in medical need arose, creating an enormous discrepancy between necessary and available medical resources at hospitals in the affected area. Workers at the hospitals were replaced by the voluntary rotation of practitioners from the same professions from Tohoku University Hospital as a human-resource center within the affected area, so that local workers could rest and then better serve local people as proper local health providers.

The background health status of the community should be recognized to respond appropriately. Most of the affected coastal areas were depopulated and aging areas. Many people were taking medications daily for chronic diseases such as hypertension, hyperlipidemia, diabetes, and other non-communicable diseases (NCDs). Many people had been using hemodialysis, home oxygen treatment (HOT) or insulin injection by periodical consultation to the local hospitals. They lost drugs, materials, and care supplies because of the tsunami and evacuation. To cope with the immediate life-threatening lack of hemodialysis capacity in the Kesennuma area, J-DMAT and the network of related physicians coordinated the wide area transportation for the first time since its establishment. First, the patients were transported to Tohoku University Hospital, where they received transit hemodialysis. They were later transported further to hemodialysis facilities in distant areas throughout Japan. Because an oxygen factory was also destroyed by the tsunami, it was necessary to transport oxygen from Niigata Prefecture on the western coast. Patients who had been on HOT visited nearby hospitals to get a new tank of oxygen. Hospitals provided oxygen tanks to the greatest extent possible, but the scarcity of backup tanks and the needs and supply were very unpredictable.

Several days later, different medical needs emerged from people who had lost their daily medications for NCDs. Some of them visited hospitals, but many people were treated by the visiting J-DMATs and other medical assistance teams in the evacuation centers. The local Disaster Base Hospitals (DBHs) served as hubs and coordination centers for each affected area, assisted by J-DMAT. J-DMATs are self-standing and equipped with necessary medications. The most often problem encountered was that people had lost their medical information because of the damage of local health facilities and lack of personal notes about their past and present medical history. The medical relief teams had to treat the patients according to the symptoms and ambiguous memory of the patients. The patients in the psychiatric hospitals were disproportionately ignored during rescue medical relief activities because the administrators of psychiatric hospitals were managed by a different division of the local government from that of the general hospitals. Most psychiatric and general hospitals were not prepared for the disaster and did not know how to receive support from outside sources (Sasaki et al. 2015).

A week or two later, psychosocial problems became apparent because people realized the situation would not improve so quickly and because of the widening recognition of loss of family, friends, pets, homes, and property. Alcohol abuse and insomnia were frequently encountered. Because the nutritional and sanitary condition of the evacuation centers are closely related with the outbreak of infectious disease, greater efforts and attention were devoted to the promotion of nutrition and sanitation. The water supply and the availability of health personnel at evacuation centers strongly affected the frequency of digestive symptoms among affected people (Tokuda et al. 2014). To avoid deep vein thrombosis (DVT), public announcements were issued to caution people against sleeping in cars waiting for fuel and the tips related to moving extremities to avoid DVT. Using an instant bed made of card board boxes significantly reduced the occurrence of DVT compared to sleeping on the floor (Nara et al. 2013).

Pneumonia was the most frequently cited reason for hospital care as an infectious disease after GEJE (Aoyagi et al. 2013), which might be prevented by appropriate air conditioning, exercise, and oral health care. Periodontal disease was also associated with insomnia (Tsuchiya et al. 2015). Existing and newly developed NCDs became the major issues of field clinics. Not only the devastation of the hospitals, but also the devastation of pharmacies created difficult situations for people and the health responders to trace medical records. Blood pressure of the affected people was elevated significantly. The incidence of heart failure and pneumonia showed a prolonged increase for more than 6 weeks (Aoki et al. 2012), suggesting that early appropriate intervention to the NCDs is crucially important.

Months and years later, the physical and psychosocial well-being of the affected people remains compromised. Psychological distress is closely related with the future vision of the affected people. In Shichigahama Town, which was severely inundated by the tsunami, the psychological distress score at one year later was significantly higher among people whose housing plan was not yet decided than that of people who had already settled in the permanent house (Nakaya et al. 2016). The longer the stay in an evacuation center or temporary residence, the greater the mental and physical exhaustion of the affected people progressed. Japanese Government officially certified disaster-related deaths in GEJE for 3472 people (Reconstruct Agency Japan 2016).

According to the earlier focal investigation of 1263 people who are from the severely affected municipalities and the forced evacuation municipalities of NPP accident, most deaths resulted from physical and mental expiration during evacuation or relocation. Half of them died within one month after GEJE. Among them, 30% died in the hospital or welfare centers, 30% died in home, 10% died in evacuation center. There was no gender difference and 90% of them were older than 70 years and 40% of them were with comorbidities. Thirteen suicides were included (Reconstruction Agency Japan 2012). Because it was well known that long-term isolation of old people caused the isolated death in temporary houses after GHAE, earlier intervention to reconstruct the community within the evacuation center and temporary houses was initiated in this phase. Mental health support teams and rehabilitation teams began to assist the physical and psychosocial activities of older people.

The recovery of the damaged local health facilities also took a long time because of the total restructuring of the town. For example, Shizugawa Municipal Hospital in Minami Sanriku Town, which was devastated by the tsunami, was relocated to an elevated area and reopened after 4 years and 9 months (Fig. 9.3). During the reconstruction, the hospital was divided into two separate facilities: an outpatient clinic in Minami Sanriku Town (Apr. 18, 2011–Dec. 13, 2015), and a ward facility using another hospital in a distant town (30 min by car, Jun. 1, 2011–Dec. 13, 2015). Because the hospital was originally a secondary hospital and not so rich in human resources, this functional division made it more difficult to provide sufficient care to affected people. The hospital was supported by the network of the medical society including Tohoku University Hospital, Tohoku Medical Megabank Organization, Jichi Medical University, Yamanashi University, and so on. During the reconstruction, when a patient had critical symptoms, the patient should be transferred to a tertiary hospital, mostly Ishinomaki Red Cross Hospital, which is always overcrowded. Newly built on the higher location, Minami Sanriku Hospital now serves as a secondary hospital and also as a welfare center of the town.

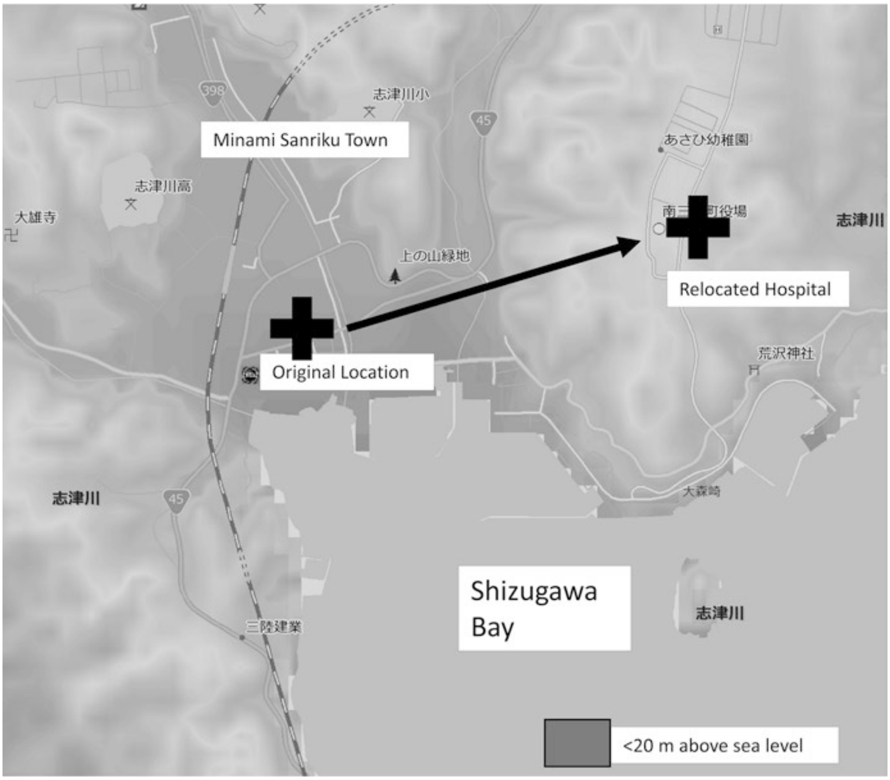

Fig. 9.3 Relocation of Minami Sanriku Hospital (Created by authors using ESRI Arc Map 10.1 (*Esri Inc. and Microsoft Power Point*))

9.3 Japanese System of Disaster Medicine

After the GHAE, the Japanese Government established a nationwide disaster medical system managed by the Ministry of Health, Labour and Welfare starting from 1996, aimed at reducing preventable disaster deaths (Ministry of Health, Labour, Welfare of Japan 1996). This system is represented by the following five structures:

1. *Disaster Base Hospitals (DBH)*

   Structurally and functionally strengthened against disaster with an anti-seismic structure, emergency power supply, water supply, stockpiles, heliport and equipped with intensive care unit (ICU) and/or emergency room (ER). DBH has the capacity to accept multiple casualties. DBH hosts at least one Disaster Medical Assistant Team (J-DMAT) to dispatch for the disaster by command from J-DMAT headquarters. DBH are also presumed to promote the resilience of the health care system in the area in peaceful times.

2. *Japan Disaster Medical Assistance Team (J-DMAT)*

   The J-DMAT system was established in 2005 to rescue affected people in natural disasters and mass casualty events. One J-DMAT includes at least one medical doctor, two nurses, and one logistician. More than 1000 teams are registered throughout Japan. Periodic recertification is required. J-DMAT teams are mainly trained in basic knowledge of disasters and principles of Command, Safety, Communication, Assessment, Triage, Treatment and Transport (CSCATTT) (Samut 2001). A J-DMAT must be self-standing for at least 72 h with a vehicle, fuel, medicines, supplies and foods and drinks for themselves. If continued operations are necessary, another team will take over the medical and public health relief activities.

3. *Wide Area Transportation and Staging Care Unit (SCU)*

   Treating patients in the affected area must typically overcome a lack of resources. To reduce preventable disaster deaths, J-DMAT coordinates transportation from the affected area to the distant DBH. SCU is frequently situated in the airport or transportation hub to classify the emergency level of the patient and to coordinate the transportation.

4. *Emergency Medical Information System (EMIS)*

   EMIS is internet-based geographical information system (GIS) based infrastructure used in exercises and real events to show the location, properties, and function of DBHs, the current position of J-DMAT, healthcare facilities, evacuation centers, and field hospitals in real time. J-DMAT and medical headquarters in municipalities or hospitals can share information and messages through EMIS.

5. *Disaster Medical Coordinators*

   Disaster medical coordinators were first assigned in Hyogo Prefecture in 1996, where GHAE occurred. They coordinate the relief operations and logistics in the municipal headquarters. Coordinators should capture the needs of affected people and the resource of medical relief so that appropriate help could be delivered to the affected area as soon as possible.

9.4 Improvement After GEJE

The Japanese disaster medical system functioned very efficiently at the GEJE as described above and without the system, far worse outcomes could be expected. At the same time, several gaps were recognized as improved.

Because the patients with psychiatry disorder faced with severe lack of relief, the Disaster Psychiatry Assistance Team (DPAT) was established after GEJE under control of Ministry of Health, Labour and Welfare. DPAT also supports the mental health of affected people and the responders. Psychological First Aid (PFA) and mental health care for the children is also promoted by DPAT. Similarly, the lack of human resources in public health emergencies was well recognized in Japan. The Disaster Health Emergency Assistance Team (DHAT) was established by the Japanese Association of Public Health Centre Directors. Rehabilitation of the affected people, especially for the injured and aged population, is critically important to reduce the burden of locomotive syndrome and disability. Japan Rehabilitation Assistance Team (JRAT 2015) was established in 2015.

To protect reproductive health, Basic and Advanced Life Support of Obstetrics (BLSO and ALSO) is promoted by a non-profit organization (OPIC) in Japan. An oral health care team is promoted and implemented by the Japanese Society of Oral Care (JSOC) because it is closely related with the onset of pneumonia and quality of life in older populations (Kishi et al. 2015).

Guiding principles of J-DMAT were revised to fill the gaps of J-DMAT activities in GEJE. The EMIS was updated completely with real-time GIS mapping of hospitals, evacuation centers, field hospitals, and J-DMAT with upgraded processing speed. Medical and public health coordinators were assigned rapidly by more than 80% of the 47 prefectures from four prefectures before GEJE (Egawa 2014). The training seminars of medical coordinators are promoted by the National Institute of Public Health and the NPO call ACT-Institute of Disaster Medicine throughout Japan. Medical and public health coordination was actually implemented at the Kumamoto Earthquake in 2016 for the first time after GEJE.

9.4.1 Sendai Framework for Disaster Risk Reduction and Bangkok Principles

In 2015, the Third World Conference for Disaster Risk Reduction was held in Sendai. The Sendai Framework was adopted (UN-ISDR 2015). The Sendai Framework specifically examines health for the first time as the international framework for DRR. The preceding Hyogo Framework for Action (HFA) included only three instances of the word "health" in a single paragraph describing the reinforcement of existing health facilities, particularly those providing primary health care. During the review process of HFA, health sectors contributed to incorporate the health aspect into the Sendai Framework (Egawa et al. 2014; Aitsi-Selmi et al. 2015).

The NPP accident in GEJE and the outbreak of Ebola virus disease in West Africa also prompted awareness of radiological and biological hazards as a disaster and the Sendai Framework took the all-hazard approach. The year 2015 is a pivotal year for international agreements starting from Sendai Framework and UN Conference on Climate Change (Sep., Paris) and Sustainable Development Goals (Dec. New York). Each framework is closely related to others and multisectoral collaboration and coordination are crucially important for implementation. In March 2016, the Bangkok Principles to implement health aspects of the Sendai Framework were adopted. They include the following seven principles (UN-ISDR and WHO 2016):

1. *Health to DRR, DRR to health*
2. *Cooperation between health and other stakeholders for DRR*
3. *Stimulate people-centered investment in DRR including health*
4. *Integrate DRR into health education and training, health into DRR*
5. *Disaster data and health data into risk assessment*
6. *Advocacy and support by science, information and technology*
7. *National policies and strategies for DRR and health*

The role of health providers is not only to respond during the aftermath of disasters, but also to promote mutual collaboration and coordination for DRR.

9.4.2 Health as a Central Indicator of DRR

In the Sendai Framework, the importance of *Building Back-Better* is emphasized (UN-ISDR 2015). Japan is a hazard prone country, but the people and the government have been coping with disasters, which have made our society resilient to disasters. At the same time, Japan has the longest life expectancy in the world (WHO 2016). The life expectancy at birth (LE) of member states is well correlated with the INFORM disaster risk index (INFORM 2016) as portrayed in Fig. 9.4.

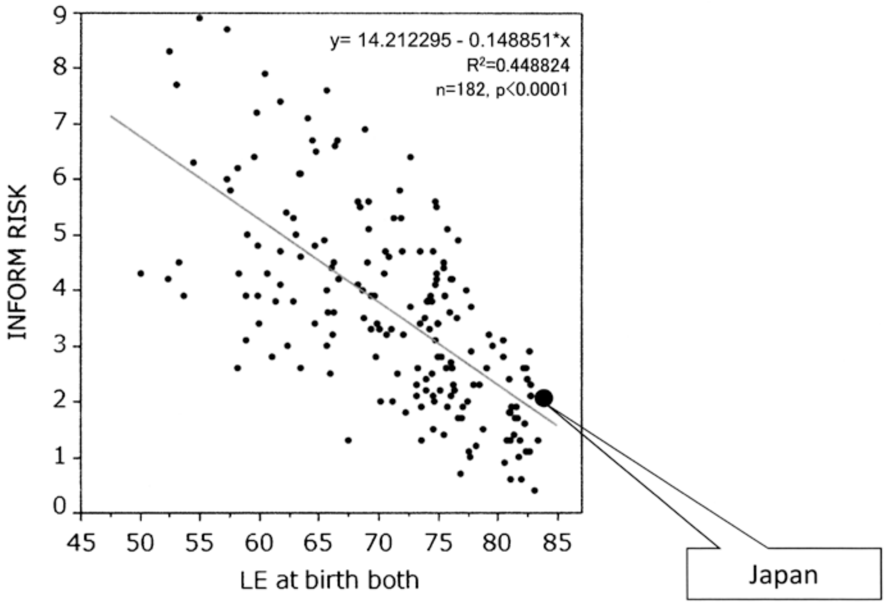

Fig. 9.4 Correlation between life expectancy at birth and INFORM risk index; according to the available 191 member states' data, life expectancy at birth (*X-axis*) was matched with the INFORM risk index (*Y-axis*) using JMP Pro 12.2.0 software (2015 SAS Institute, NC, U. S. A.) (Source: Disaster risk: (INFORM 2016 *http://www.inform-index.org*; Life expectancy *WHO* 2016 *http://www.who.int/gho/mortality_burden_disease/life_tables/en/*))

Among the factors that make up the risk index, LE correlates negatively most with the “lack of coping capacity”. Lack of coping capacity is calculated as a function of Institution of DRR and Governance, Infrastructure of Communication, Physical Infrastructure and Access to Health Care, each component having sub-indices (INFORM 2016). These results suggest that the coping capacity for disaster and the long LE are closely related, and that health promotion to extend life expectancy can produce increased coping capacity. Consequently, health is the central target of disaster risk reduction.

9.5 Conclusion

Disaster damage cannot be expressed simply as the number of deaths. The health damage sustained because of a disaster differs considerably among disasters. Resilience cannot be achieved without achieving health promotion that increases the general public health indicators and finally results in long-life expectancy. The incorporation of health into the DRR and DRR into health will make our community sustainable, healthy, and resilient against disasters.

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Part III
Urban Planning, Housing and Development

Chapter 10
Planning Challenges for Housing and Built Environment Recovery After the Great East Japan Earthquake: Collaborative Planning and Management Go Beyond Government-Driven Redevelopment Projects

Tamiyo Kondo

Abstract The author defines post-disaster as the process of restoring survivors' living and enhancing the sustainability and resilience of the built environment. It thus appear that close attention must be paid to transformation of built environment which is formed by aggregation of human habitation and housing reconstruction. What became visible after 5 years since tsunami is that individual relocation actions and collective resettlement policy lead to "polarization" between mountainside new residential area and lowland tsunami-affected area, the latter still remain checkerboard housing recovery situation even if the area are outside of hazardous zone, in which new residential building is restricted. Increase of unmanaged vacant properties and its scattered distribution destroys their built environment and community, and gives negative influence for people who decided in-situ housing reconstruction. Local government recovery planning in Tohoku is too limited to tsunami risk reduction such as land raising and collective relocation by redevelopment projects, but lacks planning technique in repopulating and regenerating neighborhoods with "spatial and temporal continuity" between pre-disaster and post-disaster. One of the alternative planning method is "collaborative planning and management" that go beyond government-driven redevelopment project which utilizes and coordinating residents' motivation to regenerate housing stock and land use management in their neighborhoods. Planning should not ignore peoples' resilience to improve their built environment and private sector's vitality in pre-disaster recovery planning with a sense of economic rationality which retain continuity between normal and catastrophe.

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V. Santiago-Fandiño et al. (eds.), *The 2011 Japan Earthquake and Tsunami: Reconstruction and Restoration*, Advances in Natural and Technological Hazards Research 47, DOI 10.1007/978-3-319-58691-5_10

Keywords Housing recovery • Transformation of built environment • Polarization • Mountainside residential subdivision • Lowland tsunami-affected area • Collaborative planning and management

10.1 Introduction

The author defines post-disaster as the process of restoring survivors' living, and enhancing the sustainability and resilience of the built environment. It thus appear that close attention must be paid to transformation of built environment following disaster which is formed by aggregation of human habitation and housing reconstruction. It has to pay attention to the spatial gradualness and time axis in order to contribute not only to quick housing reconstruction for survivors, but also to a long-term sustainable community and urban built environment for future generations. The relation between these is not one of trade-off; rather, they have to be considered together because human settlement and the built environment do not exist independently, but are interrelated: human settlement forms the built environment and the latter influences human living (Kondo and Karatani 2016). The relationship between disaster risk, resilience and the built environment suggests that a resilient built environment occur when we "design, develop and manage context sensitive buildings, spaces and places that have the capacity to resist or change in order to reduce hazard vulnerability, and enable society to continue functioning, economically and socially, when subjected to a hazard event (Amaratunga and Haigh 2011)."

Post-disaster recovery planning and projects gives influence for human habitation and built environment, but it is nothing more than one external factors for people-centered recovery. Government sector and academics tend only to look at government-driven planning and projects, such as land use control, public housing estate development and collective relocation project, in order to evaluate the post-disaster recovery planning methods. However, project focused areas are only one part of widespread devastated area by tsunami which is assumed to share one quarter of totally collapse housing concentrated area (Mano 2013). There are variety of areas such as coastal tsunami inundated area outside hazardous zone where government sector does not assert planning nor project. We have to turn our eyes not only to government-driven planning and project itself but transformation of built environment as a result which is shaped by peoples' independent decision-making in order to understand and evaluate recovery process. The understanding the mechanism and process of built environment by peoples' action should be a basis to redesign alternative planning method after mega disaster.

This chapter explains three planning challenges which is becoming clearer after 5 years, and especially focuses on built environment recovery in tsunami affected area without government-driven planning project and land use control. How has built environment in that area transformed in the past half-decade? What kind of internal and external factors trigger gap formation between plan and reality? It explains the planning challenges and necessary steps for all stakeholders to be taken over the next half-decade. The farthest-reaching parts of this chapter is to answer the following question, "How can we prepare for next mega disaster to implement pre-disaster recovery planning by utilizing lesson learnt from the Great East Japan Earthquake?"

10.2 Characteristics of Post-disaster Recovery Planning in Japan and Tohoku

Table 10.1 shows land use plan and implementation planning tools in several cities in Miyagi and Iwate Prefecture. It shows that tsunami affected local governments have quite different recovery policy and implementation tool to realize post-disaster land use plan which is developed in each post-disaster recovery plans. This section explains the characteristics of post-disaster recovery planning in Japan and Tohoku, and indicates the problems caused by these characteristics.

10.2.1 Planning by Redevelopment Project: Unsustainable for Depopulated Region

One of the characteristics of post-disaster recovery planning in Japan is that national government has strong initiatives in planning policy decision related with subsidies for local government. The nation Reconstruction Agency, established a year after tsunami, is responsible for coordinating the recovery budget and reconstruction procedures. The agency supervises 40 selected programs that relate to basic infrastructure rebuilding (Iuchi et al. 2015). These projects are funded 100% by national government so that local government tends to utilize these as much as possible to implement recovery efforts. National government explains in their "Q & A for 40 selected programs" that "national government *are prepared to respond flexible* over program operation and utilization in local", but actually, local governments cannot afford to do so because of compressed time (Schwab 2014) and their lack of planning skills.

The problems are the mega scale of projects that is inappropriate for depopulated region in terms of sustainability and also to ensure early restoration of peoples' living. It is estimated that mountainside residential subdivision construction for collective relocation needs 50–80 million yen per parcel (Tohoku University 2016). The number of parcels to provide are decided by survivors' willingness to participate collective relocation. Is this mountainside residential area attract population in 100 years' time? For example in Rikuzentakata-city, land embankment in city center through land readjustment project requires 5 years to finish by Mar. 2018 and 40 million yen per parcel (Iwate NIPPOU 2014) to level 12 m high the ground. It is uncertain that landowners will construct their housing and commercial building in

Table 10.1 Characteristics of land use planning and implementation tools in municipalities in Miyagi and Iwate Prefecture

Town/city and prefecture	Population and recovery rate (%)	Damage (human, housing and tsunami inundated)	Buffer zone	Major recovery projects to implement land use plan	Characteristics
Ishinomaki-city	160,826 (2010)	Causalities: 13,975(3.3%[b])	1696 ha	Land readjustment project for inland relocation	Inner city restoration and Inland new residential redevelopment
Miyagi Pref.	92%[a] (2016.1)	Housing damage: 20,035 buildings(33%[c])	23.2%[e]		
		Inundated area: 7300 ha (46%[d])		Elevated Road as levee	
				New JR station in new residential area	
Yamamoto-cho	16,704 (2010)	Causalities: 717 (7.8%[b])	1945 ha	Collective relocation (compact three collective relocation sight)	Compact City by Mayor's strong leadership
Miyagi Pref.	75%[a] (2016.1)	Housing damage: 2217 buildings(40%[c])	81%[e]		
		Inundated area: 2400 ha(43%[d])			High percentage of buffer zone per inundated area
				Elevated road as levee	
				JR Railroad relocation	(#1,#2 and #3 levels)
Otsuchi-cho	15,276 (2010)	Causalities: ([b])	154 ha	Land readjustment project for inland relocation and land embankment in city center	Restore city center by 2 m land embankment
Iwate Pref.	77%[a] (2016.1)	Housing damage: 3092 buildings(49%[c])	38%[e]		
		Inundated area: 400 ha(52%[d])			
Rikuzentakata-city	23,300 (2010)	Causalities: 1806(10.6%[b])	69 ha	Land readjustment project for inland relocation and land embankment in city center	Restore city center by 12 m land embankment
Iwate Pref.	86%[a] (2016.1)	Housing damage: 3805 buildings (46%[c])	5.3%[e]		Voluntary property buyout
		Inundated area: 1300 ha (43%[d])			

Source population by *MIAC* Ministry of Internal Affairs and Communications. Census 2010 and 2015, human and housing damage by Fire and Disaster Management Agency of and inundated area by Geospatial Information Authority of Japan (GSI)
[a]Population recovery rate (before/5 years after)
[b]Human loss percentage per all population (2010)
[c]Totally collapse building number per all households
[d]Inundated area percentage per building land,
[e]Buffer zone area per inundated area

the area after long-term construction work. Government-driven redevelopment project has to be minimized its size, cost and time spent for peoples' early living restoration and sustainable built environment recovery.

10.2.2 Planning Without Management: Withdraw from Government-Driven Projects and Increase of Individual Self-Help Housing Reconstruction with Relocation

It has been learned over the last 5 years that what has planned, post-disaster land use plan, is almost impossible to implement. A highly recent symbolic story in Tohoku is that local governments have been struggling to making up the difference of applicant number for government-driven projects and actual housing reconstruction action in project area. In July 2016, Otsuchi-cho, local government in Iwate Prefecture, disclosed information on private housing and commercial building construction decisions in land raising area in city center (Fig. 10.1). The results show that only 25% landowner are waiting to reconstruct their building (Otsuchi-cho 2016). Main reason that forms gap between plan and reality is the different time axis between government sector who pursue long-term recovery vision and survivors who are willing to construct their housing as quick as possible. Withdraw from government-driven projects are common to almost all local governments in Tohoku, and they have begun to take action to improve this situation by changing the rule to accept non-survivors in collective relocation project area and adding financial incentive in land raising area to reconstruct their housing.

It also becomes clear that individual voluntary relocation and housing reconstruction action are increasing in coastal areas of which spatial pattern are inconsistent with government's post-disaster land use plan (Kondo and Karatani 2016). Individual relocation is a visible phenomenon of housing recovery challenges and characteristics after the Great East Japan Earthquake. One of the challenges from standpoint of people-centered recovery is that significant percentage of housing would be controlled by post-disaster urban recovery projects such as land readjustment and raising project and collective relocations which forced people to wait for housing reconstruction. Individual voluntary relocation actions were the results of peoples' decision-making to sustain their living as quickly as possible and to avoid tsunami risk in order to achieve a feeling of security, which is considered socially sustainable and represents people's resilience (Kondo and Karatani 2016). Peoples' resilience demonstrates that it is almost impossible to control peoples' self-sustaining actions and implement what has planned right after disaster. Planning has to be more based on the reality of peoples' decision-making and action for their housing recovery especially where to live that means how to live in the region.

Fig. 10.1 Land readjustment and raising in Otsuchi-cho (Source: Photo by author in May 2016)

10.2.3 No Planning Tools for Built Environment Regeneration in Lowland Area: Polarization Between Mountainside Collective Resettlement and Lowland Tsunami-Affected Area

Individual relocation action and collective resettlement policy lead to “polarization” between mountainside new residential subdivision area and lowland tsunami-affected area, the latter still remain checkerboard housing recovery situation after 5 years even if the area are outside of hazardous zone, in which new residential building is restricted. Contrary to relocations, there are people who choose not to or cannot relocate, because of financial issues, but decided to stay on their pre-existing lots that are in-situ housing reconstruction. New residential building construction is restricted in the hazardous zone, but rehabilitation of existing building is permitted. The border of the hazardous zone divides coastal areas into non-residential buffer zone and non-relocated settlement.

Figure 10.2 shows pictures in coastal areas in Yamamoto-cho where was designated as hazardous zone. The key industry in town is agriculture such as strawberry and apple production, and many strawberry farmers’ housing and greenhouse used to locate along the coast. “Compact city” is the main concept for post-disaster recovery planning. Government sector prepared several planning tools to implement compact city. Firstly, they designated large extent of inundated area as hazardous zone to restrict new residential building, and develop three inland subdivisions

Fig. 10.2 Pre-existed housing without residents and vacant land after 5 years in Yamamoto-cho (Source photo by author in August 2016)

by collective relocation project near new station intended to become as town center. Another tool is housing reconstruction subsidy programs prepared by local government. In general, every local government in Tohoku region prepared housing rebuilding subsidy programs by using national government funding, however, the contents are quite different each other (Kondo 2016a). Yamamoto-cho gives more incentive to people who relocated to government-designated collective relocation area than other, and they give no financial assistance for people who stay in hazardous zone to rehabilitate their housing. This policy is intended to function as a tool to promote people to follow government plan. Hazardous zone(level 1) restrict "new" housing construction, but they can rehabilitate or reconstruct their housing and new construction is allowed in level 2 and 3 hazardous zone by following the rule to elevate lot or building foundation 50–150 cm high. This building restriction might be given influence for people to avoid in-situ reconstruction because of financial burden to elevate the land. However, it is uncertain that why people decided to leave or stay.

Figure 10.2 also shows that there are many owner-occupied rehabilitated housing surrounded by many unmanaged vacant buildings and lots. When the author visited the area in August 2016, a public broadcast raising an alert for children to go home before it becomes dark by outside speaker was aired, also the sound of dogs yapping for long-absent visitors was occurring. At the same time, the author saw the sign on the community center's external wall run by a church with a message in Japanese from the Bible saying "People will start inhabiting in desolated towns".

The problem is the marginalization of outside post-disaster redevelopment project area in which local government has no intervention to care about people and regenerate their deterioration built environment where people decided in-situ reconstruction or rehabilitation. In contrast to new mountainside residential area developed by collective relocation projects, majority of tsunami inundated area doesn't have a planning methods to regenerate their built environment. What local governments only prepared is housing rebuilding subsidies for individual who reconstruct or rehabilitate their housing. That is individual-based support and lacks neighborhood scale perspective. There is Aosu Inari shrine in the hazardous zone constructed in ninth century which implies that human habitation has began more than 1200 years ago in town. Is it truly right decision to abandon this settlement solely because of tsunami risk reduction?

10.3 Built Environment Recovery Without Planning: Case Study of Ishinomaki City

As mentioned in introduction, three quarters of totally collapse housing damage area does not have government-driven redevelopment project. This section explains the transformation of built environment in Ishinomaki-city as a case study of 2 m high tsunami-inundated area without government-driven redevelopment projects. How has built environment in that area transformed in the past half-decade and how has people respond in order to regenerate their environment?

10.3.1 Increase of Unmanaged Vacant Lots and Housing Without People

Ishinomaki is the second largest city and commercial area after Sendai-city in Miyagi prefecture. Its major industry is fishery, paper and dock industry. Before tsunami hits, downtown shopping street in city center began to decline, and inland area has been developed by mega shopping mall, mass merchant, car dealer and bank of which trend spur after disaster. Local government policy for recovery is to develop inland large residential area, and also revitalize downtown.

Figure 10.3 shows the government-driven collective relocation project and inland post-tsunami new constructed building that includes individual self-help housing reconstruction with relocation. It indicates that post-tsunami new building has constructed by being inserted into re-existed settlement and aggregation of individual relocation and recovery project transformed inland area as major center of the city with many population. It also indicates that many buildings existed before tsunami (2010) have not reconstructed yet that remain as vacant lot. Several elements which forms the mechanism of built environment deterioration includes such as depopulation

Fig. 10.3 Collective relocation and post-tsunami new constructed building in Ishinomaki-city (Authors revised figure from Kondo and Karatani 2016)

due to high mortality rate, extent of housing damage, peoples' different level of acceptable disaster risk and financial resources, neighborhood property market value, existence of neighborhood-based recovery actions etc. It is true that individual relocation triggers to form "sponge built environment" (Aiba 2015) which has vacant lot and blighted properties in Non-hazardous inundated area. Demography of disaster in Tohoku is unique in the sense that many people leave devastated area which is similar to every disaster-hit area, however at the same time, there are plenty of peoples' relocation within devastated city most of which are resettlement inland in order to avoid tsunami risk. This makes lower-lying area more difficult to repopulate and regenerate their neighborhoods.

Figure 10.4 shows the 24% pre-existed building before tsunami (87 out of 361) became vacant lots 5 years after tsunami in tsunami-affected Ookaido district, Ishinomaki city where has not been designated as buffer zone. Ubaura (2016) explains that "these area have been determined to be safe for construction due to seawalls or so-called secondary embankment" along with buffer zone indicated in Fig. 10.3.

Figure 10.5 shows the vacant land without management and with use by neighbors. Approximately 90% out of all vacant lots are overgrown with weeds. Vacant and unmanaged lot with grown green and damaged housing without maintenance gives negative influence for neighborhood landscape. When the author interviewed residents in August 2015 to hear the story of her living in this area, she says that

Fig. 10.4 Pre-existed housing (2010) became vacant lot (2016) in Ookaido-district, Ishinomaki. Diagram and field survey data by author in August 2016

"I am happy with finishing my housing renovation, but I feel myself as an inaccessible corner of land." This implies that housing without people and vacant lot without management given negative influence for people who decided in-situ housing reconstruction. However, taking a look at the positive side of land use, 10% are used by neighbors as agriculture field. A senior men in his seventies explains in the authors' field survey in August 2016 that he talked on the phone with residents next door to allow him to use the lot as growing vegetables. There are several lots that are in use as same situation.

10.3.2 New Housing Construction by New Residents Through Infill Development

Figure 10.6 shows the housing construction by new residents in pre-existed housing in the district which is called as infill development. The authors identified this by comparing the "Residential Map" published before and after tsunami which features the names of each building and residence including the name of household head. It means that resident A used to live in the lot, but has not reconstructed housing A after tsunami. However, resident B bought the lot from resident A and construct their new housing B. Based on the interview in the district, this case includes that resident A

Fig. 10.5 Vacant land without management and with use by neighbors in Ookaido-district. Diagram and field survey data by author in August 2016.

decided to relocate outside city or inland area in the city or enter public housing estate developed by government. On the other hand, resident B relocated from more severe tsunami hit area in the city in order to decrease the risk of tsunami. Eight percent out of all pre-existed building in 2010 absorb new residents, that implies that this district has high demand as residential area even after tsunami experience.

Figure 10.7 with photos shows the transformation of built environment 5 years after tsunami in the district. It shows that repopulation rate is still 76% in checkerboard community, however, there are many positive human habitation action such as new residents moving in the district and vacant land management with positive use by neighbors all. It is notable that approximately 500 housing units are provided within and near this district as public housing estate by local government (Fig. 10.3). The important point is not number of housing units in citywide, but where to be provided. City of Ishinomaki has started to assist to promote community formation and activities in the district including pre-existed residents, new residents by private housing construction and people who entered public housing estate. This is quite new post-disaster recovery assistance program prepared by local government in Tohoku region. It is unknown at this point that how has this public housing provision and government assistance gives positive influence to regenerate the district, however, it is expected that new community formation and stakeholders involvement in built environment regeneration activities such as using vacant lot as park and playground for kids as a tentative land use will improve built environment quality which leads to recovery of real estate value.

Fig. 10.6 Housing construction by new residents in pre-existed housing (2010) lot in Ookaido-district, Ishinomaki. Diagram and field survey data by author in August 2016

Fig. 10.7 Transformation of built environment in Ookaido-district, Ishinomaki. Photo and field survey data by author in August 2016

One of the potential of this district is that it is located near from major road stretch west to east running along with many social facilities, such as grocery, retail store, hospital and school, and JR station. The district experienced tsunami inundation, however, convenience value attracts new residents. This phenomenon has been seen in eastern part of Kobe after the Great Hanshin-Awaji Earthquake (1995) where is attractive residential area within commuting distance of mega city, Osaka. What is quite different from Kobe and Tohoku is that in-situ housing reconstruction was standard in Kobe, but tsunami experience requires people to relocate in Tohoku. Neighborhood-scale built environment recovery has been accomplished in Kobe when new housing reconstruction and new residents' construction have been finished, but population decline cannot be stopped because of peoples' relocation actions, and this make it hard for Tohoku region to accomplish low-lying area recovery.

There is one example of planning program to repopulate neighborhoods in city of New Orleans after Hurricane Katrina which are implemented through property buyout and transfer by establishing land trust. It is proved by authors' analysis that these programs are effective methods for neighborhood-scale regeneration which is achieved by encouraging multiple stakeholders to construct housing and manage properties, not adhering to housing "re"construction by pre-disaster homeowners (Kondo 2016b). As an example, "Lot next door program" gives opportunity for residents to buy lot next door, and this promotes residents to enlarge their lot which motivate them to manage their lot in order to improve their living condition. The aggregations of these actions expand in district which regenerate neighborhood-scale built environment regeneration. The limitation is that locations of sold properties have a strong correlation with neighborhood attributions such as income, race and property value which implies that government's programs function well only where has strong real estate market. Masterson et al. (2014) provides "nonstructural hazard mitigation and adaptation strategies and policies", one of which are property acquisition programs and public-private sector initiatives that includes land trusts. Recently, Japanese society raise shared awareness to disconnect property ownership between property use in order to tackle with increased of unmanaged housing and lot in depopulation. Property right transfer through land trust operate by government sector or public entities might be useful management tools for normal and post-disaster built environment regeneration.

10.4 Planning Challenge for Ongoing Recovery and Pre-disaster Recovery for the Next

Local government recovery planning in Tohoku is too limited to tsunami risk reduction such as land raising and collective relocation by redevelopment projects, but lacks planning technique in repopulating and regenerating neighborhoods with "spatial and temporal continuity" between pre-disaster and post-disaster. What is the necessary steps to be taken over the next half-decade in Tohoku region? Local governments have to get bird-eye view to see city-wide built environment transformation with understanding the gap between land use plan and actual situation. Plan is necessary to share vision for recovery, however, it is not objective itself. If there is any contradiction between what has planned and what has happened, they has to restart their planning by accepting actual built environment transformation as given condition. Especially, they also should give their full attention to area without government planning control. It doesn't mean that government has to conduct redevelopment project in the area, but support community-based management and governance by neighbors who are struggling to regenerate their built environment. One of the alternative planning method is "collaborative planning and management" that go beyond government-driven redevelopment project which utilizes and coordinating residents' motivation to regenerate housing stock and land use management in their neighborhoods. Planning should not ignore peoples' resilience to improve their built environment. Planning functions, such as management, coordination, and encouragement, are necessary to regenerate built environment by utilizing property owners' neighborhood land use management motivated by each residents' willingness to upgrade and improve their own living condition.

How can we prepare for next mega disaster to implement pre-disaster recovery planning by utilizing lesson learnt from the Great East Japan Earthquake? It is necessary for local government to promote resettlement to mountainside area to decrease the exposure by next tsunami in the area where is expected to experience high tsunami within a few seconds. This is called pre-disaster recovery planning of which importance is pointed out in various publications (Schwab 2014; Smith and Wenger 2006 etc.), but author emphasize here is not only the phase but also stakeholder collaboration for recovery. Actually, pre-disaster relocation of public facilities are promoted by national government subsidies after Tohoku tsunami, but funding for housing resettlement are not in the case. Government sector does not want to provide funding for housing construction just because it is private properties. It is in apparent conflict with post-disaster recovery policy to emphasize collective relocation by using large amount of government expenditure. Pre-disaster mitigation tools for private assets are rare in Japan even if we experience unexpected size of tsunami in 2011. One strategy is to form private-public partnership and mobilize private sector's vitality with a sense of economic rationality, which ensures social and physical sustainability following disaster. There is one ongoing practice by private sector along the pacific coast region vulnerable for tsunami that develops new residential areas or cottage as secondary house in mountainside area. The sector determines the high demands of people resettlement before next ones, and it is true that individual relocation has been increasing since 2011. Mountainside area has a nice view towards the ocean attracting people to consider having second homes for multi- habitation. These projects are not effective not only for disaster reduction but to increase residential population in depopulated society in Japan. Pre-disaster recovery planning has to retain continuity between normal and catastrophe which requires post-disaster studies to be continued with long term perspective.

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Chapter 11
Housing and Reconstruction over the Five Years After the 2011 Japan Earthquake and Tsunami

Yoshimitsu Shiozaki

Abstract In this chapter, we would like to discuss the current situation 5 years after the GEJE, mainly from the viewpoint of housing reconstruction. There are 160,000 people who were evacuated from their hometowns still without having their own houses, and 50,000 people living in prefabricated or wooden temporary housing. Three types of temporary housing were provided, namely, prefab housing, wooden housing and rental-apartment housing. The prefab temporary housing had many problems in terms of quality of life and cost. The wooden temporary housing was a new innovation and had good quality and low cost; additionally, their construction in each damaged area with local materials and local workers was helpful to the local economy. The victims welcomed the temporary rental apartments and housing, but the system had a few problems related to the process of assignment. There are two ways to get permanent housing after temporary housing, one is through the reconstruction of public housing and the other is self-reconstruction. The public-housing completion rate is 60% of the suggested plan. While the public housing system is very important for low-income victims, we should not totally rely on the system because it has some demerits. The self-reconstruction way is natural for the local victims to follow. The support system should be strengthened so that it takes assumes a larger part of housing reconstruction. In the Tohoku area, housing reconstruction is linked to reconstruction *machidukuri project*, which involves a very complicated process and takes very much time. Japan is now facing not only reconstruction from the GEJE but also preparation for the next huge disaster in the near future, therefore it is crucial to make every kind of preparation by learning from past experiences. One of the important points to be considered is to set up a permanent special organization to learn the entire lesson and to improve the system for the reduction of disaster damage overall.

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V. Santiago-Fandiño et al. (eds.), *The 2011 Japan Earthquake and Tsunami: Reconstruction and Restoration*, Advances in Natural and Technological Hazards Research 47, DOI 10.1007/978-3-319-58691-5_11

Keywords The Great East Japan Earthquake (GEJE) • Housing reconstruction • Temporary housing • Reconstruction public housing • Relocation project

11.1 Introduction

On 11 March 2011, the Great East Japan Earthquake (GEJE) struck and inflicted huge damage to a wide area of east Japan, including Iwate, Miyagi and Fukushima Prefectures, by not only seismic vibration but also tsunami inundation and nuclear contamination. The direct human damage caused by this disaster was 15,894 deaths, 2561 missing and 6152 injured; subsequently, 3472 people died after the earthquake in the three prefectures from related indirect causes, who are authorized to be considered as official victims as of March 2016 (Reconstruction Agency 2016). Additionally, 190 people in temporary housing and 19 people in public housing died alone (Asahi Shimbum 2016a), and 162 people died by suicide in the three prefectures (MHLW 2016).

This chapter discusses the current situation 5 years after the GEJE, mainly from the viewpoint of housing reconstruction.

11.2 Outline of Reconstruction

There are 160,000 people who were evacuated from their hometowns and are still without their own permanent housing, and 50,000 people living in prefabricated or wooden temporary housing. Out of the 160,000 people, 93,000 are from Fukushima Prefecture, and 43,000 people have moved out of their own prefecture as of May 2016 (Reconstruction Agency 2016).

Although most survivors still stay in temporary housing, they are moving to permanent housing currently. But the transition from temporary housing to permanent housing is not easy. The people in temporary housing have already spent these 5 years there, but some others, like in Ootsuchi Town in Iwate Prefecture, are expected to have to remain there for 5 more years (Iwate Nippo 2016). Also in Iwate and Miyagi Prefecture, it is said that 2700 households have no idea about their next housing after moving out from temporary housing (Asahi Shimbun 2016b).

The situation in the area contaminated by the nuclear accident is even more severe. The government announced that the evacuation order should be lifted by March 2017 in the currents zone, including preparation for the elimination of the evacuation-order zone and the restricted-residence area zone. However, in Naraha Town where the evacuation order was lifted in September 2015, only 6% of displaced people returned to their home town, because there is no infrastructure for daily life like a medical-care center, school, shopping center and so on.

11.3 Housing Reconstruction

The conventional program of housing reconstruction has three stages, consisting of evacuation, temporary housing and permanent housing. Evacuation facilities are usually set up at schools, community centers or training centers, etc. Right after the GEJE, up to 470,000 people stayed in those facilities. Almost all the evacuation facilities in Iwate and Miyagi Prefectures were closed by December 2011, however the evacuation centers where victims of the nuclear accident disaster were housed operated until December 2013. One hundred sixty thousand people who moved out of evacuation facilities are actually still considered to be under evacuation status without their own home.

11.3.1 Temporary Housing

One of positive characteristics of the reconstruction process after GEJE that is different from past disasters is that three types of temporary housing were provided, namely prefab housing, wooden housing and rental apartment houses. The last one is generally called designated-temporary housing (*minashi-kasetu*), because they are not temporary but permanent apartments, and the government rents them from owners to provide to victims. A large number of publications already exist on designated-temporary housing, for example, that of Matsukawa et al. (2015) in Natori city where a few Minashi kasetsu dwellings in this city were designed for four persons examined in a workshop on data-analysis research.

The number of newly constructed temporary housing units including prefab and wooden housing was 53,169 units and 113,956 people were living there at the peak time; now 49,026 people live in 24,031 units as of June 2016. Designated temporary housing provided up to 68,177 units where 162,056 people lived, and now 44,695 people live in 19,968 units (in Iwate, Miyagi and Fukushima Prefectures sites).

By Japanese law, temporary housing is a facility provided by the government that should start to be constructed within 2 weeks after a disaster, with up to 29.7 m^2 of floor space per unit for the cost of 2.3 million yen. Temporary housing should be used for 2 years or less, but the limitation on use can be extended in case of a severe disaster. In the GEJE, they have been used for 5 years already, and many parts of temporary houses have incurred damage, causing some victims to suffer from mold or rain leaks.

11.3.2 Prefab Temporary Housing

Prefab temporary housing was constructed from April to October in 2011. They had many problems.

First, the quality of life was very poor. Because temporary housing with prefab structures is not designed to meet peoples' normal living standards, the roof, wall, floor and all other building elements have low quality. In particular, their building specifications did not fit the cold region. So they needed many kinds of additional work, for instance, heat insulation, double glass windows, high-quality bath systems and so on, requiring additional cost.

Secondly, the floor space of each unit was too small. Before the earthquake, people in the Tohoku region generally lived as big families in large houses with over 100 m^2 of floor space. After the disaster, many family survivors were obliged to live apart.

Thirdly, the location of temporary housing brought many problems. At first, temporary housing was built in areas far from victims' original hometowns and without ancillary living facilities, and people entered temporary housing through a lottery system. So the victims who lived there without community suffered from many problems. In fact, those kinds of problems are well known as lessons from the Hanshin-Awaji Earthquake in Kobe in 1995 in Japan. At that time, all temporary housing was built as prefab structures in areas far from victims' original hometowns, and people who lived there, assigned through a lottery system, were separated from their former communities. As many victims lived isolated from their communities, after all, more than a few people died solitary deaths in their rooms. The number of these solitary deaths in temporary housing from 1995 to 1999 was 233 (Shiozaki 2014).

Fourthly, in spite of those problems, the cost of the prefab temporary housing was relatively high. It is estimated that the cost per unit was around 7 million JPY.

11.3.3 Wooden Temporary Housing

The wooden temporary housing started in Sumita Town in Iwate prefecture, which is small town in the mountains in Iwate Prefecture. The town had suffered no damage by the tsunami but had to receive evacuees from coastal cities. So the town decided to construct wooden temporary housing quickly, because they already had experience creating many kinds of wooden goods with their own resources in the mountains. Fortunately, the town office had in hand the design for wooden temporary housing one week before disaster. So they constructed 93 units for victims from neighboring cities.

The wooden temporary housing in Sumita Town is detached housing with 29.8 m^2 of floor space, high-quality heat insulation and sound protection (Fig. 11.1). It was very comfortable and constructed at the low cost of 3.4-million JPY. Also, wooden temporary housing contributed to the local economy by using local materials and labor.

Another experience of wooden temporary housing in GEJE is in Fukushima Prefecture. The prefectural government provided 6700 wooden temporary housing units in total for evacuees primarily from the nuclear contaminated areas.

Fig. 11.1 Wooden temporary housing in Sumita Town

The provision system of temporary housing in Japan is based on agreements between each prefectural government and the prefab-building association that was set up after the Hanshin-Awaji Earthquake. So, when a major disaster happens, prefab-temporary housing is provided almost automatically. But this time, the supply system was not enough to meet local needs, so Fukushima Prefectural government searched for another way by asking local builders to provide temporary housing.

11.3.4 Minashi-Kasetsu

This is quite different from other temporary housing, because the house building is not temporary but permanent. The victims can find some privately rented apartment houses that they think acceptable anywhere, and apply to the prefectural government for temporary housing allocation to pay the rent from national funds. The system fits victims' needs because they can avoid low-quality house and the lottery system. So the number of *minashi-kasetsu* was bigger than that of other kinds of temporary housing. In addition, it can be considered as a reasonable program because Japan has a 14% housing-vacancy rate nationally.

However, there are some problems in this system. First, many victims went to urban areas from their damaged hometowns, because many privately rented apartments are located in the metropolitan area of Sendai city, Miyagi's prefecture capital. So the population in the affected small towns and villages has decreased.

Secondly, it is difficult for NPOs and some voluntary organizations to access victims to provide some support because they cannot know victims' living location because the privacy of this information is protected by law.

Thirdly, some prefectural governments have not employed this system, because they want to recommend the use of empty public housing units to victims and not to rent them private apartments. As the system consists of agreements between the prefectural government, private owners and victims, if the prefectural government does not implement this system, victims cannot get temporary housing as they choose.

The next problem is when the rent provision comes to an end. Eighty percent of residents in *Minashi-kasetsu* want to live there from now on, although they will not be able pay the private rents by themselves (Fumitake MENO 2013). The government says that the termination date for providing the rent money will be March 2017.

As gleaned from lessons of the Hanshin-Awaji Earthquake, many kinds of activities to support victims were set up in the temporary housing after the GEJE beginning from the early stage of disaster recovery by local governments and NPOs. A large number of volunteers including students from all over Japan came to the damaged area to assist and manage meetings, festivals and community events to encourage community continuity. Some temporary housing were designed by university groups to maintain good community, and some were customized for better quality of life.

11.3.5 Public Reconstruction Housing

There are two ways for victims to get permanent housing after temporary housing. One is public reconstruction housing and the other one is self-reconstruction. Public reconstruction housing is a very important system for low-income people who have lost their homes. Public reconstruction housing is constructed by local governments and financed by the central government. The floor space is 40–70 m^2 and the rent is relatively cheap, depending on tenants' income level and each housing unit's condition. Allocation of public reconstruction housing is generally operated by a lottery system.

Provision of 30,000 units of public reconstruction housing is planned in areas damaged by the GEJE. The number completed as of May 2016 is 18,040 units (Reconstruction Agency 2016). It is said that the construction speed is very slow compared to that of the Hanshin-Awaji case, where the construction was accomplished within 5 years. It is said that the reasons for construction delay include difficulties in acquisition of land, shortage of construction workers, and cost inflation of materials and workers' wages, within the context of many public works in the Tokyo area related to the next Olympic Games in 2020.

As many victims live in uncomfortable temporary housing, it is very important to provide public reconstruction housing as soon as possible, but we also have to pay attention to some other points besides construction speed. The most important point is to provide the victims a good environment where they can enjoy their lives safely and comfortably. Those environments cannot be realized only by building houses. We also need many other good conditions, including community with neighbors and friends.

In the Hanshin-Awaji Earthquake case, 897 people died alone without community in public reconstruction housing by the end of 2015 (Shiozaki 2014). So we have to effect good planning and design to construct public housing based on what has been learned. The construction-speed pressure often generates monotonous gigantic housing blocks, which lack good quality-of-life housing.

Also public housing has fundamental limitations in many respects. The floor space, layout and facilities are limited, and each unit usually lacks a garden. Inhabitants cannot customize their houses. So public housing does not necessarily fit every kind of inhabitant. Particularly in the Tohoku area, most victims had been living previously in big houses with big families and with gardens.

From another viewpoint, it should be understood that not a few public reconstruction housing may become vacant in the future. In those areas, newcomers cannot be expected because young people move out of small towns currently. Even after vacancy, local governments have to maintain public housing with their own expenditures and manpower. The Japanese central government provides the initial costs to build public housing, which is almost 20 million JPY per unit (MLT 2014), but does not pay the maintenance cost. The maintenance cost of vacant units will be a heavy burden for local governments.

After all, we might say that, while public reconstruction housing is a very important option for low-income victims, it is a risky approach to depend heavily on this system.

11.3.6 Self-Reconstruction

It is quite natural for the victims who lost their homes to want to live in their own home as they did before. If we understand the advantages and disadvantages of the public housing system, we can say the main program to get permanent housing should be self-reconstruction. It is quite friendly to every kind of victim.

Moreover, this reconstruction mode has strong advantages in terms of cost. The governmental cost can be calculated as 24.39 million JPY per household in the case that victims live in public temporary housing and public reconstruction housing. But in the case that they live in public temporary housing and build their house by themselves with support money, the cost will be 7.43 million JPY per household (Kamei 2014). The self-build mode is much less expensive than the use of public housing, by a margin of 16.96 million JPY per household.

Although the self-build way is better than the public housing way for both victims and local governments, it does not work well without support money for victims.

The support system for self-reconstruction is operated under the Act on Support for Reconstructing Livelihoods of Disaster Victims. By this act, up to 3 million JPY is provided to households whose houses were completely destroyed and who are going to rebuild their own house.

Originally this act was set up in 1998 after the Hanshin-Awaji earthquake by the efforts of the victims. At that time, support money was only 1 million JPY per household in the maximum case. After two amendments of the act, the support money is now 3 million JPY per household. Nevertheless, it is not enough for victims to build a permanent house.

Additionally, this system has some other problems because the act does not apply in cases of half or partially damaged houses and nuclear contaminated houses. So this system should be improved soon in terms of the amount of support money and the applicable conditions. So far, the total amount of money delivered to victims in the three most damaged prefectures in the Tohoku region is 322 billion JPY, as of May 2016 (Cabinet Office 2016).

As the national system of support money is not enough to meet victims' needs, some prefectural governments have taken special measures to supply additional money to the victims of past disasters. In the Noto Peninsula earthquake in 2007, victims could receive up to 7.7 million JPY, with additional money from the Ishikawa Prefecture government. Consequently, the number of people who wanted to enter public housing decreased from 78 to 49 in Wajima City in that prefecture (Takeda 2014). In the Tohoku region, Iwate Prefecture made a unique program by which victims can receive up to 10.1 million JPY with national and prefectural money. These efforts can be considered as good practice for victims in the prefecture, but the victims in other prefectures, who are suffering from the same degree of disaster, cannot receive the benefits. So the system should be improved nationwide.

11.4 Reconstruction Machidukuri Projects

In the GEJE-damaged area, the issue of housing reconstruction is complicatedly linked to reconstruction *machidukuri* issues because the land was damaged by tsunami and/or nuclear contamination. The victims cannot necessarily reconstruct their house on the same land. Here, the term *machidukuri* means urban planning or some area-based reconstruction projects. Furthermore, in the tsunami-damaged area, after the earthquake a new law was set up called the Tsunami Disaster Reduction Neighborhood Act. By this law, each prefectural government should create a tsunami-simulation survey and share the output with municipal governments in the prefectural territory. The municipal government should decide the land-use plan based on the simulation. Also the prefectural government decides the height of tsunami-protection levees along the seashore. Municipal governments have to make a tsunami-protection plan behind the levee and also a land-use plan. Sometimes they elevate highway roads or railways to protect against tsunamis. The tsunami

Fig. 11.2 Relocation to highland by *machidukuri project,* in Ofunato city; Iwate prefecture

simulation shows that some specific areas will be inundated by the next tsunami in spite of those protections; therefore, these areas cannot be used for residential space and, hence, it is recommend that people move to safer land. In these cases, municipal governments usually use the residential relocation for disaster-reduction relocation programs, in which municipal governments purchase land in the vulnerable or high-risk areas from each household and prepare new safer housing lots on higher land or in an inland area. People then have the option to buy or rent the land (Fig. 11.2). Those projects' budget comes from the central government; once the people move, the land will be used for commercial or business purposes, sometimes through the land-readjustment projects.

That describes a typical *machidukuri project* in the tsunami-damaged area, but, as it is a very complicated scheme to understand, it is quite difficult for victims to decide which option is better for them to choose. So these projects are not progressing smoothly. The total number of planned housing lots by *machidukuri projects* in three prefectures is 19,385, and the number of lots completed is 8379 (43%, as of March 2016, Reconstruction Agency).

First of all, there are many controversial opinions for the estimation of the next tsunami, based on simulations in each area. The tsunami risk in each area depends on not only the magnitude of the earthquake but also the height of the levee. Huge levees for tsunami protection can also have negative consequences on natural resources, the townscape and the tourism industry. Some fisherman said that, because protective barriers hide the sea, the tsunami risk will increase instead, and so it is not convenient to workers in the fishing industry.

Secondly, for the victims it is not clear which way is better—to move to new estates or to take another option. It is very difficult for them to determine whether their lives, including jobs, healthcare, education, shopping and every kind of daily activity will be go well there or not. In this scheme, maximum new lot space is 300 m^2, which is quite small for some victims including fishermen or farmers who were used to living in bigger lots with two or three buildings. So victims' minds are unsettled between moving there and entering the public housing.

Thirdly, building funds for new houses is a big problem for them. Even if they can get a new lot through the project, building funds cannot be supplied by this scheme. They have to prepare the money by themselves with savings and government support money through the act-of-life-restoration support, which is 3 million JPY maximum, as mentioned earlier. On the Sendai plane, land prices in the damaged area are relatively inexpensive because the land is located close to the seashore and removed from the city center. But the land price of new lots are higher than their former lots, so they cannot have enough money to get a new lot with the former size. As a solution to this problem, the Sendai City government created a new scheme that, in the case of land leasing, rent can be exempted for up to 50 years.

The fourth problem is the project term. Generally, these kinds of reconstruction projects take a long time—three to 5 years or more. During this time, victims who lost their houses have to live while obtaining money for their living somewhere. So, if the completion of the project is delayed, victims cannot wait and instead move to other places.

Some other problems are related to project implementation. One is lack of manpower to promote consensus-building between victims. As reconstruction *machidukuri* projects consist of many complicated procedures, trained staffers are needed with high-level skills to explain and build consensus. Another problem is the project cost. It takes 30–40 million JPY or more to create one lot in this project. Even if victims live in the new lot on the highland, because they are usually aged people, no one will live there after they leave. Then, the local government will have a risk to maintain those vacant estates. On the other hand, the local government is now facing other issues such as how to use the lots that the local government bought from victims. Generally, those lots are now public land that is not contiguous but scattered throughout the damaged area. So it is difficult to use for the revitalization of the damaged area.

11.5 Conclusion

We are now facing a lot of problems in the reconstruction after the GEJE. At the same time, we must pay attention to the next catastrophe, because the Nankai-Trough earthquake in the western part of Japan or a Tokyo earthquake will occur likely within the next 30 years, and the damage may be bigger than those of the GEJE. For disaster reduction, we have not only to prepare countermeasures before the earthquakes and to create emergency response systems, but we also must focus on the improvement of reconstruction or restoration systems after disasters.

Before the next large disaster occurs, there is a need to quickly undertake at least the following measures, while also acting accordingly:

(a) The quality of life in the evacuation facilities must be improved to prevent the evacuees becoming ill or dying in them. There is a need to provide proper bedding to each evacuee, as well as comfortable toilets, showers and good quality meals.

(b) The quality of life in prefabricated temporary housing should be improved. Wooden temporary housing for evacuees should be widely introduced.

(c) The government should enable the evacuees to self-build temporary housing on their own land, while, at the same time, it should provide them with support money equivalent to that received by those already provided with temporary housing.

(d) The *minashi-kasetsu* system should become more reasonable, so that the application process, levels of rent and other related aspects are improved.

(e) The Act on Support for Reconstructing Livelihood of Disaster Victims should be amended to widen its application range and also to increase the support money. Through this amendment, the needs for public reconstruction housing after disasters can be reduced.

The above measures and actions are not difficult to undertake budget-wise. The government has already spent 26 trillion JPY since the events of March 11 occurred, and still 170,000 people cannot return to their homes as of today, and 3470 people have died subsequently. Obviously, the problem is not in the budget but rather the reconstruction institutions. As a great deal of experience has been accumulated since 1995, we must prepare every kind of countermeasure, including the above, before the next mega disaster happens. There is not much time left.

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Chapter 12
Changes in Land Use After the Great East Japan Earthquake and Related Issues of Urban Form

Michio Ubaura

Abstract Five years have passed since the Great East Japan Earthquake occurred, great progress has been made in rebuilding the affected areas. This kind of recovery from a tsunami is generally accompanied by major changes in land use. This paper aims at providing an overview of reconstruction and land use plans and going over the effects and issues posed by such reconstruction from the perspective of land use planning by categorizing the disaster-stricken regions into following three types; "collective relocation area," "rebuilding on original location area," and "non-disaster area." A "collective relocation area" is the reconstruction case, in which the affected people collectively move from low-lying land, which is at risk of tsunamis and is designated as a disaster hazard zone, to a residential site on a hill or some other safe location, mainly based on the Collective Relocation Program. In this area, the municipal governments conducted careful surveys to understand the residents' intentions and had done their best to match the supply and demand with the number of units available in the relocation residential sites. Thus, for the most part, the residential sites intended for relocation have been filled. However, some challenges still remain, such as isolation of relocation residential sites, low demand for low-lying original relocation areas. "Rebuilding on original location area" is a reconstruction case in which the affected people rebuild their houses on the affected site, since safety from tsunamis is assured through land raising or seawall construction. In this area, the rebuilding process has not progressed and a very low-density urban form is taking shape in both cases where land readjustment projects had built infrastructure and raised the ground level for safety, and those areas where no urban development projects took place and in which immediate reconstruction was allowed. A "non-disaster area" is a reconstruction case in which the affected people move and rebuild their houses outside of the original affected area individually. In cases where there were designated urbanization promotion areas and urbanization restricted areas, as seen mostly in the metropolis and core city areas based on the City Planning

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V. Santiago-Fandiño et al. (eds.), *The 2011 Japan Earthquake and Tsunami: Reconstruction and Restoration*, Advances in Natural and Technological Hazards Research 47, DOI 10.1007/978-3-319-58691-5_12

Act, development concentrated around the existing urban centers within the urbanization promotion areas, and thus achieved a highly dense utilization and was able to protect the urbanization restricted areas in the suburban zones. However, in the small and mid-sized cities where they had not made such designations, and in suburban areas where they had much looser restrictions, it was found that development was occurring in a sprawling fashion. The author concluded there has been progress in creating a denser urban form in some areas in "non-disaster areas" in the urbanized area, partly in accordance with plan and partly without plan, and "collective relocation areas," which can be evaluated as a more sustainable space. In other locations, however, the reality is that a low-density urban form is taking shape before our eyes. He also pointed to a few potential solutions such as the aggregation of land and the creating a district- or local-level land usage management system.

Keywords Land use diversion • Great East Japan earthquake • Urban form • Land use density

12.1 Introduction

On March 11, 2011, the Great East Japan Earthquake and the accompanying tsunami wreaked havoc and left the region severely damaged. More than half a decade later, great progress has been made in rebuilding the affected cities and towns. At the same time, this process has brought about several issues; one of them is the question of land use.

Recovery from a tsunami is generally accompanied by major changes in land use. That is to say, affected regions try to rebuild their cities and towns in a way that protects them from future disasters. In many cases they realize that levees and other structures are insufficient, and thus end up developing their inland farming areas or hilly lands and forests behind the coast, requiring relocation to such areas.

The resulting environment they wish to create would have the living and residential functions located in places like appropriately sized lots on higher ground to keep the town compact and safe, with the low-lying areas being turned into an industrial zone to create jobs. The goal here is to connect the industrial and residential areas in order to create a sustainable living environment. What, then, does this look like in reality?

This paper will first provide an overview of reconstruction and land use plans. Next, the author will go over the effects and issues posed by such reconstruction from the perspective of land use planning. The affected spaces will be divided into three types that have been created by such plans, and empirical evidence will be presented.

While there is scholarship on the spatial recovery process after Hurricane Katrina in New Orleans (Ehrenfeucht and Nelson 2011; Olshansky and Johnson 2010), as well as general discussions of transformations in urban spatial forms in the process of recovery from the Great East Japan Earthquake (Ubaura 2014a, b), there are few concrete and empirical treatments of such post-disaster changes. The only study on this theme (Kondo and Karatani 2016) does not focus on the land use change comprehensively as a whole.

12.2 Reconstruction-Related Land Use Planning, Regulations, and Programs

Land use planning for reconstruction is settled by each local and regional government after a disaster, and their main focus is usually on implementing measures to prevent tsunami damage in the future.

To this point, the Japanese government's Central Disaster Management Council set a certain standard in a report entitled "Report of the Committee for Technical Investigation on Countermeasures for Earthquakes and Tsunamis Based on the Lessons Learned from the '2011 off the Pacific coast of Tohoku Earthquake'" in September 2011 (Central Disaster Management Council 2011). In the report, tsunamis are divided into two categories: level-1, which is "the type of tsunami that occurs relatively frequently"; and level-2, whose "occurrences are very rare, but if they do strike, they are the largest of their class with the most devastating and disastrous effects." For level-1 tsunamis, they recommend "using structures such as breakwaters to prevent tsunamis from entering the inland areas." For level-2 tsunamis, they state that "it is important to set up countermeasures from the perspective of disaster reduction and reduce the damages to the minimum," that the "damages from tsunamis must be reduced as much as possible through hard countermeasures," and "there must be emphasis on soft countermeasures, particularly evacuation." More specifically, they recommend "constructing a secondary embankment inland, utilizing the transportation infrastructure, raising the ground higher, preparing evacuation sites and designated buildings for refugees in case of tsunamis, as well as preparing evacuation paths and stairways. Land use scenarios should take into consideration the flooding risk and construction regulations, and thus combine and implement these appropriately based on local conditions and situations."

Based on these approaches, many local governments have implemented the following land use planning policies and regulations. First, coastal levees will be built to mitigate level-1 tsunamis. Then, a simulation will be conducted of what will happen after the structures are in place when a level-2 tsunami hits. If the expected flood line rises to approximately 2 m (6′ 6″) or over, they will designate the area as a disaster hazard zone and as a rule not allow construction of homes and other buildings. The reason the standard is set at 2 m is because wooden houses have a greater chance of being washed away once the flood level rises above 2 m. The areas that were designated as disaster hazard zone will then also be designated as relocation promotion zones for the Collective Relocation Promotion Program for Disaster Prevention (Bosai Shudan Iten Sokushin Jigyo, hereafter referred as the Collective

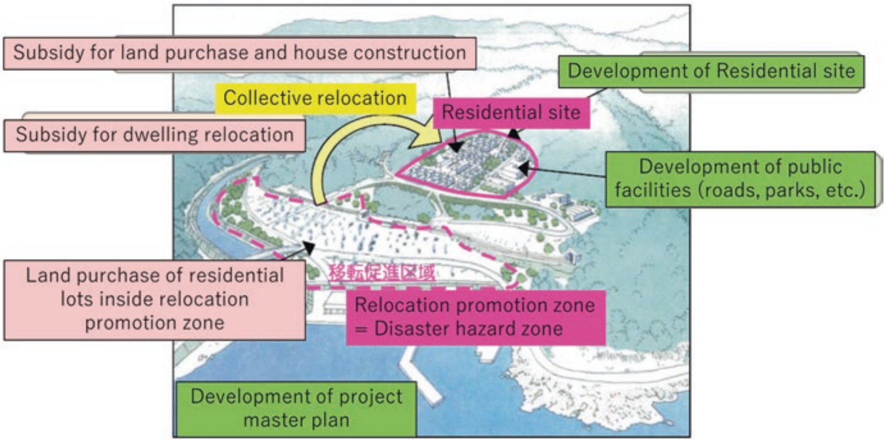

Fig. 12.1 Conceptual diagram of collective relocation project (Source: Partially modified from Ministry of Land, Infrastructure, Transport and Tourism)

Relocation Program), which means the people who live in such zones will receive government aid to relocate to a residential site on a hill or to some other safe location. At these residential sites (*danchi*), the victims could buy a partitioned lot from the government and build their home anew on their own, or decide to move into a public rental apartment house. The lots previously used for residential use in the relocation promotion zone are supposed to be purchased by the local governments (Fig. 12.1).

On the other hand, if the expected flood will be under 2 m, basically the reconstruction of homes will go forward in such areas. However, if the area has ongoing issues with the fundamental urban infrastructure before the disaster, such as the ratio of road area to district being too low or there being no parks, this will become an opportunity to make improvements through land readjustment projects.

However, some local governments have added additional levels to the regulation standards in disaster hazard zones based on the expected level of flooding. For example, in Ofunato City, all areas submerged due to the tsunami were designated as disaster hazard zones. This was not necessarily because the city wanted to emphasize safety, but rather it was done for economic reasons, so the city could utilize the Collective Relocation Program to assist those who were affected by this disaster and wished to move to higher ground. With that said, the construction regulations were divided into four categories based on how badly the area would be inundated with floodwater when the level-1 coastal levees are breached by a level-2 tsunami (Fig. 12.2). While no construction of homes will be allowed where the water would reach over 2 m in depth, if the expected floodwater inundation depth is on the shallow side, the regulations become a little looser. For example, in the areas where they expect the inundation level to be less than 1 m, the top portion of the foundation must be 0.5 m higher than street level. If no flooding is expected, then buildings

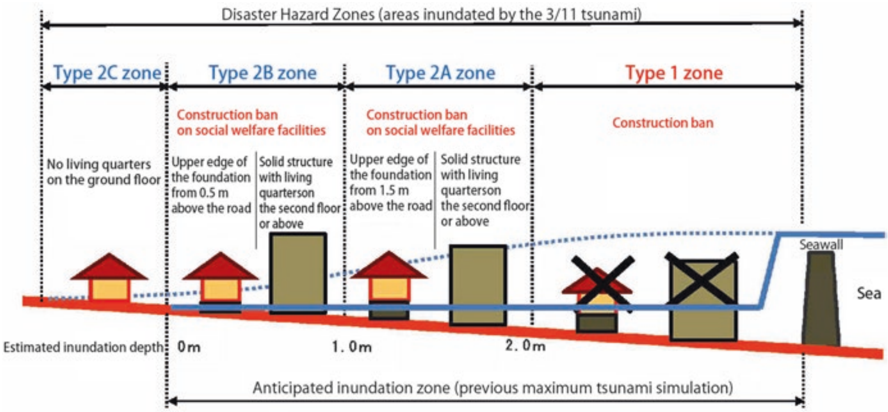

Fig. 12.2 Conceptual diagram of disaster hazard zone designations in the city of Ofunato (Source: partially revised from Ofunato city, "Summary of building restrictions through designation of disaster hazard zone")

with no rooms in the basement are permitted, which also means there are practically no regulations.

Also, in addition to programs and regulations that directly affect the creation of such an environment, there is a system in place to assist disaster victims wishing to rebuild called the "Relocating Program for Hazardous Residential Buildings Adjacent to Cliffs and other Dangerous Areas" (hereafter referred as the Cliff Program). This is a program in which disaster victims who live within the newly designated disaster hazard zone can choose to find their own land and rebuild their homes without the use of the framework of the Collective Relocation Program and still receive approximately the same amount of financial assistance as those under the Relocation Program.

With the points mentioned above as the backdrop, this paper will shed light on how the various programs and systems are shaping each space by categorizing them into three types: "collective relocation area," "rebuilding on original location area," and "non-disaster area." A "collective relocation area" is the reconstruction case, in which the affected people collectively move from low-lying land, which is at risk of tsunamis and is designated as a disaster hazard zone, to a residential site on a hill or some other safe location, mainly based on the Collective Relocation Program (Fig. 12.3). The case, in which residential construction is allowed under certain conditions in a disaster hazard zone, also comes under the mixture of this type and the following "rebuilding on original location area" type (Fig. 12.4). "Rebuilding on original location area" is a reconstruction case in which the affected people rebuild their houses on the affected site, since safety from tsunamis is assured through land raising (Fig. 12.5) or seawall construction (Fig. 12.6). A "non-disaster area" is a reconstruction case in which the affected people move and rebuild their houses outside of the original affected area individually.

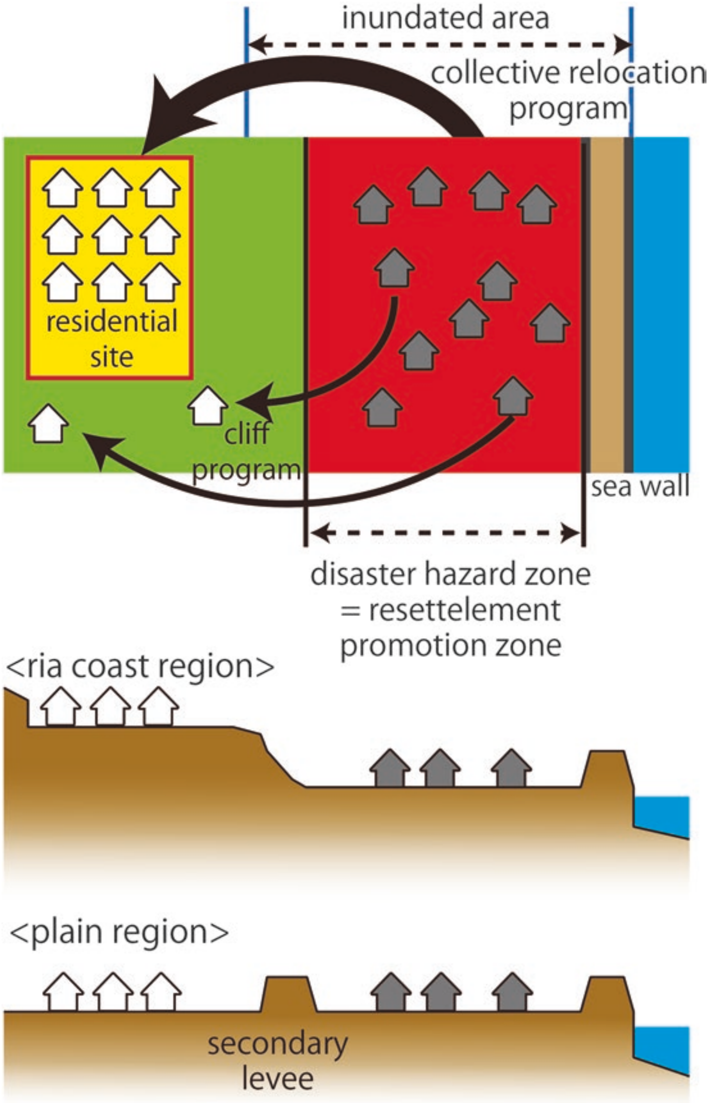

Fig. 12.3 Conceptual diagram of collective relocation area

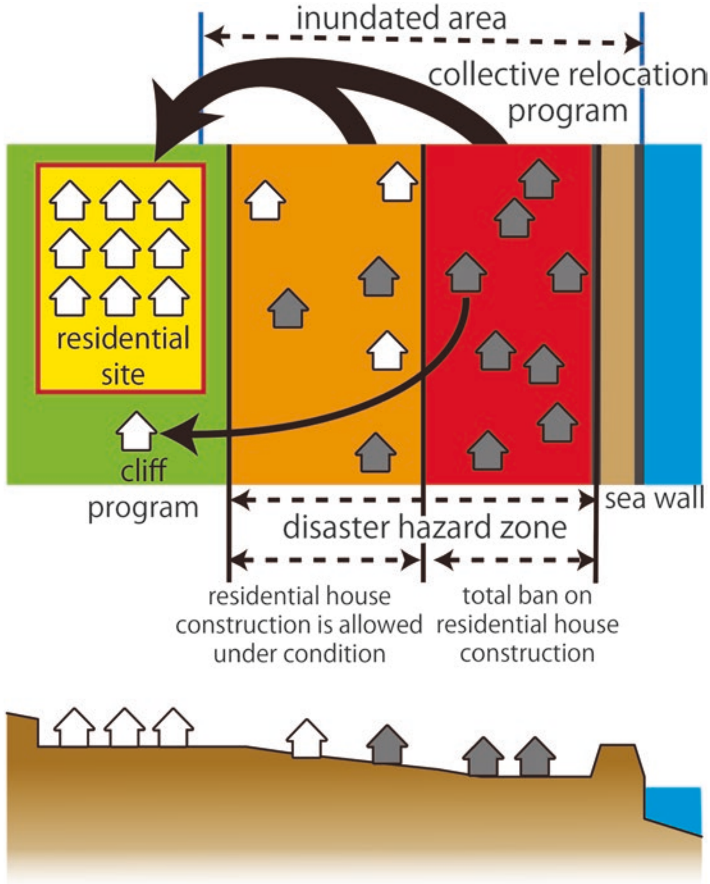

Fig. 12.4 Conceptual diagram of collective relocation area (residential construction is allowed under condition)

12.3 Reality of the Changing Landscapes of the Disaster Area

12.3.1 Collective Relocation Area

12.3.1.1 Consolidation into Key Settlements

It is important to integrate and consolidate one district into another, as represented by the term "consolidation of settlements," for many reasons. Maintaining a settlement that has only a few homes at the edge of its network costs a lot, especially providing social services, maintaining and managing infrastructure, and so on. Therefore, in the case of remote small-scale settlements, it has been considered best

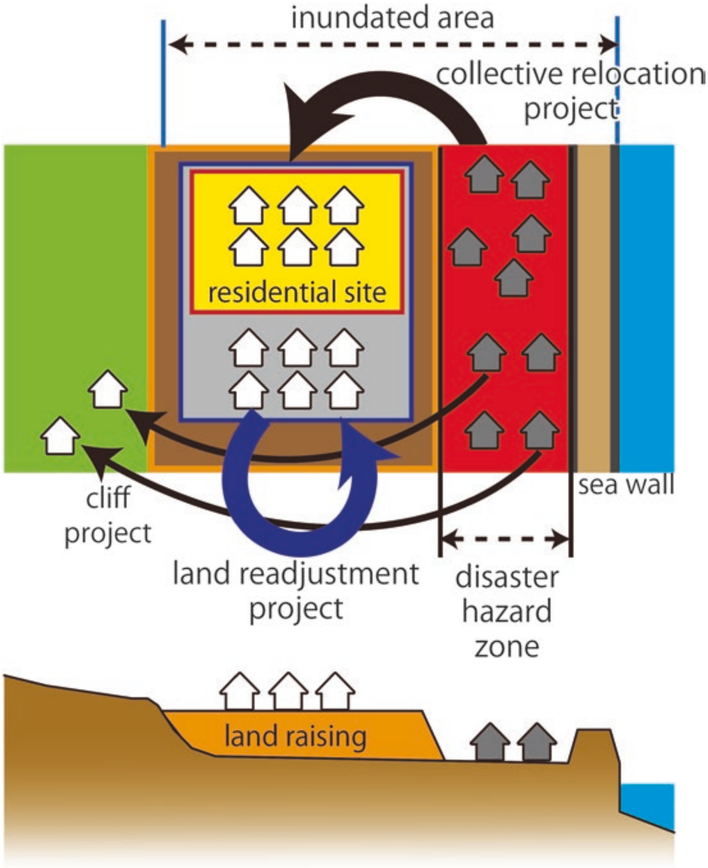

Fig. 12.5. Conceptual diagram of rebuilding on original location area through land raising

to take the opportunity provided by this natural disaster to consolidate these settlements into key settlements to reduce costs while improving their sustainability. This type of consolidation is not just simply aggregating settlements, but also expanding their scale so it becomes much easier to maintain social services, to the benefit of the consolidated settlements.

Most of the settlements that were consolidated into existing towns were from rural plains and relatively new residential areas. Specific examples are the six settlements on the coast of Iwanuma City that were relocated to Tamaura-nishi district, and Sendai City's Arahama district that was relocated to Arai district (Fig. 12.7).

On the other hand, the coastal fishing villages have not seen a progression towards such consolidations. Rather, in most cases, even though it may be just a few homes, each home in the vicinity of the fishing ports was individually relocated to higher ground. One of the typical examples of this type is Ogatsu district in Ishinomaki city (Fig. 12.8).

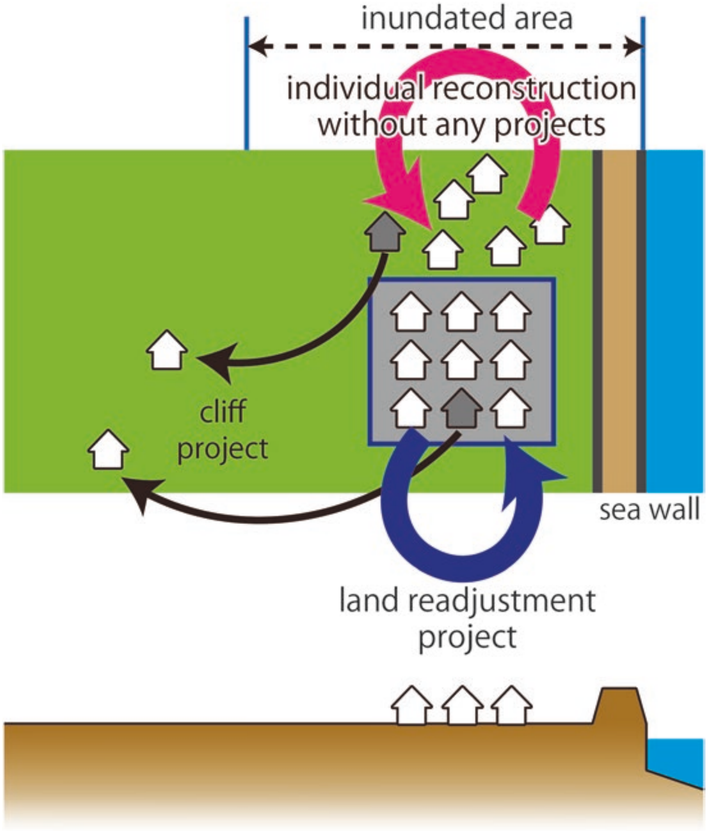

Fig. 12.6 Conceptual diagram of rebuilding on original location area through sea wall construction

However, when we evaluate this situation, it does not necessary seem that the former was a success and the latter a failure. Such matters cannot be seen in simple terms, but rather, it is necessary to consider why consolidation is being conducted in the first place. It may be true that through consolidation it is possible to reduce the cost of maintaining and managing infrastructure, as well as the costs of various social services. However, when it comes to these small-scale settlements, each household is generally engaged in fishing, and that provides the foundation of their economic lives, and at the regional level, they contribute to the vitality of the industrial activities. Also, these individuals have had community based lives where they have naturally checked on one another's wellbeing through their regular neighborly interactions. However, when these people are relocated to key settlements and metropolitan areas, the industrial activities will wither away and individual economic lives and the community's mutual assistance all weaken, which means that they become dependent on the public safety net, leading to various additional costs.

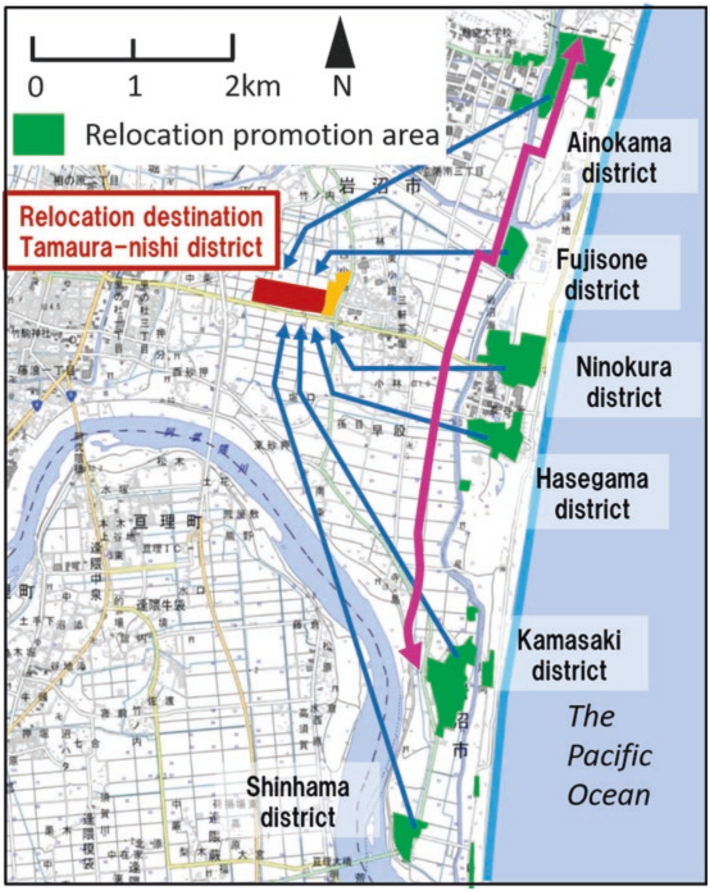

Fig. 12.7 Relocation promotion area and consolidated relocation destination of Iwanuma city (Source: author)

Therefore, in order to evaluate the merits of such relocations, it is necessary to take into consideration multiple factors and evaluate and judge the situation based on the aggregate effect.

On the other hand, what should not be forgotten is that a large-scale population migration also occurred due to individuals trying to rebuild their lives on their own and households merging or splitting. It can also be seen that people are tending to move from small-scale settlements, like Minamisanriku town or Onagawa town to key settlements and core cities, like Ishinomaki city or Ofunato city, and even on to metropolises like Sendai city or Natori city (Fig. 12.5). This means that the populations of small-scale settlements are experiencing a marked decline, and rather than succeeding in "planned consolidation," what we are seeing is an "unplanned deterioration." With such a deterioration, this type of settlement is expected to become harder to maintain. How we are to respond to this situation remains to be seen (Fig. 12.9).

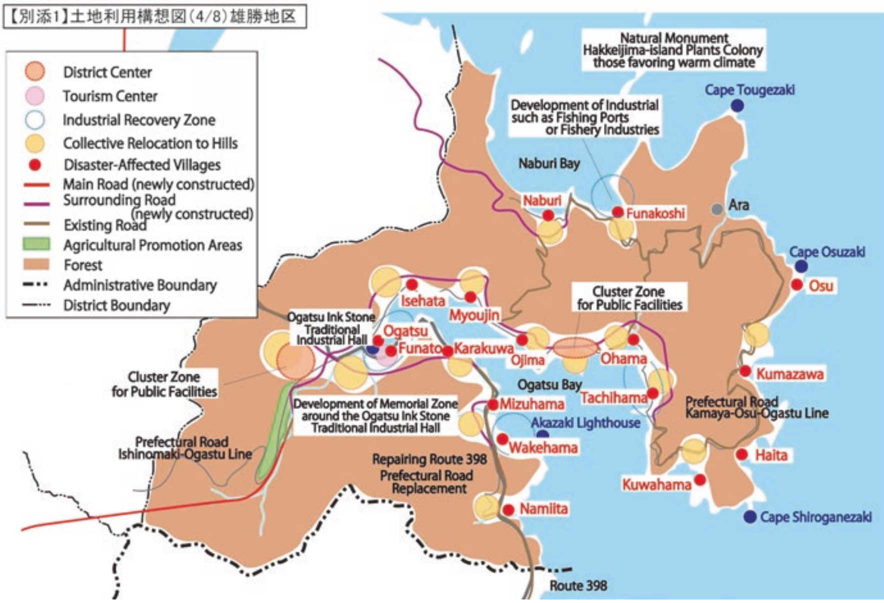

Fig. 12.8 Land use concept of Ogatsu district in Ishinomaki City (Source: Recovery Development Plan of Ishinomaki City)

12.3.1.2 Isolation of Relocation Residential Site

In addition to the issue concerning consolidation, as to the matter of the scale of the village, the area can be evaluated as a non-ideal regional spatial structure when the relocation residential site is located in the area that is isolated. Previous villages were formed in connection with major traffic axes and public transportation networks such as national roads and railways, until they were hit by a tsunami this time. The relocation sites of those villages were in many cases selected mainly from the viewpoint of tsunami safety and land availability rather than the accessibility to the public transportation network. Therefore, the spatial relationship between the relocation residential sites and traffic axes became spatially separated in some cases, or in other words, villages were pulled out of the network since their positions changed while those of the traffic axes did not. The relocation of Koizumi district in Kesennuma city is an example of such a case (Fig. 12.10). The village was moved from the original site, which was directly connected to both a national route and a railway, to a hill approximately 1.5 km away from the original site and the transportation network. Although in many cases the distance between the village and the traffic axes is just a few minutes' drive, it is still a big challenge for elderly people who cannot drive by themselves and need access to the public transportation network (Fig. 12.10).

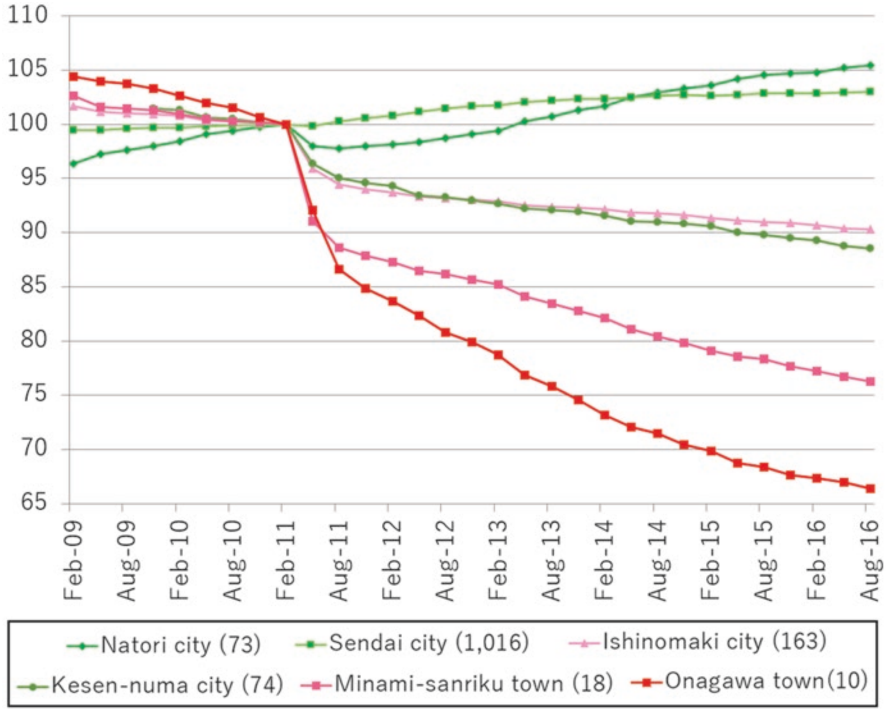

Fig. 12.9 Population dynamics on the municipal level (in parentheses: population in thousand in Feb. 2011) (Data are expressed as relative values, taking the number in Feb. 2011 as 100) (Source: author, based on basic residents register of each municipalities)

12.3.1.3 Land Use Inside Relocation Residential Site

In order for a relocation project to be approved by the Minister for Reconstruction, there must be a demand. To provide numerical evidence for such a demand, residents' intentions were ascertained through surveys.

However, residents' intentions have changed drastically over time. In particular, there were quite a few who originally desired to move to higher ground, but then the reality of the financial burden and the difficulty of obtaining a bank loan hit them and they consequently gave up on the idea. Then there were those who wished to rebuild on their own, but, due to the needs and demands of reconstruction, and the fact that the cost of reconstruction had skyrocketed due to increases in material and labor costs, they decided to wait to rebuild. Furthermore, there were those who looked at the convenience and speed in which reconstruction would occur in other municipalities and thus chose to move to other areas altogether.

Even under such circumstances, many of the residential sites that were prepared for the relocation project have a more than 90% occupancy rate. This can be attributed to the fact that as time passed, even though the regulatory conditions changed, the administration kept an accurate pulse on the changing needs of the residents and

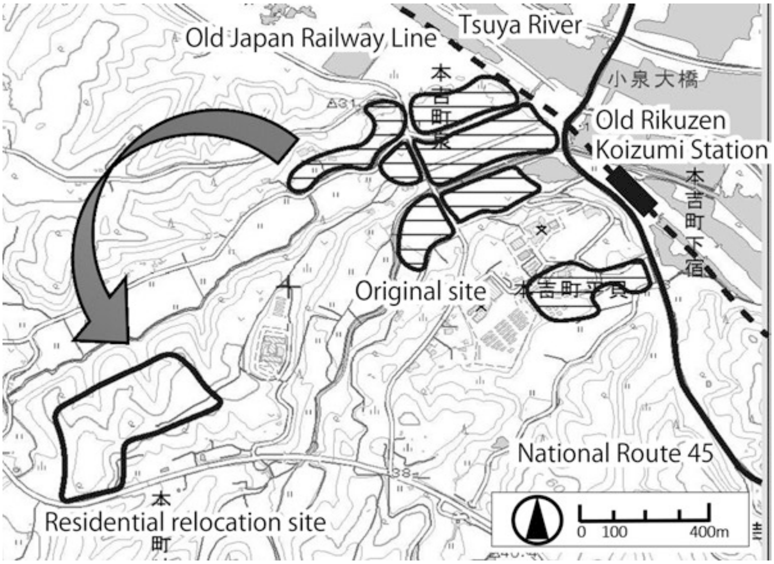

Fig. 12.10 Relocation of Koizumi district in Kesennuma city

responded with flexibility in the planned number of dwelling places. In particular, while there are so many reconstruction projects going on, the administration not only utilized a simple, rough survey to get an overview, but they also conducted individual, face-to-face interviews to grasp the intentions of the residents and get an accurate count to determine the number of partitions they would need. They kept adjusting their designs up to the last possible moment in order to determine how many units they would need, trying to address the constant changes.

Yet, it is not easy to determine beforehand what kind of demand there will be over time. Additionally, responding to changes in demand that reduce the number of units needed in a residential site once the draft of the design has been started is not easy and can lead to delays in the execution of the project.

Therefore, there are some cases where the planned residential sites became too large for the people's needs and therefore there were open lots after completion. For example, in the town of Watari, they had allocated 200 residences in the housing complex in the residential sites built under the Collective Relocation for Disaster Prevention Project based on the interviews with residents; but, they still have 20 openings (Kahoku Shimpo (2013). Likewise, in the city of Ishinomaki, though they were in the process of accepting a second round of applications, the applications submitted put some of the relocation residential sites at less than 50% capacity.

Furthermore, it must be noted that a high ratio of the relocating households has only elderly residents. That means the relocation residential sites will experience an acceleration of aging residents and with that will have many more vacant lots and homes. On the other hand, based on the current trends, there are hardly any areas for new demand to be created. That is to say, once a residence or lot becomes vacant, for the most part, it would be vacant permanently with no potential future use.

12.3.1.4 Original Relocation Area

Former residential lots in relocation promotion zones are supposed to be purchased by local governments. However, originally, residential relocation did not take place as they had a better use for the original area. Residential relocation from such places has everything to do with disaster prevention, and how to utilize the original relocation area is an afterthought. In other words, they were not purchased for a specific use, but to support the affected people. This resulted in the challenge of low-lying land utilization. This is a big issue, especially because the local governments have to pay the maintenance costs of the land for as long as they do not take any measures.

In this regard, one of the greatest obstacles is low demand for the land. The affected land in the metropolitan area has begun to be utilized for industrial use since such land is in demand. In most cases, however, demand for those areas is very low since the population declined, whereas the urbanized area has grown larger. In particular, the use of most of the original relocation areas in the lowland areas of small fishing villages along Ria coast has not been decided yet.

What makes the utilization of these areas much more difficult is that public and private land ownership are spatially mixed. When it comes to relocation projects, not all land that was designated part of the relocation promotion zone became available for the local government to purchase. These districts were also designated as disaster hazard zones, and usage became restricted, but what was banned were primarily residences, and thus business, industrial, and agricultural lands were not considered up for sale under these programs. Moreover, if the land had been passed down through generations, even in cases where it was used for a residence, the landowners would not sell, or could not sell due to matters of inheritance. There are even cases where it was no longer clear who owned the land legally, leaving the municipal governments unable to find the other party to negotiate. In any case, this meant that there were lands scattered across the districts that the local governments could not purchase. Some of the lands housed buildings for businesses and industries, while there is hardly any demand for effective use of the land when it comes to small-scale settlements. The result was nothing more than super low-density use of low-lying land (Fig. 12.11). How to maintain the newly acquired public land and/or utilize such land remains an open issue.

Fig. 12.11 Actual situation of relocation promotion zone in Kamaishi city (Photo by author)

12.3.2 Rebuilding on the Original Location Area

12.3.2.1 Land Readjustment Project Area for Land Raising on the Original Location

This is the rebuilding type in the areas devastated by a tsunami this time, but will be protected from a level-2 tsunami through raising land by conducting land readjustment project. Land readjustment projects are plane-oriented development efforts to change the form or nature of land in order to improve public facilities (roads, parks, etc.) and promote housing and other land use on land within city planning areas, in accordance with the Land Readjustment Act. Since it is prohibited to enhance the value of private land through land raising at the government's direct expense, this type of project is adopted to make the value of private land equal before and after land raising by reducing the amount of private land following land reallocation or collecting settlement money. These projects, when conducted on the original sites, are also expected to encourage the disaster victims to stay in the area by developing the urban infrastructure and improving the living environment.

In fact, while the price of land remains relatively stable, since roads, parks, and other public utilities and infrastructures are to be built, the area will become a depreciation compensation district, in which public agency has to purchase more land than the amount of increment value of whole building sites. In many cases, since a lot of public housing will be built for disaster relief, the appropriate land will be acquired by public agencies, which will create an intentional secondary effect of potentially having the victims' wishes to sell their land come true as well.

However, from the viewpoint of community development as well as efficient utilization of subsidies, how the land will be used and how the newly rebuilt town will be morphologically formed are important issues.

From this aspect, the greatest issue is that these projects take a considerable amount of time. Now, 5 years since the disaster, most areas are still under construction and in most places it will take several more years for all rebuilding projects to be completed. This passage of time—along with the fear instilled by the disaster—has led to an increase in people wishing to leave the area. In such cases, they tend to hold on to the land they had, but, since they have already rebuilt in another location, the land will have a greater chance of going unused. As many as 43% of those under the disaster areas' land readjustment projects wish to sell their land or move out of the area, with about 50% wishing to continue to live in the area or hold on to their land (Yomiuri Shimbun 2014). In this way, while a significant amount of public money has been poured into these land readjustment projects, the land that has been developed is not being effectively put to use, and as a result, a low-density urban landscape is starting to form.

The areas, which were devastated by a tsunami this time but protected from a level-2 tsunami thanks to the construction of a second line of levees, and in which land readjustment projects are being conducted for the improvement of the living environment, are facing at similar situation.

12.3.2.2 Original Location with Permission for Immediate Reconstruction

What if the areas did not need to go through readjustment programs and instead approved immediate reconstruction on the original sites? Would such an area manage to avoid creating urban areas with such low density? The answer is no.

"Original Location with Permission for Immediate Reconstruction" are areas that experienced flood-related damages in the last tsunami, but with the construction of coastal levees are now safe (that is to say, in case of a level-2 tsunami simulations indicate that their level of inundation would be under 2 m). They also already have a certain amount of urban infrastructure in place, and no particular projects, including superficial ones, are planned.

Such places allow for individuals to independently start the rebuilding process, and for the homes that had floodwater right under or above their floor, and in areas where the tsunami's speed was relatively slow and caused relatively minor damage, repairs and rebuilding took place rather quickly. There are also areas that experienced severe and destructive damage from the last tsunami, but a simulation showed that through the construction of coastal levees they are now safe, even against a level-2 tsunami, and thus immediate reconstruction efforts were greenlit. In such areas, only small amount of houses have been rebuild because of fear of tsunami.

Fig. 12.12 An example of super low-densely used urban area in Higashi-Matsushima city (Photo by author)

Moreover, while the area may be designated as a disaster hazard zone, since the regulations regarding construction do not entirely prohibit all homes from being constructed, there are cases where permission to rebuild was granted as long as the foundation level (or the ground floor level) was raised, or as long as there was no basement. In such cases, the residents were allowed to receive aid within the framework of the Collective Relocation for Disaster Prevention Promotion Program if they desired to relocate while working on selling their land and moving away. At the same time, if they decided to rebuild in the same location, they were free to remodel or rebuild their home. In other words, each landowner had options, and they could decide whichever way they wished to go. The other side of the coin here is that when it comes to land use, there are areas where the owners tore down their home and sold the lot back to the local government, which left the lot bare and vacant, right alongside homes that were rebuilt (Fig. 12.12). At this point, we can expect that all who wish to rebuild on their own have already done so, and we cannot expect to have too many new homes rebuilt in the area. Instead, there is a much higher chance that such situations are going to be permanently fixed in place. It can be said that the desire to grant the victims' wishes as much as possible while creating land use regulations and a framework for reconstruction projects has caused this aftermath.

12.3.3 Non-disaster Area

First, let us look at how the urban space is changing in the non-disaster areas in relation to individual and independent relocation and reconstruction efforts, including those utilizing the Cliff Program. What heavily shapes the urban space and environment are the land use regulations based on the City Planning Act.

The cities and surrounding areas "that require integrated urban improvement, development, and preservation" (City Planning Act, Article 5) are designated as urban planning zones. In medium to large cities, the urban planning zones are further divided into urbanization promotion areas and urbanization restricted areas. In the urbanization promotion areas urbanization is to be achieved in the coming decade and construction is allowed provided that it is within the designated area and purpose. On the other hand, urbanization restricted areas are basically areas that do not allow development. Additionally, small to medium cities generally do not make this distinction. In such cases, as long as the purpose of the building matches the designated purposes within that specific urban area, then construction is allowed. In such cases, as long as the purpose of the building matches those purposes designated in some areas within the urban planning zones, then construction is allowed. Furthermore, in the suburbs, outside of the designated areas of the urban planning zones, in principle there are no restrictions as to the type of buildings that can be built. Additionally, in the rural villages outside the urban planning zones, there are basically no regulations based on the City Planning Act and people are free to build no matter the location.

In the urbanization promotion areas where infrastructure has been developed, there are efforts to fill the pockets centering on open lots and remaining farmlands in the previously and currently developed areas within the city (Fig. 12.13). In these areas, there is an ongoing issue where there is an abundance of farmland and open lots that could not possibly be urbanized within a decade, and thus this low utilization density has been the subject of concern and debate when it comes to land use. However, the low utilization density has actually helped buffer the sudden surge in housing demand after the disaster. As a result, the density within the urbanization promotion areas has progressed and contributed to shaping efficient urbanization.

Fig. 12.13 Spatial use before (Jun. 2010, *left*) and after (Apr. 2014, *right*) the Great East Japan earthquake in Watanoha district, Ishinomaki city (Source: Google earth)

Fig. 12.14 Spatial use before (Apr. 2011, *left*) and after (Oct. 2014, *right*) the Great East Japan earthquake in Takkon district, Ofunato city (Source: Google earth)

Next, in the urbanization-restricted areas, though there is some construction going on in the currently standing communities, in other areas development has been restricted. This is especially the case with collective farmlands, as such areas have been protected from sprawling development under Agricultural Land Act. Presumably, this is due to the fact that there are certain restrictions based on the diversion of agricultural land and even the aforementioned City Planning Act.

In the suburban areas in the small to mid-sized cities where there are no restrictions on land usage, or those outside the urban planning zones, because of the loose regulatory standards regarding what buildings can be built, sprawling development was an ongoing reality before the disaster struck. That trend continued even after the disaster, and this is creating a widespread, low-density urban form, as the example of Ofunato city shows (Fig. 12.14). This has led to the problems of mixed urbanized and agricultural land, inefficient infrastructure, and deterioration of the landscape.

12.4 Discussion and Conclusions

As mentioned above, the disaster stricken areas are going through major changes in the reconstruction process, and their spaces and sceneries are changing. First, with individual relocations, where there are regulations based on the City Planning Act, they are managing to create a compact and tight, high-density urban form (and that also means that the nearby collective farmlands are being preserved). On the other hand, in areas where the regulations are loose, sprawling development is evident. When it comes to collective relocation to higher ground or inland areas, for the most part, they have been able to create relocation residential sites that meet the demand, though some areas are left with vacant lots. In areas where original locations are used for reconstruction, whether they have a readjustment project or not, the reconstruction rate is extremely low, resulting in minimal land use, creating a low-density urban area. Additionally, when it comes to the original relocation area that people were urged to vacate, as housing related usage is prohibited, it has hardly seen any use so far.

In this way, some areas have managed to create a compact and highly dense space, or in other words, a more sustainable space. In most areas, however, they have only managed to create spaces with low-density usage, resulting in lower sustainability.

So then, what kind of response could we consider in situations like this? When it comes to the original relocation areas with a lot of vacant lots where most of the land is owned by the local government, it becomes necessary to consider "aggregation." That is to say, the scattered privately owned land should be aggregated and then separated from the public land, which will allow for large-scale land use. If there is the potential for industrial usage of such land, land readjustment projects could be implemented to aggregate the land and build an industrial complex, for example.

On the other hand, there are many areas with scattered small lots. In cases where some land is used for residential purposes, or cases where micro sprawl is seen in the land use, to go through a readjustment program and aggregate or consolidate the land use is not quite cost effective. Therefore, in such situations, an agile, case-by-case approach would be best.

What will be called for in such a situation is a district-level land use management system. Similar to how previous districts built their towns, not only should there be a function for evaluating how the land should be used within a district, if the owner is not around, and in cases where the land is not well maintained, the district should have the right to manage it, or even transfer usage rights for that land. If such a system is to be created, it will also be necessary to change the legal structure, with ownership, management, and usage concepts all being reconsidered.

In either case, whether there will be an attempt at aggregation or considered micro usage, it is important to explore a usage system that will generate some benefit; however, this also means there will be maintenance costs and thus potentially a negative effect. Therefore, in some cases, there should also be a choice to not utilize the land at all, and there should be an aggressive movement towards designating some land to be left alone and returned to nature.

In this study, the author looked at the aftermath of the Great East Japan Earthquake and designated the disaster-stricken regions as "collective relocation area," "rebuilding on original location area," or "non-disaster area." Based on these designations, each location type was examined to see what types of spaces and environments were being created and what issues exist.

In the "collective relocation area," in many cases, the municipal governments conducted careful surveys to understand the residents' intentions and had done their best to match the supply and demand with the number of units available in the relocation residential sites. Thus, for the most part, the residential sites intended for relocation have been filled. However, there are some such relocation residential sites with quite a few vacancies, and with the decline of Japan's population worsening, the chance of those units ever being occupied is close to zero. Other challenges also remain, such as isolation of relocation residential sites, low demand for low-lying original relocation areas.

In the locations designated as "rebuilding on original location area," in both cases where land readjustment projects had built infrastructure and raised the ground level for safety, and those areas where no urban development projects took place and in which immediate reconstruction was allowed, since it is taking too much time, or because of the vivid memories of the disaster, the rebuilding process has not progressed and a very low-density urban form is taking shape.

The "non-disaster area" hardly sustained any damage from the tsunami and victims are utilizing the Cliff Program and other programs to look for land on their own and rebuild their homes. In cases where there were designated urbanization promotion areas and urbanization restricted areas, as seen mostly in the metropolis and core city areas based on the City Planning Act, development concentrated around the existing urban centers within the urbanization promotion areas, and thus achieved a highly dense utilization and was able to protect the urbanization restricted areas in the suburban zones. However, in the small and mid-sized cities where they had not made such designations, and in suburban areas where they had much looser restrictions, it was found that development was occurring in a sprawling fashion.

In this way, while in some areas there has been progress in creating a denser urban form, in many locations the reality is that a low-density urban form is taking shape before our eyes. In order to resolve this issue, the author has pointed to a few potential solutions such as the aggregation of land and the creating a district- or local-level land usage management system.

Acknowledgement This work was supported by JSPS KAKENHI Grant Numbers 15H04092 and 25,242,036.

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Chapter 13
Housing Recovery and Displacement from Fukushima: Five Years Post-Nuclear Meltdown

Elizabeth Maly

Abstract Recovery from the 2011 Great East Japan Earthquake and tsunami is ongoing in Japan's northeast Tohoku region. Facing aging and depopulation even before the tsunami, planning and implementation of recovery projects to support the reconstruction of residents' lives and ensure a sustainable future of tsunami-devastated coastal towns is complex. In addition to earthquake and tsunami damage, people and communities in Fukushima Prefecture face additional challenges from contamination by nuclear radiation and resulting long-term displacement. Based on established approaches to disaster recovery in Japan, Tohoku's recovery policies and projects were developed after 2011. Recovery planning for Fukushima towns includes projects used in municipalities throughout Tohoku, along with initiatives to address issues related to radioactive contamination and displacement after the meltdown of the Fukushima Daiichi Nuclear Power Plant. For housing and life recovery of affected residents, these policies form a patchwork approach. Compared to earthquake-damaged houses that can be repaired or rebuilt on former lots, or even decisions in tsunami-affected communities about where to rebuild residential areas, questions of recovery for residents displaced by radioactive contamination are more complex. Based on 'hometown recovery,' existing Japanese approaches to disaster recovery and housing reconstruction are not designed to address issues faced by nuclear evacuees from Fukushima. Key questions about disaster recovery and housing reconstruction in Fukushima include: how should policies support housing and life recovery when people can't go home, or communities are split between returnees and evacuees? This chapter considers the issues of housing and life recovery in Fukushima's disaster recovery context 5 years after the triple disaster.

Keywords Displacement • IDP • Housing recovery • Recovery planning • Fukushima • Great East Japan Earthquake

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V. Santiago-Fandiño et al. (eds.), *The 2011 Japan Earthquake and Tsunami: Reconstruction and Restoration*, Advances in Natural and Technological Hazards Research 47, DOI 10.1007/978-3-319-58691-5_13

13.1 Introduction

The M_w9 Great East Japan Earthquake on March 11, 2011 was the largest ever recorded in Japan (Mimura et al. 2011). The resulting tsunami caused massive damage over more than 500 km of Japan's northeast Tohoku coastal area, devastating homes and communities across multiple prefectures and many municipalities. Close to 20,000 people lost their lives, and in the first few days more than 470,000 people evacuated from their homes (Reconstruction Agency 2016a). Including not only the earthquake and tsunami of historic scale, this is the first mega-disaster ever recorded with both a nuclear accident and massive natural disaster (Ranghieri and Ishiwatari 2014). After the nuclear meltdown of the Fukushima Daiichi Nuclear Power Plant, winds carrying radiation contaminated nearby towns, causing widespread and long-term displacement. More than 5 years after the triple disaster of 3.11, as of July 2016 almost 148,000 evacuees are still living in various temporary/interim housing situations throughout Japan (Reconstruction Agency 2016a). Of the almost 48,000 evacuees from Fukushima, unlike the majority of survivors from other prefectures, a vast majority (nearly 41,000) have evacuated to areas *outside* their home prefecture (Table 13.1).

Based on past experiences, Japanese disaster recovery policies focus on rebuilding existing towns. National recovery strategies introduced after 2011 combined guidance for land use planning for future disaster risk reduction with support for housing reconstruction projects similar to those used after past disasters (Iuchi et al. 2015). However, the situation of long term displacement of people from Fukushima to areas outside their towns and prefecture is not easily addressed by recovery projects designed to support housing reconstruction and/or residential relocation *within* municipalities.

With no clear solutions for how to address nuclear displacement and recovery of contaminated communities, the situation in Fukushima can be understood as a *wicked problem* with no correct answer. Nuclear displacement from Fukushima includes all Kolko's (2012) criteria for a wicked problem: incomplete/contradictory knowledge; involvement of large numbers of people and opinions; a large economic burden; and interconnectedness of these and other problems. Although there are no solutions to "fix" nuclear displacement and contamination, as Rittel (1973) emphasized, the goal in addressing a wicked problem should be improvement of the situation—in this case for the lives of evacuees. This chapter poses the following questions: towards a people-centered recovery for the nuclear evacuees of Fukushima, what is the potential impact of current recovery processes, and what issues should be considered for long term implications for life recovery of affected residents?

Table 13.1 Damages from the Great East Japan Earthquake

	Casualties			Evacuees (as of 7/29/2016)		Damaged houses (as of 9/12/2016)		
	Direct (12/9/2016)	Missing (12/9/2016)	Indirect (*kanrenshi*) (3/31/2016)	Within pref	Outside pref	Totally damaged	Partially damaged	Inundated area
Iwate	4,673	1,123	459	18,788	1,390	19,507	25,528	58 km^2
Miyagi	9,540	920	920	33,970	5,930	83,000	387,258	327 km^2
Fukushima	1,613	197	2,038	47,850	40,982	15,194	222,441	112 km^2
Total	15,893	2,556	3,472	147,772		121,739	1,019,466	561 km^2

Data sources: Reconstruction Agency (2016b, 2016c), National Police Agency of Japan (2016), Fire and Disaster Management Agency (2017)

13.2 Nuclear Accident and Evacuation

13.2.1 Disaster Communication, Evacuation and Displacement

In the days following March 11, 2011, information about what was happening during the nuclear accident was not clear to people in areas near the Fukushima Daiichi Nuclear Power Plant (NPP). Local governments and residents were not provided with accurate and timely information about the actual spread of radiation, and evacuation of nearby areas affected by nuclear radiation varied widely (FAIRDO/IGES 2013). Initial evacuation zones were announced based on the distance from the NPP. The first evacuation order was issued for people within 3 km of the NPP (those within 10 km were told to stay inside their homes); it was then raised to 10 km, and then 20 km with people within 30 km told to stay inside (Fukushima Prefecture 2016a; Fukushima on the Globe 2015; FAIRDO/IGES 2013).

In the days and weeks after the meltdown, information showing the actual dispersion of radiation was available through SPEEDI (the System for Prediction of Environment Emergency Dose Information), however this information was not made public until March 23—too late to help people northwest of the NPP who were unknowingly directly beneath the plume (Japan Times 2012). As Fig. 13.1 shows, this was the case for Namie Town and Iitate Village, where an evacuation order was not given until a month after the meltdown, and where high levels of radioactive contamination were measured outside the 20 km and 30 km zones. Not only were residents falsely led to believe they were safe, others evacuated *into* this area from areas that were geographically closer to the NPP but had less contamination. Contamination levels in Namie Town today remain in the highest category—the same as areas immediately adjacent to the NPP itself (Fukushima Prefecture 2016a; Fukushima on the Globe 2015). On April 22, 2011, evacuation orders were revised to those shown in Fig. 13.2: within 20 km was the "restricted zone"; areas measuring higher radiation levels outside 20 km were "deliberate evacuation zones"; and other areas within 30 km were "evacuation preparation zones."

Early evacuation of affected areas varied greatly; residents moved together to designated places, as groups to multiple evacuation sites, or scattered individually. These various patterns of collective and scattered displacement continued in the months and years that followed, with groups of residents from certain towns living in evacuation shelters and then temporary housing in various host communities inside and outside Fukushima Prefecture. What most families have in common is multiple moves; many family members have also evacuated and continue to live separately.

In March 2012, evacuation zones were reclassified into three categories, based on the estimated cumulative level of radiation at that time[1]; each zone has their

[1] Based on the levels of radiation since in March 2012, the three zones were decided as follows: Difficult-to-Return Zone (Restricted Access Zone)—annual cumulative dose exceeded 50 mSv as of March 2012, may not be lower than 20 mSv, even 6 years after the nuclear disaster; Restricted Habitation Zone—annual cumulative dose estimated from the air dose rate has been confirmed to be above 20 mSv; Preparatory Zone for lifting of Evacuation Order—annual cumulative dose

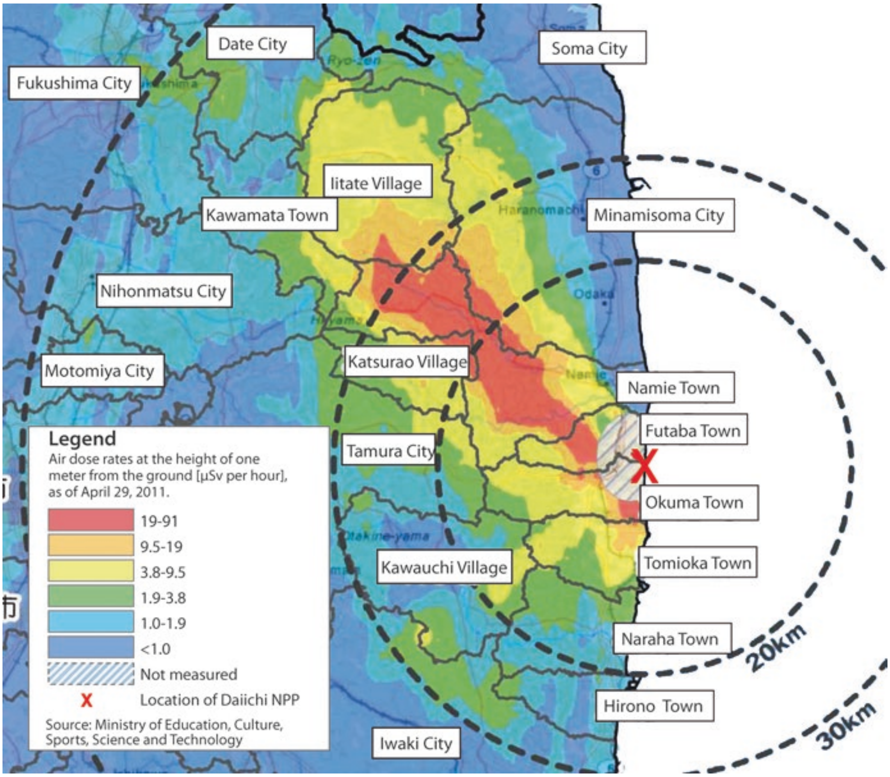

Fig. 13.1 Radioactive contamination from SPEEDI data, compared to areas 20 km and 30 km away from the NPP that were the initial basis for evacuation (Modified from information from the Reconstruction Agency and Fukushima Prefecture)

respective restrictions. Entry was forbidden to the most contaminated areas, euphemistically named the "difficult to return" zone. In the next "restricted habitation" zone, residents can enter during the day, but may not stay overnight, which is also the case for the third "preparing to lift the restriction" zone (Fukushima Prefecture 2016a). These use of these categories of evacuation zones has continued, even as the areas have been revised over time, as shown in Figs. 13.3 and 13.4. While these categories are based on scientific measurements of radiation, measurements are taken at certain spots, and can not therefore be perfectly generalized to area zones. Some towns include multiple zones; boundaries between zones sometimes follow a street—with one side where entry is forbidden—and sometimes follow boundaries between towns.

With the logic that areas will be safe for inhabitation after radioactive material is removed, decontamination efforts are the foundation for the premise that residents

estimated from the air dose rate has been confirmed to be above 20 mSv (Fukushima Prefecture 2016a).

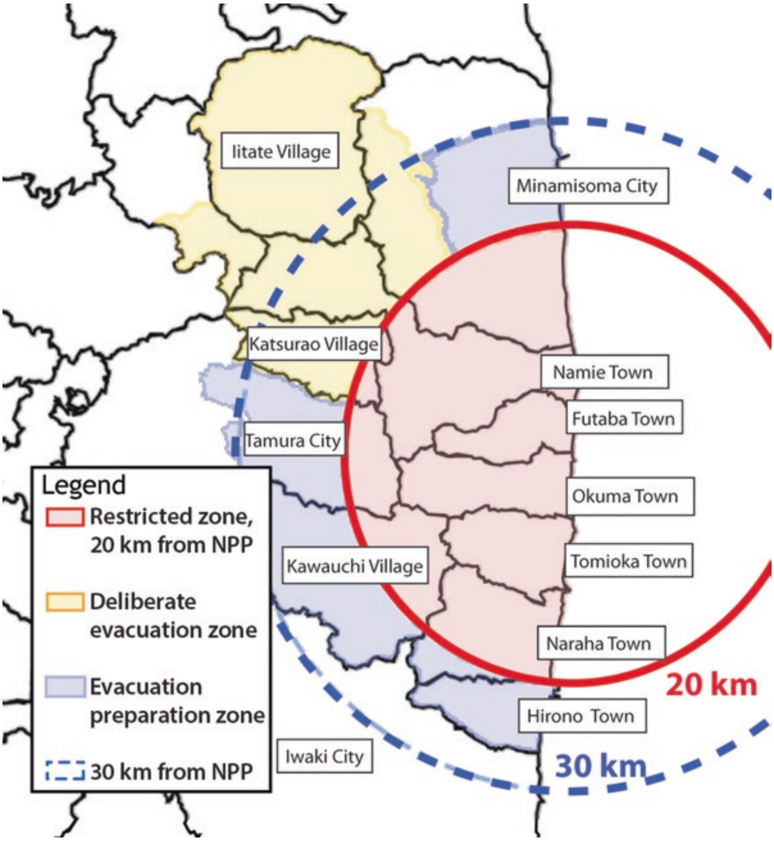

Fig. 13.2 Evacuation zones revised as of April 22, 2011 to include: "restricted zone" within 20 km from the NPP; a "deliberate evacuation zone" for areas more than 20 km from the NPP but with higher levels of contamination; and "evacuation preparation zones" for other areas within 30 km of the NPP

can return to these areas. The reality of decontamination, impact on the local area, and people's return is much more complex. The removal of radioactive material (leaves, stones, soil) is a large scale project with varied implementation (FAIRDO/IGES 2013) and issues of permanent storage of material have not been resolved (Kawasaki 2014). Areas such as wooded slopes can not be decontaminated and could cause future *re*contamination if materials are carried by wind or water to decontaminated areas. Finally, carrying out decontamination will not guarantee that residents of that area or those nearby will agree that the area is actually safe.

Over the last several years, evacuation zones have been revised several times, as shown in Figs. 13.4 and 13.5. Evacuation orders have been lifted for several areas in "preparing to lift evacuation" zones as follows: part of Tamura City in October 2014; Kawauchi Village in October 2014 (other "restricted habitation" zones were also changed to "preparing to lift evacuation") and a year later for all of Naraha Town in September 2015 (Fukushima Prefecture 2016a). In June 2016, evacuation

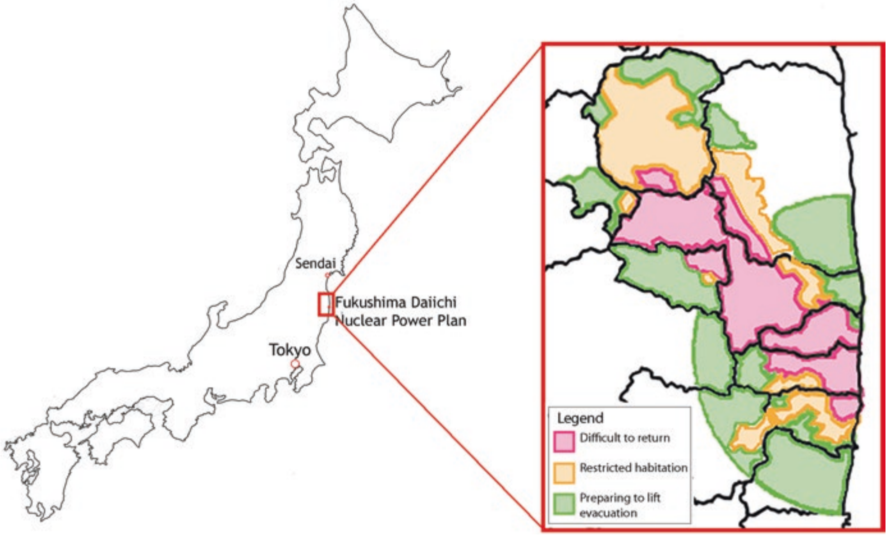

Fig. 13.3 After the reclassification of evacuation zones in March 2012 to include "difficult to return," "restricted habitation" and "preparing to lift the restriction" zones, the extent and boundaries of the zones have been revised multiple times; this map shows the situation as of August 2013. (Image modified from the Reconstruction Agency)

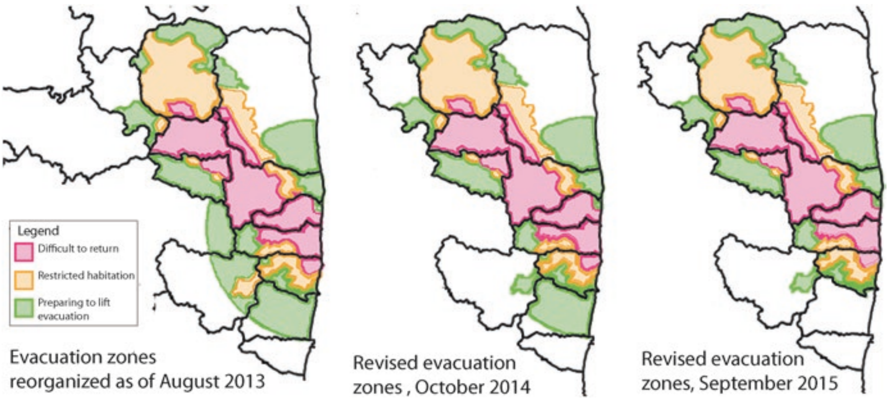

Fig. 13.4 Revision of evacuation zones from Aug. 2013, Oct. 2014, and Sept. 2015 (Images created based on information from the Reconstruction Agency)

orders were lifted in the remaining "preparing to lift evacuation" areas of Kawauchi Village and for all of Katsurao Village, which had also included several small "restricted habitation" zones. This was followed 1 month later in July 2016, by the lifting of the evacuation order for all of Minami Soma, which affected 10,000 residents, the largest number yet, including large areas of "restricted habitation" (Kim 2016, Asahi Shimbun 2016a, 2016b).

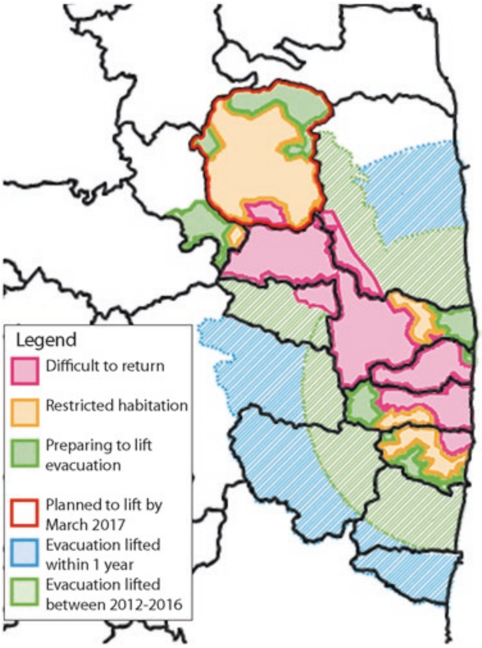

Fig. 13.5 Current evacuation status as of July 2016, including areas where evacuation orders have been lifted, and areas (Iitate Village) where they are planned to be lifted by March 2017 (Images created from information from Fukushima Prefecture and the Reconstruction Agency)

The government is pushing forward to accelerate lifting the evacuation orders for all but the most contaminated "difficult to return" areas, including plans to lift the order for most of Iitate Village by March 2017 (Fig. 13.5), the end of the 2016–2017 fiscal year, which coincides with the planned completion of decontamination efforts 6 years after the disaster (Fukushima Prefecture 2016a). However, even after they are permitted to return, only a small fraction of primarily elderly residents do (Funakoshi 2016; Flores 2016). Not only are people (especially young families) hesitant to return to areas with radioactive contamination, but also services and facilities are limited, and over several years' people have reestablished their lives in other places. The designation of evacuation zones, and subsequent lifting of this designation, is also tied to compensation and other support for nuclear evacuees, as are the categories of mandatory/voluntary evacuees discussed in the following sections.

13.2.2 Different Categories and Support for 'Mandatory' vs. So-called 'Voluntary' Evacuees

Since the initial chaotic days in March 2011, people made various evacuation decisions based on information they had, with or without directives from local or national government bodies.[2] In the following months, new officially designated "safe" levels

[2] The phrase 'so-called "voluntary"' evacuees is used intentionally to emphasize the critical distinction in this terminology; whereas referred to as voluntary evacuees, this title is in itself misleading. The use of "so-called voluntary" or quote "voluntary" evacuees is common practice among

of radiation were established, which became the basis for the categorization of evacuation zones described earlier; these zones in turn have led to a critical yet misleading distinction between groups of people referred to as (official) "evacuees" or "voluntary evacuees" (Mosneaga 2015; Tomoyasu et al. 2015; Mainichi Shimbun 2015; Maly et al. 2015; Maly 2016). Those in the first category are from areas (still) included in the official evacuation designation; those in the second category are not. The term "voluntary" evacuees is misleading (Tomoyasu et al. 2015; Hasegawa 2015), as the choice to evacuate was not made lightly and not a strictly voluntary one—rather a decision to avoid living in a place potentially hazardous for their family's health.

Policies for government housing support and compensation differ for (official) 'mandatory' and 'voluntary' evacuees. Compensation payments, actually financed by the Japanese government since TEPCO came under state control in 2012 (Inajima and Okada 2012), vary according to the level of contamination and other factors; 'mandatory' evacuees receive monthly compensation payments while 'voluntary' evacuees received a one-time payment to support relocation expenses (Mosneaga 2015). Linked to the designation of a mandatory evacuation zone, compensation payments will end after the evacuation order is lifted in the respective area.

13.3 The Context and Evolution of Housing Recovery Policy in Japan

The large scale displacement and long term evacuation from nuclear contamination after 3.11 are unprecedented in Japan. Some current government programs supporting housing reconstruction and community recovery have been newly created as attempts to address these challenges. However, current policies are closely connected to established recovery precedents after past (natural) disasters. Japan's current legal framework for assisting disaster survivors has been in place since the 1960s and has been revised after subsequent natural disasters to provide increased support for individual housing recovery (Maly and Shiozaki 2012; Maly 2014; Iuchi et al. 2015).

13.3.1 Temporary Housing Support

Although similar, temporary housing support has varied between tsunami and nuclear evacuees, and mandatory and "voluntary" evacuees, and some gaps have emerged 5 years after 3.11. Earthquake and tsunami survivors, and mandatory and voluntary evacuees, have been able to receive temporary housing support in the form of the use of pre-fabricated temporary housing units, available public housing units, or private apartments whose rent is paid through the 'designated' temporary housing program. Japanese law stipulates temporary housing should be provided for

scholars and authors writing about displacement and Fukushima, including Hasegawa (2015), Mosneaga (2015), Tomoyasu et al. (2015), Mainichi Shimbun (2015), Maly et al. (2015), and Maly (2016).

2 years' use; after several 1-year extensions, in 2015 this was extended until the end of March 2017. Along with the planned lifting of evacuation orders for all but the "difficult to return" zones in Fukushima by March 2018, on July 15 2016 it was decided to extend temporary housing support to *mandatory evacuees* for 1 more year, until March 2018 (Fukushima Minpo 2016). Temporary housing support to voluntary evacuees is scheduled to end in March 2017. After the temporary housing phase, Japanese policies provide permanent housing support to disaster survivors, discussed in following sections. However, only mandatory evacuees will be eligible (Fukushima Minpo 2016).

13.4 Japanese Precedents for Post-disaster Permanent Housing Recovery

The Great Hanshin Awaji Earthquake, which struck the urban area of Kobe City in the early morning of January 17, 1995, was the largest natural disaster in Japan post-World War II, until 2011. In residential areas, many fires (cause by electrical wires/appliances, gas, or kerosene) that broke out could not be extinguished because of lack of water and access for fire trucks, and devastated large areas of low-rise wooden housing. Housing reconstruction in Kobe focused on the provision of public housing for disaster survivors, and reconstruction of individual houses was up to residents themselves (Hirayama 2000). Along with targeted urban redevelopment projects, reconstruction projects in Kobe created wider roads and infrastructure in disaster damaged areas by using land readjustment projects, in which some land within the project area is exchanged or given up by property owners. As most temporary housing and then public housing was built in areas outside of the center of Kobe City, many survivors who moved into government supported public housing moved away from former neighborhoods (Hirayama 2000). With limited support for individual rebuilding of private homes, some survivors who could not rebuild on their own were not able to move back to their former neighborhoods. However, including redevelopment projects, as post-earthquake reconstruction, most housing recovery took the form of on-site reconstruction.

Almost 10 years later, the 6.8 magnitude Chuetsu Earthquake struck a rural mountainous area of Niigata Prefecture on October 23, 2004; resulting landslides caused heavy damage to area villages. After Kobe's recovery, laws had been revised to allow more support for reconstruction of private homes. In Chuetsu, recovery also used the Collective Relocation for Disaster Mitigation program (Iuchi 2010) to move residents away from areas at risk of landslide, including acquisition of former land (designated hazardous) and provision of new land for rebuilding. In Chuetsu, this program was used for the small-scale relocation of communities; newly created residential areas included lots for rebuilding homes, as well as construction of single family public housing.

13.4.1 Housing Recovery Policy and Projects After 3.11 in Tohoku

After the Great East Japan Earthquake, recovery policies and programs were developed for implementation in municipalities throughout the disaster-affected region of Tohoku. Along with the establishment of the national Reconstruction Agency (http://reconstruction.go.jp/english), the government announced a menu of 40 recovery projects that would be funded by the Japanese government (Iuchi et al. 2015). Although the role of the Reconstruction Agency was to coordinate recovery after the GEJE, each affected municipality has the responsibility to create their town's recovery plan. In Japan, local governments have the primary responsibility for disaster response as well as disaster recovery planning.[3]

Although they received support from other local and regional governments, local municipalities faced challenges to create their recovery plans. From the menu of recovery project options presented by the national government (Reconstruction Agency), most towns' plans include collective relocation, land readjustment, and the construction of public housing as the major projects supporting housing recovery. Similar to the Chuetsu Earthquake 7 years earlier, Collective Relocation for Disaster Mitigation was used to move residents to high land areas in tsunami affected Tohoku municipalities, including the designation and acquisition of former land area (tsunami inundated) as 'hazardous' (rebuilding is forbidden), and the provision and development of new lots (rented or purchased) for residential rebuilding in new high land areas. Many high land relocation areas include single-family public housing and lots for private rebuilding.

Public housing in Japan is rental housing and government-subsidized based on income. As after past disasters, the provision of Disaster Recovery Public Housing is a primary support for housing recovery in Tohoku. All tsunami-affected households are eligible for Disaster Recovery Public Housing; after an initial subsidized period of several years, future rent will be based on household income. Public housing includes both single-family detached houses and multi-family apartment–style buildings.

[3] Although Japan has a Cabinet (national) level Disaster Management Council, and prefectural level Disaster Management Councils, these structures primarily function to support disaster management at the municipal level. Unlike other countries such as the United States, where the Federal Emergency Management Agency (FEMA) functions as a professional emergency response agency, disaster response in Japan is coordinated at the local level, with support from other emergency workers and backup from higher levels of government if needed.

13.4.2 Recovery Planning in Fukushima Towns

Although Fukushima[4] has become known around the world because of the nuclear meltdown at the Daiichi NPP, towns within Fukushima Prefecture also suffered earthquake and tsunami damage, and each town's situation and challenges are unique. Some towns outside of radioactive contamination areas have communities that were damaged by tsunami, some coastal towns near the NPP had both tsunami damage and heavy radioactive contamination in overlapping or different areas, and some inland towns without tsunami damage have various levels of radioactive contamination. Residents' individual and household situations also vary greatly. As a backdrop to individual household decisions about where to move, how long to stay, if and when to return to areas (where, and when allowed), there are various recovery policies and programs available based on location, level of radioactive contamination, and type of disaster damage (Maly et al. 2015; Suzuki 2015).

Towns in Fukushima that had tsunami damage can use the same menu of recovery projects available to municipalities throughout the tsunami-affected region of Tohoku, such as Collective Relocation projects and the construction of Disaster Recovery Public Housing. As was the case after previous disasters in Kobe and Chuetsu, in these disaster recovery projects implemented in municipalities throughout the Tohoku region, all residential relocation *occurs within the same municipality*. With control of recovery customarily at the local level, laws and policies guiding recovery support are based on *natural* disaster events, premised on return to former communities, and the implementation of 'hometown' recovery (Maly 2016; Maly et al. 2015; Suzuki 2015). Towards this goal, temporary housing is intended as short term support for evacuees until they once again return to their hometowns (Maly et al. 2015; Suzuki 2015). However, for communities with high levels of radioactive contamination (Fukushima Prefecture 2016a) and facing long term displacement and uncertain futures (Maly et al. 2015), this one-way path towards 'hometown' recovery does not match the reality of residents' actual lives and needs (Maly 2016). Support for many people living outside former towns throughout Fukushima Prefecture and Japan requires additional coordination at the prefectural and national levels, including the provision of housing and other services for residents.

As the 3.11 triple disaster affected a wide area, national level policies for the provision of temporary housing, implemented at the prefectural level, were made to support evacuees displaced throughout Japan. After previous natural disasters, temporary housing has been mainly provided in the form of newly constructed prefabricated housing units; this kind of newly built temporary housing was also used after 3.11, including prefabricated as well as wooden construction. However, after 3.11 more households used the system of "designated temporary housing", in which the government pays rent for survivors to use private apartments as temporary housing;

[4] In international media, "Fukushima" is often mistakenly used to describe the entire Great East Japan Earthquake and tsunami disaster of 3.11—the actual situation and affected areas of Tohoku are actually much more varied and include several other prefectures and many other disaster-affected towns.

available apartments in public housing were also made available (Shiozaki, Chap. 11 this volume). Although 'designated' temporary housing presents challenges for implementation and provision of services, it allowed for more flexibility for evacuees to make their own housing choices. For evacuees from Fukushima, these kinds of temporary housing available to all disaster survivors across Japan after 3.11 helped support their lives outside their hometowns or prefecture. However, as discussed earlier, the planned end of temporary housing support is an issue of concern, especially for 'voluntary evacuees' (Mosneaga 2015).

The provision of Disaster Recovery Public Housing is coordinated by prefectures and municipalities; throughout the tsunami-affected Tohoku region, these housing units are built in new areas within former towns, for the residents of that town. In Fukushima Prefecture, close to 3000 units of this "Disaster Public Housing," for earthquake and tsunami survivors are being constructed in tsunami-affected municipalities; the majority has been completed by 2016. In an example of coordination at the prefectural level, Fukushima Prefecture is also providing close to 5000 units of "Recovery Public Housing" throughout the prefecture for nuclear evacuees outside of their former hometowns (Fukushima Prefecture 2016b).

13.5 Wicked Problems and Unanswerable Questions

Residents and communities affected by radioactive contamination, along with leaders and policy-makers, are facing issues that are not just massive, complex, and unprecedented. They are also unresolvable. Indeed, they represent a puzzling reality or 'wicked problem.' As explained by Kolko:

> A wicked problem is a social or cultural problem that is difficult or impossible to solve for as many as four reasons: incomplete or contradictory knowledge, the number of people and opinions involved, the large economic burden, and the interconnected nature of these problems with other problems. (Kolko 2012)

In Fukushima, finding solutions to support the life recovery of nuclear evacuees is difficult for all four of these reasons: (1) *Incomplete or contradictory knowledge* about the future impact of radiation, how long and what it will actually take to fully decommission the failed reactors; (2) the *large number of people* involved have drastically different opinions about whether or not to return, or what kind of support is needed in former communities or current living places; (3) the extent of the *economic burden,* from TEPCO—actually from the national budget since the TEPCO was nationalized—(Inajima and Okada 2012)—but moreover for the unknown costs of long term decommissioning and decontamination; and (4) these problems (as well as issues of health and welfare, livelihood, life recovery and community-building, not to mention people's individual decision-making process) are completely interconnected.

Towns affected by contamination are facing incredibly difficult situations and impossible decisions. Within the Japanese established policy precedent of 'hometown recovery,' questions include the following. How should leaders/local officials of contaminated towns think about their future? How and what should they communicate to residents who are dispersed and scattered? How should they address various needs and divergent desires of residents—some who never want to return, some who want to return as soon as possible? As mentioned earlier, the main responsibility for recovery planning rests at the municipal level. Even if a conclusion was reached that a town was uninhabitable, it is hard to imagine a town mayor dissolving the town itself. Towns in exclusion zone have established "branch offices" within city halls of host municipalities where evacuees are living, which is an unprecedented yet temporary solution. Local town recovery plans call for supporting the lives of disaster survivors wherever they are living; at the same time, plans must also include future visions for former towns.

For years, Japan has been facing a low birth rate and shrinking population; Tohoku's rate of aging is even higher than the national average, and the region was already losing population before 2011 (Hino 2011), as young people move away to urban areas. In this context, future viability of contaminated towns is highly questionable, as young families will not return as long as there is a chance that radiation could harm their children, even if official measurements are "safe." On the other hand, there are also residents who want to return to their hometowns as soon as possible, especially elderly (Funakoshi 2016) for whom exposure to radiation is unlikely to have any effect in their lifetime.

Decisions about lifting evacuation orders, of residents *becoming able to return,* are also directly connected to the end of other benefits, such as temporary housing support or compensation from TEPCO, as mentioned earlier. Therefore, these decisions and residents' feelings about them are entangled with not only fears of radiation, but also issues of loss of compensation and support for daily life. TEPCO compensation amounts vary based on residents' former home, livelihood, and family size, and the process to apply for this compensation has been criticized for being extremely complicated and difficult to navigate. Although the amount of compensation is not small, it is also not a long-term solution. Compensation has led to conflicts between residents because of disparities, and also resentment towards recipients on the part of non-recipients, as has been reported in places such as Iwaki City, one of the largest municipalities in the coastal area outside the contaminated area where many nuclear evacuees moved. Some Iwaki residents resent the fact that nuclear evacuees are living for free in Iwaki and are able to purchase property using their compensation money, thus also driving up local land costs (Saito and Slodkowski 2014; Fukushima on the Globe 2014; Kawazoe 2014).

For nuclear evacuees, displaced from their homes for long/unknown lengths of time, compensation is justified as just that—compensation for damages and disruption to their lives; furthermore, these funds are needed to support daily life needs. Although some survivors were able to use their compensation money to purchase new housing, compensation payments are a stop-gap measure and not a long term solution to support community and life recovery. Compensation should be adequate to support evacuees' needs, the issue of compensation is more than a question of the appropriate amount but rather the intrinsic difficultly of putting a price on the loss of home and livelihood, and destruction of culture and community.

13.6 Conclusion: Where Do We Go from Here?

With the understanding that the question of how to support Fukushima residents and long term life recovery of nuclear evacuees may be part of a *wicked problem*, one of the characteristics identified by Horst Rittel may offer a direction, as follows:

> Solutions to wicked problems can be only good or bad, not true or false. There is no idealized end state to arrive at, and so approaches to wicked problems should be tractable ways to improve a situation rather than solve it. (Rittel 1973)

Unlike an earthquake or tsunami, a nuclear accident is a man-made disaster, caused by and resulting from a number of failures or mistakes made by individuals, including corporate and government representatives. The nuclear meltdown at Fukushima Daiichi has resulted in an area where people cannot live, and long term displacement from communities, which have been forever altered. These wrongs cannot be righted; what has been lost can never be restored. This situation cannot be solved, but as a developed society there is a moral obligation to try to improve it, to guarantee the human rights of nuclear evacuees, and improve their lives on the path toward long term life recovery.

Five years have already passed since the tsunami and nuclear meltdown, and looking forward, issues of long term displacement are unavoidable. Current issues of displacement exceed Japanese precedents and disaster recovery policies that focus on hometown recovery, and compensation payments are not a long term solution. In this context, it is important to remember that disaster survivors are guaranteed human rights based on international standards. The United Nations Inter-Agency Standing Committee's Operational Guidelines on Human Rights and Natural Disasters (IASC Guidelines) emphasize that disaster survivors retain their human rights even in displacement (IASC 2010). As Gould (2009) explains, supported by these international documents, both health and housing should be considered as matters of rights for those affected by disaster. A framework based on human rights and human dignity, with a dual focus on the rights of evacuees as IDPs (Internally Displaced Persons) and their rights for health should be a baseline towards guaranteeing an improvement in the situation for nuclear evacuees from Fukushima. Until now, nuclear evacuees in Japan have rarely been recognized as IDPs (Hasegawa 2015), and correspondingly they have also been denied rights they are entitled to according to international guidelines. The following section considers the implications of this international human rights framework for Fukushima evacuees.

13.6.1 The Rights of Internally Displaced Persons (IDPs)

The United Nations Guidelines defines Internally Displaced Persons (IDPs) as follows:

> Persons or groups of persons who have been forced or obliged to flee or to leave their homes or places of habitual residence, in particular as a result of or in order to avoid the effects of armed conflict, situations of generalized violence, violations of human rights or natural or human-made disasters, and who have not crossed an internationally recognized State border. (UN 1998)

Evacuees from Fukushima were indeed 'obliged to leave their homes' to 'avoid the effects of natural or human-made disasters.' In fact, all people who evacuated from tsunami-affected areas within Japan can also be considered temporary IDPs; those facing long term displacement from Fukushima continue to be IDPs. As opposed to refugees, who cross international borders to escape conflict or disasters, IDPs leave their homes but stay within the borders of their country—exactly the situation of nuclear evacuees from Fukushima.

However, since the framework for IDPs is usually applied to developing countries, addressing the issue of IDPs has been especially difficult in developed countries such as Japan (Hasegawa 2015), as national governments feel confident that they can handle the situation on their own, and international organizations are hesitant to get involved.[5] This was also the case after Hurricane Katrina in the United States in 2005, marking perhaps the first time that significant efforts (US Human Rights Network 2016) were made to apply the globally emerging framework of IDPs to a developed country. In post-Katrina New Orleans, this human rights framework based on principles of the rights of IDPs focused on evacuees' Right to Return (Amnesty International 2009, 2010; Buckner 2007). In terms of nuclear disaster precedents, 25 years before the meltdown at Fukushima Daiichi NPP, people living near Chernobyl suffered from the exposure caused by that nuclear catastrophe in April 1986. Although there was early evacuation for some close by areas, without dissemination of accurate information and lacking a long term resettlement plan, it can be said that the human rights of Chernobyl victims were not protected (Meybatyan 2014). Five years after the meltdown the disintegration of the USSR and resulting transition made the situation of Chernobyl and responsibility for the affected people more complex (Meybatyan 2014). As the concept of IDPs did not become firmly established until the 1990s, it was not widely applied to people affected by Chernobyl.

As Hasegawa points out, officially recognizing evacuees from Fukushima as IDPs would go a long way to ensuring their rights are met and support their ability to advocate for themselves effectively (Hasegawa 2015; Hasegawa 2016). As IDPs,

[5] This situation parallels that of international involvement in emergency relief post-disaster—wealthier countries often chose to reject offers of international aid, and rarely engage in international humanitarian channels to request aid. The underlying principle (which the author does not support) is that international aid, as well as international humanitarian/human rights standards, are to be applied *by* certain (*developed*) countries *to* certain (*developing*) countries.

evacuees should have the right to have 'durable solutions' for housing, which according to IASC guidelines means that they either 'return,' or achieve 'local integration' or 'resettlement;' to be considered "sustainable, each settlement option has to respect the right of IDPs to decide for themselves" (Mosneaga et al. 2016). Currently, it can not be said that nuclear evacuees from Fukushima have these rights, especially looking forward to April 2017, when the elimination of housing support may leave few choices and many people may be forced to return to still contaminated towns. Related to housing options, Hasegawa points out that there should be more and flexible options, as compared to the current artificial dichotomy between "return" and "not return," and calls for proposing "local integration and resettlement on equal terms with return" (Hasegawa 2015). The bottom line is there should be equal support for other options and long term resettlement—and no evacuee should be forced to return to affected areas.

13.6.2 The Right to Health

In 2012, the UN Special Rapporteur on the right to health visited Fukushima and issued a report with a series of recommendations to improve the situation related to human rights for health. Echoing the importance and need for evacuees' input in decisions as mentioned above, the Special Rapporteur was also concerned that the voices of affected people had not been included in decision-making, emphasizing that the right to health framework requires that "the affected people in Japan need to be part of the decision-making process as well as of the implementation, monitoring and accountability procedures" (UN News Center 2012).

Five years after the 3.11 triple disaster, there are two main issues related to the health of evacuees looking forward towards long term recovery. First of all, there are still unknown long-term health impacts from exposure to radiation, and the continued provision of health monitoring and health care to the affected people over the course of the long term process of life recovery will be needed for many years to come. Whereas the impact of low-impact radiation is not well known, the acceptable guidelines for exposure to radiation were raised. A related policy suggestion would be to "incorporate the existence of scientific controversies on low-dose radiation effects into policymaking and communications" (Hasegawa 2015), which would be more accountable to residents' experiences.

Secondly, the issue of "secondary" deaths after 3.11 is a critical concern, combined with related lessons from previous disasters. The Japanese government recognizes "secondary" death, or deaths of people who passed away because of indirect impacts of the disaster. Of the 3472 people whose deaths have been recognized as *kanrenshi* as of March, 2016, 1837 of the 2038 people from Fukushima Prefecture were over 66 years old (Reconstruction Agency 2016b), suggesting that for Fukushima residents and especially the elderly, the impact of evacuation and life in the years after 3.11 has had a large negative effect on their health.

A related issue is that of "solitary death" or *kadokushi* in Japanese, a well-known phenomenon since the Great Hanshin-Awaji Earthquake in Kobe City 20 years ago. In Kobe, housing recovery support mainly took the form of construction of high-rise subsidized public housing apartments, an unfamiliar living environment for the mainly elderly survivors who had lived in low-rise housing integrated into the local community before the quake. Starting with the displacement from their former communities into massive settlements of pre-fabricated temporary housing, and continuing after moving into public housing in high-rise apartment buildings, the number of *kadokushi* continued to rise. With the literal translation of "solitary death"—meaning the person passed away without anyone to notice their absence—the existence of *kadokushi* speaks to the impact of the post-disaster living environment on people's mental and physical health. Whereas the definition of *kadokushi* is an unnoticed death, the reality includes larger and often more tragic contexts, such as people suffering from depression, alcoholism, and including cases of suicide.

13.6.3 Human Rights, Housing, Recovery and Displacement

Based on the experience and knowledge from the past 5 years as well as from past disasters, the importance and multiple connections between health and housing can be identified as a key factor for supporting the human rights of disaster survivors, and identifying priorities for supporting long term life recovery. Beyond the direct disaster impact, the stress and pressures of long term evacuation and uncertainty can have serious impacts on survivors. Supported by various human rights guidelines and legal decisions, the rights of all evacuees, including so-called 'voluntary' evacuees, to have a say and be in charge of making their own recovery decisions is crucial.

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Part IV
The Environment: Research, Damage and Recovery

Chapter 14
Restoration Measures After the 2011 Tohoku-oki Tsunami and Their Impact on Tsunami Research

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Abstract Following the 2011 Tohoku-oki tsunami, many studies were carried out to provide insights into processes involved with this event, as well as to assess its impact on the landscape and the environment, evaluate the evidence that was left behind and how it changed with time. Much can be learned from analogues of events that have occurred in the past, the study of which providing information that is required to improve hazard preparedness. This can best be achieved if deposits of the latest tsunami and any previous events have been left undisturbed. On the other hand, restoration measures needed to be implemented shortly after the 2011 tsunami, in order to allow operations of vital infrastructures and agricultural activities to resume. While these measures are required for social and economic reasons, they are unfortunately in conflict with tsunami research, as they have led to the loss of the 2011 and even older deposits in many areas. As such, much of the geological record is missing in a number of places. A few case studies are presented in this chapter, with an emphasis on the area north of Sendai airport in the Miyagi Prefecture. There

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V. Santiago-Fandiño et al. (eds.), *The 2011 Japan Earthquake and Tsunami: Reconstruction and Restoration*, Advances in Natural and Technological Hazards Research 47, DOI 10.1007/978-3-319-58691-5_14

we show how a study focussing on the temporal changes and preservation potential of the tsunami deposit and associated chemical signatures was affected by restoration measures. Further examples from the Miyagi, Iwate and Fukushima Prefectures are also briefly presented.

Keywords 2011 Tohoku-oki tsunami • Restoration • Anthropogenic disturbance • Preservation potential • Tsunami deposit • Geological record

14.1 Introduction and Background

Recent tsunamis, while devastating, have however also provided a unique opportunity for researchers to study them as analogues for older events, and thereby to gain a better understanding of the processes involved. The knowledge acquired through these studies can help improve hazard mitigation measures and tsunami preparedness. One of these events was the Tohoku-oki tsunami, which was generated by a M9.0 megathrust earthquake on 11 March 2011, and impacted hundreds of km of coastal land on the Pacific Coast of Honshu and Hokkaido Islands in Japan (Fig. 14.1a) (e.g. Mori et al. 2012) but also elsewhere in the Pacific (e.g. Dunbar et al. 2011).

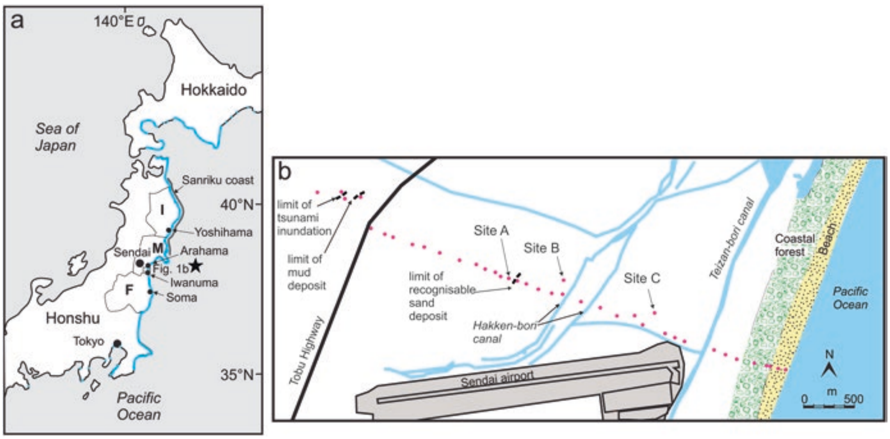

Fig. 14.1 (**a**) Map of Honshu and Hokkaido Islands, Japan. The star marks the epicentre of the 11 March 2011 Earthquake. The coastal areas affected by the tsunami are marked with a *thick blue line* (based on Mori et al. 2012). The locations of the map in **b** near Sendai airport, as well as of other sites discussed in the text (Yoshihama, Arahama, Iwanuma, Soma) are shown. The extent of the Sanriku coast is marked with a *grey thick line*; I, M and F indicate Iwate, Miyagi and Fukushima Prefectures, respectively. (**b**) Detail of study area where post-depositional changes were described and assessed following the 2011 Tohoku-oki tsunami. Every *pink dot* on the shore-perpendicular transect indicates a sampling site, as reported by Chagué-Goff et al. (2012a, b). The limits of the recognisable sand deposit (>0.5 cm thickness), mud deposit and tsunami inundation, are also shown

Extensive research has been carried out, mostly in Japan, not only immediately after the event, but also in following years. Many studies have aimed to assess the impact of tsunami inundation on land, water, agriculture, people and infrastructure, as well as evaluate the recovery process. Some have focussed on offshore deposits and the impact on the offshore environment. Much work has also been carried out to search for further evidence of historical and prehistorical tsunamis, and thereby extend the geological record both temporally and spatially. This will help refine the recurrence interval of large events, as well as the extent of their impact, and can therefore provide a better understanding of tsunami hazard and risk for the region.

Geological studies rely most often on the preservation of the sedimentological evidence of old events, although geochemical and/or microfossil evidence is also increasingly being recognised as a valuable tool (e.g. Chagué-Goff 2010; Pilarczyk et al. 2014; Dura et al. 2016; Chagué-Goff et al. 2017). Event signatures are however affected by post-depositional changes. It should be noted that while these not only affect onshore deposits, but also offshore deposits, the latter are not discussed in this paper that focusses on research dealing with onshore deposits and impact of post-tsunami restoration.

The effects of post-depositional changes on tsunami deposits have recently been reported in tropical (e.g. Thailand following the 2004 Indian Ocean Tsunami: Szczuciński et al. 2007; Goto et al. 2012b; Szczuciński 2012), arid (e.g. Peru following events in 1996, 2001 and 2007: Spiske et al. 2013) and temperate/arid climates (e.g. Chile following the 2010 Maule tsunami: Bahlburg and Spiske 2015; Chagué-Goff et al. 2015). The preservation potential of the 2011 Tohoku-oki tsunami deposits in a temperate climate is also being assessed (e.g. Chagué-Goff et al. 2012a, b, 2014; Shinozaki et al. 2016). The knowledge gained from follow-up studies can be applied to palaeotsunami research, in order to better define the estimated extent and magnitude of precursor events. While coastal areas of Japan have been impacted by multiple large tsunamis in historical times (e.g. Goto et al. 2012a; Garrett et al. 2016), and palaeotsunami research has been ongoing for decades, it appears that it is the first event which has led to studies investigating post-depositional changes affecting its deposits.

Tsunami researchers are well aware that deposits are more likely to be better preserved in low-lying coastal wetland, lagoon or lacustrine environments, because these quiescent ecosystems not only provide enough accommodation space, but are less likely to be subjected to anthropogenic disturbance (e.g. Goff and Chagué-Goff 1999). It does not preclude natural post-depositional processes, including rainfall, bioturbation, aeolian action, or even erosion due to storm or tsunami. Indeed, the loss of up to 1100-year of the geological record by the 2011 tsunami in a coastal lake has been reported by Shinozaki et al. (2015). Nevertheless, this is usually the best place to look for undisturbed tsunami deposits. The Sendai Plain with its low-lying flat topography, as well as many low-lying valleys in the Sanriku region further north, although of limited extent, offer such optimal settings for the preservation of tsunami deposits. However, as in most countries around the globe, pressure due to increase in population and demand for more available agricultural and habitable land has over time resulted in disturbance and loss of these wetland and lagoon ecosystems. Many have been drained and converted to rice paddy fields and/or urban/industrial areas, as observed on the Sendai Plain and Sanriku region (even before the 2011 tsunami). Thus, areas where the geological evidence of past tsunamis is preserved are more limited.

The Sendai region has been severely affected by two or possibly three large historical tsunamis prior to the 2011 Tohoku-oki tsunami: the 869 AD Jogan tsunami, which is considered the predecessor of the 2011 event (e.g. Minoura et al. 2001; Goto et al. 2012a), the 1454 AD Kyotoku tsunami (Sawai et al. 2015) and/or the 1611AD Keicho tsunami (Goto et al. 2012a). Much research has been and is still being carried out to search for their geological evidence and spatial extent.

The 869 AD Jogan tsunami deposit, which is fairly easily identifiable as it is often only separated from the overlying 915 AD Towada-a tephra by a thin peat layer, can still be found in many locations on the Sendai Plain (e.g. Minoura et al. 2001; Sawai et al. 2008; Sugawara et al. 2011), despite its occurrence at shallow depth, often about 50 cm or less. This is remarkable, as rice paddy fields dominate the Sendai Plain, but also possible, because paddy fields are shallow and do not require deep ploughing (e.g. Wopereis et al. 1992). Nevertheless, before the development of modern, geometrically-arranged rice paddies, which occurred much earlier than 2011, undulated fields were flattened to acquire better aqueous distribution and drainage systems. Surficial soils were moved from one place to another. Thus, the disturbance of surficial sediments is partly responsible for the discontinuous nature of the Towada-a tephra and the Jogan tsunami deposit in places (Sugawara et al. 2010).

The possible 1454AD Kyotoku and 1611AD Keicho tsunami deposits on the other hand, are only rarely found on the Sendai Plain. In fact, Sawai et al. (2015) suggest that no definitive evidence of the 1611AD tsunami deposit has been reported so far and that what is believed to be evidence for the 1611AD event might be that of the 1454AD Kyotoku tsunami. The extent of these possible two events was maybe also more limited than the 869AD Jogan and if the deposit was thin (only a few cm thick), then bioturbation and pedogenesis could have resulted in its loss, as also observed elsewhere (e.g. Szczuciński 2012; Chagué-Goff et al. 2015). The deposit is probably shallower and thus is more likely to have been disturbed through agricultural practices. The 1611AD Keicho tsunami happened in the early stage of the Edo Period, when the Sendai Plain region was developed as large-scale rice paddy fields (e.g. Ebina 2014). Therefore, the tsunami deposit might have been removed in many places. The early stages of the Edo Period also saw the planting of coastal forest and the construction of artificial canals, including the Teizan-bori canal. Much of this coastal forest was destroyed by the 2011 tsunami, while much waste filled the Teizan-bori canal, whose banks were also damaged by the tsunami.

Following the 2011 Tohoku-oki tsunami, restoration measures were fairly quickly implemented, in particular in areas that had been less affected by tsunami inundation and/or that required a rapid return to operation, such as Sendai airport for example. They occurred within a few weeks to months in areas near the tsunami inundation limit in order to be able to resume agricultural activities and within a few years in other areas to remove the sand blanketing many areas of the Sendai Plain and the low-lying reaches of valleys, and reduce salinisation of the soil (e.g. Nakai et al. 2015). The restoration effort followed guidelines provided in July 2011 by the

Japanese Ministry of Agriculture, Forestry and Fisheries of Japan (MAFF) for salt removal from farmlands, including reference concentrations of chloride for crops, maintenance of drainage systems, removal of tsunami deposits, dispersal of calcareous matter, salt flushing and ploughing (MAFF 2011).

Japan is unfortunately often affected by natural disasters (e.g. earthquakes, tsunamis, landslides, typhoons, floods) that generate a lot of ‘disaster’ waste. Thus, there are also guidelines for countermeasures and also countermeasures in place for the treatment of disaster waste (Disaster Waste Management Information Site (DWMIS) 2016). Based on DWMIS (2016), the 2011 earthquake and tsunami resulted in about 31 million tonnes of disaster waste across six prefectures, including houses that were demolished. Of this, 10.6 million tonnes were classified as ‘tsunami disaster waste (tsunami deposit)’ that included sandy and muddy sediment brought in by the tsunami, but also waste material mixed with it, such as paper, concrete, plastic, wood, metal and oil (DWMIS 2016). In March 2015, 99 % of the tsunami deposits had been transported and treated, with 100 % from the Miyagi and Iwate Prefectures, but only 48 % from the Fukushima Prefecture. It is also worth noting that 99 % of the ‘tsunami deposits’ have been recycled and have been used for the recovery construction efforts (DWMIS 2016). One example is the “Millennium Hope Hills’, in Iwanuma, south of Sendai airport (Fig. 14.1a), which consist of a memorial for the victims of the 2011 earthquake and tsunami but also artificial hills made using recycled concrete debris and tsunami rubble and sediment. These hills, which are being replanted, can, together with the newly built seawall, help slow down the energy of any future tsunami waves, and can also serve as evacuation areas (Fig. 14.2). The average cost of transport and treatment for the disaster waste, including ‘tsunami deposit’, has been estimated at 37,000 JPY per tonne (equivalent of approximately 364 US$ or 325 Euros). This however also

Fig. 14.2 Millennium Hope Hills, Iwanuma, Miyagi Prefecture (see Fig. 14.1a for location). (**a**) Artificial hill built with recycled concrete debris and rubble from the earthquake and tsunami. The hill can also serve as evacuation area (the top is 11 m above mean sea level). The *black arrow* on the *left points* to the sign indicating the height of the 2011 tsunami (Photo Kazuhisa Goto); (**b**) Plaque *at the bottom* of the hill showing the design of the hills and indicating that they were constructed using tsunami disaster waste, including concrete debris and tsunami deposits (Photo Catherine Chagué-Goff)

means that almost all the 2011 tsunami deposit in the Iwate and Miyagi prefectures has been completely removed, and with it any geological evidence of the event.

While it is acknowledged that restoration is necessary after such a devastating event, and that it is important for social and economic reasons to return to pre-disaster conditions, if possible, and re-establish land conditions suitable for farming and living, this is unfortunately in conflict with tsunami research. Researchers attempt to learn not only from the tsunami itself, but also the recovery process and post-depositional effects on tsunami deposits, to better understand processes that affected historical and prehistorical deposits and that might prevent or complicate their identification in the geological record. Post 2011, much effort has also been devoted to improve the record of past tsunamis, and in particular their spatial extent in the region, in order to gain a better understanding of the recurrence intervals and also magnitudes of these events. While many studies were carried out in the 2 years following the tsunami, there is still a need to further this research. As described below, this effort has been somewhat hampered by restoration measures. Here we report on a few examples on the Sendai Plain, Sanriku region and Fukushima Prefecture, where remediation measures led to loss of the geological evidence.

14.2 Case Studies

14.2.1 Case Study 1: Transect Near Sendai Airport, Miyagi Prefecture

A post-tsunami survey was carried out in May 2011 along a shore-perpendicular transect north of Sendai airport, Sendai Plain, that extended about 5 km inland (Goto et al. 2011). Samples were collected every 50 m or 100 m along the transect (Fig. 14.1b), and analysed for sedimentological characteristics, heavy minerals, diatoms, nannoliths, foraminifera, magnetic fabric and geochemical signatures including salts, inorganic elements and stable isotopes (Chagué-Goff et al. 2012a, b; Jagodziński et al. 2012; Pilarczyk et al. 2012; Richmond et al. 2012; Schneider et al. 2014; Szczuciński et al. 2012). Inverse and forward modelling were also conducted using data from that transect as a basis (Jaffe et al. 2012; Sugawara and Goto 2012). While most studies were conducted based on the survey carried out in May 2011, changes in water-leachable ions were measured over time to assess the environmental impact of tsunami inundation (Chagué-Goff et al. 2012b) and effects of salinisation on rice production (Chagué-Goff et al. 2014). Chagué-Goff et al. (2012a) also investigated the short-term changes in the chemical composition of various sediment types between May and October 2011, and concluded that chemical signatures were likely to be better preserved in fine-grained organic-rich sediment. Further study has been carried out, with repeat sampling and analysis over the years, to gain a better understanding of the preservation potential of chemical markers in a temperate climate, with implications for palaeotsunami research.

While the research was conducted on one single shore-perpendicular transect, it included various geomorphic and sedimentological settings, including a beach, coastal forest and low-lying land, with a deposit ranging from sand to mud (e.g. Goto et al. 2011; Richmond et al. 2012). This site represented a unique natural laboratory for examining the longevity of chemical signatures, due to the variety of settings encountered. The low-lying topography led to ponding of seawater over a few months in some areas, associated with evaporation and concentration of salts, both in sandy and mud-dominated deposits (Chagué-Goff et al. 2012a, b). One aspect of the research was to assess how well marine and mineral markers could be preserved, as previous studies had shown that saltwater indicators could form strong bonds with organic matter and be retained over thousands of years (Chagué-Goff and Fyfe 1996). The study was also linked with the evaluation of the preservation potential of the 2011 sandy to mud-dominated deposit.

Ultimately, sandy and muddy deposits associated with large amounts of salts are certainly not favourable for agricultural purposes. Paddy fields dominated the study area before the tsunami, and measures were undertaken to restore the land, so that rice production could resume. This included ploughing and mixing of the thin mud deposit with the soil, and flushing of salt with freshwater (e.g. MAFF 2011; Nakai et al. 2015) (Fig. 14.3), mostly from 3.4 km from the shoreline, about 500 m further landward of the limit of the recognisable sand deposit (0.5 cm thickness) (Fig. 14.1b). As a result, there was no tsunami deposit left landward of 3.4 km in February 2012, as seen in Fig. 14.4, and samples are labelled as soil. While rice production was planned for 2012, soy bean crops were observed in September

Fig. 14.3 Sign indicating restoration measures for salt removal of the paddy soil near Sendai airport, 3.4 km inland (February 2012) (Photo Catherine Chagué-Goff)

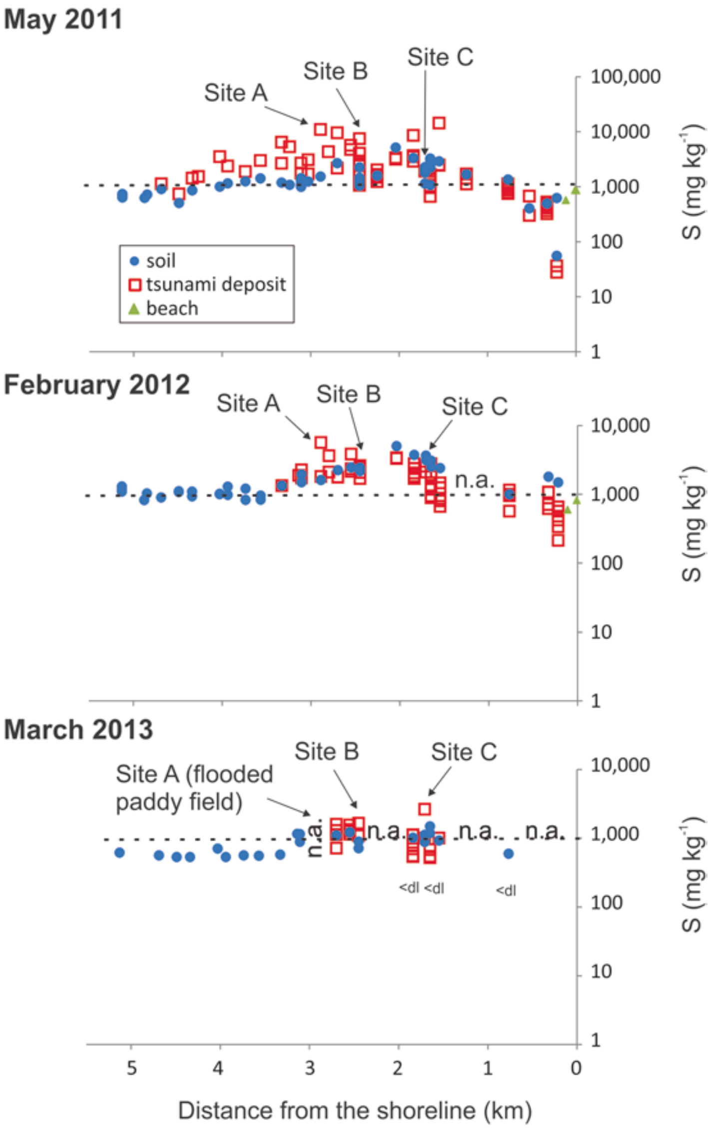

Fig. 14.4 Sulphur concentrations (mg kg^{-1}, shown in logarithmic scale) as determined with an Olympus INNOV- X portable XRF, in tsunami deposit, soil and beach samples in May 2011, February 2012 and March 2013. As multiple samples were usually collected from a trench at each site and analysed, results are shown as multiple data points for each trench location. The *dashed line* marks 1000 mg kg^{-1}. Note the different scale in May 2011, as concentrations exceeded 10,000 mg kg^{-1} in a few samples. The *arrows* for Site A, Site B and Site C point to the highest concentrations measured at the trench (*n.a.* not available, as sites not available for sampling due to restoration measures; < *dl* below detection limit)

Fig. 14.5 Site A – May 2011, February 2012, March 2013. See Fig. 14.1b for site location (Photos Catherine Chagué-Goff)

2012, thus suggesting that the water and/or soil quality was still not adequate for rice production (see Chagué-Goff et al. 2014 for details). While guidelines for rice crops refer to chloride concentrations (MAFF 2011; Chagué-Goff et al. 2014), the salinity levels were also reflected in the still elevated sulphur concentrations in the soil in February 2012 (see Fig. 14.4).

In May 2011, salt crusts were observed and high salt concentrations measured at a site immediately landward of the limit of the sand deposit dominated by thick cracked mud (Site A, Fig. 14.1b; Figs. 14.4 and 14.5a), and attributed to seawater ponding and evaporation (Chagué-Goff et al. 2012a, b). Electrical conductivity exceeding that of seawater was also measured at a nearby site, where water was still ponded in May 2011, reflecting the effects of evaporation (Chagué-Goff et al. 2012a). Elevated concentrations of salt (e.g. NaCl, KCl) and sulphur, the latter mostly as sulphate, were also measured in February 2012 at the site, where tractor tracks were observed (Figs. 14.4 and 14.5b). In March 2013, new paddy fields had been established (Fig. 14.5c), after flushing of the remaining salt, and thus no data are available at site A (Fig. 14.4). Electrical conductivity measurements indicated that the paddy fields were inundated with freshwater (unpublished data).

On the landward side of Hakken-bori canal (Site B, Figs. 14.1b and 14.6), the tsunami deposit consisted of a 5 cm thick sand overlain with a thin mud cap. The site was still damp, due to prolonged seawater ponding, and extremely high salt concentrations were recorded in May 2011 in the surface mud layer (Chagué-Goff et al. 2012b and see Fig. 14.4). The seawater had leached through the sand and high concentrations were also measured in the underlying fine-grained soil. Follow-up studies indicated that the salt had been diluted due to rainfall, although elevated seawater indicators were still measured in 2012 (Chagué-Goff et al. 2014) and 2013 (Fig. 14.4). In 2015, high sulphur concentrations were recorded immediately above the hardpan (unpublished data), due to the low permeability of the compacted hardpan, which is artificially created to prevent water loss from rice paddy fields (e.g. Wopereis et al. 1992). This was measured, despite some visible disturbance at the surface of the site (Fig. 14.6d). So while saltwater indicators were not preserved long-term in the tsunami deposit itself, research showed that they could be retained in the underlying soil, although further research is required to ascertain the possible influence of rice farming and fertiliser application on sulphate concentrations. This represented a unique opportunity to record and study the longevity potential of

Fig. 14.6 Site B – May 2011, February 2012, March 2013, May 2015, March 2016, July 2016. See Fig. 14.1b for site location. The *black ellipse* marks the location of the house in photos taken in May 2011, May 2015, March and July 2016. In March 2016, the soil above the hard pan was removed and new organic-rich soil laid down (Photos Catherine Chagué-Goff)

chemical signatures of tsunami inundation, and investigate whether a change of chemical forms occurred with time. However, as observed in March 2016 (Fig.14.6e), the soil above the hardpan had been removed and was being replaced with organic-rich soil, to allow the re-establishment of extensive rice paddies, as seen in July 2016 (Fig. 14.6f). Thus no further research could be undertaken at that site.

High concentrations of saltwater indicators were also recorded in March 2013, 2 years after the tsunami at site C (Figs. 14.1b and 14.4), where the tsunami deposit consisted of a 1 cm thick sand layer over sandy soil (Fig. 14.7a–c). The low contents measured in May 2015 (unpublished data) can be attributed to mixing of soil and flushing with freshwater, which most certainly occurred prior to planting of rice paddies in 2014, as indicated by remains of rice plants in the paddy field (Fig. 14.7d). However, no new crops had been planted in May 2015 at that site, but larger paddy fields were being re-established in March 2016 (Fig. 14.7e), as also observed in July 2016 (photo not shown).

Further seaward, while the tsunami deposit had been left undisturbed in 2012, the remnants of the destroyed coastal forest were removed and by March 2013, the land had been raised by a few metres behind the newly built seawall, and seedlings were planted to re-establish a new coastal forest.

Thus, it appears that, within 5 years of the 2011 event, not much of the tsunami deposit has been preserved. While it is understandable that remediation measures are required for the wellness of the inhabitants, it is a loss for science, as this means that most of the sedimentological evidence for the event has been removed from the region. Thus future generations of researchers will lack the geological evidence for this event that was so important not only in geological but human terms.

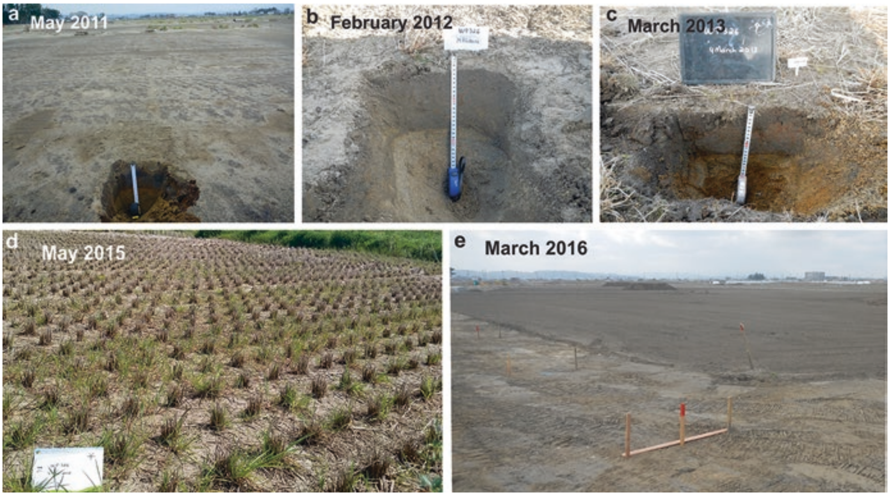

Fig. 14.7 Site C (WP326) – May 2011, February 2012, March 2013, May 2015, March 2016. See Fig. 14.1b for site location (Photos Catherine Chagué-Goff)

14.2.2 Case Study 2: Arahama, Sendai Plain, Miyagi Prefecture

Previous research in Arahama, which is about 10 km N of Sendai airport, included extensive investigations to determine the extent of the Jogan tsunami deposit (Sawai et al. 2008; Sugawara et al. 2010, 2011), whereby many cores were taken with a geoslicer along a number of transects. These studies revealed that the 869AD Jogan sandy deposit and 915AD Towada-a tephra mostly occurred at about 50 cm depth, with often only a thin peat layer between both. More recently, a preliminary investigation compared the chemical signature of the sandy deposits left behind by the 869AD Jogan tsunami and the 2011 Tohoku-oki tsunami from a core collected in May 2011 at a site 1.5 km inland from the present shoreline, with results suggesting that the source material was similar (Chagué-Goff et al. 2012a). Another study was carried out in May 2013 at a nearby site by Watanabe et al. (2014), as part of an investigation at multiple sites on the Sendai Plain, to determine the age of the tsunami deposits preserved in the sedimentary record. While the occurrence of the Jogan deposit is often inferred from his position almost immediately below the Towada-a tephra, as reported by Sawai et al. (2008) and Sugawara et al. (2010, 2011), the tephra is not always present, thus leading to uncertainty regarding its identification. Plant residues picked from immediately below the sand deposit were analysed by ^{14}C AMS at Nagoya University and returned an age of 940–1,060 year cal BP (2σ), thus confirming that the sandy deposit was indeed the Jogan deposit (Watanabe et al. 2014).

However, recent restoration work using heavy machineries was carried out in the area. As seen in Fig. 14.8, it has resulted in an extensive loss of older deposits in

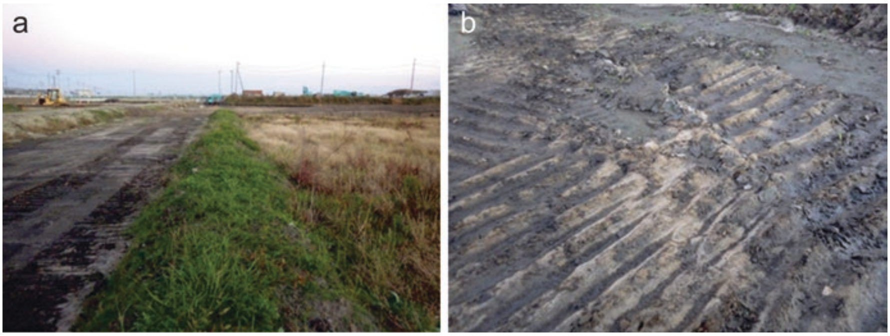

Fig. 14.8 Arahama, Wakabayashi, Miyagi Prefecture. See Fig. 14.1a for location. (**a**) Machine-equipped restoration work (November 2014); (**b**) The *light grey colour* represents the exposed 915AD Towada-a tephra and the 869AD Jogan tsunami deposit, which could positively be identified due to the previous extensive research in this area. These units were then removed as a result of the machine-equipped restoration work (November 2014) (Photos Daisuke Sugawara)

places, including the 915AD Towada-a tephra and the 869AD Jogan sand layer, which had previously be studied by Sawai et al. (2008) and Sugawara et al. (2010), and can thus easily be identified within the peaty substrate. Thus, not only the 2011 deposit but also a geological record of more than 1200 years, or even longer, have been removed, thus hindering further research in the area.

14.2.3 Case Study 3: Yoshihama, Iwate Prefecture

Before the 2011 event, Yoshihama, in the Sanriku region, northern Honshu (Fig. 14.1a) had been hit by the 1896AD Meiji tsunami and 1933AD Showa tsunami, with both resulting in fatalities in the village. Tsunami deposits left behind by these events consisted of sand, but also a large boulder that was transported inland by the 1933AD Showa tsunami, as reported by witnesses. It is possible that the sandy deposits from the 1896AD and 1933AD events might have been disturbed, as the area was used for paddy fields prior to 2011 (Fig. 14.9a). It is also interesting to note that the large boulder described above was uncovered by the 2011 tsunami (Fig. 14.9b).

After the 1933AD Showa tsunami, inhabitants were instructed to move further inland, which saved many lives and properties in the village in 2011 (Tohoku Regional Bureau, Ministry of Land, Infrastructure and Tourism 2014). In 2008, a stone monument was erected, as a reminder of the 1933AD event, indicating that the tsunami run-up was 3 m higher than the top of the monument, and also stating that the monument was erected so that lessons from the tsunami are not forgotten (Fig. 14.9c). A number of stone monuments have been observed in the Sanriku region, often marking the run-up heights of previous events, warning of tsunami

Fig. 14.9 Yoshihama, Sanriku region, Iwate Prefecture. See Fig. 14.1a for site location. (**a**) Area near the shoreline, with paddy fields that were inundated by the 2011 tsunami (Photo Yuichi Nishimura); (**b**) Boulder that had been deposited by the 1933 AD Showa tsunami and that was uncovered by the 2011 event (Photo Catherine Chagué-Goff); (**c**) Tsunami stone monument erected in 2008 warning residents of the tsunami danger (see text for further explanation) (Photo Catherine Chagué-Goff)

danger. Housing was also moved further inland, which often saved many lives during the 2011 tsunami.

A reconnaissance survey was undertaken in October 2013, as part of a region-wide study searching for evidence of precursors of the 2011 event. A record of previous tsunamis was found in Yoshihama, and is believed to go back at least 1100 years, as it includes a tephra layer, most likely a product of the Towada volcano in north Japan, possibly the Towada-a tephra (915AD) or even another older tephra (inset Fig. 14.10a). However, as seen in Fig. 14.10a, this area was also subjected to remediation measures to restore the pre-tsunami land. As a result, the record was bulldozed away (see Fig. 14.10b). No further research can be undertaken at that site because the geological record has been heavily disturbed, thus preventing any meaningful interpretation.

14.2.4 Case Study 4: Matsukawa-ura, Soma, Fukushima Prefecture

Matsukawa-ura Lagoon is a semi-enclosed lagoon located in Soma, northern Fukushima Prefecture, and the area landward of the lagoon was used as paddy fields before the 2011 event. The tsunami inundation height (height of tsunami water level above mean sea level) was 16–21 m near the coast and 5–8 m in the paddy fields, while the inundation distance reached about 3.9 km (e.g. Mori et al. 2012 and personal observation by Y. Nishimura, June 2011). At least 3 months after the tsunami, some parts of this area, especially close to the lagoon, remained flooded (Fig. 14.11a), partly due to subsidence in this area. When the area dried, cracked mud was left on the surface, as also observed within a few months further inland (Fig. 14.11b). The tsunami deposit was composed of sand and mud showing a sharp boundary between the layers (Fig. 14.12a). In February 2012, extensive thick salt crusts were still observed on top of the mud (Fig. 14.12a) and attached to rice sheaths (Fig. 14.12b),

Fig. 14.10 Yoshihama, Sanriku region, Iwate Prefecture. See Fig. 14.1a for location. (**a**) October 2013. The *white oval* indicates the study site (inset with detail – the *white arrow* points to the position of the tephra layer which was retrieved at the base of the outcrop, below the water table). The site was levelled with bulldozers a few days after the survey and the geological record destroyed (Photo Catherine Chagué-Goff); (**b**) February 2014. Photo shows the extent of restoration measures (Photo Kazuhisa Goto)

with concentrations of water-leachable chloride and sulphate reaching 14,000 mg kg^{-1} (1.4 %) and nearly 40,000 mg kg^{-1} (~4 %), respectively (Chagué-Goff et al. 2014). These elevated concentrations, which were about one order of magnitude higher than those reported north of Sendai airport at the same time (Chagué-Goff et al. 2014), were attributed to the extended ponding of seawater following the tsunami at the site and the lack of extensive restoration measures undertaken by that time.

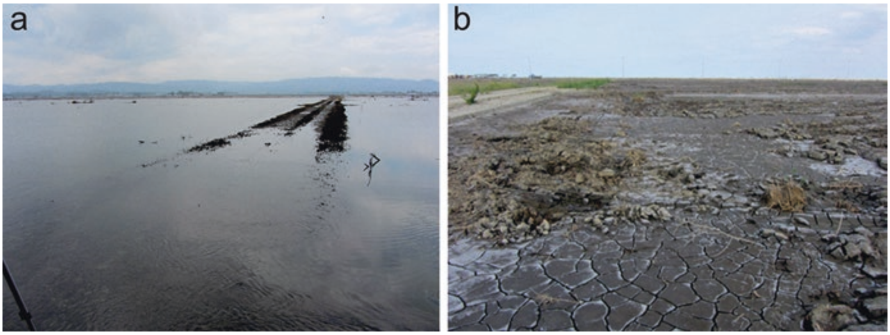

Fig. 14.11 Soma, landward of Matsukawa-ura Lagoon, Fukushima Prefecture. See Fig. 14.1a for site location. (**a**) Photo showing that the area 1.6 km from the shoreline was still inundated by seawater on 14 June 2011; (**b**) Site 3 km from the shoreline, showing salt crusts on top of cracked mud on 15 June 2011 (Photos Yuichi Nishimura)

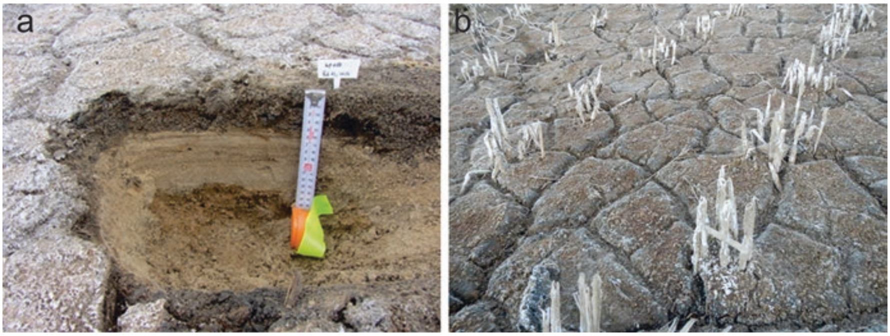

Fig. 14.12 Soma, landward of Matsukawa-ura Lagoon, Fukushima Prefecture. See Fig. 14.1a for site location. (**a**) Tsunami deposit consisting of sand overlain by a thick mud cap, with salt crusts at the surface, 2.2 km from the shoreline, 21 February 2012 (Photo Yuichi Nishimura); (**b**) Salt crusts on rice sheaths, 1.6 km from the shoreline, 21 February 2012 (Photo Catherine Chagué-Goff)

Restoration work started near the inundation limit and expanded toward the lagoon with the reconstruction of drainage ditches, as observed in May 2013 (Fig. 14.13). The tsunami deposit was also removed at that time.

14.3 Conclusions

Restoration measures were instigated after the 2011 Tohoku-oki Tsunami, in order to rehabilitate the areas that had been affected by the disaster. They followed guidelines for countermeasures for the treatment of disaster waste which were implemented shortly after the event, and which direct the removal, transport and treatment

Fig. 14.13 Soma, landward of Matsukawa-ura Lagoon, Fukushima Prefecture. See Fig. 14.1a for site location. Restoration and reconstruction of drainage ditches, 2.6 km from the shoreline, as observed 10 May 2013 (Photo Yuichi Nishimura)

of such waste. As a result, most of the 2011 tsunami deposit has been removed, and with it, also often much soil and sediment in the subsurface. While the rehabilitation is required for social and economic reasons, to allow agricultural activity to resume and as much as possible permit a return to pre-disaster conditions, these measures have unfortunately led to the loss of much of the sedimentary record of the 2011 tsunami, and in places most probably a record getting back at least 1000 years or so. This therefore conflicts with the need of tsunami researchers who rely mostly on this sedimentary evidence left behind by recent and older tsunamis, to gain a better understanding of the hydrodynamic and depositional processes during these events. The identification of historical and prehistorical tsunami deposits also allows the estimation of the recurrence interval of these events, thus providing vital information for disaster preparedness and tsunami mitigation measures. Here, we have shown how restoration measures have affected the study of post-depositional changes over 5 years, with particular emphasis on geochemical signatures, along a shore-perpendicular transect north of Sendai airport, Miyagi Prefecture. We also provided examples from Arahama, Miyagi Prefecture, as well as Yoshihama, Iwate Prefecture, and Soma, Fukushima Prefecture, illustrating the effects of the post-tsunami rehabilitation on tsunami research.

We acknowledge that it is important to allow pre-disaster activities and conditions to return. However monuments cannot replace the geological evidence, and it is somewhat sad to consider that there might not be much left of the 2011 tsunami deposit for future generations of researchers to study, bearing in mind how devastating the event was. There might be a few limited sites in Japan, where deposits of the 2011 Tohoku-oki tsunami and/or those of previous events, are still preserved. If this was the case, we would suggest that local and/or regional authorities should consult with the public and tsunami researchers, so that these sites can be left untouched, and become 'natural' memorials for the 2011 Tohoku-oki tsunami and its predecessors. It however appears that such attempts have been made in a number of places, but had to be abandoned, for a number of reasons. Therefore it is not clear whether this represents a feasible option.

Acknowledgements Financial support was provided to CCG through a visiting fellowship at the Institute of Seismology and Volcanology, University of Hokkaido (2012), financial support from the Japan Ministry of Education, Culture, Sports, Science and Technology (2016) and an Invitation Fellowship from the Japan Society for the Promotion of Science (No. L16535) (2016), both at Tohoku University. Thanks are due to an anonymous reviewer for comments that improved the manuscript.

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Chapter 15
Impact of the Great East Japan Earthquake on the Seaweed (*Eisenia bicyclis*) Habitat at Oshika Peninsula, Miyagi, Japan

Hitoshi Tamaki and Daisuke Muraoka

Abstract The objective of this study was to examine the effects of the earthquake and tsunami event on the seaweed (*Eisenia bicyclis*) habitat and environmental conditions at Tomarihama on the Oshika Peninsula by comparing them before and after the event. After the event, due to the land subsidence caused by the effects of the earthquake, water depths increased by approximately 1.0 m, and the underwater-light intensities between November 2012 and May 2013 were significantly lower than those before the event.

In July and August 2011, loss of *E. bicyclis* due to the tsunami was limited. On the other hand, sea urchins, the primary herbivore, largely decreased after the earthquake. The decrease in the sea urchin density led to the reduction of their grazing and resulted in the increase of juvenile *E. bicyclis* in the seaward areas of the transects. Some of these juveniles survived and grew into adult *E. bicyclis,* leading to an expansion of *E. bicyclis* habitat. The appearance of adult *E. bicyclis* in the seaward areas suggested that light conditions were sufficient for the survival of *E. bicyclis,* even though the underwater-light intensity was reduced by the earthquake. In 2015, the density of sea urchins appeared to increase gradually, and then the forests of adult *E. bicyclis* in the seaward areas were largely decreased by the grazing of sea urchins.

After the event, sediment deposits on the rocky shore were consistently confirmed, while showing a fluctuation at each monitoring place, and juvenile *E. bicyclis* individuals decreased in relation to the increase in sediment deposits on the sea floor. This result suggests that the increased sediment deposits on the rocky shore negatively affected the recruitments of *E. bicyclis*.

Keywords Seaweed bed • *Eisenia bicyclis* • Sea urchin • Earthquake • Tsunami • Sediment deposit

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V. Santiago-Fandiño et al. (eds.), *The 2011 Japan Earthquake and Tsunami: Reconstruction and Restoration*, Advances in Natural and Technological Hazards Research 47, DOI 10.1007/978-3-319-58691-5_15

15.1 Introduction

On March 11, 2011, the Great East Japan Earthquake occurred off the Pacific coast of northeastern Honshu Island of Japan with a momentous magnitude of 9.0. The earthquake and subsequent tsunami severely impacted the coast of northeastern Honshu Island and resulted in the loss of many people's lives and devastated the coastal areas, as well as the marine ecosystems in this region (Tamaki and Muraoka 2011, 2016; Seike et al. 2013; Takami et al. 2013; Urabe et al. 2013; Kawamura et al. 2014).

Eisenia bicyclis is a perennial macroalgae which grows in rocky coastal areas. Forests of *E. bicyclis* are highly productive components of coastal ecosystems (Terawaki 1996). They provide suitable habitats for many commercial fishes, shellfishes and benthic animals, such as sea urchins and abalones (Terawaki 1996; Takami et al. 2003; Muraoka 2008). Along the Pacific coast of northeastern Honshu Island, which was severely damaged by the earthquake and massive tsunami, *E. bicyclis* habitats form a valuable fisheries resource and also play important roles in the food web of the rocky coastal ecosystem (Terawaki 1996; Muraoka 2008). The magnitude of the effects of the Great East Japan Earthquake and tsunami on the fishery resource of *E. bicyclis* habitat requested an examination of the possible effects (Tamaki and Muraoka 2011, 2016).

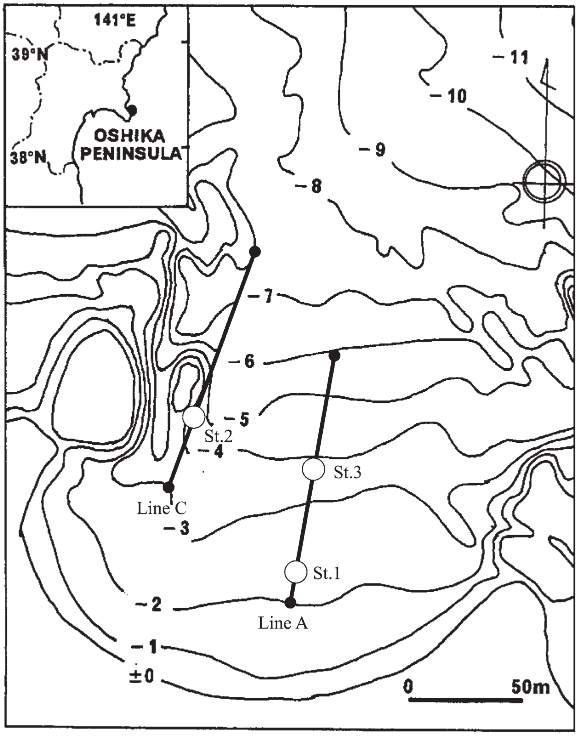
The objective of this study is to examine the effects of the earthquake and subsequent tsunami on the *E. bicyclis* habitat and environmental conditions. We carried out a comparative study of the abundance of *E. bicyclis* and other algae, the density of benthic animals, the relative depth change due to land subsidence, the underwater-light intensity and the sediment deposits on the rocky shore, using data from before and after the earthquake and tsunami event at Tomarihama on the Oshika Peninsula, which is the nearest coastal area to the epicenter of the Great East Japan Earthquake.

15.2 Materials and Methods

15.2.1 Study Site

This study was conducted in the rocky subtidal area at Tomarihama (38° 21′ N, 141° 32′ E) on the Oshika Peninsula, which is 130 km from the epicenter of the Great East Japan Earthquake (Fig. 15.1). The coastal structures up to a height of 12.5 m above the sea level were destroyed by the event, implying that the tsunami reached at least 12.5 m in height in this region. As the study site is a small bay that is open to the Pacific Ocean, this area is directly exposed to the impact of waves. We deployed two 100 m × 1 m belt transects from the nearshore areas (Lines A and C). The distance between two survey lines is approximately 50 m.

Fig. 15.1 Location of the study area and two belt transects (Lines A and C) at Tomarihama on Oshika Peninsula in Miyagi Prefecture



15.2.2 Change in Water Depth Due to Land Subsidence

Water depths at intervals of 10 m along the two 100 m × 1 m belt transects were recorded to estimate the relative depth change due to land subsidence between June 2008 and December 2015.

15.2.3 Change in the Underwater-Light Intensity

We also selected three fixed stations (Fig. 15.1) to estimate the change in the underwater-light intensity before and after the event. Stations 1 and 3 were located at 14 m and 55 m along the transect from the starting point of Line A. Station 2 was placed with 21 m from the starting point of Line C. At Stations 1 and 2, a survey before the earthquake confirmed the distribution of *E. bicyclis*. On the other hand, Station 3 was a barren-ground area dominated by crustose coralline algae before the event. From November 2007 to April 2008, underwater-light intensities with the interval of 10 min at 7 cm above the bottom at each station were recorded by an ultra-miniature light-intensity recorder (MDS-MkV/L, JFE Advantech Co. Ltd., Japan).

The data retrieved from the light-intensity recorder was calibrated using an underwater-light sensor (LI-193SA, LI-COR, Inc.). After the event between November 2012 and May 2013, we measured light conditions over 20 s with an interval of 30 min at 25 cm above the bottom at each station using a logger version PAR sensor (COMPACT-LW, JFE Advantech Co. Ltd., Japan). Cumulative daily light intensities at each station were calculated using the data sets of underwater-light intensity.

15.2.4 Quantitative Surveys

The percentage cover of *E. bicyclis* and other macrophytes, and the population of sea urchins (*Strongylocentrotus nudus* and *Strongylocentrotus intermedius* with a test diameter of 1 cm or greater) and abalones (*Haliotis discus hannai* with a shell diameter of 4 cm or greater) were quantified in the 100 m × 1 m belt transects along Lines A and C by scuba divers in June 2008, July and August 2011, October and November 2012, July 2013, January 2014 and June and December 2015. These belt transects were divided into several surveyed sections classified by the differences in macrophyte composition and the density of benthos. Following Taniguchi and Kato (1984), individual *E. bicyclis* were recorded by classifying them into juveniles (less than 1 year old and not yet showing dichotomous branching) and adults (more than 1 year old and having dichotomous branching). We confirmed there was no notable difference in the distributions of *E. bicyclis* between June 2008 and before March 2011 through interviews with local fishermen in this region.

As sediment deposits on the rocky shore was frequently confirmed after the event, the percentage cover of sediment deposits (sediment thickness less than 2 mm) on the sea floor at 0.5 m × 0.5 m quadrants was recorded along both transects with intervals of 20 m between July 2011 and December 2015. After December 2011, we also measured the density of juvenile *E. bicyclis* concurrently with the recording of sediment deposits. The location 30 m away from the starting point at Line A for the monitoring of sediment deposits was added starting October 2014. In November and December 2012, the percentage cover and the amount of sediment deposits on the rocky shore was quantified using quadrants of 0.1 m × 0.1 m at sites of 0 m, 20 m and 60 m away from the starting point of Line C and Stations 1, 2 and 3. Deposited sediments on the sea floor were collected using a syringe. The suspensions of accumulated sediments in the syringe were filtered through a glass-fiber filter (pore size = 2 μm, Multigrade GMF150) and then weighed (after drying at 100 °C) to estimate the amount of sediment deposits per area. As the percentage cover of sediment deposits was positively related to the amount of deposits as mentioned later, the coverage of deposits was converted to the amount of sediment deposits in this study.

We used water temperature data measured at Enoshima Island (near Tomarihama; 1 m in depth) provided by the Miyagi Prefecture Fisheries Technology Institute from January to March in 2011. Water temperature was recorded around Station 1

(−3.4 m depth relative to chart datum level (C.D.L.)) between June 2011 and November 2013, and Station 3 (−4.5 m depth relative to C.D.L.) after January 2014, using temperature loggers (MDS-MkV/T, JFE Advantech Co. Ltd., Japan).

15.2.5 Data Analysis

The relationship between the percentage cover of sediment deposits and the amount of the deposits was examined by regression analysis. Changes in the underwater-light intensity before and after the earthquake and tsunami event and effect of the amount of sediment deposits on the rocky shore on the density of juvenile *E. bicyclis* were tested using Student's t-test. All statistical analyses were carried out with the SPSS version 23 statistical computer software (IBM Japan Co. Ltd., Japan).

15.3 Results and Discussion

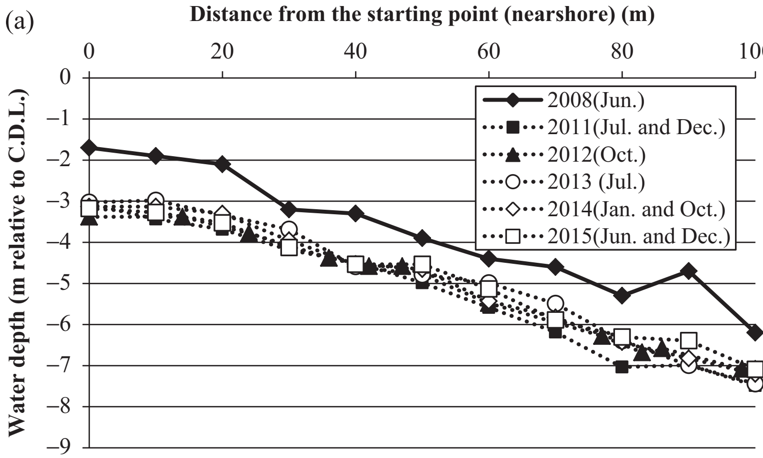
15.3.1 Changes in Water Depth and Underwater-Light Intensity

Figure 15.2 shows the changes in the water depth at the study site before and after the event. In 2011, the water depths at both lines increased by approximately 1.0 m as a result of land subsidence due to the earthquake when compared to the water depths recorded in June 2008. No notable change in the water depth was found between 2012 and 2015 for Lines A and C.

Changes in the cumulative daily underwater-light intensities before and after the event are shown in Fig. 15.3. The cumulative daily underwater-light intensities at each station between November 2012 and May 2013 were significantly lower than intensities before the event ($p < 0.05$). Water depths before and after the event changed from −2.1 to −3.2 m at Station 1, from −3.5 to −4.4 m at Station 2 and from −2.5 to −3.6 m relative to C.D.L. at Station 3. Increase in water depths due to the subsidence by the earthquake seemed to be a factor responsible for the reduction of cumulative daily underwater-light intensities after the event.

15.3.2 Impact of the Great East Japan Earthquake on E. bicyclis *Habitat*

Figure 15.4 shows the change in seawater temperature between January 2011 and October 2014. The average seawater temperature in winter (February–March) was 7.6 ± 0.9 °C in 2011, 5.6 ± 1.0 °C in 2012, 7.8 ± 0.8 °C in 2013 and 7.7 ± 0.5 °C in



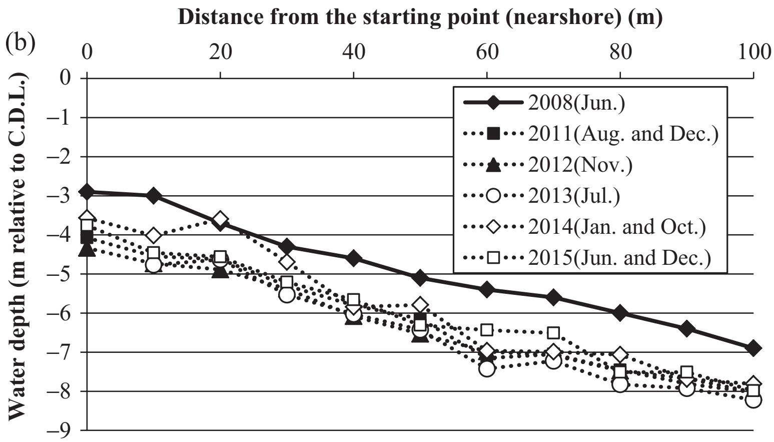


Fig. 15.2 Changes in the water depths before and after the earthquake and tsunami event at Lines A (**a**) and C (**b**)

2014 respectively, indicating that the cold Oyashio Current extended south to surround the study site in winter 2012.

Figures 15.5a, b and 15.6a, b shows changes in the percentage cover of macrophytes and the density of benthos along Lines A and C before and after the event. In order to examine the effects of tsunami or algal herbivores on the seaweed habitat, the distribution of macrophytes and benthos along the line is shown in these figures. A survey before the earthquake revealed that adult *E. bicyclis* occurred up to 28 m and 30 m away from the starting point (nearshore) at Lines A and C, respectively (Figs. 15.5a and 15.6a). On the other hand, at more than 30 m away from the nearshore on both lines, sea urchins (mostly *S. nudus*) occurred in high densities, and crustose coralline algae were remained by the feeding behavior of urchins.

Four and five months after the earthquake (in July and August 2011), although scuba observations found that several large rocks were turned over on the sea floor by the tsunami and seemed to have been damaged, the localized *E. bicyclis* habitat,

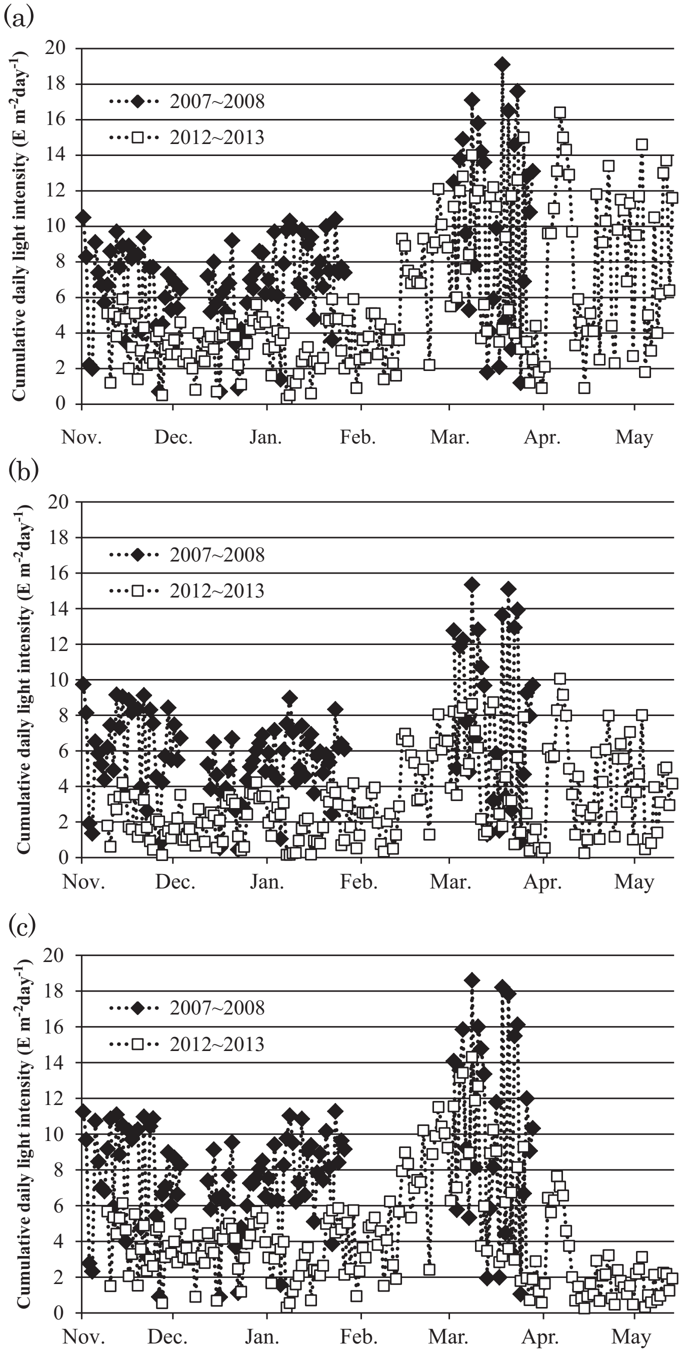


Fig. 15.3 Changes in the cumulative daily underwater-light intensities before (2007–2008) and after the earthquake and tsunami event (2012–2013). (**a**) St. 1, (**b**) St. 2, (**c**) St. 3. Water depths before and after the event changed from −2.1 to −3.2 m at Station 1, from −3.5 to −4.4 m at Station 2 and from −2.5 to −3.6 m relative to C.D.L. at Station 3

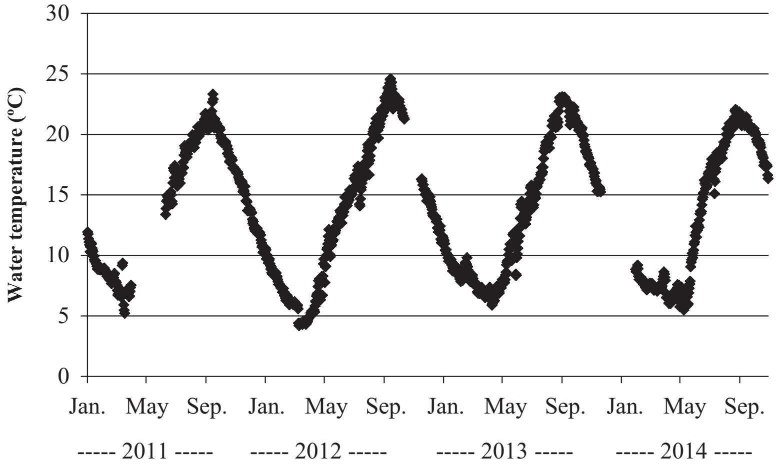


Fig. 15.4 Changes in water temperature between 2011 and 2014

however, displayed no notable differences in the distributions of adult *E. bicyclis* (25 m and 28 m away from the starting point at Lines A and C) when compared to distributions before the event (Figs. 15.5 and 15.6). The strong adhesion to the rock substrates and flexible stipe of *E. bicyclis* might enable survival against the tsunami disturbances. These results allow us to conclude that the loss of adult *E. bicyclis* individuals by the tsunami was limited immediately after the event. On the other hand, the density of sea urchins largely decreased after the earthquake, implying that sea urchins were seriously affected by the tsunami disturbance. This is considered to be a result of the fact that most of the sea urchins were displaced to deeper areas by the tsunami (Kawamura et al. 2014). A decrease in sea urchin density led to the reduction of their grazing (Muraoka 2008; Tamaki et al. 2009) and resulted in the increased survival of juvenile *E. bicyclis* in seaward areas on Lines A and C.

A year and 7 and 8 months after the earthquake (in October and November 2012), a high percentage cover of juvenile *E. bicyclis* occurred on both lines and had the most luxuriant growth during the survey period. Low seawater temperature was recorded in winter 2012 (Fig. 15.4) and had a positive effect on recruitment of the *E. bicyclis* habitat (Arai and Terawaki 2003). Therefore, in addition to the reduction of sea urchins as the dominant algal herbivores, the lower seawater temperature in winter 2012 seemed to be a factor responsible for the increase in juvenile *E. bicyclis* in this region.

Some of these juvenile individuals remained and grew to be counted as adult *E. bicyclis* in July 2013 and January 2014 to contribute to the expansion of the *E. bicyclis* habitat. The appearance of adult *E. bicyclis* in seaward areas of transects that were deeper than those before the event suggested that the light condition was enough for the survival of *E. bicyclis,* even though the underwater-light intensity

(a)

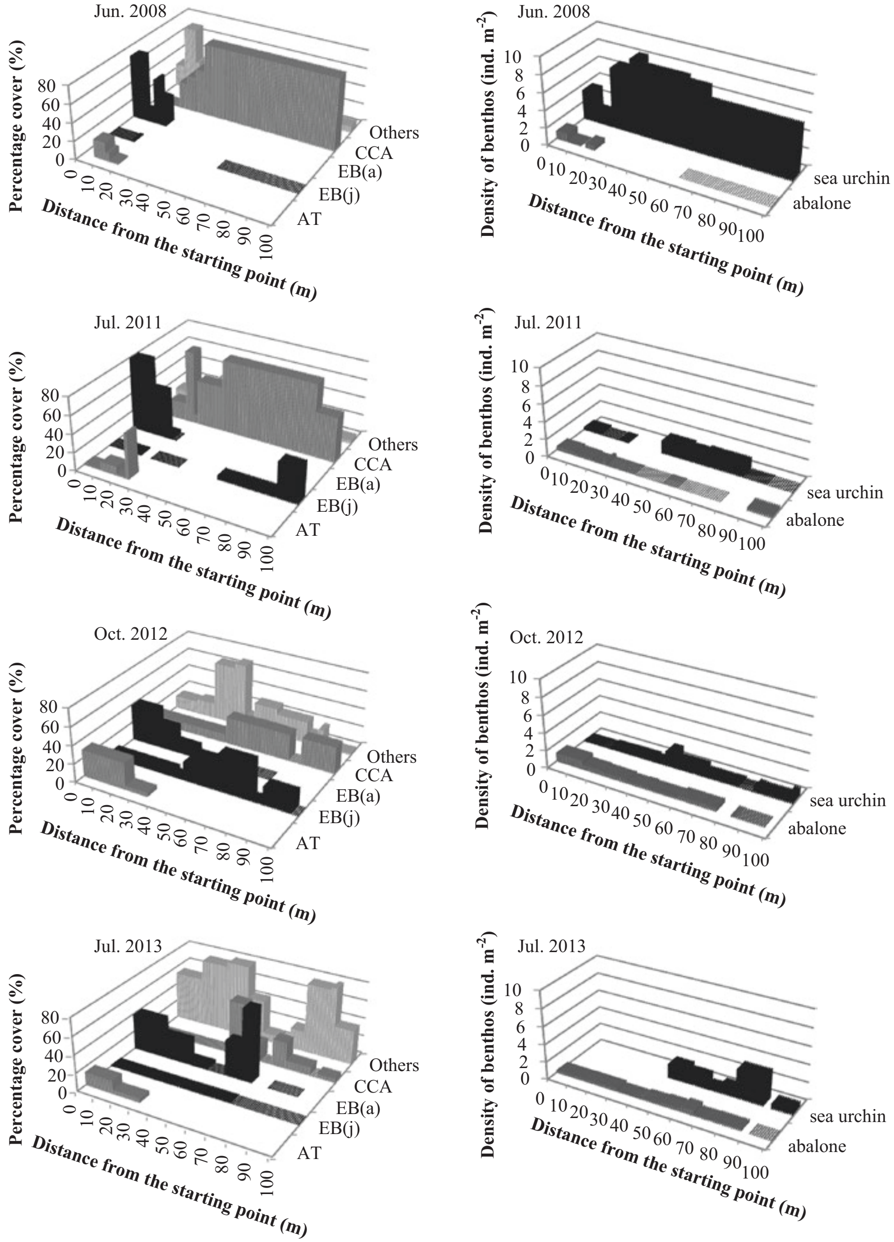


Fig. 15.5 (**a**) Changes in the percentage cover of macrophytes and the density of benthos along Line A between June 2008 and July 2013. AT, algal turfs composed of *Gelidium elegans* and *Pterocladia capillacea*; EB(j), juvenile *Eisenia bicyclis*; EB(a), adult *Eisenia bicyclis*; CCA, crustose coralline algae; others, macroalgae mainly dominated by *Sargassum* spp., *Undaria pinnatifida*, *Ralfsia* sp., *Colpomenia sinuosa*, *Dilophus okamurae* and *Acrosorium polyneurum*

(b)

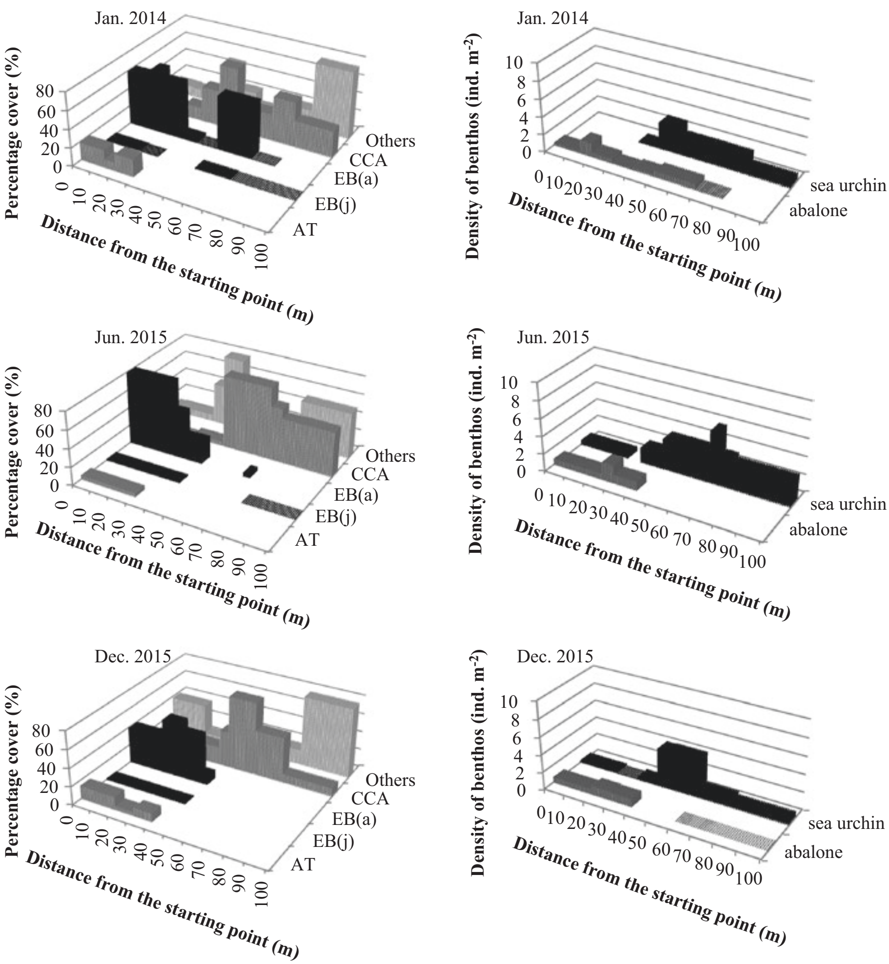


Fig. 15.5 (continued) (**b**) Changes in the percentage cover of macrophytes and the density of benthos along Line A between January 2014 and December 2015. AT, algal turfs composed of *Gelidium elegans* and *Pterocladia capillacea*; EB(j), juvenile *Eisenia bicyclis*; EB(a), adult *Eisenia bicyclis*; CCA, crustose coralline algae; Others, macroalgae mainly dominated by *Sargassum* spp., *Undaria pinnatifida*, *Ralfsia* sp., *Colpomenia sinuosa*, *Dilophus okamurae* and *Acrosorium polyneurum*

was reduced by the earthquake (Fig. 15.3). Sea urchin densities remained at relatively low levels.

In 2015, the density of sea urchins (mainly large individuals) at both lines appeared to increase gradually (Figs. 15.5b and 15.6b). It might be possible that the sea urchins carried away to deeper zones by the tsunami came back to shallow areas (Kawamura et al. 2014). Meanwhile, small sized sea urchins were not observed at either line. The survey in June 2015 found many adult *E. bicyclis* individuals that were located at more than 60 m away from the starting points of both lines had bite

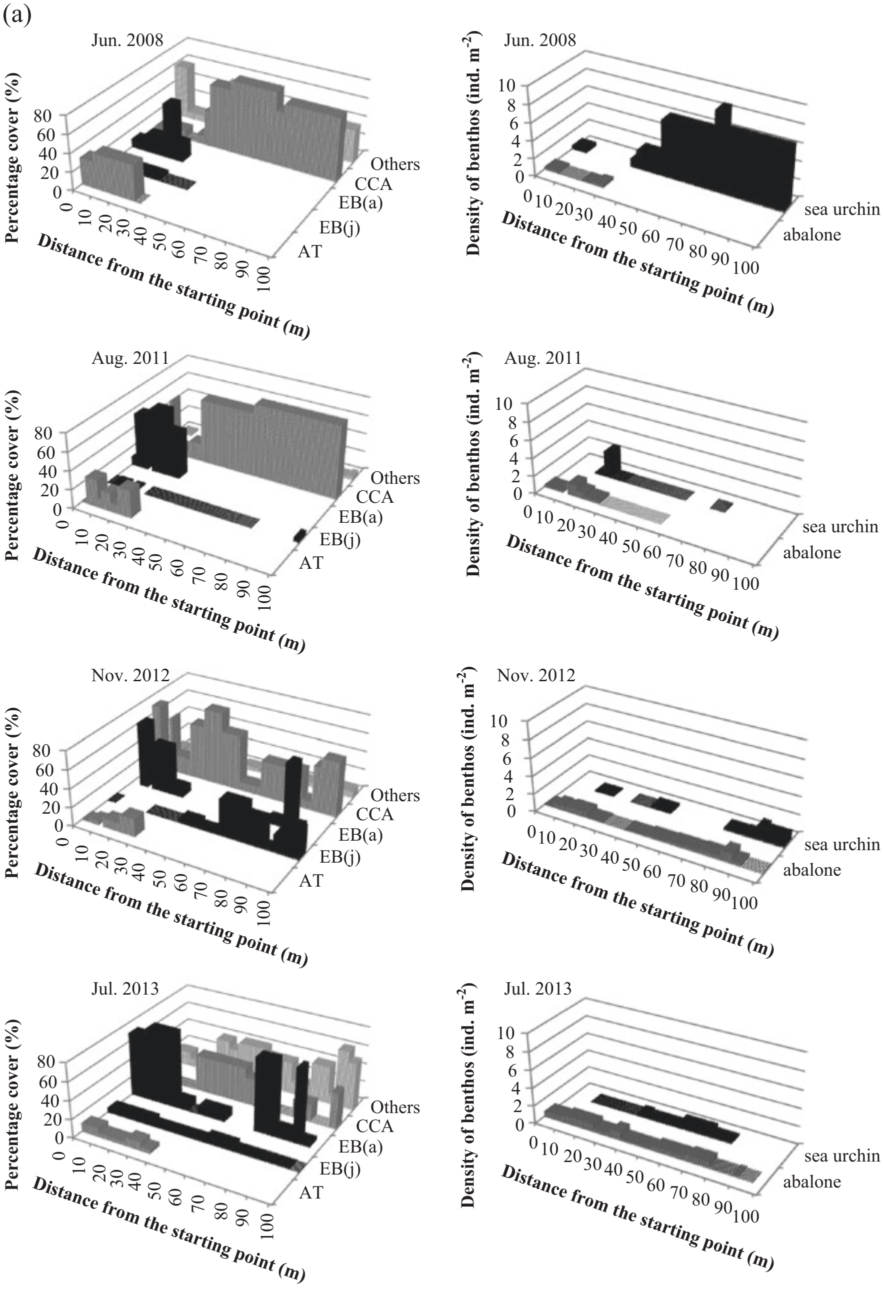


Fig. 15.6 (**a**) Changes in the percentage cover of macrophytes and the density of benthos along Line C between June 2008 and July 2013. AT, algal turfs composed of *Gelidium elegans* and *Pterocladia capillacea*; EB(**j**), juvenile *Eisenia bicyclis*; EB(**a**), adult *Eisenia bicyclis*; CCA, crustose coralline algae; Others, macroalgae mainly dominated by *Sargassum* sp., *Undaria pinnatifida*, *Ralfsia* sp., *Colpomenia sinuosa*, *Dilophus okamurae* and *Acrosorium polyneurum*

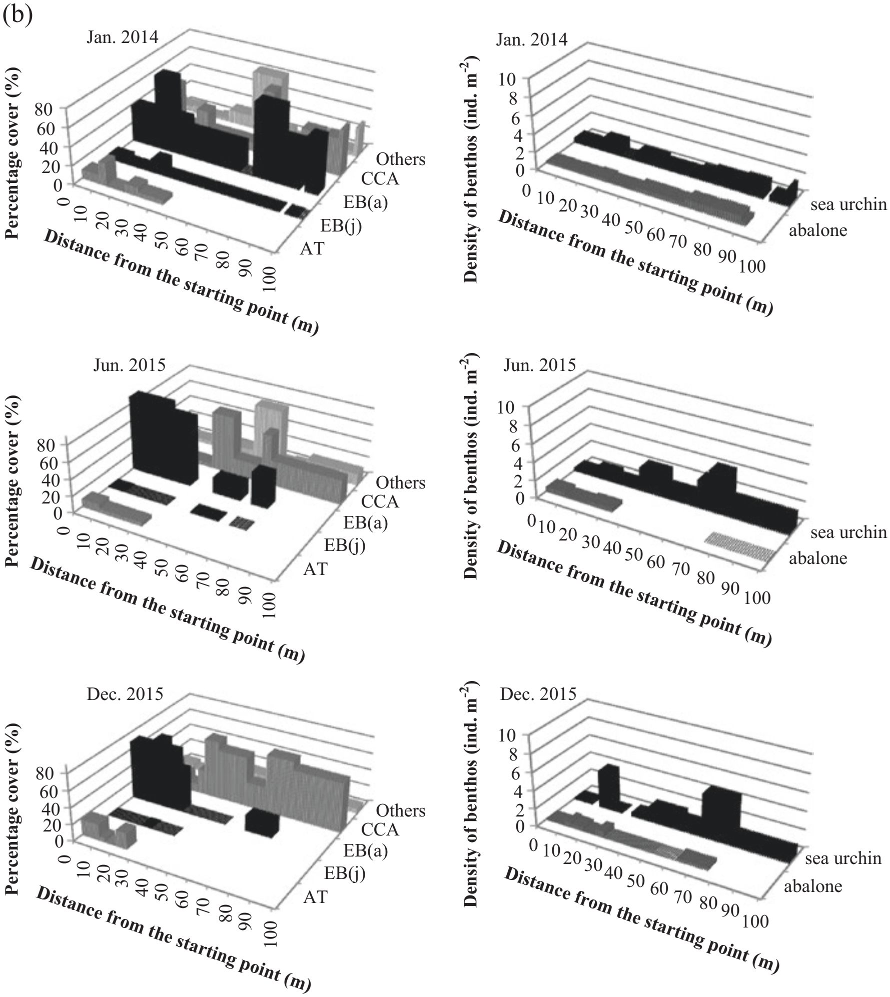


Fig. 15.6 (continued) (**b**) Changes in the percentage cover of macrophytes and the density of benthos along Line C between January 2014 and December 2015. AT, algal turfs composed of *Gelidium elegans* and *Pterocladia capillacea*; EB(**j**), juvenile *Eisenia bicyclis*; EB(**a**), adult *Eisenia bicyclis*; CCA, crustose coralline algae. Others, macroalgae mainly dominated by *Sargassum* spp., *Undaria pinnatifida*, *Ralfsia* sp., *Colpomenia sinuosa*, *Dilophus okamurae* and *Acrosorium polyneurum*

marks of sea urchins, and, in December 2015, forests of adult *E. bicyclis* in seaward areas had disappeared on Line A and decreased on Line C due to grazing by sea urchins (Figs. 15.5b and 15.6b). Furthermore, the invasion of sea urchins was confirmed at the front of the shallow area of the *E. bicyclis* habitat located 40 m away from the starting point on Line A and resulted in a decrease of the percentage cover of adult *E. bicyclis* from 25 to 10% between June 2015 and December 2015.

Before the event, it was thought that the *E. bicyclis* habitat in the shallow area was protected from the invasion of sea urchins into the bed by the disturbance due to water flow (Muraoka 2008; Tamaki and Muraoka 2016). Due to the land subsidence that occurred as a direct effect of the earthquake, however, there is a possibility that there would be a reduction in turbulent flow and, subsequently, that the sea urchins could invade and graze the *E. bicyclis* habitat. Consequently, it might be possible that the *E. bicyclis* habitat will recede due to grazing by sea urchins in the future.

The percentage cover of small red algae (AT) composed by *Gelidium elegans* and *Pterocladia capillacea* were 10% at Station 1 and 40% at Station 2 before the event. On the other hand, average coverage of *G. elegans* and *P. capillacea* between July 2011 and December 2015 were 14.2% at Station 1 and 8.5% at Station 2, respectively. These results seem to suggest that the reduction in the underwater-light intensity after the event (Fig. 15.3) had a negative effect on the growth of the small red algae at Station 2 in the deeper area.

Takami et al. (2013) reported that the population of abalone, especially juvenile abalones, significantly decreased in this region after the event, although unfortunately we could not find any apparent difference in the mean densities of abalone because we did not use the abalone density just before the earthquake but the density in June 2008 as the control.

15.3.3 Sediment Deposits on the Rocky Shore

Because the relationship between the percentage cover and the amount of sediment deposits on the rocky shore is a linear function by regression analysis ($r = 0.90$, $p < 0.05$), the data sets of the coverage of sediment deposits were converted to the amount of sediment deposits on the sea floor and shown in Fig. 15.7. After the event, sediment deposits on the rocky shore were consistently confirmed on both lines, while showing a fluctuation at each monitoring place. This sedimentation is probably caused not only by the tsunami disturbance but also by the land subsidence triggered by the earthquake (Takami et al. 2013). Around the study site, a downward change of the ground level was observed after the event, and sediment might have been continuously flowing into the coastal waters from the area flooded after the subsidence (Tamaki and Muraoka 2016; Muraoka et al. unpublished). The sediment inflow into the coastal area also seems to have contributed to the reduction of the underwater-light intensity after the event (Fig. 15.3).

Evidence has led investigators to suggest that sediment deposits on the sea floor result in negative impacts on the adhesion of zoospores of kelp including *E. bicyclis* and on their subsequent survival (Kawasaki and Yamada 1991; Airoldi 2003; Arakawa 2005). Kawasaki and Yamada (1991) pointed out that the sediment deposits on the substrate below 10 mg D.W. cm^{-2} was suitable for the *E. bicyclis* habitat. A field survey indicated that sediment accumulations on the rocky shore of more than 10 mg D.W. cm^{-2} had frequently occurred at both lines, and juvenile *E. bicyclis*

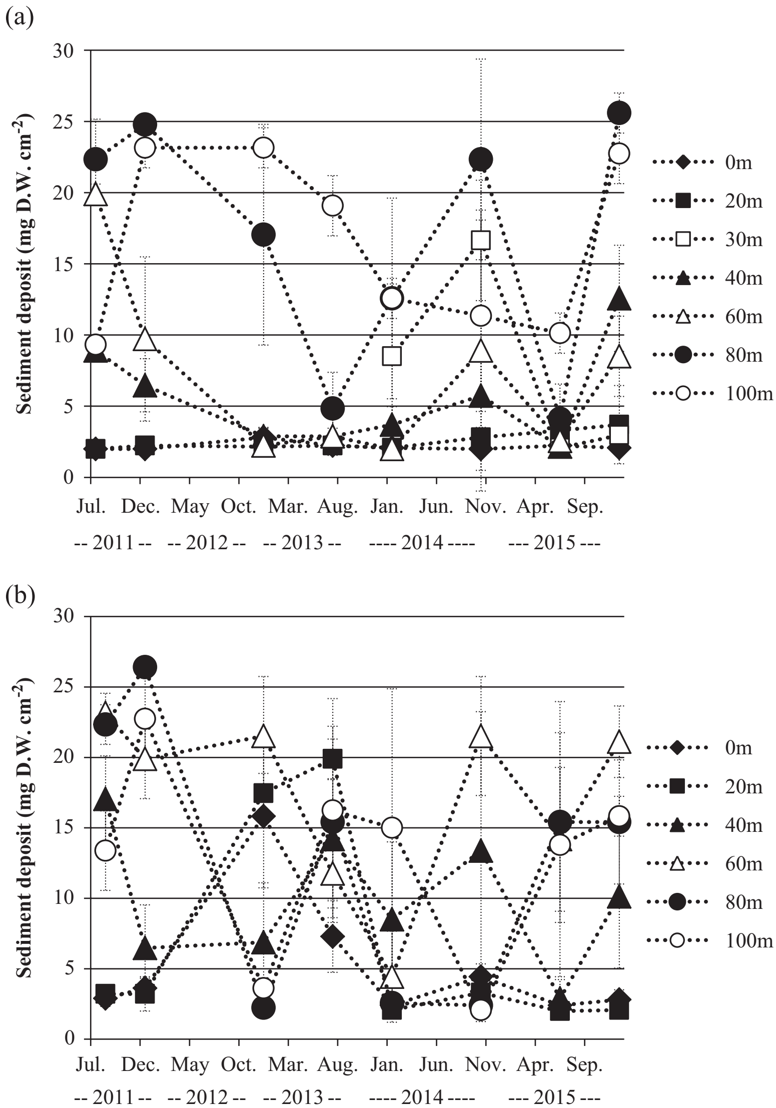


Fig. 15.7 Changes in the amount of sediment deposits on the rocky shore along Lines A (**a**) and C (**b**). The *symbols* in the figure indicate the distance from the starting point of the line

individuals decreased in relation to increase in the sediment deposits on the sea floor ($p < 0.05$). Furthermore, the harmful effects of sedimentation have been reported for early stages of abalone and sea urchin (Takami et al. 2013). For the small abalone *Haliotis diversicolor*, the increase in sediment deposits on the substratum caused a decrease in the rate of larval metamorphosis (Onitsuka et al. 2008). The new recruitment of *E. bicyclis*, sea urchin and abalone seemed to be negatively affected by the increased amount of sediment deposits on the rocky shore.

15.4 Conclusions

The objective of this study was to examine the effects of the earthquake and tsunami event on the seaweed (*E. bicyclis*) habitat and environmental conditions at Oshika Peninsula by comparing them before and after the event. After the event, water depths increased by approximately 1.0 m when compared to depths recorded in June 2008. The underwater-light intensities between November 2012 and May 2013 were significantly lower than the intensities before the event, due to the effects of the land subsidence by the earthquake.

In July and August 2011, the loss of *E. bicyclis* caused by the tsunami was limited. On the other hand, sea urchins, the primary herbivore, which occurred in high densities in June 2008, largely decreased after the earthquake. The decrease in sea urchin density led to the reduction of their grazing and resulted in the increase in juvenile *E. bicyclis* in seaward areas of transects. Some of these juveniles remained and grew to be counted as adult *E. bicyclis* to contribute to the expansion of the *E. bicyclis* habitat. The appearance of adult *E. bicyclis* in seaward areas suggested that the light condition was sufficient for the survival of *E. bicyclis,* even though the underwater-light intensity had been reduced by the earthquake. In 2015, the density of sea urchins appeared to increase gradually, and then forests of adult *E. bicyclis* in seaward areas of transects largely decreased due to the grazing of sea urchins. Our field survey seemed to suggest the possibility that the *E. bicyclis* habitat will recede due to the grazing by sea urchins in the future.

After the event, sediment deposits on the rocky shore were consistently confirmed, while showing a fluctuation at each monitoring place, and juvenile *E. bicyclis* individuals decreased in relation to the increase in the sediment deposits on the sea floor. This result suggests that the recruitments of *E. bicyclis* were negatively affected by the increased sediment deposits on the rocky shore.

Acknowledgements We especially thank Mr. Minji Fukuda and Mr. Kaito Fukuda for their support and assistance during the course of this study. This research was supported by the Tohoku Ecosystem-Associated Marine Sciences of the Ministry of Education, Culture, Sports, Science and Technology Japan, the Steel Foundation for Environmental Protection Technology and the project of the Ministry of Agriculture, Forestry and Fisheries Japan.

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Chapter 16
Temporal and Spatial Changes in a Coastal Ecotone in Shizugawa Bay, Sanriku Coast Due to the Impacts of the Tsunami on 11 March 2011 and the Following Artificial Impacts

Teruhisa Komatsu, Shuji Sasa, Masahiro Hamana, Shingo Sakamoto, Minami Asada, Genki Terauchi, Ryou Tsujimoto, and Tetsuo Yanagi

Abstract The Great East Japan Earthquake produced the huge tsunami on 11 March 2011, which hit and changed a coastal ecotone consisting of ecosystems that forms a transition zone between the land and the sea and provides ecosystem services for human societies and habitats for marine living resources along the Sanriku Coast. Therefore, it is important to identify temporal and spatial changes in the ecotone and its succession under natural-system processes and the following human impacts on the terrain. This is particularly relevant in Sanriku Coast, Japan, because tsunami events commonly repeat at intervals of several decades to 100 years. Since October 2011, we have observed a succession of the coastal ecotone in Shizugawa Bay, Sanriku Coast, which was seriously impacted by the tsunami. The tsunami did not seriously damage seaweed beds on rocky substrates, but it did impact seagrass beds on sandy substrates in the bay head due to large displacement of sand being moved by the tsunami. However, the seagrass beds may have fully recovered by 2014 in most areas except those near the river mouth where restoration and construction activities to raise the land for houses to a safe height have caused turbid

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V. Santiago-Fandiño et al. (eds.), *The 2011 Japan Earthquake and Tsunami: Reconstruction and Restoration*, Advances in Natural and Technological Hazards Research 47, DOI 10.1007/978-3-319-58691-5_16

waters. The tsunami restored tidal flats and saltmarshes along the coast, which had been destroyed by land reclamation before the tsunami event. However, they are being destroyed again by public works, such as the construction of huge seawalls, roadways, and the elevation of the ground level by piling up sand. The area over which the seaweed beds are distributed has increased because the hard substrates needed for seaweed attachment (such as fragments and debris of buildings, broken seawalls or wave-dissipating concrete blocks) were shifted seaward from the land and shore by the tsunami. The seaweed beds not seriously affected by the tsunami have gradually decreased in size because of the removal of hard substrates from the bay. They are now suffering grazing pressure due to an increase in the number of sea urchins since 2014 (3 years after the tsunami) due to the resulting of lack of fishing pressure on sea urchins. The Government of Japan and local governments decided to construct high seawalls to protect against large-scale tsunamis along the Sanriku Coast based on computer simulations. The Government of Japan decided that Environmental Impact Assessment Law is not apply to the construction of huge seawalls with a height of ~8 m above the sea level with deep and wide bases because the law doesn't include construction of seawalls and embankments along the shore and the river bank. These seawalls prevent materials and organisms from flowing or migrating between the land and the sea and often destroy tidal flats and saltmarshes forming the coastal ecotone. It is necessary to keep constant material flows between the land and the sea to maintain healthy coastal waters and prosperous, sustainable coastal fisheries.

Keywords Great East Japan Earthquake • Coastal ecotone • Seagrass • Seaweed • Sanriku Coast

16.1 Introduction

The Great East Japan Earthquake on 11 March 2011 (9.0 magnitude) generated a huge tsunami that hit the Sanriku Coast (Fig. 16.1). The tsunami destroyed not only artificial structures but also ecosystems in coastal zones. However, the Ministry of Land, Infrastructure, Transport and Tourism of Japan decided to finance prefectural governments to construct huge seawalls[1] without an environmental impact assessment to evaluate their impacts on coastal environments because Environment Environmental Impact Assessment Law doesn't include construction of seawalls along the shore and embankments along the rivers that the Coastal Law and River Law don't target (Abe and Masuzawa 2016). However, this is refutable because the size of newly-constructed seawalls are completely different from older ones. Seawalls

[1] In Japan, seawalls are generally call "huge seawalls" among scientists and environment protection groups, while the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) may call them "large seawalls" (note by the author).

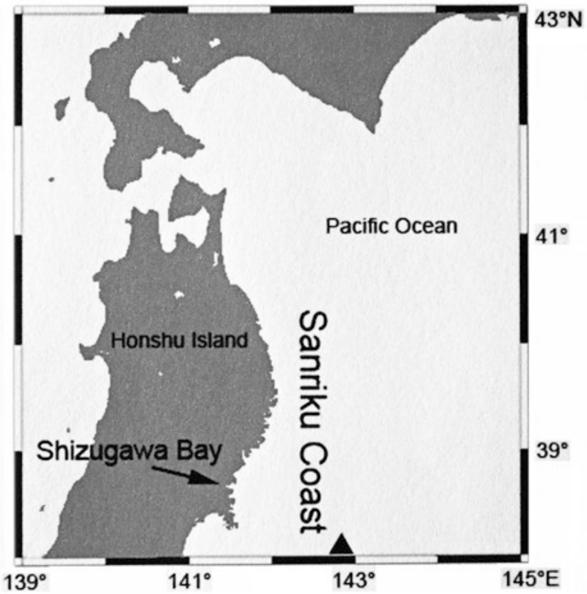

Fig. 16.1 Map showing Sanriku Coast, the epicenter of East Japan Great Earthquake (*closed triangle*) on 11 March 2011 and Shizugawa Bay facing the Pacific Ocean, in Japan

more than 8 m above the sea level, of which the maximum is about 14 m high, are already under construction even though there is major opposition by local people and environmental-protection groups. The construction of new huge seawalls surely impacts costal ecosystems (Nature Conservation Society of Japan 2013) including the ecotone, which is the transitional zone between adjacent ecosystems. The ecotone formed between land and the sea consists of ecologically important habitats such as salt marshes, tidal flats, seagrass beds and seaweed beds. They are indispensable for sustainable fisheries and biodiversity. Costanza et al. (1997) estimated such habitats as very valuable and important for human societies.

To study coastal ecosystems such as seagrass and seaweeds beds, remote sensing has become a powerful tool that is widely used for mapping seagrass and seaweed beds (e.g., Sagawa et al. 2008; Komatsu et al. 2012; Noiraksar et al. 2014). Based on analysis of satellite images, Sasa et al. (2012) and Sakamoto et al. (2012) reported damage to seagrass and seaweed beds in Shizugawa Bay, on the Sanriku Coast hit by the huge 2011 tsunami. Archived satellite images with high-spatial resolutions provided by Google Earth are freely used for research.

This chapter aims to elucidate spatial and temporal changes in the coastal ecotone such as seagrass and seaweed beds, salt marshes and tidal flats, in Shizugawa Bay, on the Sanriku Coast, due to the huge tsunami on 11 March 2011, by using satellite images together with in situ observations.

16.2 Materials and Methods

16.2.1 Study Area

Shizugawa Bay is located on the southern Sanriku coast (Fig. 16.1), which is classified as an enclosed bay by the Ministry of Environment of Japan (2010). It has a wide mouth (6.6 km), a relatively short longitudinal length of 7.7 km and the deepest bottom depth of 54 m at the bay mouth (Fig. 16.2). Tohoku Earthquake Tsunami Joint Survey Group (2011) estimated that mean run-up height of the tsunami in the bay on 11 March 2011 was 14.4 m through field observations.

Fig. 16.2 Shizugawa Bay and the study area (*yellow rectangle*) shown on a satellite image provided by NASA and Digital Globe for Google Earth

16.2.2 Field Surveys

Field surveys were conducted at intervals of 6 months from October 2011 to October 2013, and at intervals of about 3 months since 2014 until now. Field surveys consisted of visual observation and drop-camera observation from the small fishing boat, visual observation from the shore and on land, and inquiries directed to fishermen.

16.2.3 Satellite Images and Analysis

We used satellite images from Digital Globe provided via the internet by Google Earth from 2010 to 2016. Images of a bay head area in Shizugawa Bay were downloaded as JPEG images and processed with Adobe Photoshop CS2 (Adobe) to extract seagrass and seaweed beds under the sea and ponds in salt marshes on land, which this study analyzed and reported. Using software (Photoshop CS2), these habitats were extracted from the images by selecting pixels that have values similar to a representative pixel that was chosen for each habitat. The range of pixel values was also tuned for detection of habitats. We selected one area located northwest of the bay where three rivers flow into the bay and form estuaries with rocky coasts (Fig. 16.2).

16.3 Results

- *25 June 2010*: seagrass beds were distributed near the river mouths and in the port (Fig. 16.3). Seaweed beds were distributed along the coast west of the bay and rocks set around the tip of piers in the center of the image (Fig. 16.3). No broad tidal flats were found except inside the river.

- *6 April 2011:* About 1 month after the tsunami on 11 March 2011, no seagrass beds were distributed (Fig. 16.4). However, seaweed beds remained along the coast west of the bay, although their spatial area had decreased by 25 % from those of 2010. Ponds filled with brackish water appeared on land and also tidal flats along the coast north of the bay after the seawalls were broken. The image also showed that a part of the pier in the port along the east-west direction had disappeared.

- *19 March 2012:* 1 year after the tsunami hit, the area covered with seaweed beds was increased by 127 % of that in 2010 (Fig. 16.5). New seaweed beds appeared around the river mouth of Araita River where the pier had been spread before 2011. An area covered with seaweed beds along the coast west of the bay

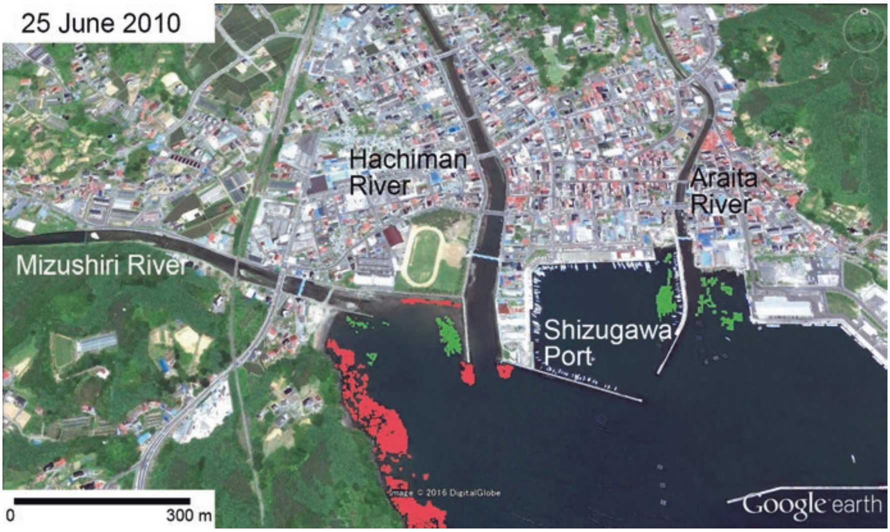

Fig. 16.3 Seaweed (*red area*) and seagrass (*green area*) beds extracted from and overlaid on satellite image on 25 June 2010 provided by NASA and Digital Globe for Google Earth

Fig. 16.4 Seaweed beds (*red area*) and seagrass beds (*green area*) and ponds filled with brackish water (*blue area*) extracted from and overlaid on satellite image on 6 April 2011 provided by NASA and Digital Globe for Google Earth

Fig. 16.5 Seaweed beds (*red area*) and seagrass beds (*green area*) and ponds filled with brackish water (*blue area*) extracted from and overlaid on satellite image on 19 March 2012, provided by NASA and Digital Globe for Google Earth

increased from 2011 to 2012. On the other hand, seagrass beds were still not found in *March 2012*. On land, the ponds area filled with brackish water appeared after the event had decreased by 74 % of that in 2011. Tidal flats disappeared east of the Mizushiri River mouth due to landfill activities, although those around the mouths of Hachiman River and Araita River remained. As construction started on land, two fan-shaped and one triangulate beach appeared along the shore between the Hachiman River and Mizushiri River.

- *27 March 2014:* 3 years after the tsunami, the area covered with seaweed beds again had increased by 103 % of that in 2010 (Fig. 16.6). Seaweed beds that had grown on the remains of the partly broken and submerged pier disappeared due to the reconstruction of the new pier on the site of the past one. The seaweed beds that had been distributed along the port and near the mouth of Araita River in March 2011 disappeared. On the other hand, seaweed beds increased along the west of the bay and off the Muzushiri River mouth. The ponds filled with brackish water that appeared on land in 2011 decreased by 67 %. Tidal flats near and east of the river mouths of the Hachiman River and Araita River remained. Then shores of Shizugawa Port and the port at the mouth of Araita River were covered with a newly rebuilt bulkhead in 2014 except east of the port. On land, public works leveling the ground up to a height of 8 above the sea level with sand started west of the Hachiman River mouth; two fan-shaped and one triangulate beach appeared more clearly along the shore between the Hachiman River and Mizushiri River from 2014.

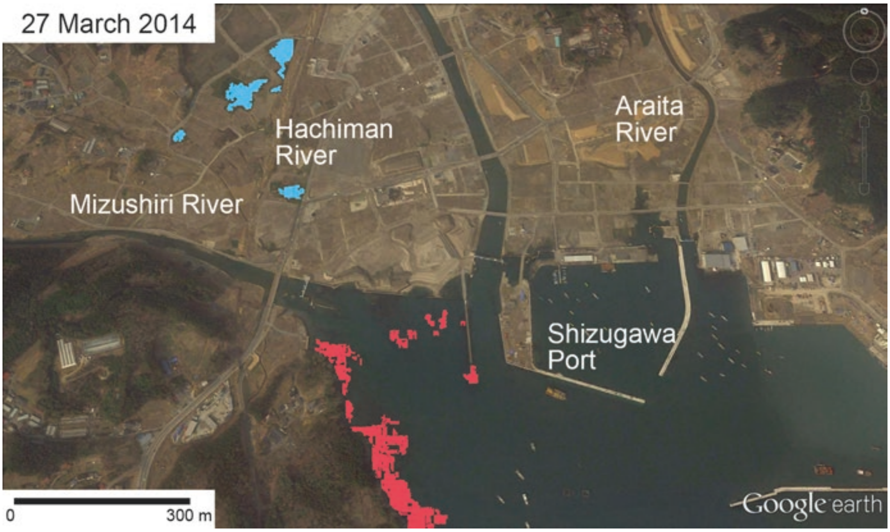

Fig. 16.6 Seaweed beds (*red area*) and seagrass beds (*green area*) and ponds filled with brackish water (*blue area*) extracted from and overlaid on satellite image on 27 March 2014, provided by NASA and Digital Globe for Google Earth

Fig. 16.7 Seaweed beds (*red area*) and seagrass beds (*green area*) and ponds filled with brackish water (*blue area*) extracted from and overlaid on satellite image on 1 June 2015, provided by NASA and Digital Globe for Google Earth

Fig. 16.8 Seaweed beds (*red area*) and seagrass beds (*green area*) and ponds filled with brackish water (*blue area*) extracted from and overlaid on satellite image on 13 November 2015 provided by NASA and Digital Globe for Google Earth

- *1 June 2015*: The area covered with seaweed beds decreased by 93 % of that found in 2010 (Fig. 16.7). Patches of seaweed beds shrunk from March 2014 to June 2015. Small patches of seagrass appeared off the river mouth of Mizushiri River for the first time after the tsunami, although their total area was only 4 % of that in 2010. An area of ponds filled with brackish water decreased by 23 % from that in 2011. Tidal flats disappeared due to the construction of the seawalls and landfill. The public works leveling and raising the ground up to a height of 8 m above the sea level were clearly observed north of Shizugawa Port, east of the Araita River and west of the Hachiman River.

- *13 November 2015*; an area covered with seaweed beds decreased by 83 % of that in 2010 (Fig. 16.8). Patches of seaweed beds shrunk in the period from June 2015 to November 2015. However, small patches of sparse seagrass appeared off the Mizushiri River mouth since March 2015, although their total area was 3 % of that in 2010. The ponds filled with brackish water that had appeared on land in 2011 decreased by 1 % of the size after 2011. On land, public works continued to be active.

16.4 Discussion

The area covered with seaweed beds in 2011 decreased by 25 % of that in 2010 in the bay-head area after the tsunami hit. On the other hand, those growing on rocky beds in the center and the bay mouth of a rias-type bay, such as Otsuchi Bay in Iwate Prefecture, were less impacted by the tsunami (Komatsu et al. 2015). One of the reasons for this difference is that the tsunami impacts the seaweed beds in shallow water, when its wave height becomes greater as the bottom depth becomes shallower (Japan Weather Association 2016). Since the rias-type bay has a U-shape horizontal profile, the wave height in the bay head was much higher than that in the bay mouth (Japan Weather Association 2016). The resulting powerful spilling waves and undertows transported some seaweeds growing on the rocky coast in the bay head. Aoki et al. (2013) reported that the tsunami partly damaged some fronds of *Eisenia bicyclis* (Kjellman) Setchell 1905 kelp beds, particularly within innermost portions of Shizugawa Bay. This observation supports our results.

In March 2012, 1 year after the tsunami, an area covered with seaweed beds increased by 127 % of that in June 2010. Sakamoto et al. (2012) also observed an increase in seaweed beds after the tsunami in Shizugawa Bay. The huge tsunami broke buildings near the shore, breakwaters and piers to pieces and carried them out to the sea. These hard substrates provided good habitats for seaweeds. In the spring of 2012, the young of *Sargassum* species and *Saccharina japonica* (Areschoug) C. E. Lane, C. Mayes, Druehl & G. W. Saunders 2006 kelp grew on hard substrates. Since damage to seaweeds by the tsunami wasn't serious, they could reproduce immediately during their mature season in the summer of 2011.

During the period from March 2012 to March 2014, debris in the port and near the Araita River mouth, as well as those of seawalls of the port destroyed by the tsunami, were removed. This led to a reduction of hard substrates; hence the seaweeds were decreased from their distribution area in March 2012 to March 2014.

Drastic decreases in seaweed beds of *E. bicyclis* growing on rocky beds were observed in other areas of the bay from 2013. This was caused by an explosive increase in the number of sea urchins. In Sanriku Coast, fishermen harvest sea urchins in summer, corresponding to their mature season, to sell their ovaries. However, in the summer of 2011 and 2012, after the tsunami, fishing boats, processing facilities and workers to remove ovaries from sea urchins were unavailable because of the damage by the tsunami and the evacuation of workers from the coast. Since sea urchins could survive the huge tsunami and the seaweeds grew luxuriantly on the Sanriku Coast in 2011 (Komatsu et al. 2015) and 2012 as observed in this study, the urchins succeeded in reproducing in the summer of 2011 and 2012 with abundant seaweeds as their food and without fishing pressure. Sea urchins spawned in the summer of 2011 and 2012 might actively feed on *E. bicyclis,* which they prefer to other seaweeds from 2014. Since predators of sea urchins are rare and fishermen did not take the sea urchins on the Sanriku Coast from 2011 to 2014, their populations kept growing. They continue to feed on *E. bicyclis* and transform their beds into devastated rocky beds. When the *E. bicyclis* beds are devastated, ovaries of these sea urchins are not well developed due to the insufficient quantity of seaweeds that they feed upon. Because sea urchins without a well-developed ovary in summer have no commercial value, fishermen don't take such sea urchins. Hence, fishermen cooperative and local government are hiring divers to remove these sea urchins from 2015 for recovering seaweed beds.

In 2012, the seagrass beds were well recovered in the central part of Shizugawa Bay (Sasa et al. 2012), but not those in its bay head area. It is thought that the tsunami removed seagrass and sand together from the river mouth and left debris there. Reconstruction projects started near the shore and port in 2012. The governor of Miyagi Prefecture, which Minamisanriku Town including Shizugawa Bay belongs to, decided to elevate the banks of the rivers and the seawalls. Local people and governments decided to elevate the ground level for reconstruction of houses to a height of more than 8 m above sea level. The works produce turbid water both in the river and along the seashore. Eventually, turbid water and debris in the bay-head area prevent seagrass from recovering, and seagrass beds near the river mouths could not recover until 2015, when land elevation works had been nearly completed (Fig. 16.8). However, they cannot fully recover as long as the construction works continue.

Saltmarshes and tidal flats had been widely distributed in coastal land where rivers flow into the sea on the Sanriku Coast before the economic development of Japan in 1970s. They were then reclaimed to construct roads, ports and seawalls from this period. However, the huge tsunami on 11 March 2011 created ponds filled with brackish water that produced saltmarshes around them and tidal flats along the seashore. Moreover, diastrophism due to the Great East Earthquake lowered the ground level by 60 cm in Shizugawa Bay (Geographical Survey Institute of Japan 2011). During the spring tide, the high tide inundated the low land around Shizugawa Bay (Meteorological Agency of Japan 2011). Flooding had supplied seawater to the saltmarshes and ponds until provisional banks and bulkheads were built. The Government of Japan and Miyagi Prefectural Government decided to reclaim them again, intending to reinstitute the land use as that before the tsunami. Thus, the saltmarshes have been shrunk back since 2012 when the provisional banks and bulkhead were built along the coast. The Ministry of Environment of Japan (2012) designated the Sanriku Coast as Sanriku Restoration National Park in 2012 to learn about natural threats and to reconstruct sustainable coastal society living in harmony with nature, namely, society with sustainable and healthy coastal environments. Therefore, it had been a good opportunity to conserve some saltmarshes to learn about their ecological functions, as well as the ecosystem services they may have been providing.

Tidal flats are also one of the very important coastal habitats. The huge tsunami restored tidal flats that had existed long ago before the reclamation. Local people went to the tidal flats that appeared near the river mouths to collect Manila clams after the tsunami (Innami *per. com.*). However, the construction of huge seawalls and banks have again destroyed the tidal flats. The two fan-shaped and one triangulate beaches along the shore between the Hachiman River and Mizushiri River appeared in 2012, instead of the natural tidal flats in 2011. The artificial beaches are encircled with concrete bulkheads and isolated from the natural land biotope, therefore the full ecological functions of these beaches may be limited because materials flowing between the land and the sea are to be blocked by the wide and deep bases supporting huge concrete seawalls along the coast and embankments along the rivers.

The law of construction of tsunami disaster-prevention areas was adopted in 2011 after the tsunami of 11 March 2011 (Government of Japan 2011). Based on this law, the Ministry of Land, Infrastructure, Transport and Tourism of Japan (2011) delineated tsunamis into the two categories of Level 1 (occurring at intervals of several decades to hundred years) and Level 2 (occurring at intervals of several hundred years), such as the tsunami on 11 March 2011, deciding to construct seawalls against tsunamis of the former category (Ministry of Land, Infrastructure, Transport and Tourism of Japan 2011). Prefectural governments decided heights of Level-1 and Level-2 tsunamis based on historical data and modeling of tsunamis at each coast divided according to geomorphological continuity. Another measure to avoid harm from tsunamis to humans is that the houses of local people are constructed only on grounds safe from Level 1 tsunamis, with a combination of multiple barriers against the Level 1 tsunamis, such as an elevated national-road base and previous seawalls. Local people could choose whether to live on ground elevated up to more than 8 m above the sea level, as determined by historical records of tsunamis or computer simulation in a case of lack of the records, or on ground with a height above the sea level deemed safe from Level-1 tsunamis (Miyagi Prefecture 2011). Some residents don't want the large seawalls planned against Level-1 tsunamis because high seawalls prevent them from seeing the seascape (Asahi Shinbun 2015) and think that the seawalls with heights of 3–5 m that existed before the tsunami on 11 March 2011 are sufficient for their daily life (Deutsch-Japanisches Synergie Forum 2016). When the tsunami hit the coast on 11 March 2011, residents who saw the pulling wave could escape from the tsunami. Thus, it is important for residents to see the sea (Kahoku Shinpo 2014). Most residents preferred seawalls with a height of 4 m that existed before the tsunami to huge seawalls with a height of ~8 m planned by the reconstruction plan of seawalls after the tsunami by the law through inquiries to residents at Yoriki, Minami Sanriku Town (Sanriku Project of Harvard University and Miyagi University 2012). Moreover, the seawalls against normal storm surges are sufficient to protect fields where agriculture has been abandoned due to depopulation (Yokoyama 2014).

This study shows that the succession of the ecotone, particularly in some parts of the Sanriku Coast, is very dynamic and is also becoming more variable under the influence of human activities. Unfortunately, construction and reconstruction works are destroying important habitats, such as the saltmarshes and tidal flats restored by the tsunami. On the other hand, decisions by the authorities like constructing huge seawalls and river embankments, which disrupt completely the material and biological flows between the land and the sea, seem to put into question the environmental sustainability and recovery of the Sanriku Coast. Even though the Government of Japan has already decided on policies concerning the sustainable development of society in harmony with nature, the decision on the policy to construct huge seawalls lacked discussion among stakeholders and contradicted the policies. Our lessons from this study highlight the need to initiate discussion among local people, fishermen, and local and national governments before another huge tsunami hits coasts because it is very difficult to conduct discussions with all the stakeholders right after a huge tsunami disaster, and so to avoid instituting a restoration policy that conflicts with national policies that have already been decided.

Acknowledgement This study was partly supported by the Mitsui and Co., Ltd. Environment Fund (FY2011 Restoration Grants; R11-F1-060), by Tohoku Marine Science of Ministry of Culture, Sports and Education and also by S(9) and S(13) of Strategic Research Funds of Ministry of Environment of Japan. The authors express sincere thanks to Mr. Norio Sasaki, President of Shizugawa Bay Management Council of Miyagi Fisheries Cooperative, and Mr. Toshimitsu Sato and Mr. Fujio Abe, Head of Tokura and Shizugawa Branches of Miyagi Fisheries Cooperative for their help in conducting the field survey.

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Chapter 17
Reconstruction and Restoration After the Great East Japan Earthquake and Tsunami; Tohoku Ecosystem-Associated Marine Sciences (TEAMS) Project Activities

Akihiro Kijima, Kazuhiro Kogure, Hiroshi Kitazato, and Katsunori Fujikura

Abstract The Great East Japan Earthquake and Tsunami on March 11 in 2011, caused immense damage to marine ecosystems and marine products (fisheries and mariculture), both nearshore and offshore, on the Pacific coast of northeastern Japan (the Tohoku region). The rebuilding of towns and recovery of fisheries is proceeding only slowly because of the extensive devastation. Therefore, helping the restoration of marine ecosystems and revitalizing the fisheries and marine-product industries in these coastal areas have become pressing issues. In order to accomplish these urgent tasks, as well as to learn how to cope with such disasters in the future, scientific investigation is essential to understand the effects of such strong disturbances on marine ecosystems and to monitor the process of their recovery. However, such large-scale investigation is impossible by an individual or an independent research institution. Accordingly, the *TEAMS* (Tohoku Ecosystem-Associated Marine Sciences) project was created as a project at the national level. This paper introduces the overview of the *TEAMS* project.

Keywords GEJE (Great East Japan Earthquake and Tsunami) • TEAMS (Tohoku Ecosystem-Associated Marine Sciences) • Restoring our rich ocean • Reconstruction from GEJE • Science for society

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V. Santiago-Fandiño et al. (eds.), *The 2011 Japan Earthquake and Tsunami: Reconstruction and Restoration*, Advances in Natural and Technological Hazards Research 47, DOI 10.1007/978-3-319-58691-5_17

17.1 Introduction

17.1.1 What Happened in the Ocean Following GEJE and Tsunami; Damage to Marine Ecosystems and Fisheries

A massive earthquake of magnitude 9.0 occurred in the Tohoku district in Japan at 14:46 on March 11, 2011. The epicenter was the offing of Sanriku, 38°6.2′N and 142° 51.6′E at 24 km deep and located 130 km ESE off the Oshika Peninsula (Miyagi Prefecture). About 30 min after the earthquake, a large tsunami hit a wide area of the Pacific Ocean side of Japan, especially along the Tohoku Pacific coast. Fatalities and missing persons of the events are 15,894 and 2558 respectively as of the end of March 2016 being about 90% of those in Miyagi and Iwate Prefectures (National Police Agency of Japan 2016). Many houses and buildings, roads and railways were destroyed on the coastal area facing the Pacific Ocean. The functions of cities and towns in coastal area of Tohoku stopped completely for several weeks. Figures 17.1, 17.2, 17.3, and 17.4 were taken immediately taken after the tsunami hit the coastline showing the devastation of Onagawa town (Miyagi Prefecture); while those of Fig. 17.5 were taken 50 days afterwards. The town was totally destroyed presenting a large amount of accumulated debris, it did not start functioning until 50 days after the GEJE occurred still having about 75% of debris without being disposed off.

Along the coastal areas the tsunami destructed breakwaters and tide embankments, land subsidence due to the earthquake resulted in one meter sinking along the coast of southern Sanriku in many areas. Flooding ensued along coastal plains; numerous debris from the land were deposited into the ocean, from the subtidal zone to deep-sea bottom; crude oil and other toxic chemical compounds spewed into the ocean; and seaweed forests and plenty of tidelands were obliterated. Overall,

Fig. 17.1 *Left*: tsunami reaching Tohoku University Onagawa Field Center of Tohoku University at 3:19 pm. *Right*: tsunami at 3:20 pm on March 11, 2011. Large tsunamis waves reached Onagawa town at least three times within the day (Pictures taken by Yoshiyuki Suzuki; Tohoku University)

Fig. 17.2 *Left*: the tsunami encroaching on the mountain area with many houses neighboring the Tohoku University Onagawa Field Center at 3:24 pm. *Right*: view after the first Tsunami wave withdrew leaving debris rested behind the Field Center at 3:42 pm on March 11, 2011 (Pictures taken by Yoshiyuki Suzuki; Tohoku University)

Fig. 17.3 *Left*: debris accumulated on 12th March at the back yard of the Field Center. *Right*: heavy oil tank displaced from the hill flowed out to sea (March 13, 2011) (Pictures taken by Yoshiyuki Suzuki; Tohoku University)

Fig. 17.4 *Left*: removal of debris by people 2 days after GEJE events rubble. *Right*: total destruction of the central part of Onagawa town (March 14, 2011) (Pictures taken by Yoshiyuki Suzuki; Tohoku University)

Fig. 17.5 *Left*: Onagawa town center partially flooded and not functioning 50 days after the events of March 2011. *Center* and *Right*: destroyed mariculture and fishing equipment for salmon, scallop, oyster and ascidians (sea squirt) floating at sea on May 1, 2011 (Pictures taken by A. Kijima; Tohoku University)

the marine environments and related ecosystems were impacted in various forms and intensity.

Marine products (fisheries and mariculture) are the mainstay of industry in Tohoku. Most fishing facilities including vessels, nets, mariculture equipment, and processed marine products factories were almost all destroyed. Damage of fisheries was highest in Miyagi Prefecture followed by Iwate Prefecture (Table 17.1) as approximately 85% of damage was concentrated on these two Prefectures.

The GEJE was a catastrophic disaster ranking alongside the most destructive in history in Japan and the world; plenty of video records exist in the internet presenting both the earthquake and the tsunami for example Daishu Channel (2013) and RT (2011) respectively.

For revival from the disaster, reconstruction of the fisheries which are the key industry of the coastal area is essential. It has been a pressing concern to understand the damage situation of the marine environments and a marine ecosystems used as fishery grounds. However, since it is difficult to observe the ocean directly, it is also difficult to get to know the damage situation under the ocean. For this purpose, scientists needed to perform research using sophisticated and special equipment including research vessels and other specific research apparatus.

Large number of scientists and researchers went into the stricken area immediately after the disaster to undertake field investigations producing a great deal of information, most of the studies have been published in the specialized journals and scientific magazines. However, the information was both fragmented and covered a limited area, therefore it became necessary to unify various research fields, systemized the information as well as to widen the covered area. For the purpose forming a joint research organization became desirable.

Table 17.1 Damages to Fisheries industries in Japan affected by the GEJE and Tsunami

Prefecture	Fishing boats		Ports		Aquaculture	Processing	Facilities	Prefecture total	% of total damage
	Numbers (%)	Amount of damage (billion Yen)	Numbers %	Amount of damage (billion Yen)	Amount of damage (billion Yen)	Amount of damage (billion Yen)	Amount of damage (billion Yen)	Amount of damage (billion Yen)	
Miyagi	12,029 (87.3%)	116.048	142 (100%)	424.286	81.889	108.137	45.767	667.990	52.90
Iwate	13,271 (91.5%)	33.827	108 (97.3%)	285.963	26.261	39.195	51.270	397.321	31.44
Fukushima	873 (81.7%)	6.022	10 (100%)	61.593	0.833	6.819	13.915	82.363	6.52
Others	2439	26.317	59	51.198	24.540	9.704	13.921	115.976	9.18
Total	28,612	182.214	319	823.040	133.523	163.855	124.873	1,263.650	

17.1.2 What Is Tohoku Ecosystem-Associated Marine Sciences (TEAMS)

The Government of Japan established the Reconstruction Agency in response to the Great East Japan Earthquake (2011) creating the "*Basic Guidelines for Reconstruction in response to the Great East Japan Earthquake*". The *Guidelines* stated that *"it is necessary to investigate marine ecosystems that were drastically changed by the disaster, to reconstruct fishery grounds, and to form networks among universities, research institutes and private companies that are conducive to the creation of related industries"* and that *"restoration of fishery grounds and marine resources is necessary through reconstruction of seedling production systems for salmon and trout, restoration of seaweed beds and tidal flats, and understanding the environment of fishery grounds and managing resources appropriately on the basis of scientific findings."*

In addition the report "The state of research on marine bioresources" was published by the Ministry of Education, Culture, Sports, Science and Technology of Japan (MEXT 2011). Within the report, the formation of a network of marine science researchers in universities and research institutes all over Japan, and the establishment of a center for marine science in the Tohoku region, on which the network is to be based to continually and systematically promote research and development in the Pacific coastal areas of the Tohoku region was considered. The center for marine science was expected to also cooperate with overseas research institutes and private companies, and to develop and continue as an international research center for marine science in the future.

Against the backdrop above the *Tohoku Marine Science Center*, led by the Tohoku University, the Atmosphere and Ocean Research Institute (AORI) of the University of Tokyo, and the Japan Agency for Marine-Earth Science and Technology (JAMSTEC), a program to support the restoration and reconstruction and undertake investigations and research on the marine ecosystems in the coastal and offshore areas of the Tohoku region in cooperation with local governments and relevant ministries and agencies, with the aim of reconstructing the Tohoku region was established. As result the research project of "Tohoku Ecosystem-Associated Marine Sciences (*TEAMS*)" was created and subsidized by MEXT.

The organization of *TEAMS* is shown in Fig. 17.6. The purpose of *TEAMS* is to clarify the impact of the earthquake and subsequent tsunami on the marine ecosystems of the Tohoku coastal areas, highlight the restoration process of the ecosystems based on scientific research, and contribute to the reconstruction of the fishery industries in the Tohoku region. In order to achieve the purpose, *TEAMS* has set up four major subjects or areas of concentration:

1. *Studies on Ecological Succession of Coastal Fishery Grounds* conducted by Tohoku University in collaboration with Kitasato University;

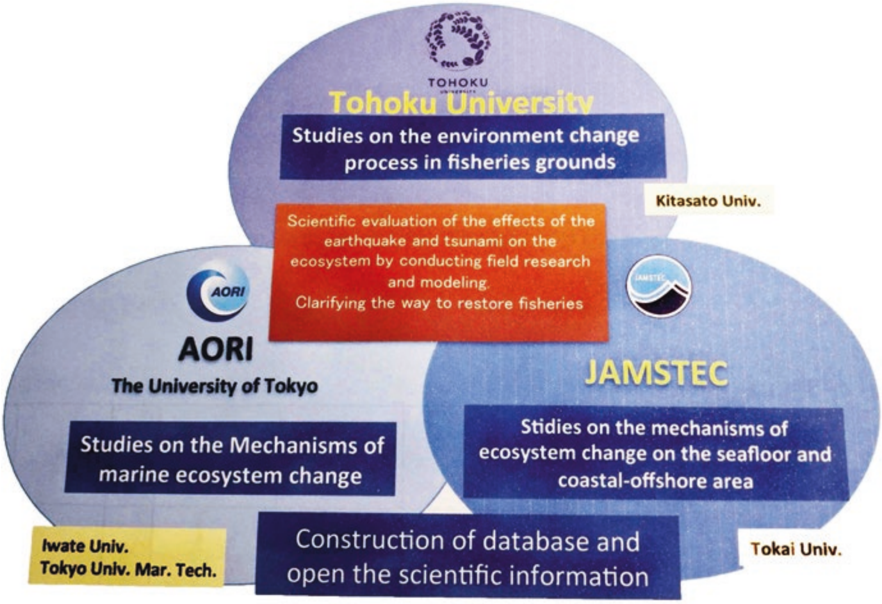

Fig. 17.6 Organization of *TEAMS*

2. *Research on Factors controlling Marine Ecosystem Dynamics* conducted by AORI in collaboration with Tokyo University of Marine Science and Technology and Iwate University;
3. *Research on Factors controlling Open-Ocean Benthopelagic Ecosystem Dynamics* conducted by JAMSTEC in collaboration with Tokai University;
4. *Data Sharing and Publication by Development and Operation of Information Systems for TEAMS* conducted by all three organizations and mainly managed by JAMSTEC.

More than 200 marine scientists from universities and institutions have joined from all over Japan and have carried out research activities in their professional scientific fields as the member of *TEAMS*.

During the 5 years after the GEJE, it has been shown what kind of damage has occurred in marine environments and marine ecosystems. Many valuable results have been achieved not only for new scientific knowledge but also for the reconstruction of fisheries. *TEAMS* activities have been able to continue for a further 5 years. However, the organization has been improved for the second 5-year period, though the original mission and major structure of *TEAMS* were not changed. Five *Task Groups* were set up (Fig. 17.7):

1. ***Biological and Environmental Monitoring***. This group offers a site for *TEAMS* to exchange and discuss scientific ideas related to biological and environmental monitoring;

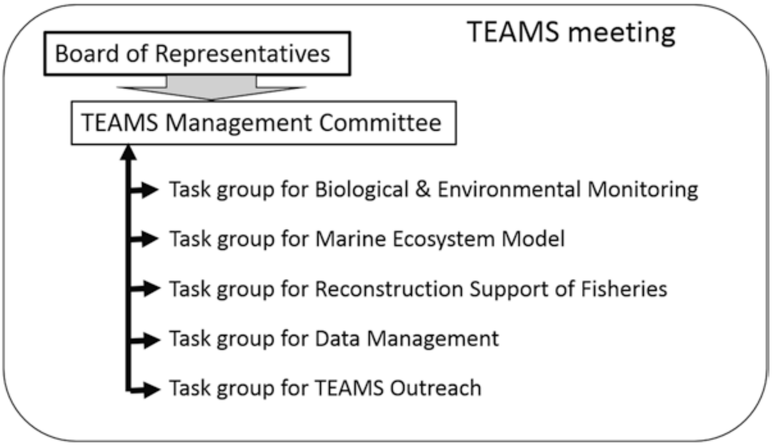

Fig. 17.7 Reorganized five task groups after the first 5 years

2. ***Marine Ecosystem Model***. This group is developing marine ecosystem models based on biological and oceanographic monitoring data before and after the 2011 GEJE;
3. ***Reconstruction Support of Fisheries in the Disaster Area***. This group exchanges information on the activities of fishery reconstruction support in each organization, and summarizes them as *TEAMS* results;
4. ***Data Management***. This group promotes methods for gathering *TEAMS* project accomplishments, and evaluates development of *TEAMS* databases;
5. ***TEAMS Outreach***. This group aims at carrying out overall promotion of *TEAMS* activities.

17.2 *TEAMS* Activities

Five years since the GEJE, *TEAMS* has surveyed the effects of the GEJE on marine ecosystems and environments in various disaster areas from the view point of various scientific fields. A large amount of valuable results in Biology, Chemistry, Physics, Geology, Oceanography, and Fishery science have been obtained and some of them have been published in scientific journals and/or general papers (*TEAMS* website). Summarizing these results can roughly be divided into five fields as follows, though the data collected in each field are utilized mutually.

17.2.1 Monitoring of a Marine Environments

TEAMS has been monitoring marine environments continuously in the Sanriku waters mainly in the Onagawa and the Otsuchi Bays. The observation data set has been recorded in the *TEAMS* database "RIAS: Research Information and data Access Site of *TEAMS*". Most of the debris was removed from under sea routes and aquaculture areas by 2014, but much rubble remains in a sandy bottom and deep-sea areas. In Otsuchi Bay, the dynamic state of the seawater inside and outside the bay was clarified. In addition, *TEAMS* has been surveying marine quality, such as the dynamics of the chemical substances and nutrients, and the composition of plankton. Large changes from the normal state were observed immediately after the GEJE, but after 2 or 3 years, the levels returned to the baseline existing before the GEJE.

17.2.2 Survey of Marine Ecosystems

TEAMS has been conducting an ecological change in a variety of areas, such as tidal zone, sandy bottom, rocky area, from surface to bottom in inshore to offshore areas. Although fauna and environments of coastal areas such as the tidal flat, seaweed forests and seagrass area were seriously affected by the disaster, they have begun to recover favorably. However, it is still unknown whether a new ecosystem is constituted and whether it will recover to the point it at before the disaster. The sea urchin started to breed immediately after the disaster appeared in large quantities and areas were serious damage occurred were identified. Genetic changes in the population have not been observed after the disaster.

Besides the environmental consequences brought by the disaster, some impacts due to the reconstruction of towns, ports, and traffic systems have been observed. For example, invading species appeared, increasing turbidity of coastal seawater and decreasing the space for juveniles and/or larvae, etc. In light of this, monitoring of the marine environments and related marine ecosystems is indispensable during the period in so long as the reconstruction process continues.

17.2.3 Contribution for Fishery Reconstruction

TEAMS activities have largely contributed to improve the fisheries' recovery. For instance, the distribution of debris in the sea bottom provided the information required for the smooth operation of fish trawlers. Moreover, information about sunken ships contributed to the improvement of fisheries and also in various other directions. Research and information provided by *TEAMS* is at present utilized for fisheries restoration. Examples include direct surveillance on salmon return, distribution of potential toxic plankton for shellfish, development of fishing method and the assessment of the environmental capacity for scallop marine aquaculture amongst others. *TEAMS* activities have contributed to actual fishery recovery both directly and indirectly.

17.2.4 Construction of a Database

Disasters caused by earthquakes and tsunamis have occurred not only in Japan but also in many other countries and will also occur in the future. However, almost no data of the impacts and effects of disasters on marine environments and ecosystems have been scientifically taken, systematically analyzed and gathered in the world. Therefore, as part of this project, *TEAMS* is creating an original database for not only the recovery of Japan but to contribute to future international recovery efforts. The data can be seen on the specific *TEAMS* website. For example, the research data sets of marine environments are available in the "RIAS" database. Moreover, data sets of marine organisms are available in another database named "BORAS: Biological Observation Record Archive System". However, since the construction of a database has just begun not all data can be perused, but a more substantial database will be planned from now on. The data can be freely accessed from the *TEAMS* website.

17.2.5 Public Relations of TEAMS Activities

This Program is strongly supporting fisheries restoration while also contributing to the "*Build Back Better*" concept. The legacy of data and research undertaken by *TEAMS* are available in its website, its transferred within Japan and abroad particularly in countries where large hazardous events like the one of March 2011 may occur. On the other hand, *TEAMS* also holds a large number of activities such as symposiums and meetings for the public and professional including administrators, local governments officials, fishery related organizations, associations, cities, towns and villages while also undertaking international activities. Some of the relevant ones are mentioned below:

- Symposium *How was the northeast coast of Japan changed?* Tokyo, November 2013
- Symposium *From an earthquake disaster to reconstruction of the northeast coast of Japan*. Tokyo, October 2014
- International Symposium *How Did the Great East Japan Earthquake Affect Marine Ecosystem?* Third UN World Conference on Disaster Risk Reduction Public Forum. Sendai; Miyagi Prefecture. March 14, 2015
- Joint Symposium *Now of the northeast coast of Japan -The results of research and fishery reconstruction for 4 years* Executive board symposium of the Japanese Society of Fisheries Science together with The National Research and

Development Agency, Japan Fisheries Research and Education Agency (FRA) and *TEAMS*; 2015 Sendai (Miyagi)

- International Symposium on *Restoration after Great East Japan Earthquake – Our Knowledge on the Ecosystem and Fisheries.* Tokyo, March 2016.
- Special session *Science for a Huge Disaster-Lessons from the Great East Japan Earthquake and others in Asian Countries.* 23rd Pacific Science Congress, Academia Sinica (Taipei, Taiwan); June 13–17, 2016

Moreover, in the local disaster area, *TEAMS* have held briefing sessions and lecture meetings for fishermen and fishery related organizations on *TEAMS* activities and the importance of scientific research in reconstruction from the disaster to high school students, college students, and graduate students. For further details visit the *TEAMS* website.

The results of the *TEAMS* research studies are summarized by Kijima et al. (2015), Kogure et al. (2016), Tsuda et al. (2016), and Kijima (2016). Also some results of *TEAMS* research studies were published in a special feature edited by Takeuchi and Watabe (2015) and a summary of the symposium edited by Watabe et al. (2015). More than 120 papers have been published including scientific reviews (more than 50) plus posters at conferences and meetings as well as over 400 presentations.

17.3 Towards the Future

TEAMS Activities have been strongly supported by many partners and people over the last 5 years due to its relevance and importance; in particular people in the local areas where the disaster occurred are particularly interested in the continuation of the interdisciplinary surveillance.

In the international symposium held in March 2016, scientists from abroad evaluated *TEAMS* activities as scientifically, internationally, and socially valuable, because of the rarity of the data related to the effects of natural disasters on marine environments and ecosystems accumulated for long term. Therefore, *TEAMS* wishes to continue working towards its goal, i.e. restoring the rich ocean and aiding in reconstruction of fisheries destroyed by the GEJE, and also contribute to the concrete revival and restoration of fisheries. Accordingly, monitoring of the marine environment has continued mainly in Otsuchi and Onagawa Bays and the construction of the ecosystem models such as physical currents and biological production have continued for sustainable yield of living marine resources.

TEAMS will continue improving its database system, hold symposia and lectures for fishermen and citizens not only for Japan but also in other countries. Finally, the *TEAMS Program* is considering holding a symposium to present the recovery of Japan from the GEJE in 2020, when the Tokyo Olympic Games will take place.

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Chapter 18
The Coastal Environment and the Reconstruction Process After the Great East Japan Earthquake: A Few Notes

Vicente Santiago-Fandiño and Erick Mas

Abstract Most of the world's coastal areas have been shaped and transformed by tsunamis from prehistorical times with origins varying from cosmically related events to tectonic plate dynamics and atmospheric disturbances. The most devastating tsunamis involve large meteorite strikes, followed by massive submarine landslides and volcanic eruptions. However other comparatively devastating tsunamis have originated from earthquakes, surface landslides and seafloor displacement. Since 1960, four major tsunami events can be considered to be the most relevant as a result of their size and associated destruction: two events off the coast of Chile, one in the Pacific and Indian Oceans that reached many countries along its path, and the March 2011 Great East Japan Earthquake and Tsunami. The latter badly damaged infrastructure, the social milieu, local communities and cities, industries and the environment of Japan's northeastern coast, prompting the government to engage in an intense 10-year restoration and reconstruction process. The environment vastly suffered the impact, which was reflected in important biodiversity alterations as well as in the presence, abundance and distribution of various coastal ecosystems and biological species. Apart from the ongoing natural restoration process, Japan's government has also decided to support and enhance the process that has developed and has enacted important statutes and statutory frameworks for this purpose, including the 2012–2020 National Biodiversity Strategy, which turns on certain fundamental components, such as the valuation of ecosystems services, and implementation of Environmental Impact Assessments and Environmental Strategic Assessments, among others. Controversial issues, including construction of sea

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V. Santiago-Fandiño et al. (eds.), *The 2011 Japan Earthquake and Tsunami: Reconstruction and Restoration*, Advances in Natural and Technological Hazards Research 47, DOI 10.1007/978-3-319-58691-5_18

fences (such as seawalls or coastal dikes), the potential damage to the coastal environment, effectiveness and costs of certain measures, among others, resulted from **the established reconstruction policies and** differences in perceptions between the government and local inhabitants throughout the reconstruction process. As result of intense interaction between the stakeholders and the government, many of the initial decisions regarding the characteristics of these structures have been revised, although their impact on the environment will certainly remain large and often unpredictable.

Although the present chapter is not intended to be a comprehensive analysis nor a compilation of information, it is intended to provide a brief overview regarding tsunamis, in terms of their origin and types, while giving some relevant examples of the most devastating tsunamis in historical terms and since 1960 to date as a result of their environmental impacts. A deeper analysis is made of the March 2011 event in Japan in which some examples are offered regarding the decimation and or alteration of the biodiversity and ecosystems in some of the affected coastlines. Moreover, this chapter highlights some efforts that Japan's government has undertaken in the 5 years since March 2011 by developing and enacting relevant legal frameworks and related aspects. Finally, this chapter also addresses the contents of the discussion regarding construction of sea fences along the coastline in the Tohoku region (northeastern coast of Japan).

Keywords Tsunami • Environment • Impacts • Biodiversity and frameworks • Restoration and reconstruction • Seawalls and fences • Tohoku • Japan

18.1 Introduction

18.1.1 Tsunamis Origin and Some Related Major Events

Tsunamis are associated with earthquakes, land and submarine slides, volcanic eruptions, meteorite strikes and changes in atmospheric pressure (meteotsunamis), albeit combinations of the foregoing causes are also not uncommon. Boris and Nosov (2016) made a summary of the origins of tsunamis; the NOOA/WSD Global Historical Tsunami Database (n.d.) avers that 73% of tsunamis were generated by seismic events, 3.4% resulted from landslides, 4.7% were caused by volcanic eruptions and 3.6% resulted from meteorological causes, whereas the remaining 10% are due to unknown causes. Tsunamis resulting from meteorite impacts could be considered as the most devastating; the marks of meteorites falling on land are easier to find than the marks of those falling at sea, as their traces are mostly lost at sea; for example 174 meteorite craters have previously been identified on land (University of Oxford 2008), whereas at sea there seem to be none. However, Stephens (2003) claims that traces in inland deposits and the seafloor have been found in disturbed sediment layers. The identification of palotsunamis and historical tsunamis events requires the application of a variety of technical approaches; however geochemistry has recently been recognized as one of the most powerful tools for the purpose (Chagué-Goff et al. 2016).

The Chicxulub meteorite event that occurred 65 million years ago in the Gulf of Mexico may be the only meteorite landing at sea to leave a clear mark. It is thought to have been so catastrophic that many experts believe that it was strongly connected with the massive extinction of species including the dinosaurs (UCB 2015; Strong and Kinsland 2014; Hand 2016; Harmon 2010; SCI 2014). The resulting tsunami waves are likely to have reached coastal areas around the world (Shonting and Ezrailson 2017). Other studies related to paleotsunamis originated from meteorite falls include those of Glikson (2004), Bourgeois et al. (1988) in the USA and Goff and Chagué-Goff (2012). The Eltaning meteorite (late Pliocene) hit the Pacific Ocean 2.6 million years ago, mathematical modeling has shown that the tsunami waves generated by that meteor may have reached up to 50 m height and impacted as far as the Antarctic and South American coasts (Gersonde et al. 2005). This event most certainly had catastrophic consequences for the affected coastal environments. Amor et al. (2008) concluded that large meteorite strikes off of northeastern Scotland may have occurred millions of years ago, whereas Haslet and Bryant (2008) likewise concluded that the southern coast of Britain suffered from meteorite-related tsunamis as recently as 1000 AC. Clearly, the environmental devastation produced by these events along the coastlines would have been enormous.

Tsunamis originating from landslides could also be devastating, such as the Shimabara bay event (Dudley and Min Lee 1988), and the Storegga event that occurred approximately 8000 years ago (the largest and oldest recorded tsunami in historical times), which was the result of 2440–3200/3500 km^3 submarine landslide in the North Sea (offshore Norway). Fruergaard et al. (2015) identified sediments from this event in a freshwater paleolake in Denmark while the large consequences of the Storegga tsunami on contemporaneous societies, on the regional geography and on the environment have been previously documented (Bondevik et al. 2003, 2005, 2012; Bryant 2005; Bryna et al. 2005; Collins et al 2014; Weninger et al. 2008; Klug and Wagner 2008; Wagner et al. 2007; Hill et al. 2014a, b; Haflidason et al. 2005; Smith et al. 2004). In Alaska, Lituya Bay suffered a large earthquake (M_w8) in 1958, displacing 30.6 thousand km^3 of rock that fell into the Gilbert inlet, creating the largest tsunami ever recorded. The tsunami measured 525 m high with corresponding enormous environmental consequences as both fauna and flora were wiped out up to 524 m above sea level, and about 4 square miles of forest suffered the same fate (Miller 1999, 2011; Geology.com n.d.; USC Tsunami Research Group n.d.; NOAA/US Tsunami Warning Center n.d.).

In the southern part of the Pacific Ocean, one of the most relevant tsunamis formed from a volcanic episode was the Krakatau explosion (Indonesia in 1883), which completely destroyed the island and generated waves up to 30 m high by the Sundai straits. Moreover, large swaths of costal areas were destroyed, and there were a large number of casualties (Australian Government 2016; GEO net 2016; Pelinovski et al. 2005). Surprisingly, the small Anak Krakatau volcano continued to grow, eventually developing a tropical forest (Thornton et al. 1988; Thornton 2007; Bush and Whittaker 1991; Whittaker et al. 1999).

Most tsunamis are not as massive and destructive as those discussed above, and the majority range from numerous centimeters to a few meters high. Nevertheless, tsunamis with waves larger than 2–3 high can be devastating to the environment and to society. Doocy et al. (2013) analyzed the impacts of 94 tsunamis measuring 2 m high or more from 1900 to 2009 and concluded that aside from the enormous environmental impacts, 2.5 million people were affected, resulting in 300,000 casualties (including deaths); the largest numbers were associated with the 2004 Indian Ocean tsunami, as it represented 89% of the total amount of casualties.

18.2 Large Tsunami Events in Recent Decades

Tsunamis have been more common along the Mediterranean and Caribbean Seas, while the Indian and Pacific Oceans have been the most active (Earthquake Track n.d.; UNESCO-ITIC 2016; Papadopoulus 2016). Iida et al. (1967) and Soloviev et al. (1992) produced early catalogues of tsunamis occurring in the Pacific Ocean, whereas Soloviev (1990), Soloviev et al. (2000), Papadopoulos and Fonkaefs (2005), and Fonkaefs and Papadopoulos (2007) listed those in the Mediterranean Sea showing also a large number. Compared to all other areas, the Pacific Ocean and interrelated seas are by far the most tsunami and earthquake-prone areas followed by the Indian Ocean as a result of the seismic and volcanic activity from their highly dynamic plates.

A compilation of tsunami events from 2000 BC to 2008 AC is available in the National Geophysical Data Centre – NGDC (2015) – which contains more than 2400 events of all kinds. Satake (2005) and Satake et al. (2011 and 2012) addressed a number of tsunamis events while Satake and Imamura (2005) compiled findings of tsunami surveys, numerical simulations and records, studies on dynamics, and tsunami hazards from 1992 to 1994. Cummins et al. (2009a, b) compiled and discussed papers related to the development of tsunami science after the 2004 Indian Ocean Earthquake, including mathematical techniques that now lead the development of tsunami models, tsunami propagation and the application of tsunami modeling, observation and data analysis. Rabinovich et al. (2016) published a series of papers on the state of the art and the latest findings regarding the tsunami in the Pacific (focusing mainly on the Tohoku 2011 earthquake and Tsunami) and Atlantic Oceans and in the Mediterranean Sea. Other relevant publications, including certain case studies, such as Kontar et al. (2014), Santiago-Fandiño et al. (2015, 2016), and Suppasri et al. (2015).

The most devastating tsunamis since 1960 include the Chilean earthquake of 1960, which is considered to be the strongest earthquake ever recorded (Mw9.5) (Fujii and Satake 2013); this event had enormous impacts along the Chilean coastline as ground uplift and subsidence also occurred, thus altering coastal rivers, creating shallow banks and wetlands – particularly at Rio Cruces (Reinhardt et al. 2009). The ensuing tsunami reached as far as Japan, the Philippines, Hawaii, New Zealand, Australia and Alaska (NOAA 2016). In 2000, until the time this chapter was written, the most devastating ones were the 2004 Indian Ocean Earthquake and

Tsunami, 2010 Chilean Earthquake and Tsunami and the 2011 Great East Japan Earthquake and tsunami (GEJE); their social and economic impacts as well as the environmental debacle they produced were massive. Beaches, water bodies, seafloor, coastal forests and intertidal coastal ecosystems such as wetlands and coastal lagoons were wiped out or heavily damaged as shown below.

18.2.1 Indian Ocean Tsunami, 2004

The Indian Ocean or Sumatra-Andam earthquake of 2004 (Mw9.1) is considered to be the largest in 40 years and although it generated a tsunami similar in size to that of the Chilean 1960 earthquake (Satake 2014), it became the deadliest event in history mainly due to the enormous number of casualties (Satake et al. 2007). The tsunami's environmental impacts in the affected countries varied depending upon their coastal and seafloor characteristics, morphology, ground height as well as tsunami wave size, type, frequency, power, run-up and run-off. However, the most common impacts found along the coastlines included coastal alteration, erosion and morphological changes, vegetation uprooting and wash-off, coral reef destruction, wetlands alteration and destruction, mangrove and coastal forests obliteration and or uprooting, fauna and flora decimation. Likewise, soil compacting, texture composition and alteration were affected, and surface and ground water salinity was found to have increased. Many publications have focused on the specific impacts of the most affected countries including Indonesia, India, Sri Lanka, Thailand, the Maldives, the Seychelles and Yemen (UNEP 2005a; Satake et al. 2007, 2013; Research Group on The December 26, 2004 Earthquake Tsunami Disaster of Indian Ocean 2007; Srinivas 2015; The UN Atlas of the Oceans 2011; Kontar et al. 2014; Suppasri et al. 2015). Santiago-Fandiño et al. (2015, 2016) compiled a series of case studies providing further examples.

In Aceh Province (Indonesia), thousands of hectares of mangrove forests, other coastal vegetation, wetlands and reef ecosystems were destroyed as a result of ground uplift and subduction (UNEP 2007; Brown et al. 2015). Tidal communities and coastal fauna were likewise devastated. Sri Lanka had large sections of its coastal vegetation impacted, although its mangrove forest was impacted only to a lesser extent (Jayatissa et al. 2016). The Katchal, Nicobar and Andam Islands shorelines (India) were heavily altered, particularly the Katchal Island, which suffered a significant reduction in surface area (Yunus et al. 2016).

In Thailand, Szczuciński et al. (2006) found that the inundation in the coastal zone due to the tsunami reached beyond 1.5 km being above 10 m, considering the average sea level. The environmental assessment concluded that coastal erosion took place along the coastline, the inundated area was covered by a 0.5 m of sand and inland waters suffered from salination. Heavy metals were found in the tsunami deposits. Severe effects on ecosystems – such as sea grass beds – as a result of siltation and sand sedimentation (3.5%) and complete habitat destruction (1.5%) were found; 13% of the coral reefs in the Andam coast were severely damaged, whereas mangroves were less affected. Large swaths of land vegetation were impacted as trees were uprooted or broken while other types of plants withered, leading to the conclusion that in some cases the environmental consequences might be perennial.

In the Maldives, Richmond and Gibbons (2005) found that although there were not large waves comparatively speaking (2.0–2.5 m, although 3.25 also occurred), the effects were nonetheless significant in some areas due to flooding, morphological alterations, beach and coastal erosion, sand deposits and the devastation of coral reef lagoons. Further, Fritz et al. (2006) assessed the damages in most of the Maldives islands and found that the impacts on the landmasses (mostly not higher than 2 m) varied widely from those of the coral reefs. These authors concluded that the impact of the tsunami was reduced due to the topography and bathymetry as well as the presence of deep channels that separate various atolls. UNEP (2005b) also made a detailed evaluation of the impacts and identified the effects on groundwater, siltation and vegetation destruction. This tsunami had certainly created havoc on the exposed coral reefs by breaking up colonies, removing see weed, destroying habitats and also altering the abundance and distribution of fish and other marine species.

The Seychelles islands were not spared, as drastic changes occurred on beaches, coral reefs and coastal vegetation and to a lesser extent on sea-grass beds; moreover, siltation of wetlands and alteration of the landscape was also found (UNEP 2005c).

18.2.2 Chilean (Maule) Tsunami, 2010

Resulting from a Mw8.8 earthquake, this tsunami had devastating consequences, as it impacted 500 km of the Chile's coastline with waves up to 10 m tall, although in some places they reached up to 14 m in height (SMS-Tsunami Warning 2016; NOAA 2010, 2016). As with the previous event in 1960, the earthquake also caused important ground lifting and subsidence (1–2.5 m) heavily affecting the coastal ecosystem and biota (Farias et al. 2010; Choi 2012). Focusing on the effects of the tsunami on sandy beaches and also the intertidal fauna and flora, Jaramillo et al. (2012) found that colonization dynamics and species variations changed depending on the existing manmade structures and ground level modifications in the affected areas. When subsidence occurred along the intertidal zones, organisms were wiped out as well as the intertidal zone itself, as with the uplifting of rocky sub-tidal areas. Where coastal fences existed and beach uplifting occurred, the colonization of specific intertidal habitats was promoted. Although it appeared to have been difficult to separate the ecological impacts resulting from the tsunami from the earthquake on the affected beaches, it became clear that many species had washed away, had disappeared and or had their numbers drastically reduced. Communities existing in the intertidal zones were heavily affected as well as those living along the sea fences. The study also concluded that extreme events resulting in coastal sinking or uprising in which there was a presence of manmade structures (sea fences) ecologically significant long-term alterations are likely to be found. Quezada et al. (2012), reported large coseismic lifting and subsidence along the coastlines in the Biobio and between the O'Higgins and Valparaiso regions as a result of the earthquake, while the ensuing tsunami dragged sand and vegetation deep onto land, all leading to enormous environmental alterations.

18.3 The Great East Japan Earthquake and Tsunami, 2011

Based on studies and historical documents, during the last 500 years, the Tohoku region has been hit by large earthquakes and tsunamis, i.e., 1611 (Sanriku), 1677 (Boso-oki), 1763 (Aomori-oki), 1793 (Miyagi-oki), 1896 (Sanriku) and 1933 (Sanriku). Tsunamis generated from afar likewise hit the Sanriku coastline, such as the 1700 Cascadia and 1960 Chilean events (Goto et al. 2013; Satake 2014). The largest recorded earthquake in Japan, the Tohoku-oki or the Great East Japan Earthquake (GEJE) occurred off Miyagi prefecture on March 2011 in association with an M_w 9.0 earthquake (although preempted and followed by two M_w 7.0 tremors).

The earthquake produced large land subsidence while the tsunami displaced an enormous amount of soil and sediments with run-ups as high as 40 m in some areas. In Tohoku, the tsunami inundated area was 2.6 times larger than that of the 1960 Chilean Tsunami (Liu et al. 2013).

Nearly 600 km of coastline were deeply affected by altering and destroying marine and coastal ecosystems including both habitats and related fauna and flora; moreover, 500 of the most important wetlands and bird sites included within priority conservation areas were destroyed. From Aomori to Chiba Prefectures, approximately 576 km^2 were flooded. Coastal vegetation, such as afforested areas along beaches planted with black and red pine trees (*P. thunbegii and P. densiflora*) and other types of vegetation growing in wetlands, in addition to freshwater bodies, such as rivers, ponds and marshes, among others, suffered the same fate (MOE 2014).

After the earthquake and tsunami struck in March 2011 (Fig. 18.1), the Ecological Science Working Group, Integrative Biology Committee of Science Council of Japan focused on the ecosystem and biodiversity impacts particularly those related to agriculture, forestry and fisheries. The main problem in the assessment was the absence of prior basic data, although there were a few older studies on the distribution of critical plant communities by the government from 1976 (JFS 2011). Plenty of Japanese and international research institutions, scholars, NGOs and international organizations are undertaking research at present to assess these effects, including the Biodiversity Centre of Japan (2013) and the Tohoku Ecosystem-Associated Marine Sciences Program or TEAMS, which brings together a large number of them (Nakano 2015; Yamakita et al. 2015; JAMSTEC 2016).

Fig. 18.1 Common view found along the stricken Tohoku coastline after the 2011 tsunami (Photo by V. Santiago-Fandiño)

18.3.1 Examples of Environmental Effects on the Coastal Fauna and Flora

Komatsu et al. (2014) examined the effects of the tsunami on the landscape in Aneyoshi (Sanriku coastline), as large erosion occurred and the vegetation washed away, altering the characteristics of the coastline. Likewise, Udo et al. (2015) having analyzed the southern part of the Sendai coastline, concluded that the tsunami eroded and or accumulated sediments along the existing seawall depending of its dynamics, while in the Yamamoto coastline more than fifty percent of the shore sand was washed at sea resulting in severe erosion. Macrobenthic species in intertidal flats in Sendai Bay were studied by Urabe et al. (2013) finding that 30–80% of the originally inhabiting taxa disappeared; moreover, the changes in the dwelling fauna found in the lower tidal zones proved that the tsunami removed many of the existing benthic taxa while also bringing others from afar. Okumura et al. (2015) looked at the short-term effects on phytoplankton quantity and diversity in Ofunato and Kesennuma Bay and concluded that the quantity of phytoplankton increased while diversity changed, which also depended upon the particular geographical characteristics of the locations.

Large extensions of eelgrass beds (*Z. marina*) and other type of marine flora growing along the beginning of the sandy continental shelf were devastated or heavily reduced (MOE 2014). Sakamaki et al. (2016) stated that in Matsushima Bay (Miyagi prefecture) eelgrass beds decreased from 2.2 km^2 in 2007 to 0.02 km^2 by May 2012; light reductions due to land subsidence and raw water from a damaged sewage plant at the time prevented their regrowth. In Moune Bay (Miyagi Prefecture), Tanaka and Hatakeyama (2016) found that a large initial decrease of marine species occurred after the March 11 events as the sea bottom became covered by muddy sediments that heavily impacted seaweed beds. Santiago-Fandino 2014; Santiago-Fandino et al. 2015, 2016 published general overviews of the impacts along the coastline in certain areas of Miyagi, including an assessment of the potential pollution from wood preservatives from tsunami construction debris after the March 11 events. Likewise, Chagué-Goff et al. (2014) studied soil salinization resulting from flooding in agricultural fields and found that 1 year after the event, the soil still was not suitable to grow rice and that remediation measures were required to restore the damaged soil. Nakai et al. (2015), worked on the rehabilitation of tsunami-damaged agricultural fields using genetically selected rapeseed plants with some success.

Other studies on marine species included those by Takami and Kakaie (2015) on an Ezo Abalone (*Haliotis discus hannai*) community, and these authors found that it suffered the most in the algal forest and was likely to be affecting the numbers of individuals in the coming years. Komatsu et al. (2015) showed that sea-grass and seaweed beds in Otsuchi were variably affected; thus, for example, the former growing by the bay's mouth were completely destroyed. Addressing the importance of the potential impacts of seawalls, the author stressed the fact that large walls could threaten the recovery of the species as the continuous flow of materials between land and the ocean could be affected and result in the destruction of ecotone and seagrass beds. Okoshi (2015) examined other bivalves in tidal flats and likewise concluded that they have suffered substantial impacts that were mainly due to soil liquefaction, as the organisms were exposed to turbulence, and the transformation of the intertidal into subtidal zones due to land subsidence particularly in the Mangoku-ura sea (Miyagi Prefecture) resulted in the destruction of the tidal flats and affected the existing fauna and flora. The author also stressed the need to research on the potential impacts as a result of the construction of large tsunami seawalls as they are expected to affect the land-ocean interaction continuity; thus the author recommended that before the structures are built, environmental impact assessments should be undertaken.

18.3.2 *Examples of Natural Recovery and Adaptation of the Coastal Fauna and Flora*

Some studies have revealed that the effects of the tsunami have not been as significant or as devastating as forecasted for certain coastal and marine communities and species. Looking at meiofauna assemblages in sandy beaches in Sendai (Miyagi Prefecture), Grzelak and Szczucinski (2014) found that new assemblages developed in the newly formed beaches soon after the event. In Otsu chi, Nishibe et al. (2016) looked at the changes of zooplankton after the first 2 years since the tsunami struck and found no significant variations in mesozooplankton/holozooplankton taxa (copepods, cladocerans and appendicularians). Tachibana et al. (2016) likewise found no serious effects on the phytoplankton community structure in the same bay up to 2013. Moreover, Fujimura et al. (2016) concluded that the numbers of bacterial communities structures came back to the original condition 2 years after the event in the same bay, although distinct groups were found in and outside the bay.

Using remote sensing and previous research work in some areas of Tohoku, Hara (2014) found that the worst tsunami effects on coastal vegetation along the Tohoku occurred in sandy beaches, lowlands and coastal forest; moreover, the author also found that recovery is occurring in many areas. Seike et al. (2013) examine the impacts on the seafloor as well as on benthic species in Otsuchi and Funakoshi bays and show that a distinct pattern of distribution succession occurred based on the changed characteristics of the seafloor. However, the succession pattern of two of the same species varied between the two bays. The author further concluded that reestablishing certain benthic communities began 18 months after the events.

Tanaka and Hatakeyama (2016) likewise found that once a previously existing wetland in Moune Bay used for agriculture became permanently flooded due to ground sinking, it became once again a growing field for Manila clam juveniles (*Ruditapes philippinarum)*. Moreover, Masuda (2012) studying the effects of the tsunami ion fish species in the same bay found that although they were heavily impacted due to the creation of a muddy substrate, they began to reappear once it washed off.

Watanabe et al. (2014) examined macroinvertabrate communities in 15 rivers along the coastline in Sendai (Miyagi Prefecture), and the records were taken 2 and 6 months after the tsunami event. The results showed that there was a significance change in taxon richness (−54% average) and total abundance (−91%) up to 25 km away from the tsunami-inundated areas from the estuary; spatial variations were also found between communities exposed and not exposed to the tsunami. Nevertheless, the authors concluded that variable recovery rates appeared in degraded communities after 16 months, highlighting that some fish species were able to recover faster.

Ito et al. (2016) focused on the Natori river (Miyagi) and found that the heavily affected brackish-water clam (*C. japonica*) and the sweet fish or Ayu (*P. altivelis altivelis*) populations recovered; in the case of the fish, the original status as well as other fish species was clear, although the clam took somewhat longer. The results led the authors to conclude that fish communities recover quickly even after a large tsunami hit the river.

Conducting research in Otsuchi Bay on sea urchins (*S. nudus*) and abalones (*H. discus hannai*), Kawamura et al. (2014) found that the populations were beginning to recover or adapting to the new type of environment after the tsunami, although there is a difference between the speed and the change processes vary between the locations. Dyer (2016) founding that a larger number of species are thriving in concrete and other type of tsunami debris lying on the seafloor.

Kanaya et al. (2012, 2014, 2015) looked at the changes occurring in a shallow eutrophic brackish lagoon (Gamo Lagoon; Sendai) after being hit by the tsunami; the results showed that immediately after the event, a large majority of reed marshes were heavily reduced (from 7.8 to 1.2 ha) as well as the macroalgal patches (from 7.8 to 1.8 ha). Moreover, the transformation of the sediments and the macrozoobenthic assemblage in affected places together with physical stress devastated the original benthic community. On the other hand, this change will significantly improve the habitat quality for macrozoobenthos, thus enhancing the recovery of estuarine soft-bottom habitats. Moreover, the authors also found that some opportunistic species such as polichaetes worms and amphipods were able to recover rapidly within the first months while some species of macroalgae and a number of invertebrates only began to reappear and grow in 2012–2013.

Studies performed on benthic marine communities by Toyofuku et al. (2014) found that a rapid recovery and a flourish of the communities and the formation of new ones replacing the original occurred. Further, the possibility was highlighted that the long-term recovery might take place such that the abundance and diversity could be the same as before the tsunami occurred.

Shimizu et al. (2014) compiled a series of papers related to improving watersheds and the coastal environment due to the exiting strong connectivity between the sea and the forest benefiting the tsunami-impacted coastal areas. Moune bay, which was heavily impacted by the tsunami (Tanaka 2012) during recent years since the event occurred, is going through an important natural recovery (Chiba et al. 2015) most likely due to this connectivity.

The connectivity or linkages between forests, rivers, the sea and rural communities to preserve the services provided by the ecosystem and related species, its crucial play in the natural restoration of tsunami-decimated fauna and flora in coastal impacted areas, as well as the need to preserve and enhance biodiversity is focused on by the National Biodiversity Strategy of Japan 2012–2020 (MOE 2012b) and other frameworks.

18.4 National Biodiversity Strategy of Japan and Other Related Frameworks Toward the Restoration of Tsunami Affected Areas After March 2011

Large tsunamis heavily impact biodiversity in coastal areas, sometimes with such enormous consequences that species populations of communities may never recover. Biodiversity keeps the environment functioning; species and their interactions allow for the formation of healthy ecosystems and habitats – hence, its enormous importance.

To protect and preserve biodiversity, the government of Japan by 1995 had formulated its Biodiversity Strategy emphasizing then that species degradation and habitats as well as biodiversity and ecosystem services were suffering due to excessive human activities and development (MOE 2010a, 2012b). Thereafter, the Japan Biodiversity Outlook Science Committee established by the Ministry of Environment produced the first Japan Biodiversity Outlook, JBO report in 2010 (MOE 2010b; Nakashizuka 2010), which concluded that reduced tidal flats and natural coastlines as well as coastal erosion were among the most pressing issues; in particular, it highlighted that tidal flats, seaweed beds and sandy beaches shrank by 40% over 50 years from 1945, emphasizing also that other ecosystems have also been heavily and negatively affected due to development, land reclamation and dredging, sea gravel extraction and the creation of artificial shorelines. Other highlighted aspects stated that gravel extraction from rivers and the sea – in addition to the construction of dams in the upper watershed – resulted in large reductions of sediments into the coastline, thus worsening erosion. Finally, it was also stressed that rocky shore denudation heavily impacted large seaweed forests along the coastlines. As a result, the biodiversity decreased overall in shallow coastal waters.[1] Finally, the report also stressed that although some studies were still required the loss of biodiversity had an important impact on the supply of ecosystem services. The Second Japan Biodiversity Outlook Report (MOE 2016) added the fact that the impact of climate change on species distribution and ecosystems will increase over time. Moreover, the Report also highlighted that many of the ecosystem services have been declining or at best are remaining the same as well as the biodiversity.

Based upon the principles and concepts considered in the National Biodiversity Strategy of 1995, the enormous impact of the March 2011 event and the lessons learned therefrom, the government developed the National Biodiversity Strategy of Japan 2012–2020[2] (MOE 2012b). This framework considers biodiversity as a social related issue that must be understood from a socio-economic point of view rather

[1] *In the Conservation Strategy of Japan, Coastal water was defined as the "water from the inter-tidal zone to the continental shelf that is less than 200 m in depth, which is subject to significant impacts by human activities",*

[2] *The National Biodiversity Strategy of Japan 2012–2020 is the fifth one counting from the first National Biodiversity Strategy formulated based on the CBD, and the second strategy formulated based on the Basic Act on Biodiversity* (MOE 2012b)

than from a strictly natural scientific perspective, thus bringing a complementary concept. The 2011 events gave the opportunity to the government to review the relationship between the natural environment and mankind while also addressing its impact on biodiversity as a result of the environmental damage in the coastal areas. The resulting Basic Guidelines for the Reconstruction highlights the need to study and monitor the environmental situation as well as the use of disaster prevention and reduction measures such as forest restoration and the link between forest, rural communities, rivers and the sea. Moreover, it also identified the Tohoku Ecosystem-Associated Marine Sciences Project as a mechanism to find the alterations occurring in the marine ecosystem off the Sanriku coast.

The goals of the Strategy include the following, among others:

- *To restore the connection between people and the sea and the rich biotas that are inherent in coastal areas in which the land is in contact with the sea.*
- *To restore coastlines such that people can approach and enjoy them by prioritizing the conservation of existing neritic sea areas including tidal flats, salt marshes, seagrass beds and coral reefs, as well as the conservation of natural coastlines, all by restoring and creating habitats for diverse organisms.*
- *To promote sustainable fisheries based on resource management.*
- *To revitalize sustainable fisheries in coastal areas through efforts for forest development in upstream areas, water quality improvement, etc.*
- *Promote the conservation and restoration as well as the sustainable use of coastal areas, which must remain safe, secure, and in harmony with the natural environment, through the restoration of coastal disaster prevention forests, etc.*

The Strategy also addresses the need to build ***Ecological Networks*** to restore damaged endemic biota while also conserving it and paying attention to the *"hydrologic cycles involving coastal areas and water systems and including rivers and flood plains, lakes, wetlands, ground water, spring water and paddy fields"*. The Ministry of the Environment in 2013 contemplated the development and implementation of the *Reconnecting the Forests, Rivers, Sea and Satoyama* project among others (IUCN 2013). Within the ***Ecological Network*** component, forestry and the restoration of ocean and coastal areas as well as the need to strengthen and/or increase marine national or quasi-national parks, the distribution of seagrass beds, tidal flats and coral reefs is highlighted. Likewise, the need for restoring affected areas – while also strengthening the ecosystems services – by aiming to strengthen the linkages between forests, rural communities, rivers and the sea is stressed. Finally, the need to conserve and restore the environment toward the sustainable development of the region after the reconstruction works of the March 2011 events have ended is underlined.

Last – but not least – the Marine Biodiversity Conservation Strategy of Japan (MOE 2012a) strongly recognizes biodiversity not only based on its own value but also based on its associated ecosystem services, thus requiring the need for land-sea integrated management.

Long before the March 11 events took place, the government already knew the coastal biodiversity, ecosystem and relevant species problems, although it appeared that through the years instead of the panorama being improved it had instead worsened on many courts. Then, after the 2011 earthquake and tsunami, the situation must have further worsened as many of the already degraded coastal ecosystems and the biodiversity were impacted. Through implementation of the National Biodiversity Strategy 2012–20,120, particularly in the tsunami-affected areas, the situation is expected to change but the problem in ensuring that the process moving toward reaching goals is successful is enormous. The fact that different agencies and government bodies are involved in the restoration of the March 11 affected areas, the particular needs and priorities of the local coastal communities and industries, in addition to those of the government, the associated financial mechanisms to ensure that the targets and goals are achieved as well as other socially direct or indirect aspects will certainly make the process to be most challenging and difficult. Although nature is working on its own already by regenerating or adapting lost habitats and/or ecosystems and biodiversity, there is a need for the government and people in general to realize the economic value that biodiversity and the ecosystem services provides to all. This will certainly help them unite toward achieving the goals once becoming aware about the richness they have at hand and how to better benefit from the process.

18.5 Economic Values of Biodiversity and Ecosystem Services in the Coastal Zone

The economic value of biodiversity and related ecosystem services are considered an important component of the National Biodiversity Strategy of Japan 2012–2020. It highlights that the proper valuation and visualization through economic (monetary) valuation methods will reveal their worth to the public, while also facilitating their inclusion in the decision-making process. The fact that the Strategy also calls for the introduction of the Beneficiary-Pays Principle (beneficiaries pay part of the costs in proportion to the benefits they receive) is a large step forward to complement the Polluter-Pays Principle and the Full Costs Recovery Principle.

The destruction and substantial damage to biodiversity such as that suffered along the Tohoku coastline after the Earthquake and Tsunami of 2011 represent an enormous loss in the form of ecosystems services[3] (use and non-use values[4]). Since the coastal zone is a thin interface between the land and the sea that is home to sensitive and vulnerable ecosystems and habitats for a large number of marine and estuarine species, it provides essential services such as shore protection, economic

[3] "*The benefits that mankind obtain from the services of ecological systems and the natural capital stocks that produce them are critical to the functioning of the Earth's life-support system. They contribute to human welfare, both directly and indirectly, and therefore represent part of the total economic value of the planet.*" Constanza et al. (1997)

[4] *Use values: direct use value, indirect use value and option value; Non-use values; bequest value, altruist value and existence value* (Unai and Muradin 2010).

benefits like fisheries, wetlands and priceless aesthetic value among other values. Moreover, the land-dominated global processes intensively interact with the marine processes along the coastline, presenting unique and diverse ecosystems and climate that allow for nutrient flux and biogeochemical processes to occur reflected in high biological productivity (Crossland et al. 2005). However, coastal areas are highly vulnerable to extreme natural events, such as earthquakes and tsunamis as well as to mankind's activities and interventions.

The more that coastal biodiversity and ecosystems are degraded or destroyed, the larger the loss of the services they provide. Therefore, it is most important to assess the ecosystem services along coastal areas prior to the occurrence of catastrophic events to ascertain not only their richness and value to society but also the losses after the events occur. Once the ecosystem services are under pressure or degraded, their capital value is bound to increase, and if it completely disappears, the value becomes infinite as the services no longer exist (Constanza et al. 1997), thus becoming a total economic loss. Most likely, this may have occurred in certain areas along the northeastern coast of Japan impacted by the earthquake and tsunami of 2011. Paraphrasing Tanaka and Hatakeyama (2016) *"the maintenance of natural capital*[5] *requires the preservation of cohesive ecosystems, the structure and diversity of the system are important to ensure the long-term sustainability of the resources generated…"* de Groot et al. (2012) further argued that the degradation of the ecosystems services will have a negative impact on future generations and the poor while if restored they become a benefit; therefore, the assessment of the conditions of the ecosystems and their respective services as well as their relation to mankind's well-being requires an integrated approach (UNEP 2015).

In the first attempts to put a value (in 1994 US dollars) to the ecosystem services provided by a number of biomes,[6] including some found along coastlines, Constanza et al. (1997) calculated that *wetlands*, for example, which provide gas regulation, disturbance regulation, water regulation, water supply, waste treatment, habitat and refuge, food production, raw materials, recreation and cultural aspects, equals US$19,580; *swamps and flood plains*, which provide disturbance regulation, water regulation, water supply, waste treatment, habitat and refuge, food production, raw materials, recreation and cultural aspects, were valued at approximately US$19,580; while *estuaries* which provide disturbance regulation, nutrient cycling, biological control, habitat/refuge, food production, raw materials, recreation and cultural aspects, totaled US$22,832.00. *Seagrass and algal beds* by giving nutrient cycling/raw materials equaled US$19,004.

Ninan and Inou (2013) calculated that the annual economic value of the Oku Aizu forest reserve in Japan was worth US$1.27–1.481 billion meaning US$17,016–17,671/ha; the authors highlighted the need by both government and society when

[5] The OECD defines Natural Capital as "natural assets in their role of providing natural resource inputs and environmental services for economic production" comprising "three principal categories: natural resources stocks, land, and ecosystems."

[6] *Biomes are large regions in the planet holding a large-scale community of organisms shaped by common environmental conditions (which in turn comprises a variety of ecosystems).*

deciding development or conservation. Natuhara (2013) calculated the economic value of the ecosystem services of rice paddies cultivation in Japan and highlighted that rice fields provide groundwater recharge production of non-rice food, flood control, soil erosion and landslide prevention, climate change mitigation, water purification, cultural and landscaping as well as supporting the ecosystem and biodiversity; this value equals US$72.8 billion. On the other hand, the Ministry of the Environment of Japan made an assessment of the economic value of the wetland's ecosystem services in the country by focusing on marshes and tidal flats, and posited that the former was worth between US$ 8.1 and 9.4 billion, whereas the latter is approximately US$5.9 billion (JFS 2014).

Using a different approach, and to better understand the types, spatial variations, abundance and provisioning of ecosystem services from social–ecological landscapes, Hashimoto et al. (2015) preformed a study focusing in the Noto Peninsula in Japan. The methodology included evaluation and mapping the ecosystem services (provisioning, regulating and cultural) along the peninsula using questionnaires surveys, literature statistical analysis and GIS. Moreover, Hara et al. (2015) using remote sensing found that vegetation in some sections in Sendai plain has been recovering naturally after the tsunami, highlighting its importance in developing strategies aimed at restoring of vegetation, biodiversity and ecosystem services.

A monetary[7] analysis was undertaken by de Groot et al. (2012) looking at ten biomes, including the *coastal zones* (estuaries, continental shelf and sea grass and without tidal marshes, mangroves and salt water wetlands), and these authors concluded that its worth is US$28,917.00/ha per year and that *coastal wetlands* worth is US$193,845.00/ha per year. The authors note that their calculations only included less than half of the ecosystem services provided by most of the Biomass; hence, the economic values have been underestimated. It is also clear that fauna and flora also play a crucial role in ecosystem services and that research to identify and better understand the linkages between services, functioning and biodiversity has improved (Atkins et al. 2013). In light of this, Bateman et al. (2011) integrated the ecosystem services in an economic analysis to support policy orientation and decision-making.

Tanaka and Hatakeyama (2016) already assessed the importance of the economic value given by the ecosystem services provided by mud tidal flats and some of its species; for their purposes, they referred to a study performed in Mikawa Bay (Japan) in 1996 related to the economic assessment of the water purification value provided by the Asari clam. The study claimed that to remove the amount of nitrogen produced by the clam population living along the watershed at the time a sewerage treatment plant would have been required, The cost of the facility, personal and maintenance would have amounted to approximately 100 billion Japanese Yen[8] over 50 years. On the other hand, this expenditure might be averted if the mud flat with

[7] *Values for each service per biome (values in Int.$/ha/year, 2007 price levels)*

[8] *Approximately 1 billion USD dollar the time (note by the authors).*

the Asari clam were preserved. Moreover, the clam as a food resource could have had an equal economic value and be harvested.

To internationally harmonize concepts, definitions and accounting rules (Boyd and Banzhaf 2016), the System of Environmental-Economic Accounting Central Framework (UN-SEEA 2014) was released in 2014 based on the work performed by the Committee of Experts on Environmental-Economic Accounting (UNCEEA). Adding to the harmonizing benefits of SEEA is the fact that it can be adapted to the specific characteristics and needs of a given country. Thus, using previous versions of SEEA, an assessment that was undertaken in Japan by Takahiko and Nakamura in 2000 compiling SEEA and Green GDP (Environmentally Adjusted Domestic Product), who concluded that ascribed environmental costs as a proportion of the National Domestic Product (NDP) in this country went dawn from 8% in 1970 to 1% in 1995. It is likely that after the March 2011 events, the result would be widely different.

On the other hand, a mechanism to envisage the potential negative alterations on biodiversity and ecosystem services, hence the potential loss of their economic value resulting from proposed particular works, actions and or plans reveals a need to previously undertake an assessment. This is particularly important in coastal areas due to the high vulnerability of the ecosystems and biodiversity. If the works are to be undertaken in already critically affected areas such as after the coastline has been badly hit by a tsunami, the assessment becomes more imperative, although governments may not support this approach due to specific policies, emergency conditions and so on, such as the ongoing works in the coastline along the Tohoku region in Japan.

18.6 Environmental and Strategic Impact Assessment (EIA-SEA) and the March 2011 Earthquake and Tsunami

Environmental Impact Assessments is one of the most accepted and used tools there are to identify and assess the consequences on the environment of a variety development projects, works and/or activities prior to their implementation, while the Strategic Environmental Assessment focuses on plans, programs and or policies. Their objective is not only to ameliorate or mitigate the potential impacts but also to provide the best solutions for the purpose. Comparisons between EIA application approaches undertaken in various countries and Japan have been undertaken by King and Hoiberg Olsen (2013). In Indonesia, the undertaking of EIA is based on processes and activities that may hold large potential impact to the environment, leading to its damage, degradation and use among other aspects (BAPEDAL 2001). Kultip et al. (2015) highlighted that the EIA screening process in China and Thailand depends on the potential impact while in Japan it depends on the scale of the project.

The Environmental Impact Assessment system in Japan was initially introduced in 1972 to cover public works; thereafter, in 1999, the "Environmental Impact Assessment Law" was enforced; by 2011, a revision was made whereby a "Primary Environmental Impact Consideration, Impact Mitigation Reporting" was introduced and by 2013 the revised Environmental Impact Assessment Law[9] was implemented. The law only considered certain areas for application i.e., roads, rivers, railways, airports, power plants, waste disposal sites, landfill reclamation, land readjustment, new residential areas development projects, industrial state projects, new town infrastructure development, distribution center complex development projects and residential or industrial land developments by Specific Organizations (Environmental Policy Bureau 2012).

The EIA screening process system considers three classes of projects i.e., ***Class-1*** in which the assessment is required (mandatory), ***Class-2*** in which a possibility for *the local government to judge if the project requires or not the EIA is feasible* (optional) and ***Others*** which is too small to require it (Environmental Policy Bureau 2012). Class 1 projects include in turn those to be approved or licensed or conducted by the national government, projects receiving funds from the national government and those conducted by special organizations.

The prefectures and most of the large cities in Japan have included EIA assessments in their local ordinances; therefore to avoid overlapping and confusion, the EIA Law contains provisions related to the EIA systems implemented by local governments, and they may include the addition of specific projects,[10] holding public hearings and developing procedures for third-party organization evaluations. As has been made available to the public, the project proponent cannot start implementing just any part of the project.

Nishikizawa (2015) indicated that although there are an important number of EIAs annually undertaken in Japan (30–50), there is also a need to further develop research efforts on topics such as pro-active sound decision making for sustainability, the effectiveness of the EIA from the proponent's perspective to increase public acceptance and the use of quantitative and qualitative methodologies.

After a large catastrophic event such as an earthquake or tsunami in Tohoku, there are plenty of public and private works in which the EIA could be applied

[9] *Article 2 of the Law states: "environmental impact assessment" shall mean the process of (a) surveying, predicting, and assessing the likely impact that a project (hereinafter meaning changes in the shape of the terrain [including dredging being conducted simultaneously], and the establishing, modifying, and expanding of a structure for specific purposes), will have on various aspects of the environment (if the purpose of the project includes business activities and other human activities on the project land or within a project structure after the implementation of a project, the impact of such activities is included) (hereinafter referred to simply as "environmental impact"); (b) studying possible environmental protection measures relating to the project; and (c) assessing the likely overall environmental impact of such measures"* (MOE (2013)).

[10] *"The projects subject to the Environmental Impact Assessment Law are projects to be approved, authorized, subsidized or conducted by the national government. In other words, the government can decide whether the projects will be implemented or not. The Environmental Impact Assessment Law includes provision not to give authorization to projects that do not take enough environmental protection into account".* (Environmental Policy Bureau 2012)

through the restoration and reconstruction phase; these may include roads, waste disposal sites, landfill reclamation, land readjustment, new residential areas development projects, new town infrastructure development and residential or industrial land developments, among others. In the case of the construction of large tsunami sea fences, such as seawalls, coastal dikes, embankments as well as other types of related facilities, the application of EIA lies in the prefectural law and the ultimate decision to apply it or not lies in the hands of the Governor. This has led to substantial criticism and debate in the country and beyond as certainly the impacts of such structures on the coastline are expected to be enormous.

In examining the impact that government planning activities and projects may have on the environment, the Strategic Environmental Assessment (SEA) appears to be a potential approach. This mechanism is conceptualized as a policy tool to assess the potential impacts of policies, plans and programs on the environment by bringing the possibility of integrating the social, economic and environmental considerations into the decision-making process (Saddler et al. 2011; GWP-WMO 2013). Although a widely used tool in many countries, its definition has been under discussion for many years and there seems to not be one specific approach to suit all cases (Hayashi 2007; MOE 2003). However, in Japan, initial discussions about the SEA began when the EIA Law was discussed (MOE 2003; Environmental Policy Bureau 2012), but by 2008, the legislator has not been fully developed it (Li 2008; Nishikizawa 2015) further stated that genuine SEA is currently not practiced in Japan. However, Kurasaka (2016) claims that there is more recognition in Japan regarding the use of this tool in the country and the Ministry of the Environment will begin undertaking research projects on SEA. It would have been important for the government to already have this tool at his disposal to better evaluate the potential impacts of the developed policies toward the restoration of the March 2011 tsunami-affected areas.

18.7 Seawalls, Coastal Dikes and Others

Sea fences are manmade structures that protect the coastline from natural hazards such as sea surges, flooding, high tides, tsunamis and others; such as to prevent large seawater flooding in Jakarta. As the city is sinking, the government will build a "Giant Sea Wall" (Widiatmini Sih Winanti 2015; Koch 2015). The 40 billion USD project proposes the reclamation of 17 islands and the construction of an outer dike together with the Giant Sea Wall shaped as the Garuda Bird, the Indonesian national symbol.

Coastal defense structures vary in form and function; the United Nations Framework Convention on Climate Change (UN 1999) includes breakwaters (rocky and concrete complex double-sided structures aimed at reducing wave energy), storm surge barriers (protection from unexpected high tides in estuaries, tidal inlets and rivers), revetments slopes (made with loose or interlocking units used in general to protect banks and cliffs), groins (structures perpendicular to the coastline that are mainly to protect beaches made of wood, rocks and concrete), armor units (precast concrete interlocking heavy structures of different forms and sizes aimed at withstanding wave's embattlement generally used to protect other types of sea fences), textile bags (made of high-strength materials filled with sand or mortar that can be used to protect slopes, river and beds), bulkheads (made of wood, concrete and or interlocking rocks to protect the shore from light to moderate waves) and seawalls (large expensive non-flexible concrete structures aimed at protecting the shore from large waves, with complex designs that can frequently cause severe damage to the coastline and the ecosystem due to beach erosion and dawn-drift).

Dikes (also referred as sea or coastal dikes, embankments, levees, flood banks and stop banks that may also include revetments) are the most common structure to protect low-lying coastlines. They can be built with a variety of materials and various types of slopes (Tuan 1999; ClimateTechWiki n.d.; Raby et al. 2015). The difference between dikes and seawalls is found in their design and construction, while the former have characteristic slope ratios, the latter are vertical; seawalls have smooth surfaces while dikes may be rough and have revetments, and seawalls require careful design as their size and shape depend upon the characteristic of the sites in which they will be built, as the more complicated the site, the heavier the wall, hence its foundations depth is important. In terms of protection, seawalls and dikes are not perfect in all conditions (Jan van de Graaff 2009), therefore they should be designed considering resilience but also the possibility of "failing gracefully" or not fully collapsing (Ranghieri and Ishiwatari 2014). For instance, in Miyagi Prefecture in Japan, it has been observed that at Suzaki Coast, near Ishinomaki, sea dikes were designed to protect the inland from storm surges and wave overtopping. There is a heterogeneous coastal structures protection in this location. Two dikes of different types; one constructed with concrete blocks and the other made out of rubble mound made of stones. It has been reported that the rubble mound section was destroyed completely by the 2011 tsunami while the concrete block dike remained unchanged (Tanaka et al. 2012). Tanaka et al. suggests that the failure of the rubble mound structure was due to its higher porosity and lack of protection to tsunami scouring at the landward toe section at the back of the dike. The latter was a predominant mechanism of seawall failure affected by the 2011 tsunami in Japan. Structural design has changed since to account for this back toe scouring process; in addition, less costly alternatives to reduce the tsunami impact, scouring and erosion are suggested elsewhere (Hazarika et al. 2016).

Alternative methods or technologies to the full concrete barriers like seawalls must be discussed. In the case of beaches, a cost analysis benefit undertaken in Connecticut (USA) comparing seawalls and other more natural structures (reinforced sand dunes with vegetation and core logs combined with mesh and geotextile tubes) to stop flooding originated from large sea surges was published by UNEP (2014). Despite the big difference between both in terms of costs, potential flexibility to adapt to a variety of conditions including rising sea levels, environmental performance and biodiversity protection as well as the long-term benefits solution to mitigate coastal hazards the seawalls were chosen as barriers. The selection was undertaken considering maintenance costs for beach nourishment in the long term and the fact that repairs should be performed as soon as possible to avoid the dunes system from braking among others. However, one of the lessons learned in this study was the fact that when the authorities, academia and local residents interact it enhances the possibilities of reaching best solutions, one more example in the decision-making process when building barriers against natural hazards.

Large seawalls and dikes require large amounts of construction materials; moreover, dikes require large amounts of land frequently resulting in creating important and lasting socioeconomic and environmental impact, as basically they are not designed to consider the coastline in which they are built. Arikawa (2015) highlighted the fact that in general sea fences last between 50 and 100 years hence requiring large amount of funds for maintenance. This type of sea fence results in permanently fixing the position of the coastline and preventing geomorphological and environmental process such as adaptation to changes in sea level rise, beach-dune interactions, and sediment transport from coastal erosion (Climate Tech Wiki n.d.). Likewise, nutrients and water flow is impaired while also largely affecting biodiversity. Finally, the structures are in general aesthetically displeasing and heavily impacting tourism activities while also detaching the local community from the sea. To ameliorate or prevent the impacts of many countries undertake environmental assessments prior their construction; furthermore it is expected that engineers involved in the designed should be aware of the problems when designing the structures (Thomas and Hall (2015). Thus, they are expected to be the subject of EIAs. Suppasri et al. (2012) concluded that today's its possible to build anti-tsunami gigantic structures which might fully provide protection against 500–1000 years return periods such as the tsunami of 2011, but they will be impractical both in terms of budget and time.

Before construction and economic appraisals, it is also necessary to examine the social and environmental cost and benefits, calculating the damage costs *vis-a-vis* prevention and maintenance costs (Jan van de Graaff 2009). This is particularly important in seawalls and dikes as they are commonly built with concrete, which although they have a potential lasting durability, they are also subject to continuous deterioration due to abrasion and erosion as well as possible subsidence – particularly in countries prone to earthquakes like Japan. Due to the country's history geological, oceanic and atmospheric activity Japan has built a large number and variety of sea fences along its 35,000 km of coastline. The structures are generally classified as facilities against *accidental incidents* and *protecting facilities*[11] (OCDI 2009), and mainly designed against sea storms and sea swells, large flooding, high waves and large tides, coastal erosion and tsunamis among other hazards.

Tanaka and Hatakeyama (2016) stress that the of seawalls after March 2011 was merely developed considering "by an analysis of the crisis in traditional economic

[11] *Accidental incidents are those in which there is danger of serious impact on life, property and socioeconomic activity accompanying damage of the objective facilities; they include breakwaters, revetments, seawalls, water gates and levees. Protecting facilities for harbors protect waterways and basins such as breakwaters, seawalls, sediment control groins, water gates and revetments amongst many others.*

Table 18.1 Total length (km) of seawalls and related percentages of the total coastline prior and after the Great East Japan Earthquake and tsunami by prefecture. Percentages increments and plan seawalls are also shown

Prefecture	Length (km) and heights (m) along the coastlines and related percentages prior March 11-2011 (NASJ)				Planed seawalls length (km); length (includes existing ones already), heights and related percentages after March 11-2011 (NASJ)				Total net increase in length (km) and %	Planned units (Mainichi 2016)	Total length of the seawall (Tanaka and Hatake-yama 2016)	Total length of the sewall Gough (2015), The Economist (2014)
	Total km and %	<5 m	>5 <10 m	>10 m	Total km and %	<5 m	>5 <10 m	>10 m				
Miyagi 830 km	154	108	45	0	239	92	143	3.6	75	355		
	19%	13%	6%		29%	11%	17%	<1%	55.1%	(133; <10 m height)		
Iwate 710 km	68.8	16.4	41.3	11.1	82.8	1.1 km	35.8	45.9	14	136		
	10%	2%	6%	25	12%	<1%	5%	6%	20.3%	(23; <10 m height)		
Fuku-shima 160 km	70.3	3.5	66.8	0	72	0.6	71.4	0	1.7			
	44%	2%	42%		45%	1%	45%		2.4%			
Total coast-line 1,700 km	293.2	128.5	153.6	11.1	394.2	94.3	250.41	49.5	101			
	17%	7.6%	9%	0.7%	23.1%	5.5%	4.7%	2.9%	34.4%			
Iwate + Miyagi + Fuku-shima (Maini-chi 2016)	294	129	154	11	395	95	250	50				
Aomori+Iwate+ Miyagi+Fukushi-ma					986	369	567	50				
+Ibaraki+Chiba 3200 km (Maini-chi 2015)					31% (to be finished by 2018)	37%	58%	5% (Iwate 46 km; Miyagi 40 km)				
Tohoku (Gough 2015; The Econo-mist 2014)										400 units	270 km	400 km

Sources: NASJ (2014), Mainichi (2015, 2016), The Economist (2014), Tanaka and Hatakeyama (2016), and Gough (2015) terms and failed to include what has been defined as natural capital". Indeed, when a government is making a coast benefit analysis for investing in a seawall program – or any other type of sea fence – the value to the national economy when comparing the differences in costs between the potential benefits versus the avoided damages is crucial. Moreover, the economic benefits can be understood as the differences in the national economic assets by having or not having structures built (Thomas and Hall 2015).

The EEFIT Reports (2011, 2014) provides a detailed analysis of the destruction and failures of sea fences as well as the state of their restoration and reconstruction up to 2014 along Tohoku and in particular in Iwate and Miyagi Prefectures. The Mainichi newspaper (2015) posits that a total of 986 km of seawalls (and or dikes) would be built along 3200 km of the coastlines of Aomori, Iwate, Miyagi, Fukushima, Ibaraki and Chiba prefectures; they will have different lengths and heights based upon the characteristics of the coastline. Table 18.1 provides some information about the number, sizes and coverage percentage of the seawalls prior to March 2011 and those planned and or in the process to be built totaling 395 km (NASJ 2014). In Miyagi prefecture the length of the structures is expected to increase by 75 km or 55.1% (154–239 km) covering 29% of the 830 km prefecture's coastline (NASJ 2014), most of their heights will be between 2.6 and 11.8 m high (Miyagi Prefectural Government 2014). Some sources (Mainichi 2016) published that the seawalls in Miyagi alone will comprise 133 separated units of various heights (<5, >5 < 10 and >10 m), while Tanaka and Hatakeyama (2016) highlighted that the highest seawall in Tohoku would reach 14.7 m height.

Already in 2013 the Miyagi Prefectural Government (MPG – Miyagi Prefectural Government 2013) published a seawall construction plan for Kesennuma City and Miyagi as a whole that provided the expected measurements; later, the Reconstruction Agency of Japan published the last edition of the characteristics of the seawalls, including the extensions (RAJ 2015) as well as (MLIT 2015) for Sendai. Some of the many examples under construction include the seawall in Kesennuma, which is a large vertical concrete straight wall of 5.5 m height (TP[12]) and 1.20 m wide (RAJ 2015) (Fig. 18.2). Around these areas, land subsidence is evident and an initial challenge when planning reconstruction and design of new seawalls (Fig. 18.3). At Koizumi city, a 2 km coastal dike measuring 14.7 m TP (AfterLandscape 2016; Bird 2016) is connected with the river's dike. In Iwate prefecture, the city of Rikuzentakata is building a large sea fence between 12 and 15 m high (Fig. 18.4), which is connected to a large river dike or embankment (Fig. 18.5). Tsunami flooding in this city reached 8.1 km along Kesen river, which was 2.7 times higher than the 1960 Chilean tsunami (Liu et al. 2013).

As seawalls and dikes did not prove to be sufficiently helpful in 2011 against the tsunami, the government of Japan has reconsidered the existing design codes and guidelines aiming at improving the coastal protection and disaster mitigation; in addition, a tsunami countermeasure policy was developed based upon potential

[12] *TP Tokyo Pale*. "*The standard sea level "T.P." is the mean sea level deviation on the coast of the Japan Sea, the west coast of Kyushu, the coast of Sanriku and the coast of Hokkaido, which differs from others in Japan* (Nakano and Yamada 1975)

Fig. 18.2 Vertical seawall constructed nearby Kesennuma Fish Market (Miyagi prefecture) (Photo taken by the V. Santiago-Fandino in May 2016)

tsunami levels. A classification was established considering two levels i.e., Level 1 (L1) for prevention (frequent tsunamis occurring once every several decades to 100 or slightly more years), and Level 2 (L2) for Mitigation (those occurring between a few hundred to a thousand years) against tsunamis. Notably, L2 also includes managerial components aiming at protecting people and reducing loses and damages (Koshimura and Shuto 2015; Raby et al. 2015; Muhari et al. 2015). Relocating the affected communities to higher grounds is likewise one of the most import components of this policy.

The development of the policy was based on the principle that sustained damages must be reduced at minimum by also undertaking "hard counter measures" including the construction of a secondary embankment and raising the ground to a higher level (CDMC 2011), restoring, reconstructing and expanding dikes and seawalls along the coastlines. Complementary solutions, such as the use of natural and artificial ecosystems for protection and disaster risk reduction along coastlines have likewise been considered (Renaud et al. 2013). On the latter, the restoration of 100 ha of forest along the coastline in Natori City (Miyagi Prefecture) as a tsunami barrier is one example (OISCA 2013). However, there is some criticism of the original coastal biodiversity and related ecosystem services potential in certain areas could be lost (Bird 2013a, b; Kunterbach 2015).

A new urban concept in Iwanuma city (Miyagi Prefecture) which includes the construction of a costal dike 7.2 m high and 9.9 km long is a complex known as

Fig. 18.3 Aerial view of a section of Kesennuma coast showing reconstruction works as well as evidence of the large coseismic subsidence (Photo taken in February 2015 by E. Mas during a joint reconnaissance flight with the Sendai Coastal Division of the Ministry of Land Infrastructure and Tourism (MLIT))

Millennium Hope Hills (a privately and community-financed complex) where a second sea fence of pine trees growing on mounds made from tsunami debris and rubble is incorporated (Kobayashi 2014; Iwanuma City 2016; MLIT 2016). The urban complex also includes the relocation to high grounds of the affected communities, separation of residential areas and workplaces as well as other multipurpose systems (Miyagi Prefectural Government 2016). In Ishinomaki, A large river-coastal dike is being built along the old Kitakami river (Ishinomaki city) 17.1 km long. This structure has been redesigned and enlarged to avoid the recurrence of the enormous damage done within the first 5 km in lower basin including the estuary at Okawa School in 2011 (Takuma et al. 2015; Tomizawa 2006; Oka et al. 2012; Koshimura and Shuto 2015) (Fig. 18.6a–c).

Many problems remain that are related to tsunami fences which brought enormous questions and criticism due to their economic and environmental sustainability visa-vi their full capabilities of coastal protection and the use of other or complementary measures like for example in Indonesia, which is a country constantly exposed to earthquakes and tsunamis and has embarked on a large national project to build tsunami forest barriers or "greenbelts" instead of seawalls along large swaths of its vast coastline (Rudianto et al. 2016). However to prevent large seawater flooding in Jakarta as the city is sinking, the government will build a "Giant Seawall" (Widiatmini Sih Winanti 2015 and Koch 2015). From the original design, it appears to not incorporate a forest barrier, although this is a city prone to suffer tsunamis.

Fig. 18.4 Aerial view of Rikuzentakata's reconstruction process showing the largest conveyor belt ever constructed (tube-like structures on each side of the river banks) to deliver dug soil from the near mountain used for ground lifting and sea dike construction (*upper left* and center by the shoreline). Tsunami waves destroyed the city and flooded deep inland (Photo taken in February 2015 by E. Mas during a joint reconnaissance flight with the Sendai Coastal Division of the Ministry of Land Infrastructure and Tourism (MLIT))

Fig. 18.5 Seawall and coastal dike construction by the Kesen river estuary in Rikuzentakata City (Iwate prefecture) (Photo taken in March 2016 by V. Santiago-Fandino)

Fig. 18.6 Old Kitakami river (**a**) estuary seaward view; (**b**)works by the former Okawa school; (**c**) upstream view from the estuary and wall (Photos taken in March 2016 by V. Santiago-Fandino)

18.8 Discussion and Conclusions

Tsunamis have occurred through millennia, while some have caused utter devastation in large scale others have not. As result coastlines have shaped and reshaped by altering land and water bodies, its morphology, geochemistry, groundwater water quantity and quality, soil characteristics, natural processes, biodiversity, ecosystems as well as species abundance and distribution. Natural restoration processes and re-adaptation by the species to the new conditions occur although it may not longer be possible any longer if the alteration was to large due to severe damage.

The impacts of tsunamis on the coastal environment mainly depends on hydrographic and morphologic features of the coastline, the tsunami magnitude *Mt.* (USGS 2016) and or Intensity (Gusiakov 2007), wave height, inundation depth and lasting time, turbulence, run-up and run-off as well as carried materials such as mud, sand, rocks and boulders. Moreover, construction debris and pollution generated during and after tsunami (Santiago-Fandino and Mi Hyung Kim 2015) also play a crucial role. Further, tsunami impacts on the environment mainly depend on the type of ecosystem,[13]

[13] "*The dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit*". UNEP-CBD (1993)

their degree of vulnerability, habitat,[14] biodiversity, fauna and flora, species distribution and abundance. Moreover, it also depends on the ecological resilience of the affected ecosystem as the larger it is the more it will allow for changes toward a new state of equilibrium by readjusting to the new environment instead of coming back to the original state (Holling 1996). This concept goes beyond the "Build Back Better" toward a new definition we would like to call "Build Forward and Better". Hirakawa and Komatsu (2014) made a comparison of the profound tsunami behavior in certain locations along Tohoku and Hokkaido in Japan concluding that it devastating power was deeply associated with man made coastal modifications, land use, alteration of river courses as well as large embankments, dredging, jetties and breakwaters and seawalls.

Japan; a country with 35,000 km of coastline has been hit by tsunamis impacting in more or less degree the coastal biodiversity and related ecosystems, but it has not been until 1995 that the important and decisive national efforts to protect and restore biodiversity and ecosystems took shape in the form of the first Biodiversity Strategy. Coincidentally, a more advanced and comprehensive Strategy known as the Biodiversity Strategy 2012–2020 was developed incorporating the lessons learned from the 2011 events. This strategy has incorporated aspects such as coastal development, biodiversity and the ecosystem protection as well as social and economic aspects, but what also makes it to be more objective is because it also incorporates the need to assess the ecosystem services as, the undertaking of EIA and SEAs as a part of its core. Last but not least, some fundamental components to reach the Strategies' ambitious targets and goals include the full restoration of biodiversity and impacted ecosystem (Aoyama 1999) as well as preservation, the assessment of the economic value of biodiversity and ecosystems services.

National and local authorities as well as coastal communities have developed mechanisms and policies to ameliorate or fence-off tsunamis along the coastlines for many years, for example the relocation to higher grounds started after the 1933 Sanriku Showa tsunami and the widespread building of protecting structures after Chilean tsunami of 1960 (Renaud and Murti 2013). After the Great East Japan Earthquake and tsunami the government followed the same policy but also decided to revise the existing design codes and guidelines for the construction of sea fences, introduced ground leveling and uplifting, built secondary tsunami barriers and evacuation programs.

In 2012 after the earthquake and tsunami hit Tohoku, local governments held talks with local associations about the build-up of seawalls the latter claim that in case they did not agree with it no financial support might have been provided in the case of another disaster, the height of the walls could not be changed and that other restoration projects would start until the seawall was constructed (Tanaka and Hatakeyama 2016). Moreover, important changes in land use occur as the construction and or rebuilding of sea defenses (as well as ground leveling the ground and or migrate to non-residential areas including mountainous or hilly areas were claimed.

[14] *"The place or type of site where an organism or population naturally occurs"* UNEP-CBD (1993)

The construction of seawalls became a large controversial issue in Japan and abroad (Bird 2016; Dooley 2014). Moreover, Arikawa (2015) concluded that the discussions about the construction of this type of structures turned into a social and political debate resulting in a strong divide; this issue is also reflected in Ryall (2015) article.

The criticism include a large number of issues such as the fact that seawalls, coastal and or as river dikes destroy or heavily alter the fragile coastal ecosystem and its functioning by for example curtailing or stopping the natural link between the land and the sea causing severe and lasting damage to the ecological networks. Moreover, the recovery of tsunami hit areas may induce important changes in land use resulting in weakening water retention from rain due to urbanization in hilly areas, increased speed of rain run-off as well as snow melt into rivers and coastal areas also affecting the fishing industry. Tanaka and Hatakeyama (2016) highlighted that after the 1933 earthquake in Hokkaido the concrete wall constructed to protect Okushiri town resulted in a decrease of the local fisheries which in turn induced a large emigration problem; another example was the reduction in the water quality along the seven kilometers embankment constructed in the Ariake sea resulting in the outbreak of harmful phytoplankton and the accumulation of toxic substances.

Other criticisms are related to the fence's characteristics such as size and their effectiveness, construction and maintenance costs, land appropriation (Bird 2013b, c; Hashimoto 2016; Sanriku Fukkuo 2014; The Guardian 2014; Hiroshige 2014; Higashi 2014; Santiago-Fandino 2016), and the fact that they do not require a mandatory EIA. From as early as 2012, the local government stressed that the construction of sea seawalls did not call for an Environmental Impact Assessment (Tanaka and Hatakeyama 2016); further based on the EIA Law No. 81 of 1977 the EIAD[15] confirm this fact in 2016 (2016 *per com*). As the decision to apply it or not the EIA is left to the local authorities discretion the topic is also became debatable; the fact that for example in Miyagi prefecture the Environmental Impact Assessment ordinance was amended to facilitate the speed of the reconstruction process hence exempting related projects of this requirement at the Governors' discretion (Hashimoto 2016) turn the issue to be more algid. However, Bird (2013c) pointed out that in Iwate and Miyagi prefectures the governments established committees in 2013 to look at the potential environmental impacts posed by the sea walls; which most likely may have been due to the criticism. To achieve proper disaster mitigation as well as ensuring a sound reconstruction process along the affected coastline the need to properly understand the limitations and effectiveness of tsunami fences such as sea or concrete dikes and sea walls is crucial (Sato 2015).

However the communities continued putting pressure on local authorities about the construction of seawalls and dikes. As result of it local governments made important concessions about their characteristics for example reducing the heights and locations in some along Miyagi prefecture, and Iwate prefecture were out of 136 structures 23 will be built smaller in size. The fact that 594 structures to be constructed between Fukushima and Miyagi prefectures 577 have been agreed for

[15] *Environmental Impact Assessment Division of the Ministry of the Environment of Japan.*

construction by the local population by January 2016 (NASJ 2014) has proven the flexibility by both the government and the citizens. One case in which the sea fence has not been built despite of the government insistence was in Moune Bay village (Kesennuma City) in which the inhabitants decided to leave without it but instead relocating in higher grounds residential areas to be constructed *(danchi*), but this was possible because the petition was made prior the approval of the structure's construction plan by the government (Tanaka and Hatakeyama 2016).

Societal wise, a study by Tashiro and Sakisaka (2015) on a cost-benefit analysis in two cities looking at the public acceptance of seawall building found that the difference between those who agreed with it and the others was mainly due to the unfavorable existing community environmental conditions, preventing them from freely expressing themselves. Moreover, he found that many citizens were supporting building the seawalls as a mean of bringing jobs while at the same time they did not want to feel rejected within the community by opposing them. It also appeared that the lack of consciousness about environmental preservation and awareness did not allow the community to look for an alternative solution but also having to accept the government proposal. Some building companies are portraying billboards with positive messages; for example at Shimizuhawa and Ohnohama towns in Miyagi prefecture (Figs. 18.7 and 18.8). In addition, Figs. 18.9 and 18.10 show the construction of the new sea dike using the already existing one and the construction of the new sea dike along Sendai's coastline.

The ecosystem approach as a management tool incorporating ecological, economic and social components while at the same time allowing for the identification of the likelihood of conflicts, interactions and possibilities of trade offs could prove useful as a part of the restoration and reconstruction process, particularly in cases when conflicts such as seawalls and similar barriers are planned. Since people are part of the ecosystem by using this approach there is a possibility for a more adaptive and flexible policy and management enforcement when phasing different situations becomes easier (Atkins et al. 2013).

Japan suffered one of the largest tsunami catastrophic events in the countries' history, therefore due to the enormous challenges the complexity of the restoration and reconstruction process as well as the goals could also be considered at the same scale. During the first 5 years after the tsunami stroke large number of achievements have taken place while at the same time failures have occurred. The authorities and institutions have intensively worked to identify the best possible approaches and solutions to adapt to the new realities and move forward considering the lessons learned even using them as guidelines[16]; for example the Coast Act of 1999, which was an itself an amendment of its former 1956 version by including disaster prevention and the coastal environment including the ecosystem (Yoshida et al. 2013), has been further amended to allow for the establishments of committees to discussion issues such as coastal disaster prevention and mitigation measures (Hiroshige 2014). The tsunami Countermeasure Law was enacted (Umeda 2013), the Biodiversity

[16] JICA (2013) *published a Report on the reconstruction process and recovery with the lessons learned from past disasters in Japan while also including the March 2011 events.*

Fig. 18.7 Seawall construction and billboard at Shimizuhama town (Miyagi prefecture) with the English message "*for the future*" (Photos taken in March 2016 by V. Santiago-Fandino)

Fig. 18.8 Coastal dike construction and billboard at Ohnohama beach (Miyagi Prefecture) with the message "*we are now building the seawall to protect Ohno District*" (in Japanese) (Photos taken in March 2016 by V. Santiago-Fandino)

Strategy 2012–2020 was developed considering the lessons learned from the March 2011 tsunami, the significance and importance of the valuation of the ecosystem services and so on.

The budget set by the Japanese government in the effort to reconstruct the affected areas and improve the wellbeing of the citizens after the March 2011 up to 2020 is set to be as high as 31.5 trillion yen or about 315 billion US dollars. The first 5 years budget (2011–2015) known as the "Concentrated Reconstruction Period" total 25 trillion yen (250 billion US dollars), while the second period or the "Reconstruction and Revitalization Period" (2016–2020) adds to 6.5 trillion yen or about 25 billion US dollars (RAJ 2016). During this second period the projects and activities will specifically be designed to accelerate the ongoing reconstruction of the affected areas (MOF 2016). Part of the budget has been already covered by the citizens and residents of Japan through the Special Tohoku Restoration Tax starting from early 2013 (2.1% of the personal income tax over) and is set to last for 25 years until 2037 (Mie 2013; Baker and McKenzie 2012).

With the above-mentioned frameworks (and others) in place, the enormous financial burden to the government, residents and citizens of the country, the know-how and research and academic institutions are fundamental that a subsequent man-

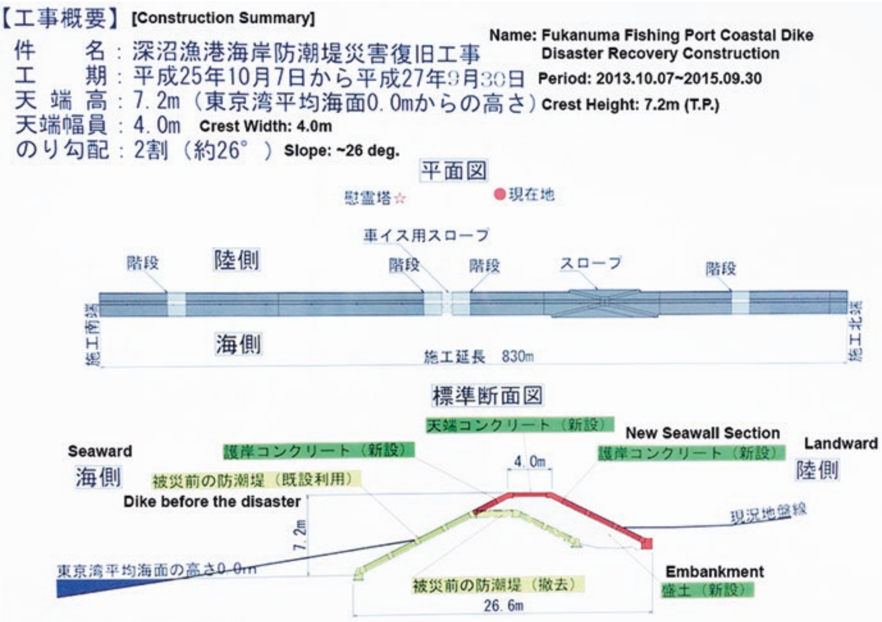

Fig. 18.9 Panel at Fukanuma Fishing Port (Miyagi Prefecture) depicting the construction of the new sea dike (*red*) over the already existing one (*yellow*). The height of the newly built sea dike is 7.2 m, the base 26.6 m wide and the *top* 4.0 m wide (Photo taken in July 2015 by E. Mas)

made costly environmental calamity due to wrong decisions making and policies be avoided. Hiroshige (2014) pointed out that the direct damage caused by the events in 2011 could be considered as the "primary disaster" while a "secondary disaster" those brought up by the recovering and restoration process. If the principle that the society should use engineering and public works to tame nature at any cost is undertaken and also that compromises between competing points of view in the political, economic social and environmental milieu prevail it will inevitably be reflected in the outcome of the reconstruction process creating further problems such as for example anti-tsunami over sized coastal engineering structures that may increase coastal vulnerability (Knight and Goff 2016). Moreover as this authors also stressed, the fact that the common top-dawn strategic planning approach in the post-tsunami reconstruction process lacking consideration to the long-term changes may cause more problems than benefits in some cases.

Udo et al. (2015) concluded that "From the perspective of a long term coastal management it is strongly required to find the vision of the future coast to also conserve the coastal environment and utilization" However when an oversized visions and works it may have be the other way around. A *manmade tsunami* could result from the wrong planning and decision-making hence jeopardizing the environmental sustainability of the coastal area along Tohoku.

Fig. 18.10 Panel of an aerial view of the recently built 830 m long sea dike at Sendai (Miyagi Prefecture) (Photo taken in July 2015 by E. Mas)

Acknowledgements The visit to the tsunami stricken areas by the main author as well as the research period was made possible thanks to the support of a number of professionals and individuals. Special recognition is made to Masafumi Nakayama, President of Nakayama Warehousing Ltd. in Shiga Prefecture, andto M.A. and Ph.D. reader at Kyoto University N. Kimura who's valuable insights and dedicated support during the field trip was crucial. The co-author would like to thank the International Research Institute of Disaster Science of Tohoku University for the kind support.

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Part V
Farming and Restoration

Chapter 19
Impact of the 2011 Tohoku-oki Earthquake Tsunami on Cultivated Soil in Miyagi Prefecture, Northeastern Japan: An Overview

Hitoshi Kanno

Abstract To investigate damage resulting from the 2011 Tohoku-oki earthquake tsunami on cultivated soil, a regional soil survey covering 344 sites of coastal farmland in Miyagi Prefecture was conducted in May 2011 as an initiative of the Agriculture Promotion Division of Miyagi Prefecture. Samples numbering 390, 344, and 340 were carefully collected from the tsunami deposit layer (TD), the surface 10-cm layer (SL1), and the next 10-cm layer (SL2) of the cultivated soil, respectively, and were used for laboratory analyses. Tsunami deposits covered the surfaces of 275 field sites of the total 344 field sites. The cumulative thickness of TD at each site represented a log-normal distribution with a median of 4.8 cm (maximum, 40.3 cm) and decreased with increasing inland distance from the shoreline. An electrical conductivity of 1:5 water leachate ($EC_{1:5}$) of TD showed a median of 5.9 dS m^{-1}, whereas that of the cultivated soil layers SL1 and SL2 was 2.1 and 1.2 dS m^{-1}, respectively. TD with high $EC_{1:5}$ mostly comprised muddy TD and that with a distribution biased to 2–4 km inland. Due to the direct impact of seawater, the $EC_{1:5}$ values of SL1 and SL2 were relatively high at the inland sites with a thin layer or no sediment. The ion exchange reaction between sodium in seawater and calcium held by soil particles caused an increase in water-soluble calcium and exchangeable sodium within the tsunami-affected area. The similarity in the exchangeable components in TD and SL1 strongly suggests that the deposits of the inland tsunami are derived from the eroded soil surface of neighboring farmland. As a result of 5 years of government-sponsored reconstruction and salt removal, the restoration of farmland has been completed in 88% (11,411 ha) of the target area in Miyagi Prefecture.

Keywords Miyagi Prefecture 2011 • Tohoku-oki earthquake • Tsunami • Farmland • Tsunami deposit

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V. Santiago-Fandiño et al. (eds.), *The 2011 Japan Earthquake and Tsunami: Reconstruction and Restoration*, Advances in Natural and Technological Hazards Research 47, DOI 10.1007/978-3-319-58691-5_19

19.1 Introduction

The Tohoku-oki earthquake (the Great East Japan Earthquake, GEJE) that occurred on March 11, 2011, followed by a devastating tsunami, resulted in serious damage to farmland along the Pacific coast of eastern Japan. The total area of tsunami-hit farmland in the Aomori, Iwate, Miyagi, Fukushima, Ibaraki, and Chiba prefectures was estimated to be 23,600 ha, 85% of which was used as paddy field (Rural Development Bureau of Ministry of Agriculture, Forestry and Fisheries 2011a). Furthermore, 97% of the area of the damaged farmland concentrated in Tohoku region and 66% (15,002 ha) of it in Miyagi Prefecture, whose area occupied 11% of the farmland in Miyagi Prefecture. In September 2011, the Rural Maintenance Division of Miyagi Prefecture (2011) announced the prospects of restoration for the damaged farmland and set the target area of restoration as 13,000 ha.

In general, the major damages to a farmland by seawater inundation caused by the tsunami included the following: (i) infiltration of seawater or salt to soil, (ii) deposition of sediment or debris overlaying the soil surface, and (iii) erosion of fertile soil. The GEJE tsunami in particular caused widespread destruction of irrigation and drainage facilities along the coastline, thereby seriously delaying the restoration of farmland.

Many post-GEJE tsunami surveys have been conducted by various researchers. Chagué-Goff et al. (2012) collected tsunami sediments and underlying soil along a transect line near Sendai Airport to assess the environmental impact of the tsunami. Goto et al. (2012) summarized the current understanding of the sedimentological, geochemical, and paleontological features of the onshore and offshore deposits based on the geological data, which were obtained by the many post-GEJE tsunami surveys involving >1,000 survey pits. Goto et al. (2014) also investigated the total balance of sedimentation and erosion and the relationship between the hydrodynamic features of the tsunami and sediment characteristics (e.g., thickness) along Sendai Bay according to the field survey of Miyagi Prefecture/Midori-net Miyagi during June–July 2011. These geological knowledge is useful for analyzing the GEJE tsunami itself and for understanding paleotsunami events. However, is insufficient to estimate the damage of the GEJE tsunami on cultivated soil and to assist in planning for recovery of the tsunami-affected farmland.

To investigate the damage caused by the GEJE tsunami on agricultural fields in Miyagi Prefecture, two types of regional surveys were separately conducted. Miyagi Prefecture/Tohoku University conducted the field survey covering 344 sites of coastal farmland as an initiative of the Agriculture Promotion Division of Miyagi Prefecture during May 2011 as a collaboration between Miyagi Prefecture and Tohoku University (Agriculture Promotion Division of Miyagi Prefecture 2011). Miyagi Prefecture/Midori-net Miyagi also conducted an another field survey covering 3,000 pits during June–July 2011 and studied the thickness and electrical conductivity (EC) of the deposits (Goto et al. 2014).

In the former regional survey, Miyagi Prefecture/Tohoku University uniquely focused on the cultivated soil possibly altered by the inundation of seawater as well as the introduction of tsunami deposits. The current paper provides an overview of the impact of the GEJE tsunami on cultivated soil based on the field survey conducted by Miyagi Prefecture/Tohoku University and the progress made of 5 years of farmland restoration in Miyagi Prefecture.

19.2 Regional Soil Survey Covering 344 Sites of Coastal Farmland in Miyagi Prefecture

Large areas of farmland were inundated by the GEJE tsunami in Miyagi Prefecture. To estimate the damage cause by the GEJE tsunami on cultivated soil and to assist in determining the plan for recovery of the tsunami-affected farmland, decision makers need to know the following: (1) the amount and composition of the sediment, which had been introduced by the tsunami; (2) the effect of seawater intrusion into the cultivated soil; and (3) the status of topsoil loss due to erosion. Therefore, the Agriculture Promotion Division of Miyagi Prefecture planned a regional soil survey covering the tsunami-affected farmland as a collaborative work between the Miyagi Prefectural Government and Tohoku University.

19.2.1 Study Area and Sampling Method

The previously selected three or four sites representing various land uses, with each 1-km grid of the tsunami inundation area were investigated with the assistance of local officials on May 11, 13, 16, 17, 18, and 19, 2011. The number of survey sites was 344, consisting of 23 in Kesennuma City, 15 in Minamisanriku Town, 11 in Ishinomaki City, 12 in Higashimatsushima City, 3 in Matsushima Town, 6 in Tagajo City, 5 in Shichigahama Town, 61 in Sendai City, 50 in Natori City, 31 in Iwanuma City, 88 in Watari Town, and 39 in Yamamoto Town (Fig. 19.1).

Samples were collected from the tsunami deposit layer (TD), the surface 10-cm layer (SL1) and the next 10-cm layer (SL2) of the cultivated soil in duplicate on the diagonal line for each site. If the sediment could be divided into multiple layers of muddy or sandy subgroups based on a judgment of the onsite texture, the thickness of TD was separately measured. From the 344 sites, samples numbering 390, 344, and 340 were collected from TD, SL1, and SL2 layers, respectively, with the exception of very thin sediment.

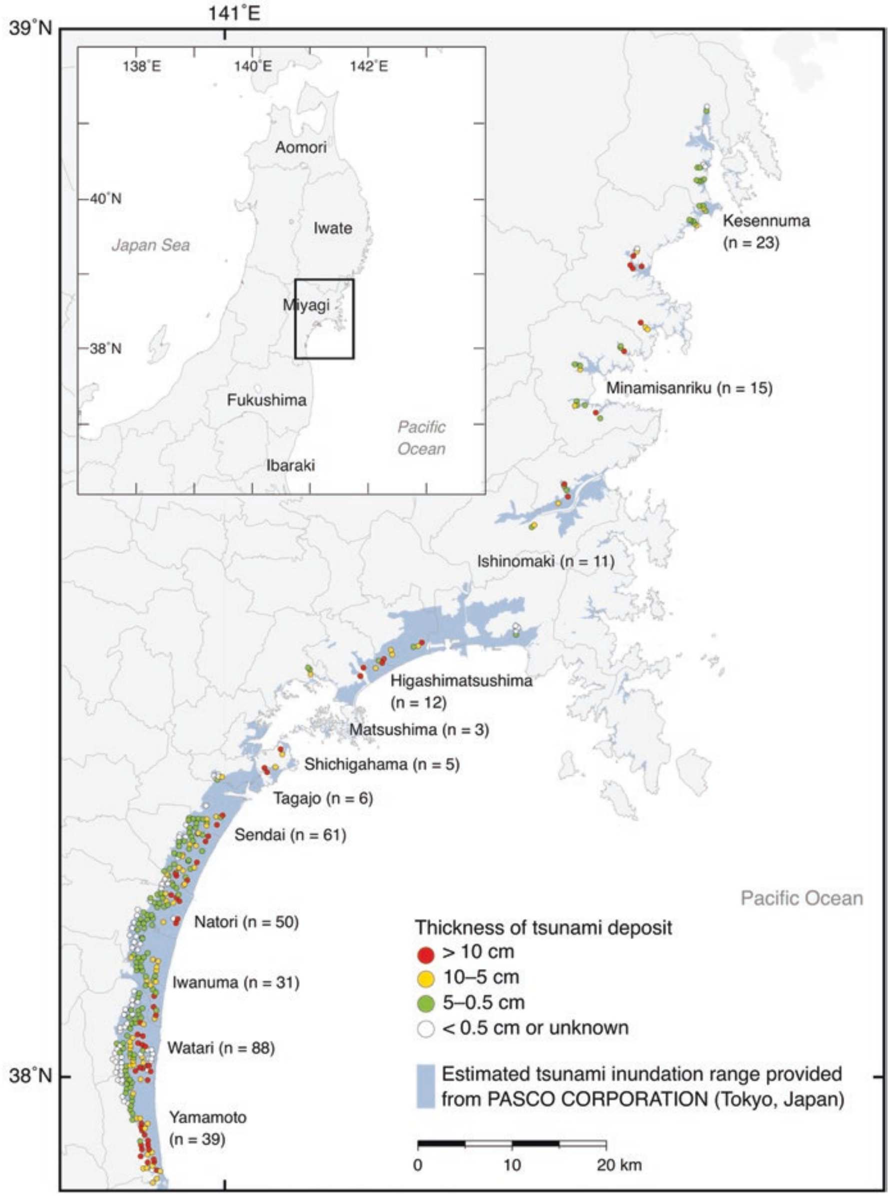

Fig. 19.1 Location and thickness of the tsunami deposit on coastal farmland (n = 344) surveyed in the Motoyoshi District (Kesennuma City and Minamisanriku Town) on May 13, in the Ishinomaki District (Ishinomaki City and Higashimatsuhima City) on May 11, in the Sendai District (Matsushima Town, Shichigahama Town, Tagajo City, and Sendai City) on May 19, and in the Watari District (Natori City, Iwanuma City, Watari Town, and Yamamoto Town) on May 16–18, 2011 (Kanno et al. 2012)

19.2.2 Analytical Methods

Air-dried fine earth fractions were used to determine selected chemical properties. Electrical conductivity ($EC_{1:5}$) values equivalent to those at the standard 25 °C were measured using a conductivity electrode at a soil/water ratio of 1:5. Water-soluble and exchangeable calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na) were determined using the sequential batch extraction procedure described below, where Ca, Mg, K, and Na were determined by atomic absorption photometry. The extract of 5 g/sample with 25 mL of distilled water for 1 h shaking contained the water-soluble cation. The residue was then extracted twice with 25 mL of pH 7.0 1 *M* ammonium acetate with 30 min shaking (Thomas 1982). The composite extracts with ammonium acetate included exchangeable cations.

Several reports using the same sample set are available (Agriculture Promotion Division of Miyagi Prefecture 2011; Kanno et al. 2012; Kanno 2012; Shima et al. 2012; Inao et al. 2013; Kanno 2014; Nanzyo 2015; Takahashi 2015). In particular, for undried TD samples, Shima et al. (2012) and Inao et al. (2013) reported detailed results of pH (H_2O), $EC_{1:5}$, pH (H_2O_2), and 1 *M* HCl extractable cadmium (Cd), copper (Cu), and arsenic (As).

19.3 Impact of the GEJE Tsunami on Cultivated Soil in Miyagi Prefecture

19.3.1 Thickness and Salinity of the Tsunami Deposits

On July 21, 2011, the Agriculture Promotion Division of Miyagi Prefecture (2011) held a press announcement regarding the preliminary results of the regional soil survey conducted in May 2011. At the time, this survey was particularly important for determining the recovery plan, as the survey determined the TD thickness as well as whether TD contained harmful substances. The survey reported the thickness and salinity status of the sediment, the possible risk of acidification by sulfide in some areas, and a marginal contamination by toxic metals accompanying the sediment (Agriculture Promotion Division of Miyagi Prefecture 2011; Shima et al. 2012; Inao et al. 2013). Fortunately, most of the sediment was of sufficiently small volumes and low Cd, Cu, and As concentrations to judge the land to be safe for use as farmland.

As demonstrated in the press announcement (Agriculture Promotion Division of Miyagi Prefecture 2011), the sediment covered the surfaces of 275 field sites of the total 344 field sites. The cumulative TD thicknesses of the sites indicated an average of 6.5 cm and median of 4.8 cm (maximum, 40.3 cm). A histogram of thicknesses represented the log-normal distribution (n = 275, Fig. 19.2). The sandy TD subgroup (median 5.1 cm) had a large contribution to the thickness as compared with the muddy TD subgroup (median 2.0 cm).

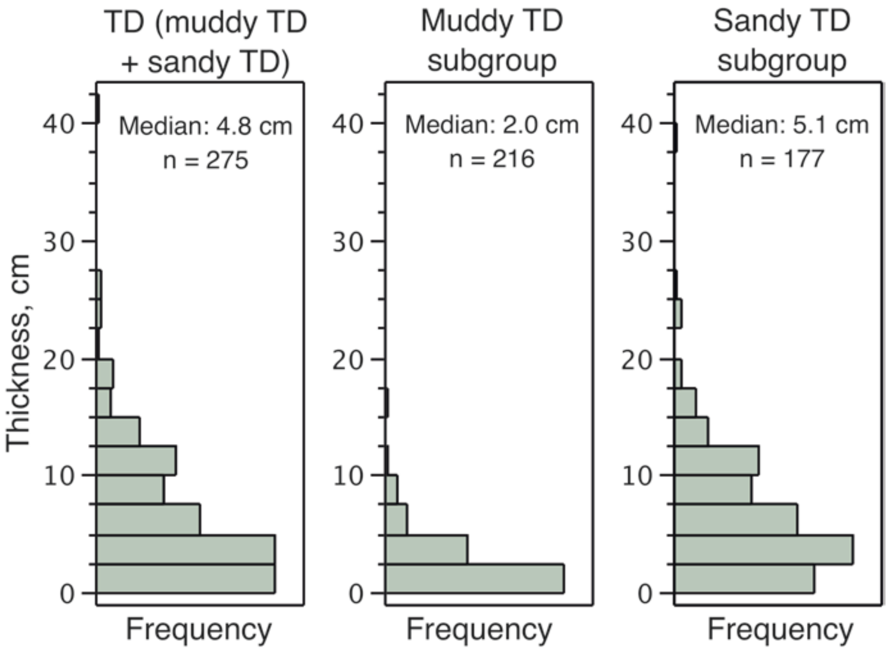

Fig. 19.2 Frequency distributions of thickness (≥0.5 cm) of the tsunami deposit (TD, n = 275), muddy TD subgroup (n = 216), and sandy TD subgroup (n = 177) on the basis of the press announcement (Agriculture Promotion Division of Miyagi Prefecture 2011)

Figure 19.1 shows that the thickness of the tsunami deposit exhibits an inverse relationship with the inland distance throughout the entire region. On the paddy field of Sendai Plain (n = 240), the spatial variability in thickness of TD according to the inland distance of each site is apparent (Fig. 19.3). The deposits thicker than 5 cm were mainly observed within 2 km from the shoreline, whereas those thinner than 5 cm were predominantly ≥2-km inland. No sediment was observed at 48 sites, with 65% of these located >4 km from the shoreline (near the inundation limit). A similar spatial trend of TD thickness was reported by Goto et al. (2014) using the dataset of the field survey conducted by the Miyagi Prefecture/Midori-net Miyagi during June–July 2011.

Electrical conductivity of 1:5 water leachate ($EC_{1:5}$) represents the salinity status and can be used as an indicator of salt damage to crops. The $EC_{1:5}$ of TD showed a median of 5.9 dS m^{-1} using the weighted average at each site, and varied depending on the nature of deposits (Fig. 19.4). TDs with a high $EC_{1:5}$ value mostly consisted of muddy TD (dark colored columns in Fig. 19.4), since muddy TD indicated a higher $EC_{1:5}$ value (n = 173; median, 12.8 dS m^{-1}; maximum, 37.8 dS m^{-1}) than those of sandy TD (n = 164; median, 2.1 dS m^{-1}; maximum, 20.0 dS m^{-1}). Generally, mud (fine particles) has a poor permeability and high water-holding capacity. Therefore, muddy TD could hold more seawater and indicates a higher $EC_{1:5}$ value than sandy TD.

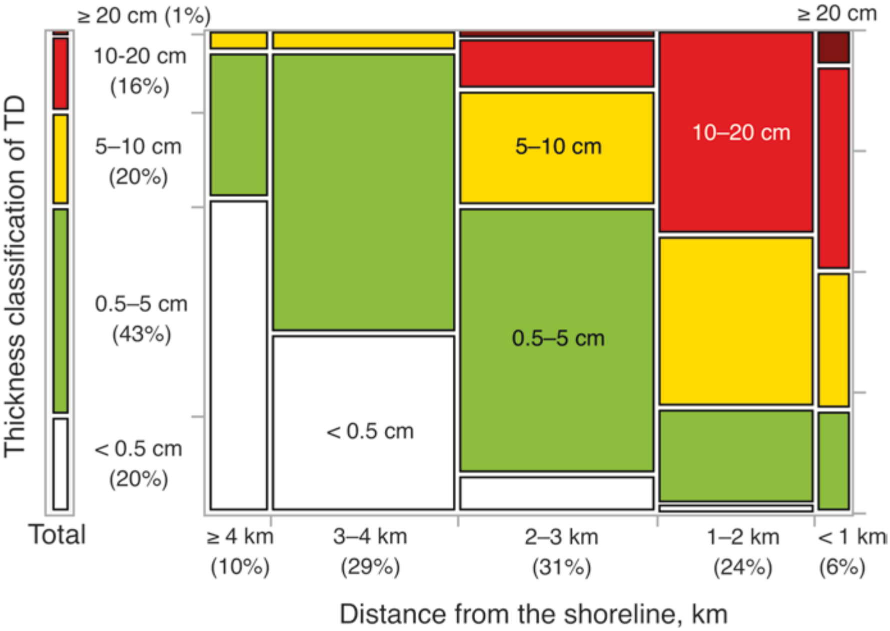

Fig. 19.3 Spatial variability of the thickness of the tsunami deposit (TD) on the paddy field of Sendai Plain (n = 240). *Computation of the inland distance at each site was conducted in cooperation with Dr. C. Yonezawa (Tohoku University)*

19.3.2 Salinity of the Cultivated Soils

The improvement in salinity status of cultivated soil is essential to restore crop production as well as the removal of the sediments or debris. Although the $EC_{1:5}$ of TD showed a median of 5.9 dS m^{-1}, those of the cultivated soil layers SL1 and SL2 were 2.1 and 1.2 dS m^{-1}, respectively (Fig. 19.4). According to the guideline announced by ZEN-NOH (2011), the $EC_{1:5}$ range required to avoid salt damage of paddy rice is ≤0.6–0.3 dS m^{-1} (salinity ≤0.2% or chlorinity ≤0.1%). During May 2011 (before the rainy season), $EC_{1:5}$ values of the cultivated soil exceeded the critical level in most sites investigated within the regional soil survey.

On the paddy field of Sendai Plain (n = 240), the spatial distribution of TDs with high $EC_{1:5}$ (≥10 dS m^{-1}) predominantly occurred within 2–4 km inland (Fig. 19.5). Although the muddy TD mainly increased the $EC_{1:5}$ value of TD, the presence of the muddy sediment layer with poor permeability resulted in the opposite effect to cultivated soil. The proportions of the moderate $EC_{1:5}$ class (2–10 dS m^{-1}) in SL1 and SL2 showed relative increases from 3 to ≥4 km inland. The sites with no sediment in which seawater directly infiltrated the cultivated soil occupied 37% of sites 3–4 km inland and 65% of sites of >4 km inland (near the inundation limit). This particular spatial trend of $EC_{1:5}$ clearly appears in SL2, where $EC_{1:5}$ increased with increasing inland distance (Fig. 19.5). Therefore, TD appears to act as a defensive

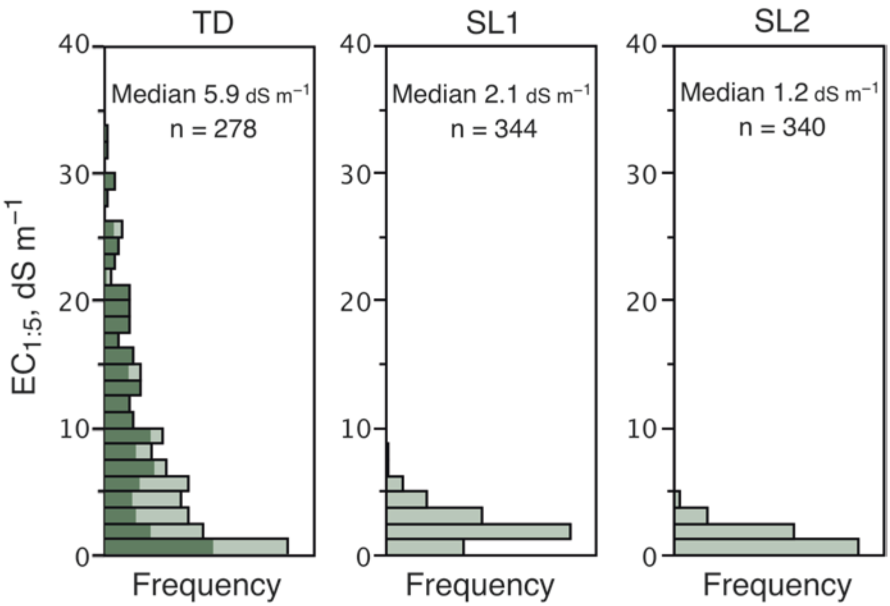

Fig. 19.4 Frequency distributions of the electrical conductivity of 1:5 water leachate ($EC_{1:5}$) of the tsunami deposit (TD, n = 278), 10-cm cultivated soil layer (SL1, n = 344), and the next 10 cm (SL2, n = 340) from the surface. Dark colored columns indicate TD composed predominantly of mud

barrier against seawater penetration into the cultivated land (salt infiltration). Chagué-Goff et al. (2012) similarly concluded that soils not covered by tsunami deposits were strongly affected by salt contamination as a result of a survey along the transect line near Sendai Airport that were set parallel to the flow direction.

19.3.3 Water-Soluble and Exchangeable Cation of Tsunami Deposits and Cultivated Soil Layers

Seawater contains approximately 35 g L^{-1} of dissolved salts and has a salinity of approximately 3.5% (US Department of Energy 1994). The most abundant dissolved ions in seawater are sodium (Na^+), chloride (Cl^-), magnesium (Mg^{2+}), sulfate (SO_4^{2-}) and calcium (Ca^{2+}) with the relative molar charge ratio of the cations Na^+:Mg^{2+}:Ca^{2+} of 0.79:0.18:0.03, whereas that of anions Cl^-:SO_4^{2-} is 0.91:0.09.

Due to the high salinity (predominantly Na^+ and Cl^-), inundation by seawater not only increased $EC_{1:5}$ values of the cultivated soil (Figs. 19.4 and 19.5), but also largely changed the original compositions of water-soluble ions. The sum of water-soluble cations ($cmol_c$ kg^{-1}) positively correlated with $EC_{1:5}$ values (data not shown). On the paddy field of Sendai Plain (n = 240), Na^+ was the most abundant water-soluble

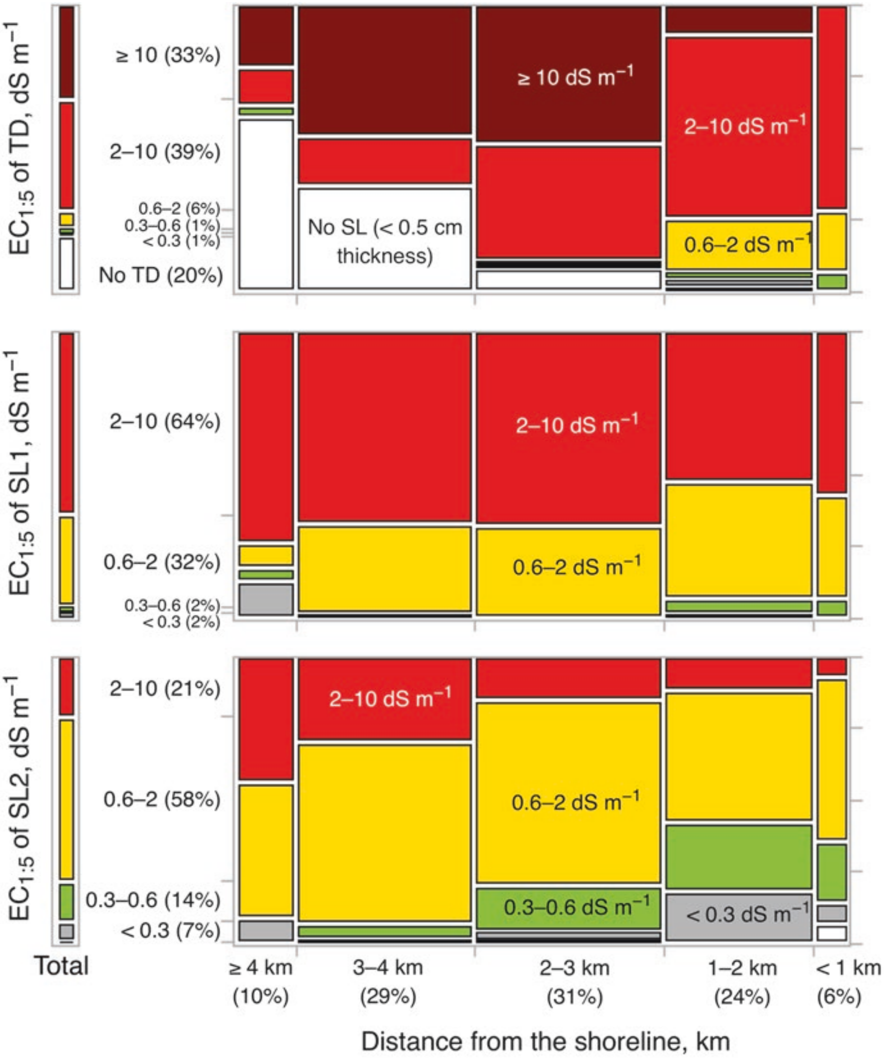

Fig. 19.5 Spatial variability of the electrical conductivity of 1:5 water leachate ($EC_{1:5}$) of the tsunami deposit (TD), 10-cm cultivated soil layer (SL1), and the next 10 cm (SL2) from the surface in the paddy field of Sendai Plain (n = 240). *Computation of the inland distance at each site was conducted in cooperation with Dr. C. Yonezawa (Tohoku University)*

cation within the three layers (Fig. 19.6). Although water-soluble Na^+ in TD indicated an extremely high level (33.3 $cmol_c$ kg^{-1}), the molar charge ratios of water-soluble Na^+/Mg^{2+} at each depth still appeared to reflect that of seawater; however, there was a large difference in water-soluble Ca^{2+}, whose molar charge ratio to Na^+ increased in TD, SL1, and SL2.

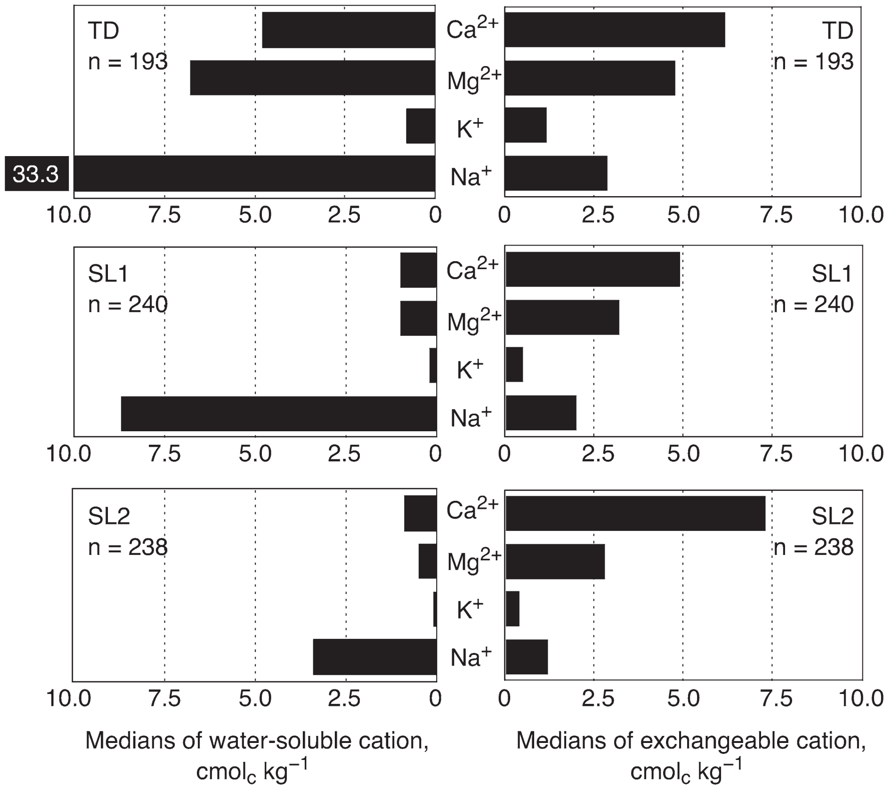

Fig. 19.6 Medians of water-soluble and exchangeable calcium, magnesium, potassium, and sodium content in the tsunami deposit (*TD*), 10-cm cultivated soil layer (*SL1*), and the next 10 cm (*SL2*) from the surface in the paddy field of Sendai Plain (n = 240)

The exchangeable cations are held on or near the surface of a solid particle (e.g., clay or organic matter) by a negative charge. In most cultivated soils, exchangeable Ca^{2+} occurs in larger quantities than other cations due to the soil improvement and fertilization, whereas Na^{+} is very low and approaches only trace quantities in the soils of many humid regions. However, dissolved cations (predominantly Na^{+}) introduced by the tsunami increased water-soluble Na^{+}, and would stimulate the ion exchange reaction in the cultivated soil. The calcium ion was the most abundant exchangeable cation of the three layers (Fig. 19.6). Exchangeable Ca^{2+} was highest in the deep cultivated soil (SL2) and decreased with SL1 and TD in that order, whereas Mg^{2+} and Na^{+} were the highest in the sediment and decreased with increasing depth.

The reaction of the seawater with the cultivated soil would increase water-soluble Ca^{2+} and exchangeable Na^{+} and Mg^{2+}, particularly in the sediment layer. Surprisingly, the exchangeable component of TD and SL1 were similar (Fig. 19.6), regardless of the difference in water-soluble cations and $EC_{1:5}$ values. This similarity strongly suggests that inland tsunami deposits are derived from the eroded surface soil of the neighboring farmland. Based on the balance of the erosion and sedimentation volumes on the Sendai Plain, Goto et al. (2014) also concluded that the major source of the muddy TD was the paddy soil, although they could not exclude the contribution of offshore mud.

19.4 Farmland Restoration in Miyagi Prefecture

19.4.1 Salt Removal by Natural Rainfall

For the restoration of tsunami-affected farmland, flushing of salt in the cultivated soil using fresh water as well as the possible removal of sandy/muddy sediments are recommended to allow crop production to resume. In some cases, natural rainfall decreased the salinity of tsunami-affected farmland. Sato (2015) investigated various declining patterns of $EC_{1:5}$ in the paddy fields of Iwate Prefecture until after 235 days from the tsunami attack with a cumulative precipitation over that period of 1,019 mm, and demonstrated the dependency of the decrease on the water permeability of the soils, which is related to the soil hardness. Ito et al. (2015) also reported on the efficiency of salt removal by natural rainfall based on the half-year observation in Miyagi Prefecture. In the paddy fields containing no sediment, precipitation of 952 mm could effectively reduce the $EC_{1:5}$ value from 4.3 dS m^{-1} (May 16, 2011) to <0.6 dS m^{-1} (October 28, 2011). However, the salt removal by precipitation was not as effective in the paddy fields with a thin muddy or a thick sandy overlaying sediment layer.

19.4.2 Reconstruction and Restoration of Farmland

The restoration of tsunami-affected farmland was conducted based on the procedure proposed by the Rural Development Bureau of the Ministry of Agriculture, Forestry and Fisheries (2011b). The excess salt in the farmland is removed by repeated flushing with freshwater; a process which completely depends on the restoration of the irrigation and drainage facilities. Flushing continues until the $EC_{1:5}$ value or chlorinity falls below the critical level. In Miyagi Prefecture, the sediment of ≥5 cm thickness removed at first, after which irrigated fresh water was used for the vertical salt infiltration method or the puddling and surface drainage method. For farmland in which the surface soil was severely eroded or under a large influence by ground subsidence, soil dressing was conducted. Moreover, many studies exist regarding the fertility of the tsunami-affected soil by Japanese researchers, and the findings of which were published as a special issue of the *Japanese Journal of Soil Science and Plant Nutrition* (Miura et al. 2015).

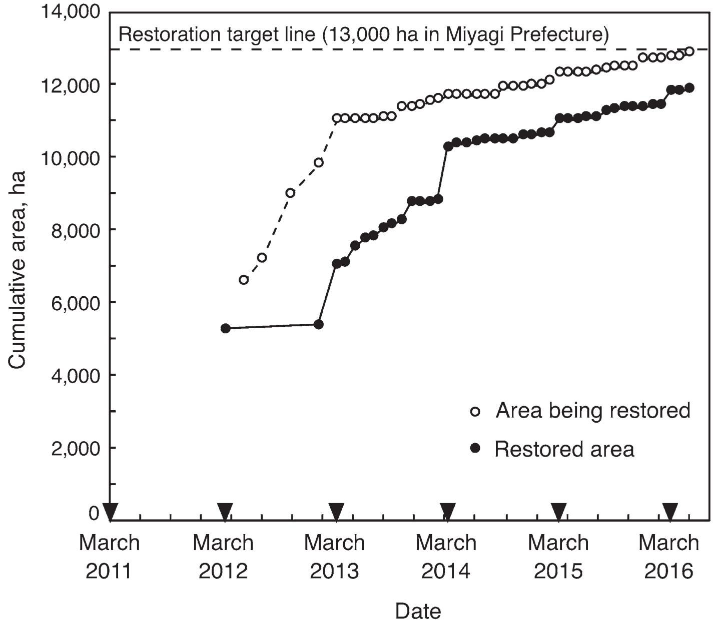

Fig. 19.7 Progress of 5 years restoration of the tsunami-affected farmland in Miyagi Prefecture on the basis of published data (Miyagi Prefectural Government 2016)

The Total area of farmland damaged by the GEJE tsunami was 15,002 ha in Miyagi Prefecture (Rural Development Bureau of Ministry of Agriculture, Forestry and Fisheries 2011a). Although the restoration of damaged farmland was severely delayed in 2011 due to the destruction of irrigation and drainage facilities, the area recovered has rapidly increased since 2012. Figure 19.7 shows the progress of the restoration of the tsunami-affected farmland in Miyagi Prefecture on the basis of published data (Miyagi Prefectural Government 2016). The restored area of the tsunami-affected farmland was 5,250 ha by the spring of 2012 and reached 10,253 ha by the spring of 2014. As a result of 5 years of reconstruction and salt-removal budgeted for by the Government, restoration has been completed in 88% (11,411 ha) of the target area in Miyagi Prefecture.

19.5 Conclusions

In this paper, an overview of the impact of the GEJE tsunami on cultivated soil based on the field survey involving 344 sites of coastal farmland in Miyagi Prefecture has been presented. A log-normal distribution in the cumulative thickness of tsunami deposit layers (TD) appeared although their thickness varied depending on their distance from the shoreline. A variation in electrical conductivity of 1:5 water leachate ($EC_{1:5}$) of TD also occurred depending on their textures and the distance from the shoreline.

Surface 10-cm layer (SL1) and the next 10-cm layer (SL2) of the cultivated soil were altered by the inundation of seawater as well as the introduction of tsunami deposits overlaying. An increase in water-soluble calcium and exchangeable sodium was found due to the reaction between sodium from seawater and calcium held by soil particles within the tsunami-affected areas. The analysis has also showed that the similarity in the exchangeable components of TD and SL1, strongly suggesting that the inland tsunami deposits are derived from the eroded soil surface from neighboring farmland.

For the restoration of tsunami-affected farmland except that the surface soil was severely eroded or under a large influence by ground subsidence, flushing of excess water-soluble components as well as the possible removal of the sediments were commonly conducted. In spite of the serious damage caused by the GEJE tsunami on agricultural fields, as a result of the continuous efforts undertaken through 5 years by the Japanese government-sponsored reconstruction and salt removal program, the restoration of farmland has been completed in 88% of the target area in Miyagi Prefecture.

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Chapter 20
The Regional Structure and Farming Resumption in a Tsunami-Affected Community: The Case Studies of Otomo and Hirota Districts in Rikuzentakata City: Iwate Prefecture

Toshihiro Hattori, Natsuki Shimizu, and Akemi Saito

Abstract Though tsunami-hit farmland extended over 21,480 hectares (ha) in six prefectures after the Great East Japan Earthquake, the recovery work proceeded smoothly, and the area under cultivation expanded to 15,060 ha by 2014. This paper aims to clarify the current status of farmland restoration and the factors affecting farming resumption. The paper uses the cases of Otomo district and contiguous Hirota district in Rikuzentakata City.

In Otomo and Hirota districts, most households carry on both farming and fishing, although they usually choose fishing as the main money-making activity. Therefore, they have had to rely on bearer-farmers (farmers who actually conduct the agriculture in an area) and the community-based farm cooperatives to continue farming. The farmers demanded a recovery-related farmland-consolidation project to establish the foundations of the bearer-farmers and the community-based farm cooperative. The structure of farming differs between the two districts, in spite of the agreement to consolidate the farmland. Paddy fields in Otomo district are grouped and cover large plots, so the farmland can be used efficiently for bearer-farmers' businesses. All farmers expect that resumption of farming will rely on bearer-farmers. On the other hand, paddy fields in Hirota district are dispersed and small in plot size. Furthermore, settlements are separated from farmlands and fishing villages, and there are no bearer-farmers in the district. Therefore, farmers expect to share roles

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V. Santiago-Fandiño et al. (eds.), *The 2011 Japan Earthquake and Tsunami: Reconstruction and Restoration*, Advances in Natural and Technological Hazards Research 47, DOI 10.1007/978-3-319-58691-5_20

in the community-based farm cooperative. Thus, Otomo and Hirota districts are making different choices due to the difference in their regional structures.

Keywords Farming resumption • Recovery-related farmland consolidation • Community-based farm cooperative • Agriculture and fishery • Regional structure

20.1 Introduction

The Great East Japan Earthquake of 2011 caused devastating damage to farmlands in the coastal area. More than 21,480 hectares (ha) of farmland between Aomori prefecture and Chiba prefecture were damaged (MAFF 2014, 2015a). The damage has varied in type: salt damage by seawater inundation, tsunami debris and sludge, and indirect earthquake damage such as destruction of irrigation ditches and ground settlement.

There are two main methods to restore the tsunami-hit farmlands (MAFF 2014; Sawaguchi et al. 2014; Onodera and Kindaichi 2016; Hashimoto 2016). One is the disaster-reconstruction measures that are intended to restore the situation to that before the disaster. The other is the farmland-consolidation project that is intended to not only restore the situation but also develop farmlands, such as by enlarging farmland units, in order to improve the prospects for future development. Generally, the disaster-reconstruction measures are used in cases where the unit scale of the tsunami-hit farmlands is small or the plots are scattered. The farmland-consolidation project is preferred when the farmland unit is large, such as an entire village.

This paper aims to clarify the current status of restoration of tsunami-hit paddy fields and the factors affecting farming resumption. The paper uses the cases of Otomo district and contiguous Hirota district in Rikuzentakata City because these districts have distinctly different agricultural production bases.

20.2 General Information on Tsunami Damage to Farmland

The affected farmlands are distributed across six prefectures along approximately 1000 km of the Pacific coast, from Aomori prefecture in the north to Chiba prefecture in the south; the damaged area reached 21,480 ha in total. Miyagi prefecture was the hardest hit, with 14,340 ha of devastated farmland (Table 20.1, MAFF 2014). This was two-thirds of the total area because Miyagi prefecture has plains on the coastal area. Fukushima (5460 ha) was second largest, and Iwate (730 ha) was third.

It was impossible to cultivate damaged farmlands just after the earthquake due to accumulated debris, sediment, and flood waters, as shown in Fig. 20.1. However, recovery work to restart farming began just after the disaster. Some farmers, whose farmlands were not much damaged, could harvest rice crops in the autumn of 2011.

Table 20.1 Tsunami-damaged farmlands area and the recovery target area (MAFF 2014)

Prefecture	Tsunami-damaged farmlands area (ha)	The recovery target area (ha)						Area converted from farmland to other use (ha)
		Total (ha)	Farming resumption area (ha)				※	
			~2014	2015	2016	2017~		
		Proportion (%)						
Iwate	730	670	450	40	20	160	–	60
		100	*67*	*6*	*3*	*24*	*0*	
Miyagi	14,340	13,710	12,030	630	500	550	–	630
		100	*88*	*5*	*4*	*4*	*0*	
Fukushima	5,460	4,880	1,630	190	580	360	2,120	580
		100	*33*	*4*	*12*	*7*	*43*	
Aomori, Ibaraki and Chiba	950	950	950	–	–	–	–	–
		100	*100*	*0*	*0*	*0*	*0*	*0*
Total	21,480	20,210	15,060	860	1,100	1,070	2,120	1,270
		100	*75*	*4*	*5*	*5*	*10*	

※Farmlands area in the evacuation areas where people are not permitted to live (ha)

Fig. 20.1 Tsunami-hit farmland (paddy field) (Taken by Hattori in Sendai city, Miyagi prefecture (April 24, 2011))

Recovery work advanced smoothly, and the area that could be cultivated expanded to 15,060 ha, which was around three-fourths of the recovery target for 2014.

However, progress has varied widely among prefectures. Aomori, Ibaraki and Chiba prefectures, where the area of damaged farmland was small, could restart farming in all recovery target areas by the 2014 fiscal year. Miyagi prefecture's conditions are also not bad, with the final 4 % of the recovery target area due to return to farming after the 2017 fiscal year. In contrast, in the case of Iwate prefecture, recovery has not progressed so smoothly. Farmlands in Iwate prefecture are located near the coast, so only 24 % of the recovery target area will have restarted farming by the end of fiscal year 2017 because of the delay in reconstructing the sea embankments to conserve farmlands.

Fukushima prefecture is in the most severe situation among these prefectures. Only half of affected farmlands are expected to have restarted farming by fiscal year 2016. Damaged farmlands and the Evacuation Order Area due to the nuclear-plant accident overlap because both are located on the seashore. The priority is to lower ambient radiation levels by decontaminating those farmlands within the Evacuation Order Area (which account for 43 % of the overall restoration target area), rather than to restart farming.

20.3 The Outline of Otomo and Hirota in Rikuzentakata City

Otomo and Hirota districts are located in the eastern area of Rikuzentakata City, with Otomo district at the base and Hirota district at the tip of the Hirota peninsula (Fig. 20.2). The main occupation in this area is fishery, meaning the area is based more on aquaculture than agriculture. The population was 1,911 in Otomo and 3,532 in Hirota as of the national census in 2010.

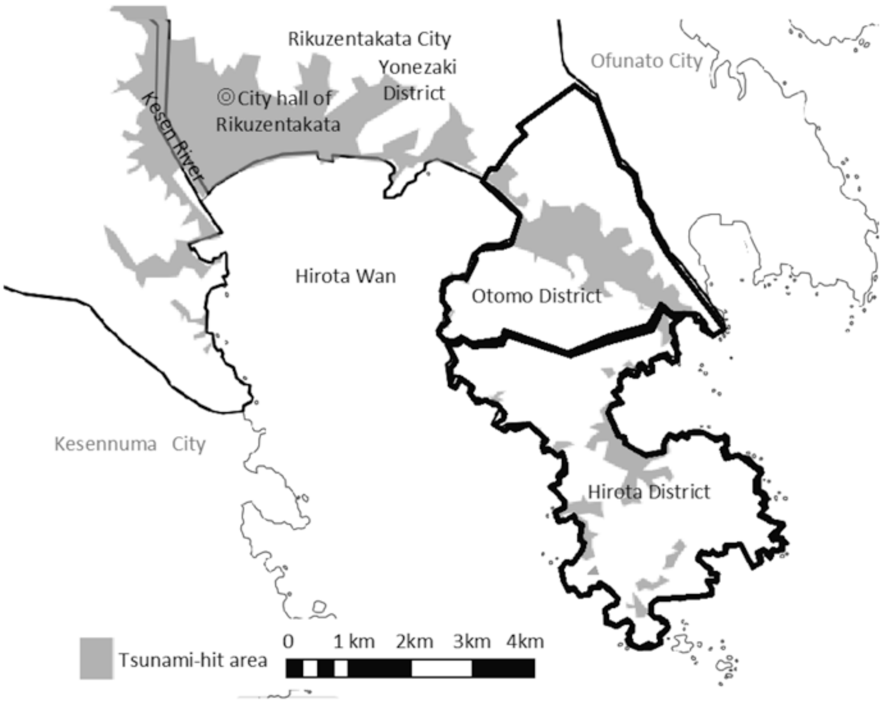

Fig. 20.2 Location of Otomo district and Hirota district (Based on The Geospatial Information Authority of Japan, Hattori and Saito 2015)

Otomo district has a group paddy field with large plots spread over more than 100 ha, which is the largest in the coastal area of Iwate prefecture. On the other hand, paddy fields in Hirota district are scattered over a number of bays and are not large in plot scale, with the smallest group of farmlands covering no more than a few hectares. Agricultural activity in both districts is largely self-sufficient, so there are few full-time farmers according to the results of the interview survey to the Otomo Irrigation Association of Kesengawa Irrigation and Drainage System.

Regarding the fishery, there are many fishing ports in these districts to run aquaculture operations of oysters and seaweed, fishery by fixed net and gathering shellfish, such as sea urchins, on both the ocean and bay sides of the peninsula.

As Otomo district had been facing an irrigation-water scarcity, the Iwate prefectural government implemented a project to supply irrigation water by pipeline from the Kesen River. A 14.5-km canal constructed from 1971 to 1991 brought water to 385 ha of farmland (The Editing Committee of the History Book of Rikuzentakata City 1996). Additionally, Iwate prefecture implemented the Kesengawa-area farmland consolidation project, covering 219 ha (mainly in Otomo district), from 1979 to 1994. Each paddy plot was enlarged to 20-ares (a) lots in these districts, although the repayment of the loans for those projects was still incomplete at the time of the earthquake. Farmers organized two associations: The Kesengawa Land Improvement District was promoted by the prefectural government to provide more specificity for the land consolidation project, while a subsidiary association named the Otomo Irrigation Association of Kesengawa Irrigation and Drainage System managed maintenance of canals in the district and collected water charges and repayments of the loans.

As farmers in Otomo district mainly engage in aquaculture, which has a high profitability for their livelihoods, the labor for agriculture had been always lacking according to the interview survey results of the Otomo Irrigation Association of Kesengawa Irrigation and Drainage System. Though the Otomo District Farming Association had a membership of 65 farming households, a few households conduct all the rice-farming activities like paddling work, planting, harvesting and drying harvested rice by themselves; they had relied previously on four bearer-farmers (the farmers who conduct the agriculture in an area) or the Otomo Community-based Farm Cooperative (Fig. 20.3). Because of this, the Otomo Farming Group for Soybean Production was organized around 1991 and was joined by all farming households (393 farming households at that time) in the district. This group took over some paddies made available by the acreage-reduction policy for rice and began crop rotation of soybeans and rice by dividing the available paddies into six blocks. The cultivation area reached 24 ha in 2012. The soybean production had been carried out by another community-based farm cooperative, which received a contract from the Otomo Farming Group for Soybean Production. This community-based farm cooperative owned agricultural machinery, employed agricultural workers and also received a contract for rice production. This group and two full-time farmers were awarded contracts as bearer-farmers in Otomo district. In addition, a full-time farmer from Yonesaki district (located northwest of Otomo district) worked as a bearer-farmer here.

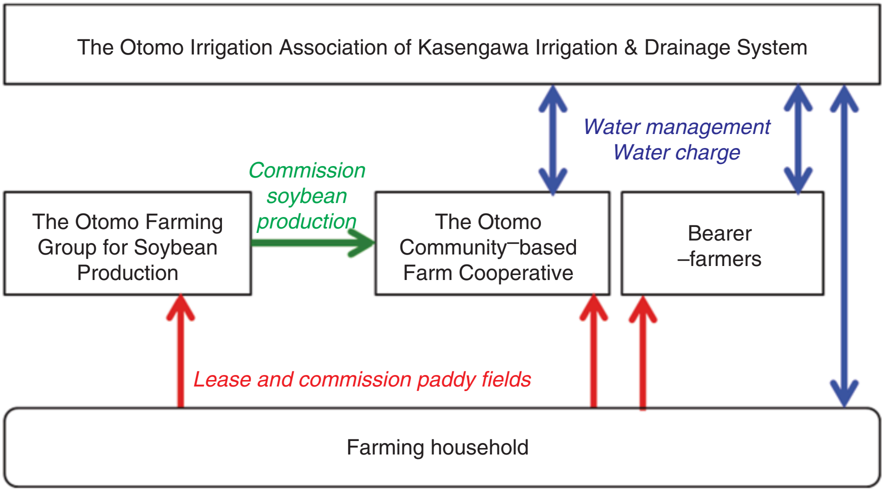

Fig. 20.3 The framework of paddy farming before the tsunami disaster in Otomo district (Hattori 2014)

On the other hand, the paddy fields in Hirota district were muddy and unimproved, as well as being scattered along the valleys to each bay (according to the interview survey of the Hirota Peninsula Farming Association). These paddy fields have been used for self-sufficient agriculture by part-time farmers whose main occupations are fishery or office work.

In Otomo district, the farmland-consolidation project was already being implemented before the earthquake, while it was not implemented in Hirota district until a long time later. However, for future farming, the prefectural government planned to begin the project in the 1999 fiscal year, as the Hilly and Mountainous Areas Comprehensive Development (HMCD) Project. The HMCD Project consolidated about 25 ha of farmland in Hirota district to improve the condition of the paddy fields that could not accommodate agricultural machinery (MAFF 2016a). Ninety-seven farming households out of 120 (the total number of farming households at that time, except for small farmland owners regarded as non-farming households) also founded the Hirota Peninsula Farming Association as a community-based farm cooperative for the improved paddy fields.

20.4 The Disaster Situation in Otomo and Hirota Districts After the Earthquake and Tsunami

20.4.1 The Disaster Situation in Otomo District Based on an Interview Survey of the Otomo Irrigation Association of Kesengawa Irrigation and Drainage System

A tsunami of 12–13-m height hit Otomo district from both the Pacific Ocean and Hirota Bay sides of the peninsula immediately after the earthquake. The tsunami damaged 120 ha of farmland as well as facilities for aquaculture (a key industry in Otomo), fishing ports and the sea embankments on both the east and west shorelines. The ground settlement of a meter and damage to the sea embankments by the tsunami made it difficult for floodwaters to drain back into the sea, and this caused a wide range of clogging damage in the damaged farmland around Hirota Bay. The tsunami also caused the runoff of top and bedrock soil and brought debris and salty sediment. This covered the area and caused the salt damage. There were approximately 80 victims of the disaster, which also completely or partially destroyed 247 of the 634 houses (Rikuzentakata City 2011). Responding to the drainage trouble caused by the ground settlement, clearing of debris and sediment and restoring lost topsoil were required to restore the tsunami-hit farmland.

Fortunately, there was no human suffering to bearer-farmers because their houses were on higher ground. However, the agricultural machinery and facilities that the farmers (both the bearer-farmers and the other farmers) and farming groups owned were located on lower ground because they were kept near the fields or had been sent to maintenance facilities to prepare them for the upcoming spring. Much of the machinery and facilities were swept away by the tsunami. Therefore, restoring the agriculture-management system will be equally as important as farming resumption to resume agriculture work.

20.4.2 The Disaster Situation in Hirota District Based on an Interview Survey by the Hirota Peninsula Farming Association

The tsunami also damaged most of the infrastructure in Hirota district: fishing ports, the sea embankments and aquaculture facilities. Most farmlands at lower elevation were damaged, too. However, there were few cases of long-term seawater flooding or accumulated debris in Hirota district because those farmlands were located in a valley with direct drainage back into the sea. This made it possible for some farmers to start recovery work immediately after the disaster. These farmers could restore paddy fields before that year's rice-cultivation season.

20.5 Restoring the Farmland

20.5.1 Recovery-Related Farmland Consolidation in Otomo District Based on an Interview Survey of the Otomo Irrigation Association of Kesengawa Irrigation and Drainage System

Most farmers in Otomo district strongly favored the implementation of farmland consolidation because they wanted to establish the base for group farming. They had been suffering since before the disaster from longstanding problems such as aging of the farmers and the shortage of successors. They knew that they had to rely on bearer-farmers and the farming groups to continue farming. On the other hand, they hesitated to agree to the farmland-consolidation project because they had to repay the loan for the farmland-consolidation project that had been conducted since 1994. They were concerned that they might face “double loan debts” because they had to bear an expense (1 % of the total expenses) if they initiated a new farmland-consolidation project while paying the loan of the previous project. However, the farmers and Rikuzentakata city reached an agreement on the farmland-consolidation project in the end because all the expenses to be paid by farmers were covered by the city government, at the farmers’ request.

20.5.2 Recovery-Related Farmland Consolidation in Hirota District Based on an Interview Survey on Hirota Peninsula Farming Association

Hirota district was under the HMCD Project when it was struck by the earthquake and tsunami. HMCD was renamed the Comprehensive Infrastructure Reconstruction Project when it was incorporated in the Disaster Reconstruction Subsidy Project. In other words, the incomplete part of the HMCD Project was taken over as a part of the Disaster Reconstruction Subsidy Project. Then, farmers were able to restart farming approximately 15 ha of farmland in the 2014 fiscal year. While it had been expected that the project would complete its initial plans by 2016, the farmland-consolidation work in areas close to the sea was interrupted because the fishing port and sea-embankment reconstruction were delayed.

20.6 Establishment of Systems for Farmland Utilization and Management

20.6.1 Establishment of the Farming Organization in Otomo District

Rice production in Otomo district had relied on the Otomo Community-based Farm Cooperative via group crop rotation and the bearer-farmers in and around the district (by contracting all or part of the work or lending farmland to them). This was because very few farmers could carry out such complex work independently before the earthquake. In this district, the Otomo Irrigation Association of Kesengawa Irrigation and Drainage System, which coordinated farmers by managing water after the prefectural farmland consolidation project (the period was from 1979 to 1994), led the discussion regarding bearer-farmers for rice-paddies management. They had decided to dissolve the Otomo Community-based Farm Cooperative and the Otomo Farming Group for Soybean Production and to establish an agricultural producers' cooperative corporation with integrative functions to manage resources and environmental factors such as farming, water management and weeding. The new "Sun-farm Otomo Corporation of Agriculture Affairs Association" (the "Sun-farm Otomo") held its initial member meeting in March 2014 to restart farming from that spring.

After that, the Sun-farm Otomo decided to integrate all farmland management in this district under the farmland-consolidation project by starting the Farmland Intermediary Management Project. This project aims to accelerate the farmland consolidation for bearer-farmers; a public corporation for farmland consolidation was established in each prefecture in 2014. They rent agricultural land from the lender (the person wishing to rent out the land) and lease the land to farmers after consolidation, which enhances ease-of-use based on the Farmland Intermediary Management Project (MAFF 2015b). This project provides a grant to the region at the same rate as farmland lending in the region, which is called a regional cooperative grant for land consolidation. The Sun-farm Otomo confronted the problem that, if they accepted the regional cooperative grant for land consolidation (24,000 JPY/10 a), it would count as profit in the fiscal balance for a single year and be taxed. They consulted with a licensed tax accountant to avoid this, and then decided to establish the "General Incorporated Association for Otomo Farmland Conservation" (known as the "Otomo Farmland Conservation Association") separately from the Sun-farm Otomo. This second entity accepted each grant, not only from the Farmland Intermediary Management Project, but also existing grants from the Direct Payment for the Hilly and Mountainous Areas (supporting the continuation of agricultural production in hilly and mountainous areas (MAFF 2016a, b) and Multifunctional Payment (supporting local resources-conservation activities including agricultural road-surface maintenance as the Farmland Maintenance Payment and supporting simple repair of channels, agricultural roads and ponds, and other cooperative activities to qualitatively improve local resources as the Resource

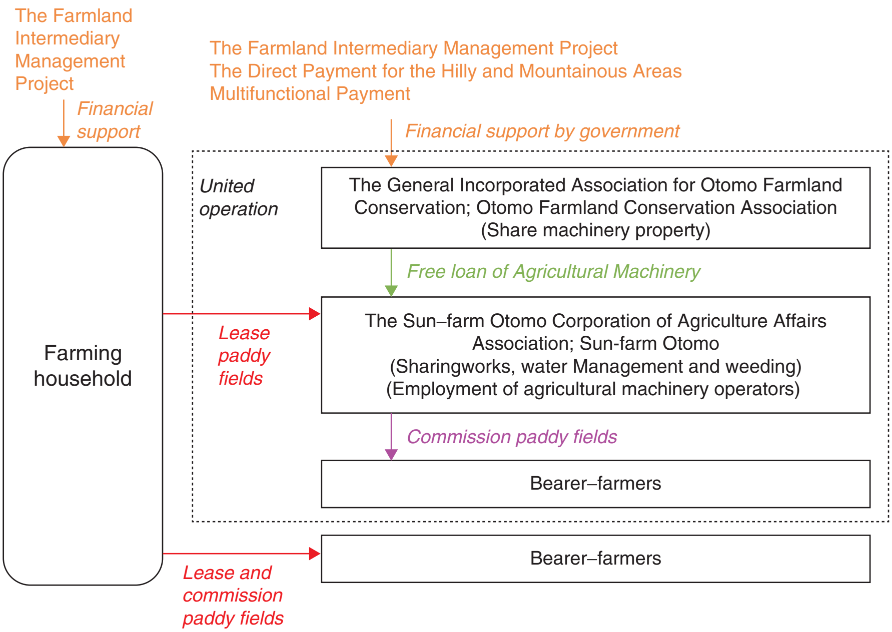

Fig. 20.4 The form of the community-based farm cooperative in Otomo District

Improvement Payment (MAFF 2016a, b). Thus, the previous system that grouped the functions (from farming to land-resource management) in one organization (the Sun-farm Otomo) had changed to another system (Fig. 20.4) that separated responsibilities into two organizations: The Sun-farm Otomo took charge of economic activity including sales and farming, and the Otomo Farmland Conservation Association took charge of land and water-resource management based on the grants or projects. They solved the problem of various organizations accepting different grants for land-resource management for the same managed farmland by sharing board members of both organizations to avoid miscommunication in farming and management of agricultural facilities, such as farm roads and canals. The Otomo Farmland Conservation Association owns agricultural machinery and provides machines to the Sun-farm Otomo free of charge, so that the farming sector in this district can use the grants indirectly.

The farming system with Sun-farm Otomo as core was established with respect for existing bearer-farmers in this district (Fig. 20.4). All bearer-farmers are aiming to resume farming through the machinery-lease program despite suffering tens of millions JPY of financial damage from the tsunami. There are two types of bearer-farmers in relationship to the Sun-farm Otomo: those working as agricultural machinery operators for the Sun-farm Otomo and those farming independently. Thus, the farmlands leased to the Sun-farm Otomo are assumed to be managed by independent bearer-farmers to optimize the use of farming resources in the whole district. In the 2015 fiscal year, paddy fields totaling 90 ha, including about 70 ha in the farmland-consolidation area and about 20 ha undamaged by the tsunami, were leased to the Sun-farm Otomo. These fields are cultivated mainly by eight farmers as agricultural machinery operators.

20.6.2 Establishment of the Farming Organization in Hirota District

The Hirota Peninsula Farming Association was established by 97 of the 120 agricultural households in the district; its eventual goal is the full participation of all agricultural households in the district. The association allocated all the farmlands leased from landowners within four branches, so that each branch took charge of the cultivation of allocated farmlands. Each branch developed a farming plan under a principal leader and had to secure agricultural-machinery operators based on the plan. The leaders assume the responsibility of farming within the branch. All branches are coordinated by the chief director of the farming department of the Association, and any problems that apply to all branches are discussed in branch-leader meetings.

As Hirota district did not have bearer-farmers, farmers continued regional farming by establishing a system that assigned agricultural work based on members' condition and skills, without relying on experts or machinery operators.

Although the Farming Association had been expected to become an incorporated association from the moment of its establishment, members including the board of directors were not motivated to incorporate; also, they needed to work hard in response to the earthquake damage and restoration. As a result, they had put off the issue. As time passed, it became impossible to put off that issue any longer, so they started discussion and proceeded to incorporate under direction of the Iwate prefecture's Ofunato Agricultural Department and Extension Center.

A problem was pointed out during the incorporation process: The new entity would have to pay a large tax bill when the processing facility, owned by the Hirota Peninsula Farming Association as a voluntary organization, was transferred to the incorporated association. As the farming association could not pay that amount of money, they decided to keep the voluntary farming association and incorporate a separate agriculture affairs association as Hirota Peninsula Cooperation of Agricultural Affairs Association to avoid the tax payment (Fig. 20.5).

Under the renewed system, the incorporated agricultural-affairs association leased farmland from farmers and consigned machinery work for a charge to the farming association that owned the agricultural machinery. On the other hand, the farming association could continue their projects by using the funds that they had obtained so far. As the farming association will not build up any new assets, those assets it owns currently will be transferred to the incorporated association after completion of repayment. Once all repayments are complete, the Hirota Peninsula Farming Association will dissolve. Until then, they need to continue the complicated accounting, such as charging work costs to both organizations.

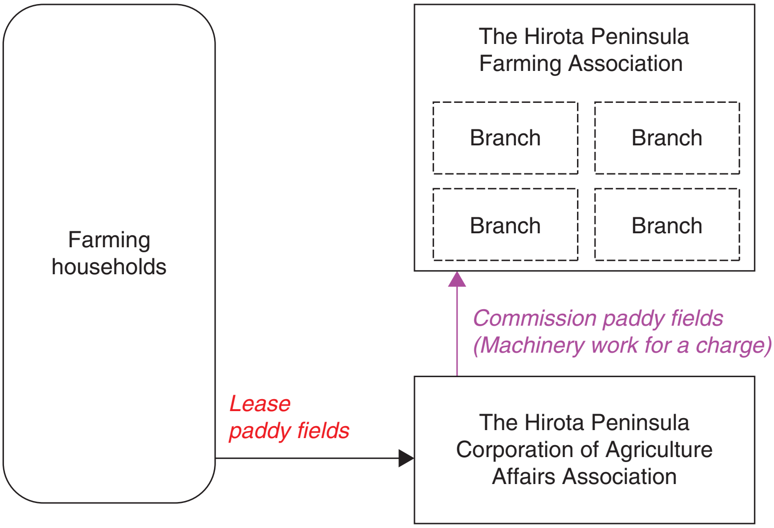

Fig. 20.5 The form of the community-based farm cooperative in Hirota District

20.6.3 The Regional Structure Defining the Farming Organization

Although the main income source in Otomo district is the fishery, there exist farming-management bodies that mainly work on agriculture based on rich farmland resources. Furthermore, because the relationships among the settlements, farmlands, fishing ports and aquaculture sites, or fishing rights and fisheries cooperative association, are not one-on-one, the community management can be carried out for the entire district (Fig. 20.6). Thus, the farming system relies on the bearer-farmers to maintain a stable existence for all. In Hirota district, geography has created a set of isolated fishing villages that extend from farmlands to beaches (Fig. 20.7). As agriculture in Hirota consists of local self-sufficient farming, there is no management body such as bearer-farmers. The result of this is that the system supported labor that could perform work in the farming units consisting of independent fishing villages.

20.7 Conclusion

The restoration of farming in the tsunami-hit area has proceeded and enabled cultivation over a short time due to the efforts of the many projects of these districts. Similarly, farmers seek labor for rice farming from the community-based farm cooperative due to their difficulties in farming by themselves. On the other hand,

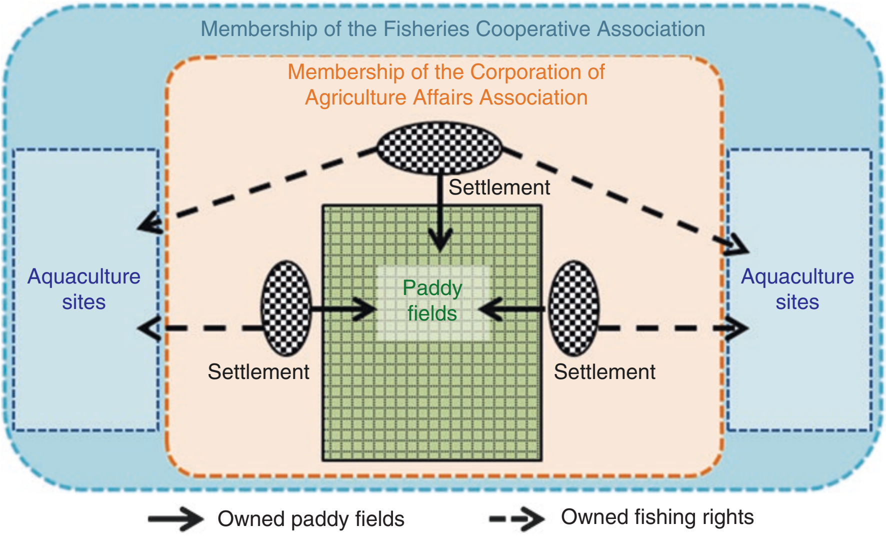

Fig. 20.6 The regional structure defining farming organization in Otomo district

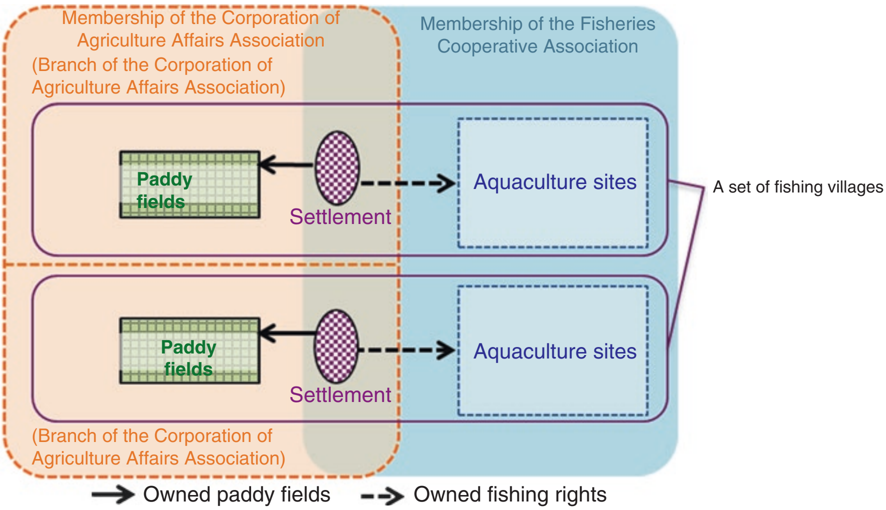

Fig. 20.7 The regional structure defining the farming organization in Hirota district

who provides farming labor practically in the community-based farm cooperative (and how they provide it) differs by the regional structure of each district.

Paddy fields in Otomo district are grouped and plot size is large, so the farmland can be used efficiently for bearer-farmers' businesses. All farmers expect that resumption of farming relies on bearer-farmers. On the other hand, paddy fields in Hirota district are dispersed and small in plot size. Furthermore, settlements are separated from farmlands and fishing villages, and there are no bearer-farmers in the district. Therefore, farmers expect to share roles in the community-based farm cooperative. Thus, Otomo and Hirota districts are making different choices due to the difference in the regional structures.

Acknowledgements We received generous support in the field survey from Mr. Mitsuo Ishikawa from the Otomo Irrigation Association; Mr. Etsuo Sato, the head of that association's secretariat; Mr. Tsuyoshi Usui, head of the Hirota Peninsula Farming Association; and Mr. Kimitoshi Sato from the Ofunato Agricultural Extension Center in Iwate prefecture.

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Chapter 21
Tohoku University Rapeseed Project for Restoring Tsunami-Salt-Damaged Farmland: Was the Wisdom of Agricultural Science Utilized for the Restoration?

Yutaka Nakai, T. Nishio, H. Kitashiba, M. Nanzyo, M. Saito, T. Ito, M. Omura, and Y. Kanayama

Abstract Five years have passed since the triple disaster of the March 2011 earthquake and the ensuing tsunami and radioactive pollution from the Fukushima Daiichi Nuclear Power Station. Along the coastline of Tohoku region, one of Japan's most important agricultural areas, activities to revive farmland that suffered salt damage due to the tsunami are still continuing to this day. This chapter documents the current state of recovery of the farmland and agriculture, the work being carried out by the Tohoku University Rapeseed Project for Restoring Tsunami-Salt-Damaged Farmland that was initiated in the immediate aftermath of the earthquake disaster, and the future vision for the project.

The data published by the university through this project has been accepted socially as being highly reliable and, moreover, there is a general feeling that the project has received a high evaluation thanks to its collaboration with affected persons, local municipalities and private companies. On the other hand, it was also felt that the legal system of the national and local governments, as well as factors such as the relationship between the various types of people who make up rural society, posed serious obstacles to the social implementation of newly developed technology and institutions for cultivation and processing. The importance of education as the mission of the university was also apparent through these activities. Tohoku Agricultural Science Center for Reconstruction was established within the university in 2014 to provide technical advice and continual support for farmers, companies and administrators and to nurture human resources who will be engaged in this work in the future.

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V. Santiago-Fandiño et al. (eds.), *The 2011 Japan Earthquake and Tsunami: Reconstruction and Restoration*, Advances in Natural and Technological Hazards Research 47, DOI 10.1007/978-3-319-58691-5_21

Keywords Great East Japan Earthquake • Reconstruction support • Rapeseed • Salt damage • Biogas

21.1 Introduction

The Great East Japan Earthquake occurred on March 11, 2011. The disaster resulted in 19,418 fatalities, 2592 missing persons, 6220 injuries (Fire and Disaster Management Agency of Japan 2011) and an area of 561 km^2 of land inundated by the tsunami (Geospatial Information Authority of Japan 2011). Compared with the Indian Ocean earthquake and tsunami (December 26, 2004), in which 286,000 people lost their lives (U.S. Geological Survey n.d.), the scale of the earthquake and the land area inundated was small. However, the tsunami also resulted in the occurrence of the accident at Tokyo Electric Power Company's Fukushima Daiichi Nuclear Power Station, in which extensive areas of land were contaminated by radioactive substances. Even now, 5 years after the disaster and accident, areas with high dose rates still remain. Areas where the air dose exceeds an annual 50 mSv have been designated "difficult-to-return zones" (original population 9000 households, 24,000 people (METI 2016) and are, in principle, off limits. The area of the "difficult-to-return zones" covers 337 km^2 (MEXT 2013). At all radioactive levels of Cesium 137, the area contaminated by the Fukushima nuclear accident was 6% (METI 2013) compared with that of the Chernobyl accident (1986), the unprecedented disaster by the nuclear power plant. Therefore, the contaminated area mentioned above was small, but the accident was assessed at the highest level on the INES scale, level 7, and was the second Major Accident to be experienced by humankind.

In this paper we report on the current state of farmland and agriculture as well as the "Tohoku University Rapeseed Project for Restoring Tsunami-Salt-Damaged Farmland" that has been underway since immediately after the earthquake disaster.

Of the farmland in Miyagi Prefecture that was affected by the tsunami, 88% has now been restored, but there are still areas in which restoration work has been conspicuously delayed. There are also fields where production has not recovered due to the properties of soil dressings or composition of the soil following desalinization.

Promotion of agriculture as the so-called sextiary (an integration of agriculture from the primary sector, food processing from the secondary sector, and distribution and sales from the tertiary sector.) sector is now being carried out through government measures and policies such as the development of large-scale agriculture through the consolidation of farmland and the integration of agricultural production, tourism, processing and sales. However, there have been problems with this, including the bankruptcy in quick succession in 2015 of two large-scale plant factories (vegetable cultivation factories) established under government earthquake disaster reconstruction subsidies. The reconstruction of agriculture as the production of living organisms will not succeed simply through the short-term injection of huge funding, but requires human resources who are well-versed in the technology and business management of agriculture and time to allow for the stabilization of the production system. At the same time, there are still a large number of areas which are contaminated by high concentrations of radioactive substances emitted by the Fukushima Daiichi Nuclear Power Station and in which evacuees are still not permitted to return to their homes. While decontamination by removal of the surface layer of farmland soil has been conducted, it is still not possible to set a date for the resumption of farming.

21.2 Overview of the Project

21.2.1 General Summary

On March 23, 2011, 12 days after the occurrence of the Great East Japan Earthquake, the Agri-Reconstruction Project (ARP) was launched with the participation of 53 members of the teaching staff of the Graduate School of Agricultural Science, Tohoku University. The activities of the project cover a wide area, from the establishment of safe, secure and sustainable food supplies to reconstruction of the agricultural, forestry, fisheries and livestock industries, and multifaceted local support for the reconstruction of agricultural and fishing villages. Among these, the restoration of tsunami-salt-damaged farmland, the production of oyster seeds, and the protection and radiation dose survey of livestock exposed to radiation have shown extremely good outcomes. In addition, a large number of down-to-earth activities have been conducted, including seabed surveys carried out with fishermen aimed at the restoration of trawl fishing, surveys of contamination of fish species by radioactive substances in the rivers of Fukushima Prefecture, and the dispatch of lecturers to speak at study meetings on agricultural reconstruction for town councilors.

Consisting of six members of the teaching staff and one office staff member, this project group, as one part of ARP, set up the Rapeseed Project for Restoring Tsunami-Salt-Damaged Farmland. In May 2011, the project was adopted by the Japan Science and Technology Agency's "Urgent Funding Programs: implementation support program in response to the Great East Japan Earthquake." (https://www.ristex.jp/examin/implementation/jisin.html) (Nakai 2011). Donations were also received from private companies and the project was pushed forward with the employment of two or three people through the use of the funds provided.

Immediately following the earthquake disaster, soil analysis of salt-damaged fields was carried out at 344 locations in Miyagi Prefecture by the Graduate School of Agricultural Science in collaboration with Miyagi Prefecture research organizations and others, later, the data became the basis for agricultural restoration activities such as desalinization. Cultivation trials of salt-resistant varieties appropriate for use with salt damage and their screening and breeding were performed using 56 lines of *B. napus* and 36 lines of *B. juncea* preserved at the Tohoku University

Graduate School of Agricultural Science Brassicaceae-related plant seed bank, which has a history of more than 50 years. Salt-resistant varieties are not limited to use on Japan's tsunami-affected farmland, but can be used on farmland affected by salt damage anywhere in the world, and ongoing research has now reached the stage of the realization of new varieties.

In the fall of 2011, rapeseed was sown on tsunami-affected farmland, resulting in yellow flowers blooming in the spring of 2012. The project group was impressed by the voices of the local residents, who said, "We have been given hope by the rapeseed flowers." The practical possibilities for the production and use of rapeseed flowers and rapeseed oil were indicated through the sale of edible rapeseed flowers, the manufacture and sale of preserved flowers, as well as the production of edible oil, biodiesel fuel, candles and other goods produced from rapeseed. At the same time, guidance was given on the cultivation of rapeseed and support for the purchase of related agricultural equipment was provided. Details of the activities have been published in Rapeseed Science -The Restoration of Tsunami-Salt-Damaged Farmland-, Tohoku University Press (Abe et al. 2014; Nakai et al. 2015).

21.2.2 Collaboration with Farmers

The Rapeseed Project, pursued by borrowing farmland from farmers in Sendai City, began with introductions to farmers by the City of Sendai Economic Affairs Bureau. Even the teaching staff at the Graduate School of Agricultural Science, who work relatively closely with actual farming situations compared with the overall research-oriented nature of Tohoku University, would normally have found it hard to ask the business operators of the farmland, the farmers, to alter their production for one crop cycle. Especially with rapeseed (*Kizakinonatane*, or *kizaki* rapeseed), since fall sowing for harvesting in the summer of the following year would require the time for two crops of rice, it would not be easy to gain the assent of the farmers to "convert" to rapeseed. The farmland damage caused by the tsunami, however, can be said to have been such a critical event that the farmers quickly assented to the sudden proposal. In fact, it was possible to borrow the farmland where rapeseed was cultivated in Sendai City at a stage where there was still no schedule for debris and sludge removal and desalinization.

The cultivation of rapeseed in Iwanuma City began with introductions to business partner farmers by Miyaka Co., Ltd. As a result, the yields in the Iwanuma City fields, cultivated by professional farmers, were dramatically higher than on the Sendai City farmland, which was managed by researchers from our project group.

As of 2016, there are no longer any sites where rapeseed is being cultivated on damaged farmland borrowed by the Tohoku University Rapeseed Project. All the Sendai City farmland has been returned to the owners after restoration to its original state. Consecutive plantings of rapeseed were not carried out on the Iwanuma City farmland and only a small-scale trial cultivation was carried out in 2012 in the vicinity of the farmland where the cultivation had been implemented in 2011. The planting of rapeseed was discontinued because the post-earthquake recovery of the farmland had proceeded to a point where the crops that had been grown before the earthquake could once again be planted. The farmers therefore wished to suspend the planting of rapeseed. Elsewhere, at Sendai City Agricultural and Horticultural Center, where cultivation of rapeseed had continued from the first year, the planting of rapeseed was suspended in 2014 due to reassignment of the designated manager.

The rapeseed project, which had begun with the concept of supporting disaster-stricken farmers, succeeded in bringing material and financial assistance to the affected farmers from the outside due to exposure of their plight in various types of media. However, it is also true that there was a perceptual mismatch between what the researchers in the group and the farmers' thought of as the "content" of support. The kind of "support" desired in the situation where the farmland, the agricultural machinery, and even the farmhouses had been destroyed, was not an activity which may have appeared to the farmers to be mere encouragement for recovery, but material and financial aid that would make it possible to restore the farming business itself. The research outcomes and concepts of the researchers' support, on the other hand, were seen as something that could be taken advantage of once the business operation had been revived. The degree to which this could have been agreed upon at the outset is an important point that might have helped to avoid later problems.

Regarding collaboration with farmers in areas contaminated by radioactive substances, it was found that there was the possibility of problems arising for those companies who aided the university as sponsors. Specifically, there were cases where there was concern that support activities in the contaminated areas would harm the brand image of the supporting companies. This is nothing less than fears of business losses to companies deriving from "harmful rumors" (consumer concern over the possibility of agricultural products grown in contaminated areas being tainted with radioactivity), but gave rise to a tendency for support for Miyagi and Iwate Prefectures to be thought of as good, while support for activities in Fukushima was to be avoided. There are some areas where, 5 years after the earthquake disaster, the return of residents to has finally begun. In these areas, reconstruction is about to get underway, but with the war-weary local administrations due to the 5-year struggle thus far, farmers and local residents used to relying on assistance, and private companies treading water on providing support, the "reconstruction" situation appears to be fraught with difficulties. The areas contaminated with radioactive substances also face a situation which once again demands the power of the effective utilization of rapeseed.

21.3 Soil Survey of Tsunami-Affected Farmland

21.3.1 Survey and Soil Analysis of the Tsunami-Affected Farmland

A huge tsunami pushed its way inland along the Pacific Ocean coastline of Japan's Tohoku region. The farmland was inundated with seawater and debris deposited by the tsunami remained after the tsunami had receded. Problems at the time included whether or not hazardous substances were present in the deposited debris and what the impact of the seawater would be. To answer these questions, in Miyagi Prefecture, where the area damaged by the tsunami was especially large, soil surveys and analyses, including of the deposited debris, were carried out at 344 locations in mid-May 2011 (Santiago-Fandiño and Kim 2014).

The items analyzed included dilute acid soluble Cd, Cu and As (designated hazardous substances under the Soil Contamination Countermeasures Act), soil pH (pH(H_2O), pH(H_2O_2)), total carbon, total nitrogen, total sulfur, soluble ions, exchangeable cations and available phosphorus. pH(H_2O) is the pH of the soil suspended in water. pH(H_2O_2) was measured in order to estimate the pH after oxidation of sulfides in the case that these were included in the soil.

As a result of the analysis, it was found that there was almost no problem concerning the three elements designated as hazardous substances and that there were locations where there was a possibility of soil acidification after oxidization of sulfides. The effect of seawater was recognized at soil depths of 20 cm or more at the time of the survey. Of the exchangeable cations, there were quite a number of locations where the ratio of sodium averaged 18% (max. 44%), reaching levels of sodium excess (15% or more), but the degree of excess could not be said to be very serious (Nanzyo 2015). The debris contained small amounts of gypsum (calcium sulfate, $CaSO_4 \cdot 2H_2O$) and the muddy sediment among the debris was thought to have originated mainly from the topsoil of the farmland (Nanzyo 2012, 2015; Chagué-Goff et al. 2013). These results were helpful in the later restoration of the farmland.

21.3.2 Monitoring of the Tsunami-Affected Farmland Soil After Desalinization and Its Contribution to Soil Recovery

The actual state of the farmland damaged by the tsunami in the Great East Japan Earthquake disaster was surveyed urgently in 2011. The soil of the affected farmland was continuously monitored thereafter by the Graduate School of Agricultural Science, Tohoku University and Miyagi Prefectural Furukawa Agricultural Experimental Station and Miyagi Prefectural Institute of Agriculture and

Horticulture and it was found that in fields with a high drainage performance, where a land consolidation project had been implemented, the cutting of mole drains was effective in the removal of water soluble salt by eluviation. Water soluble salt content in the topsoil was reduced to within acceptable limits by around 1000 mm of natural rainfall (Ito et al. 2015).

In most of the tsunami-affected farmland, desalinization work using irrigation water was carried out, bringing about sufficient removal of the water soluble salt content of the soil. Nevertheless, follow-up surveys of the soil where the land consolidation projects had been completed showed that there were some fields which had a poor nutrient balance (Ito 2015b). Since a part of the Ca adsorbed in the soil had been displaced by Na derived from seawater and washed out by the desalinization process, and while Na had remained in the exchange sites of soils, exchangeable Ca had been reduced. In soil with high concentrations of Na, crops sometimes show poor growth due to the excess adsorption of Na (Na ion stress). To lower the risk of Na disorders and restore soil fertility, it is necessary to optimize the soil salt balance in the fields where desalinization has been implemented. To solve this problem, it has been proposed that the application of Ca materials such as steel-making slag fertilizers is effective, since they contain both Ca and silica, effective for alleviating Na disorders (Ito 2015a).

On farmland close to the coastline, fertile topsoil had been removed by the tsunami itself and bulldozers were used to remove tsunami debris and deposits in some fields where those had accumulated. Soil with low fertility has been brought in and dressed on these farmlands. Restoring the soil productivity of these fields where fertility has been reduced to an extreme degree is a problem that has not yet been solved and remains as one of the most pressing tasks for the future.

21.4 The Production of Salt-Resistant Brassicaceae Crops

21.4.1 Development of Strongly Salt-Tolerant **B. napus** *Lines*

Additional *B. napus* (i.e. rapeseed) lines were provided from the Oil Crops Research Institute in Wuhan, China, and together with the 56 lines of *B. napus* genetic resources held by the Graduate School of Agricultural Science of Tohoku University, trials for salt tolerance were conducted on a total of 85 *B. napus* lines. Salt tolerance (ST) was expressed as "the ratio of the dry weight under a 100 mM condition to the dry weight under a 0 mM control condition". The large variation in the salt tolerance was observed to range continuously from 0.3 to over 0.9. We had previously evaluated *B. napas* lines.

'N343', 'N119' and 'Westar' as having strong salt tolerance (Nakai et al. 2015), and ST values for 'N343', 'N119' and 'Westar' of 0.9 or more were again indicated in this study, showing high replicability (Yong et al. 2015). After salt-treatment cultivation, sodium accumulated in leaves in the 85 lines was measured using atomic absorption spectrophotometry, resulting in a continuous distribution of values for the lines ranging from 30 to 80 mg for each 1 g dry weight (Yong et al. 2015). Since a continuous distribution for each of the characteristic traits had been indicated, it was thought that each of the traits was controlled by a number of genes. Genome Wide Association Study (GWAS) showed that a number of candidate gene loci that appeared to be involved with the traits were detected (Yong et al. 2015).

Lines with high salt tolerance and abundant growth are expected to show high growth potential right through to harvesting. The dry weights of aerial parts for *B. napus* lines treated with 100 mM NaCl were distributed over a continuous range from 0.14 to 0.95 g. Of the dry weights of 0.75 g or more, the only line that fulfilled the high level conditions of an accumulation of 50 mg of sodium, calculated over the whole plant from the dry weight, and an ST value of 0.9 or more was "N119' (Fig. 21.1). This suggested that 'N119' was not only a superior line that showed prospects of economic viability in salt-damaged farmland but also had a high potential for desalinization, and was therefore considered sufficiently hopeful as a line to be used in phytoremediation.

Transcripts of genes in the roots and leaves treated by salt stress were comprehensively investigated by transcriptome sequencing, RNA-seq. As a result, 14,719 transcripts were differentially expressed. Of these, 23 genes belonging to the LEA (late embryo abundant) protein group, a kind of compatible solute, were found to rise by between twice and 2^{15} times in the roots and leaves 1 h after salt treatment when compared with no treatment, indicating a similar result to a previous report (Nakai et al. 2015). In addition, 582 transcription factor genes and 438 transporter genes were found to vary due to salt treatment (Yong et al. 2014). It is thought that these genes collaborate in maintaining the high salt tolerance of 'N119'.

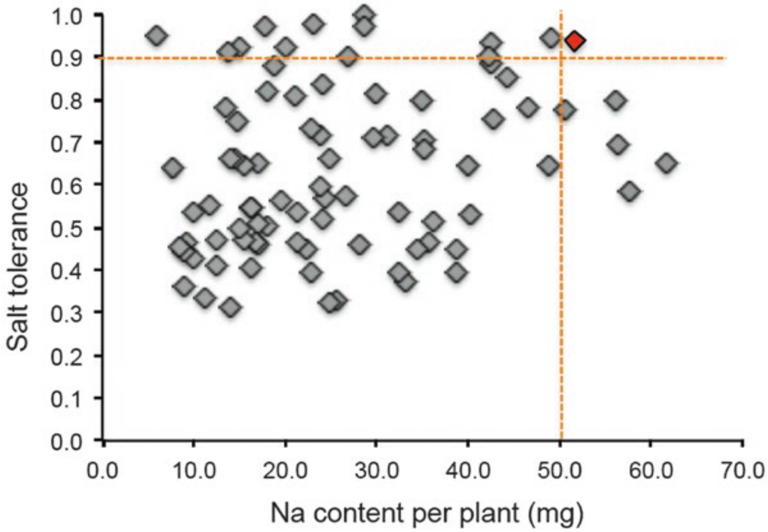

Fig. 21.1 Relationships between salt tolerance and Na content. *Red mark* remarks 'N119' line

The *B. napus* 'N119' line and the 'Westar' line were crossed to obtain the F1 generation in 2012. In 2013 and 2014, 2000 seeds of the F2 generation were obtained. At present, while making comparisons with the parent lines, trials at the laboratory level are now being implemented using NaCl concentrations of 250–500 mM to select lines whose salt tolerance has increased.

21.5 Cultivation Trials in Fields

21.5.1 Efforts Toward the Improvement of Salt-Tolerant Indian Mustard

For Indian mustard (*karashina*, *Brassica juncea*), 'J105', the line with the greatest salt tolerance of the 34 lines of genetic resources, was previously selected (Nakai et al. 2015). Of the fatty acids contained in the seeds of 'J105', a high proportion, 46.4%, is erucic acid, which is harmful to the human body. The metabolic path and enzymes by which erucic acid is synthesized are known; erucic acid is synthesized by the FAE1 (Fatty Acid Elongase 1) enzyme, which has the ability to elongate the carbon chains of fatty acids. To put 'J105' to practical use as an edible agricultural crop it is necessary to knockout only the *FAE1* gene without altering the salt tolerance and other traits. Thus 10,000 'J105' seeds were treated with the mutation-inducing agent EMS (ethylmethane sulfonate), the seeds being cultivated at Kawatabi Field Center in spring 2014 and the resulting plants sampled in August. Many individual plants did not flower during growth, but seeds were obtained from around 2000 plants. Following this, it is necessary to select from the mutated group plants that showed a mutation of the *FAE1* gene by a reverse genetics method. An analytical method that is more efficient than conventional methods is now being developed, and it is anticipated that it will be possible to obtain the desired mutated plant in the near future.

21.5.2 Rapeseed Cultivation in Former Paddy Fields in Which Desalinization Was Performed by Rainwater

The mid and southern sections of the Miyagi Prefecture coastline are low-lying areas, and it is necessary to employ drainage pumps in order to carry out irrigation in these areas. However, the drainage pump stations were destroyed by the huge tsunami of March 2011, and it was necessary to wait for the drainage pumps to be repaired in order to carry out desalinization using irrigation water. At the same time, it was known that desalinization by rainwater was effective in the restoration of farmland in past instances of damage due to high tides, and that good drainage was necessary to achieve this (Kaneko 2003). Thus at Iwanuma City, in the south of

Miyagi Prefecture, paddy fields on which salt was still deposited on the farmland surface were surveyed in November 2011, prior to the initiation of full-scale desalinization, and desalinization by rainwater attempted. The electrical conductivity (EC (1:5)) of the topsoil was 1.3–3.8 dS m^{-1}. In April 2012, open ditches were dug around the edges of the fields using a tractor, and the topsoil plowed and left exposed to rain. In late August of the same year, the EC (1:5) of the topsoil had fallen to or below 0.5 ds m^{-1}. In the fall of the same year, rapeseed was sown, which germinated appropriately and was harvested in early summer of the following year. In this area (humid climate, annual precipitation approximately 1200 mm, abundant rain in summer) desalinization by rainwater proved to be effective and the growth of rapeseed was also found to be satisfactory thereafter (Nanzyo et al. 2013).

21.6 Possibility of Crossbreeding with Other Crops in the Open Field

A large number of landraces, such as *tsukena* (*Brassica rapa* L.), turnip (*kabu* (*Brassica rapa*)) and *daikon* (*Raphanus sativus*), exist throughout Japan. Possibly due in part to the influence of the Tohoku University Rapeseed Project, rapeseed has also come to be cultivated in many parts of Japan and there is some concern about the possibility that rapeseed (*Brassica napus*) pollen is disseminated and crossbred with landraces such as turnip.

Since in recent years many genetically modified varieties of rapeseed have appeared in some countries, studies have been conducted to evaluate the possibility that genes introduced in the genetically modified plants have spread to plants growing nearby. Two studies report on an investigation of the ratio of hybrids in seed samples from *B. rapa* when cultivated in mixed planting with rapeseed. The results of the two studies differed greatly, one giving around 1% (Bing et al. 1996), and the other around 7% (Warwick et al. 2003). In the crossbreeding of turnip and *daikon*, the authors have found that the hybridization rate greatly differs depending on the turnip variety used as the parent plant, and have identified the gene loci involved in the differences between the varieties (Tonosaki et al. 2013). Moreover, it has been discovered that there is a roughly tenfold difference in the hybridization rate of turnip and rapeseed depending on the genotype of the turnip (unpublished). Thus it is thought that the differences apparent in previous research results are due in large part to the differences in the genotype of the *B. rapa* used. Since the obtained hybrids are sterile, the possibility of the spread of hybrids is extremely low.

21.7 Transfer of Radiocesium Contaminants in Soil to Crops

21.7.1 Transfer Radiocesium Contaminants in Soil to Rapeseed

To study the relationship between the contamination of the soil with radiocesium and its transfer to crops, rapeseed (*Brassica napus*) was cultivated extensively in three fields with differing states of contamination from approximately 18 months after the accident at Fukushima Daiichi Nuclear Power Station. Results of the analysis indicated that there was a high correlation between exchangeable and fixed radiocesium in the topsoil layer and in the 5 cm layer below the topsoil, that no water soluble cesium was detected, and that none of these types of radiocesium was detected in lower layers. Subsequently, the correlation between radiocesium in the various layers of the soil, stems and leaves, roots, and flowers was investigated. Results showed that there was a high correlation between the topsoil layer and stems, leaves and roots, but that the correlation with the 5 cm layer below the topsoil was low. Further, the correlation between flowers and the topsoil layer was relatively low, and it was suggested that radiocesium in the soil had a more direct impact on the level of radiocesium in the stems, leaves and roots. Moreover, radiocesium was not detected when oil was extracted from the contaminated seeds. From the above, while accumulating scientific knowledge on the dynamic behavior of radiocesium in contaminated soil and crops, it was also possible to obtain useful information on the use of areas with low-level contamination.

21.7.2 Contamination of Other Crops and So on with Radioactive Substances

During this project, a survey of wild vegetables was also conducted in order to judge the radioactive contamination of edible plants other than rapeseed.

It is the general custom for wild vegetables, fungi and other foods to be gathered for use as seasonal vegetables from forests in the mountainous areas of the Tohoku region. The forests from which the wild vegetables are gathered have also been contaminated with radiocesium. Agronomic methods to suppress the absorption of radiocesium, such as promotion of the fixing of radiocesium to clay by plowing and suppressing the absorption of radiocesium by increasing inputs of potassium fertilizer (Yamaguchi et al. 2016), cannot be applied to the case of wild vegetables gathered in the forests. Because of this, it has become crucial to gain an overall picture of the actual state of contamination through detailed monitoring. Thus the Kawatabi Field Center of Tohoku University has collaborated with the Farmers' Market at the roadside rest area "Ikezuki Michi-no-Eki" to conduct the monitoring of radiocesium in wild vegetables gathered from the forests by farmers. In 2012, around 20% of the analyzed samples exceeded the safety standard (100 Bq/kg), but in 2015 this had fallen to a few percent.

21.8 Biogasification of Organic Material Added to a Local Community Resource Recycling System

Biodiesel fuel (BDF) was produced from the rapeseed oil harvested by the project. The BDF was put to use in construction machinery and the university's experimental farm tractor as "B5" by adding 5% BDF to diesel fuel. Glycerin produced as a byproduct of the manufacturing process of the BDF is normally incinerated. The authors, however, have developed a technology for utilizing the glycerin in a methane fermentation system, thereby performing such activities as recharging an electric vehicle battery by gas power generation.

Confirmation of the fertilizing effect of the digestion fluid remaining after fermentation was performed. At the same time, using cattle rumen (the first stomach) disposed of by abattoirs, a patented technology for decomposing plant cellulose and lignin was developed (Baba et al. 2013). This made use of the function of the microorganisms that live inside the rumen. It was found that the efficiency of methane fermentation was raised by pretreating the rapeseed stems and strained lees with rumen fluid. At present, demonstration experiments have started at a 50 m^3 facility constructed in Osaki City, in the inland part of the affected areas. These experiments have led to the successful demonstration of a system for recycling organic material within the local community while carrying out energy production through BDF and methane fermentation according to the flow: rapeseed oil → BDF → glycerin → methane fermentation → return of the digestion fluid to rapeseed fields, etc. → rapeseed cultivation. The authors have implemented cultivation trials of rapeseed in contaminated areas and have shown that radiocesium does not transfer to rapeseed oil. The use of this recycling system is therefore possible on farmland contaminated by radioactive substances. This represents one option for agricultural reconstruction in the contaminated areas of Fukushima and other regions.

21.9 Issues in and the Future of the Rapeseed Project

The implementation of this project has resulted in the following considerations and conclusions for the role of universities in disaster situations.

1. Scientific data published by universities is given high credibility by society in general.
2. The fair and neutral stance of universities is easily accepted by affected areas and makes it possible for universities to perform a key role in linking affected persons, local municipalities, private companies, and so on.
3. The introduction of newly developed technology for cultivation and processing into local production sites is mainly carried out on the judgment of farmers and entrepreneurs.

4. Important decisive factors in the conversion of land to rapeseed cultivation are the relationships between the people in the rural village, agricultural administration, the subsidy system, and so on, but the university and research centers play no part in this decision making.
5. As price is a problem in the acceptance of BDF by society as a whole, government support measures, such as exemption from diesel oil transaction taxes, are necessary, and it is crucial that universities publicize the existence of this issue.
6. The main actors involved in bringing newly developed technologies and systems into actual use by society are the farmers, companies and the administration, and the scope for involvement by universities is limited. Universities, however, still have a role to play in providing advice and additional R&D for the improvement and enhancement of such technologies and systems.

Through the activities that have been conducted thus far, while the development of new technologies has been important in the reconstruction of agriculture, it is strongly felt that human resources are crucial. With the aim of nurturing diverse human resources capable of working for the restoration, in the spring of 2014 the authors established Tohoku Agricultural Science Center for Reconstruction within Tohoku University. The Center is educating both students and members of the general public to become Reconstruction Agriculture Meisters and IT Agriculture Meisters. A total of 238 people have taken the courses in the last 3 years. Tohoku University teaching staff, the meisters and the organizations and companies that the meisters belong to are working in collaboration, and are creating a platform for agricultural reconstruction. With these human resources as the core, we hope to link together rural and urban goods and information, rejuvenate rural villages and agriculture, and have these contribute to the reconstruction of agriculture in the affected areas (Fig. 21.2).

Fig. 21.2 Tohoku Agricultural Science Center for Reconstruction, Graduate School of Agricultural Science, Tohoku University, Meisters' Course on Agricultural Recovery (CAR) and Meisters' Course on Agricultural IT (CAIT). Group photo taken at the affected area extension workshop at the Community Welfare Center of Katsurao Village, Futaba County, Fukushima Prefecture

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Part VI
Coastal Engineering, Structures and Hazards

Chapter 22
The Yamamoto Coast Over Five Years; The Reconstruction of an Embankment with Tsunami-Induced Embayment

Vo Cong Hoang, Hitoshi Tanaka, Yuta Mitobe, Keiko Udo, and Akira Mano

Abstract The incident waves and return flow of the 2011 tsunami caused severe damages to the coastal morphology and the embankment along Yamamoto Coast, Miyagi, Japan. This study investigates the damages and recovery of coastal morphology and the reconstruction of the coastal embankment along the coast, based on satellite images. During the recovery process, full recovery of breaching was observed at the areas with sufficient sediment supply from adjacent sandy coasts. However, in the areas without adjacent sandy coasts, the formation of tsunami embayment was found. The relationship between the measured area of adjacent sandy coasts, A_S, and the measured area of breaching of the sandy coast, A_B, indicates that the formation of tsunami embayment takes place in case A_B greater than in A_S and vice versa. There are two types of cross sections of reconstructed embankment. Due to the formation of a tsunami embayment in several areas, a setback of approximately 30 m of the reconstructed embankment has been made. At the areas without the formation of tsunami embayment, the reconstructed embankment is elevated above the level of the embankment before the tsunami.

Keywords Yamamoto coast • Tsunami embayment • 2011 tsunami • Breaching • Recovery • Embankment

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V. Santiago-Fandiño et al. (eds.), *The 2011 Japan Earthquake and Tsunami: Reconstruction and Restoration*, Advances in Natural and Technological Hazards Research 47, DOI 10.1007/978-3-319-58691-5_22

22.1 Introduction

The 8.9 magnitude earthquake, which happened on March 11, 2011, triggered the huge tsunami waves that inundated the northern coast of Japan. The tsunami, the maximum height of which was reported to be 40 m above sea-level in Iwate Prefecture, Japan (Mori et al. 2012), caused significant damages to the coastal morphology and embankment along the affected area. Tanaka et al. (2012) reported the severe damages and subsequent recovery of the coastal morphology along Miyagi Prefecture. According to that study, one of the most common damages of morphology induced by the tsunami was breaching of the sandy coast. Breaches were formed at the places where the river mouth formerly occupied. Subsequently, Tanaka et al. (2014) investigated the mechanism of breaching of the sandy coast induced by the tsunami waves and the return flow. Later on, Hoang et al. (2015, 2016a) proposed the theoretical recovery of morphology at breaches based on the analytical solutions of one-line model.

The tsunami-induced destruction of the embankment along the Yamatomo Coast, which is located in the south of Miyagi Prefecture, was observed. Iida et al. (2014) investigated the damages of the embankment along Sendai Bay area including the one on the just mentioned coast. In addition, Udo et al. (2015) revealed the changes they found of morphology along this coast. According to that, breaching of the sandy coast and embankment was widely observed. There were two distinctly different aspects of the morphological recovery: (1) The morphology on the northern part of the coast, which has sufficient sediment supply, has recovered rather quickly, and (2) on the contrary, the one on the southern part has had no or very slow recovery due to lack of sediment supply from adjacent sandy coasts. In the latter area, the formation of the so-called tsunami embayment, which is the unfilled part of breaching during the recovery process, has been observed. The depth in the embayment remains large, and, therefore it would be difficult to carry out the reconstruction of the embankment at the same location before the tsunami, and, for this reason, a certain amount of setback needs to be implemented for the reconstructed embayment. Moreover, because the water depth in front structure at the tsunami embayment is large, the incident wave would be strong. Thus, this area becomes the weak point of the continuous embankment.

The significant changes and recovery process of coastal morphology after a huge tsunami have been also the topics worldwide for researchers, such as Ali and Narayana (2015), Choowong et al. (2009), and Liew et al. (2010). They reported the significant changes such as erosion, deposition or disappearance of sandy coasts, river mouths, and sandspits and the recovery process both over the short-term and long-term in affected areas in Andaman and Nicobar Islands of India, Indonesia and Thailand. Most of studies utilized the annual satellite images with intermediate spatial resolution and field-survey data. Results indicate that fast recovery of the coastline and beaches can be observed, whereas sand barriers, river mouths and coastal lagoons were slower to recover. Nevertheless, there was no report on the formation of tsunami embayments from these studies. Thus, the investigation of the mechanism of tsunami embayment formation, which is a unique tsunami-induced phenomenon on Yamamoto Coast, is highly required.

Altogether, this study attempts to present the mechanism of tsunami embayment formation along the Yamamoto Coast after the 2011 tsunami and the reconstruction of the embankment on this coast, based on satellite images.

22.2 Study Area and Data Collection

This study mainly focuses on the coastal area of about 7 km in length on the Yamamoto Coast, which is located on the south of Miyagi Prefecture, Japan (Fig. 20.1), bordering the Fukushima Prefecture. The northern border of the study area is Ushibashi jetty, which is located about 7 km south of Abukuma River, whereas the southern border is Isohama fishing Port, which is located about 5 km north of Soma Port.

Along the Yamamoto Coast, significant erosion occurred from 1970s in response to the erosion protection of the cliff coast in Fukushima Prefecture, which was considered as a main sediment source to maintain the shoreline of the Yamamoto Coast. In order to prevent the erosion on this coast, starting from 1990s until before the tsunami, many headlands have been installed. The name and location of these headlands are shown in Fig. 22.1.

The satellite images that have been utilized in this study are downloaded from Google Earth. Besides, several aerial photographs of study areas were also collected from the Geographical Survey Institute (hereafter referred to as GSI). All images are re-rectified to the World Geodetic System (WGS-84) using a set of control points. More details on the technique of image analysis can be found in Hoang et al. (2016b).

22.3 Morphological Changes Along the Yamamoto Coast Induced by the 2011 Tsunami

22.3.1 Assessment of Tsunami Embayment Formation Using Satellite Images

In this section, the full recovery of morphology, the formation of tsunami embayment and the mixing of full recovery of morphology and the formation of tsunami embayment on Yamamoto Coast are investigated using satellite images. Figure 22.2a presents the morphology of a 15 km length of Yamamoto Coast, from jetties at Torinoumi Lake to Isohama fishing Port, before the tsunami (December 10, 2009). The erosion in this coast became significant in the 1970s, due to reduction of longshore-sediment supply from the cliff coasts in Fukushima Prefecture, after the start of counter measures to prevent coastal erosion were implemented (Udo et al. 2015). In order to protect the coast in Yamamoto, several headlands were constructed there, starting from the south, since the 1970s. Figure 22.2b illustrates the

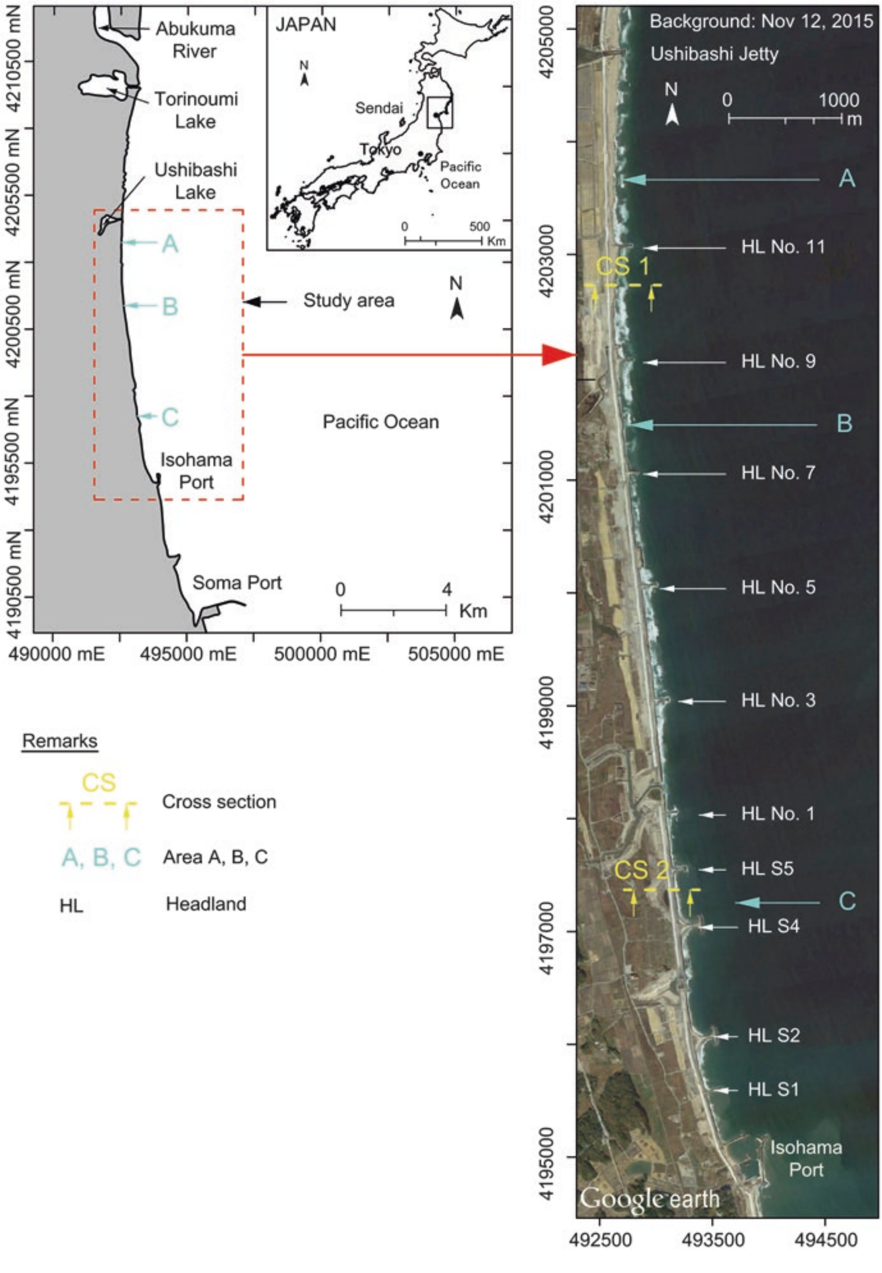


Fig. 22.1 Location map of study area

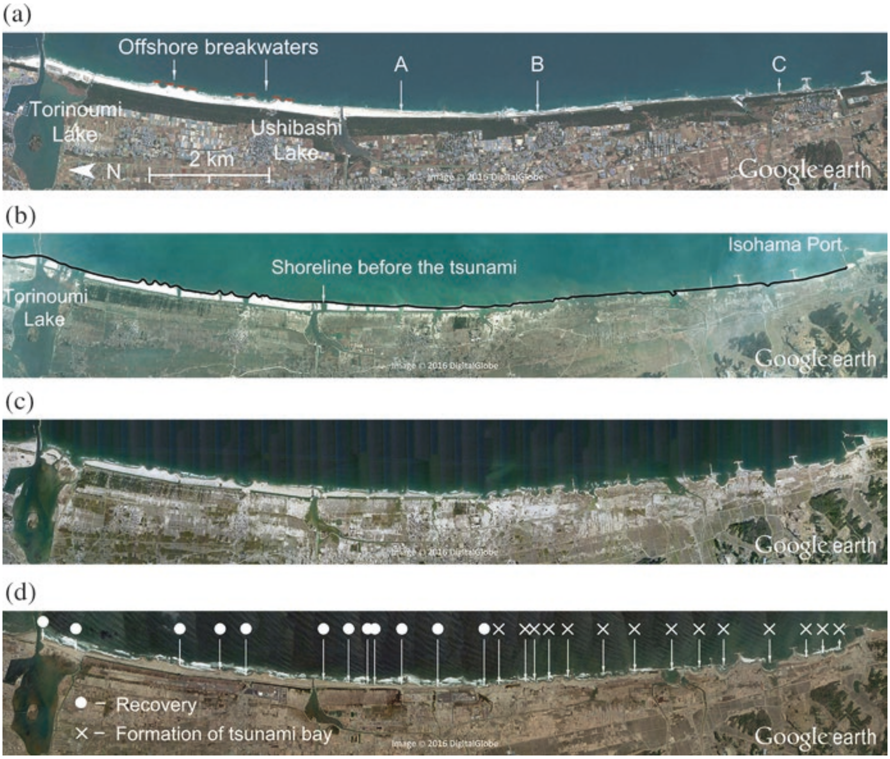


Fig. 22.2 Satellite images of the Yamamoto Coast before and after the 2011 tsunami. (**a**) December 10, 2009. (**b**) March 14, 2011. (**c**) April 6, 2011. (**d**) April 12, 2012 (○: non-formation of tsunami embayment, ×: formation of tsunami embayment)

morphology of the Yamamoto Coast 1 day soon after the tsunami (March 14, 2011). Breaching of the sandy coast and the coastal embankment can be observed at several places along the coast. In addition, on the northern part of the coast, a shore-parallel trench was created due to the erosion behind the coastal embankment. The formation of this trench was investigated by Sakai et al. (2012). According to that image, the tsunami run-up with a height of 19.2 m above MSL, which is about three times higher than the crown height of the embankment, was indicated as the main reason. Figure 22.2c shows the recovery of morphology about 1 month after the tsunami (April 6, 2011). The significant recovery of breaching on the left part of the sandy coast can be observed, however breaching on the right part of sandy coast was still remained. Due to the shape of the unrecovered breaching, this is called a tsunami embayment. Figure 22.2d demonstrates the recovery of morphology of the coast about 1 year after the tsunami occurrence (April 12, 2012), the places where tsunami embayment was not formed are indicated by the "○" sign, while the places where the tsunami embayment was formed are denoted by the "×" sign. By applying this definition, the coast is divided obviously into two parts: The formation of tsunami embayments can be seen on the right-hand part of the coast, whereas breaching on the left-hand part of the coast remained connected. On the left-hand part of the coast, the indented shoreline has disappeared except at the locations of offshore breakwaters, and, finally, the smooth, continuous sandy coast has reformed.

For more details, hereafter the morphological changes and recovery in Areas A, B and C (see Figs. 22.1 and 22.2a) will be investigated. Firstly, concerning Area A, Fig. 22.3 shows the details of morphological changes and recovery in this area. The morphology of this area before the tsunami is shown in Fig. 22.3a, whereas the condition right after the tsunami is shown in Fig. 22.3b. According to the latter figure, the trench behind the embankment was created, and the breaching connected this trench to the ocean. However, the sandy coast (excluding breaching points) was not damaged significantly by the tsunami (Fig. 22.3b). Subsequently, the morphology of Area A has recovered quickly (Fig. 22.3c). After all, it has almost returned to the morphology before the tsunami (Fig. 22.3d, e), and the formation of tsunami embayment was not observed in this area.

Secondly, the morphological changes and recovery in Area B are shown in Fig. 22.4. The morphology of this area before the tsunami is presented in Fig. 22.4a. The right-hand part of this area has a narrower width of sandy beach compared to the left-hand part, and, generally, this area has a narrower width of sandy coast compared to Area A. The morphology right after the tsunami is presented in Fig. 22.4b. Accordingly, this area has similar damages to Area A. There were two breechings, which were separated by a short concrete-blocks beach. The recovery process of morphology in this area is shown in Figs. 22.4c–e. The straight shoreline at the left breaching and the formation of tsunami embayment at the right breaching can be observed.

There was a sandy beach along most of left-hand side of the left breaching, whereas there was not (or very short and narrow) a sandy beach on the right part. This indicates that longshore sediment from adjacent sandy beaches could be playing an important role in the recovery of breaching. Thirdly, in Area C, the changes and recovery of morphology are illustrated in Fig. 22.5. The serious erosion of the sandy beach and the forming of breaching were observed (Fig. 22.5b). However, it exhibited distinctly different behavior of its recovery compared with these other two areas; the morphology in this area has shown no recovery. The formation of tsunami embayments at the locations of breaching was observed clearly.

22.3.2 Mechanism of Formation of Tsunami Embayments

Following the discussion in the previous section, the measured area of breaching, A_B, the measured area of the adjacent sandy coasts that are bounded by headlands at the both ends, A_S, and two cases of morphology recovery, with and without formation of tsunami embayment, are schematically defined and shown in Fig. 22.6a, b. It is noted that the headlands at both ends are considered as the rigid boundaries that interrupt completely the longshore sediment extending beyond the bounded region. Values of both of the area parameters are extracted from rectified aerial photograph

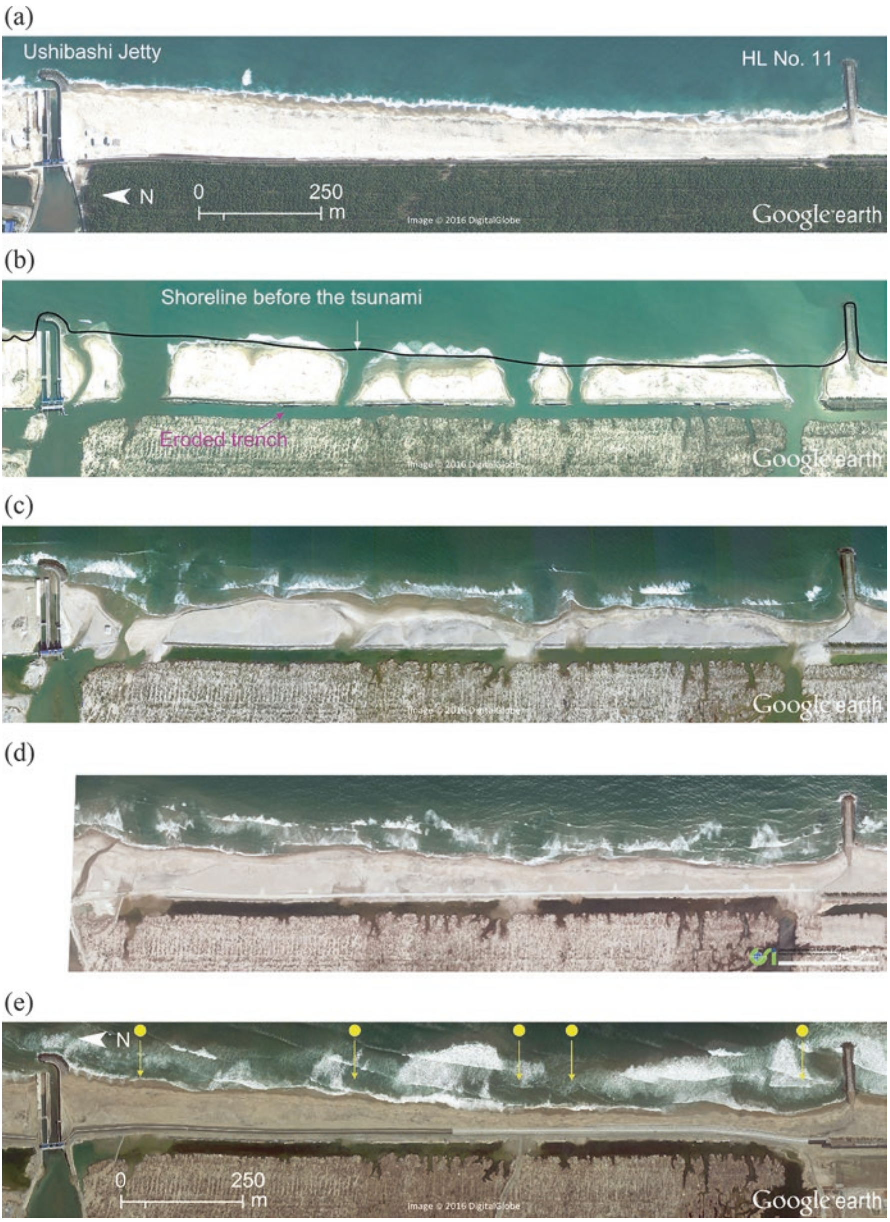


Fig. 22.3 Satellite images of Area A on the Yamamoto Coast (non-formation of tsunami embayment). (**a**) December 10, 2009. (**b**) March 14, 2011. (**c**) April 6, 2011. (**d**) May 24, 2011 (GSI). (**e**) April 12, 2012 (○: non-formation of tsunami embayment)

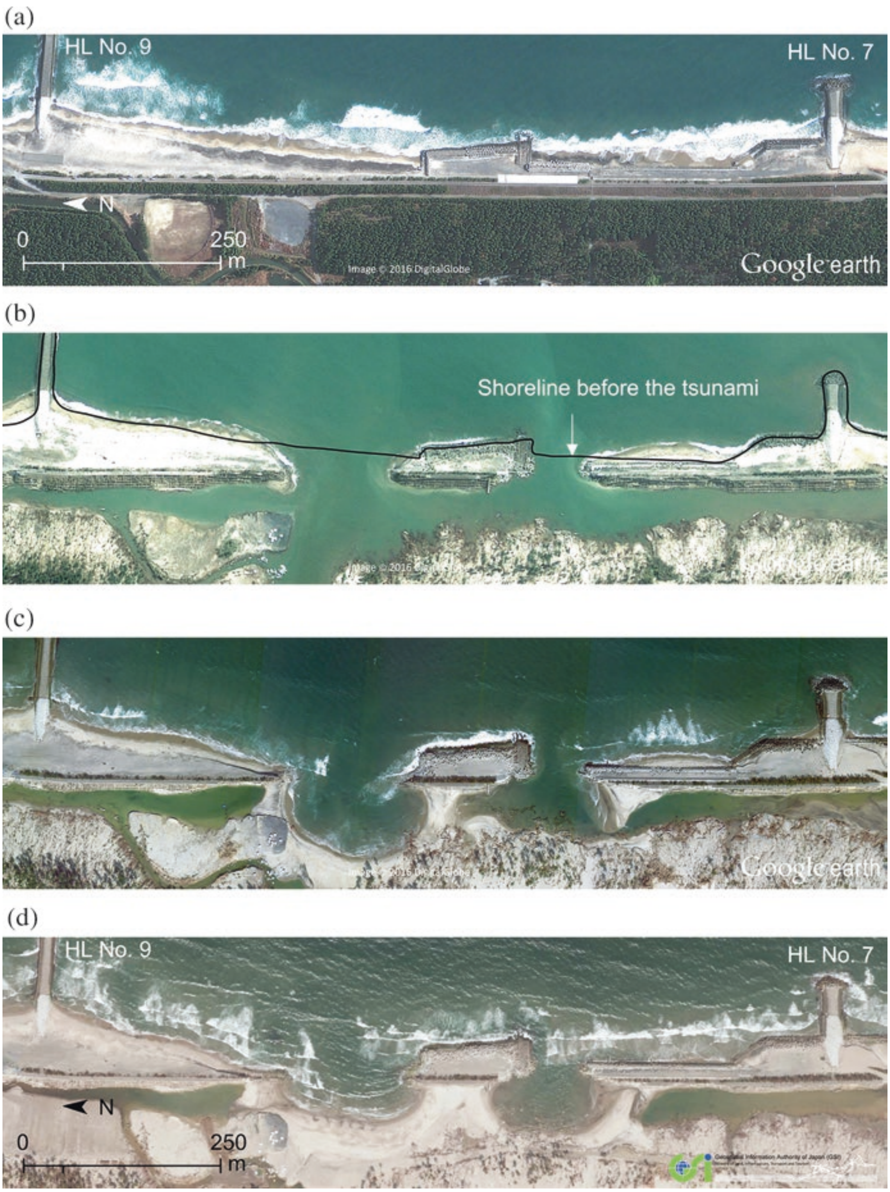


Fig. 22.4 Satellite images of Area B on the Yamamoto Coast (mixing non-formation and formation of tsunami embayment). (**a**) December 10, 2009. (**b**) March 14, 2011. (**c**) April 6, 2011. (**d**) May 24, 2011 (GSI). (**e**) April 12, 2012 (○: non-formation of tsunami embayment,×: formation of tsunami embayment)

(e)

Fig. 22.4 (continued)

taken right after the tsunami (March 14, 2011). A_S represents the source of sediment that supplies and leads to the recovery of breaching. The process, by which sediment from adjacent sandy coasts is transported into the breaching and leading to the advance of the shoreline position, is considered a backfilling process. Details about this process have been presented in Hoang et al. (2016a, b). If A_S is much greater than A_B (A_S>>A_B), breaching recovers fully (Fig. 22.6a). On the other hand, if A_S is much smaller than A_B (A_S<<A_B), it is expected that the sediment source for the recovery of breaching is probably insufficient (Fig. 22.6b).

Figure 22.7 presents the relationship between A_B and A_S of breaching along the coast. Corresponding to each case, it is denoted as "×" if the tsunami embayment has been formed or "●" if the morphology has fully recovered (non-formation of tsunami embayment). According to the results shown in Fig. 22.7 that "×" and "●" are classified according to the magnitude of A_S and A_B. When the area of breaching needing to be filled in the recovery process and the area of sediment source are the same, i.e., A_B=A_S, one expects tsunami embayment formation to be limited. It is represented by the dashed line in Fig. 22.7. When this line is added into the figure, the results are clearly separated into two groups of "×" and "●". From this, A_B=A_S is considered as the formation condition of tsunami embayment.

22.4 Reconstruction of the Coastal Embankment Along the Yamamoto Coast

Figure 22.8 presents the aerial photographs of the Yamamoto Coast before, right after, 3 years and 4.5 years after the tsunami. These aerial photographs were obtained from the report of the Tohoku Regional Bureau, Ministry of Land, Infrastructure, Transport and Tourism, Japan (hereafter referred to as the Tohoku Regional Bureau). The morphology of the coast before the tsunami is illustrated in Fig. 22.8a. As mentioned previously, there numerous headlands had been installed along the Yamamoto Coast since 1990s to prevent the erosion on this coast. In addition, embankments

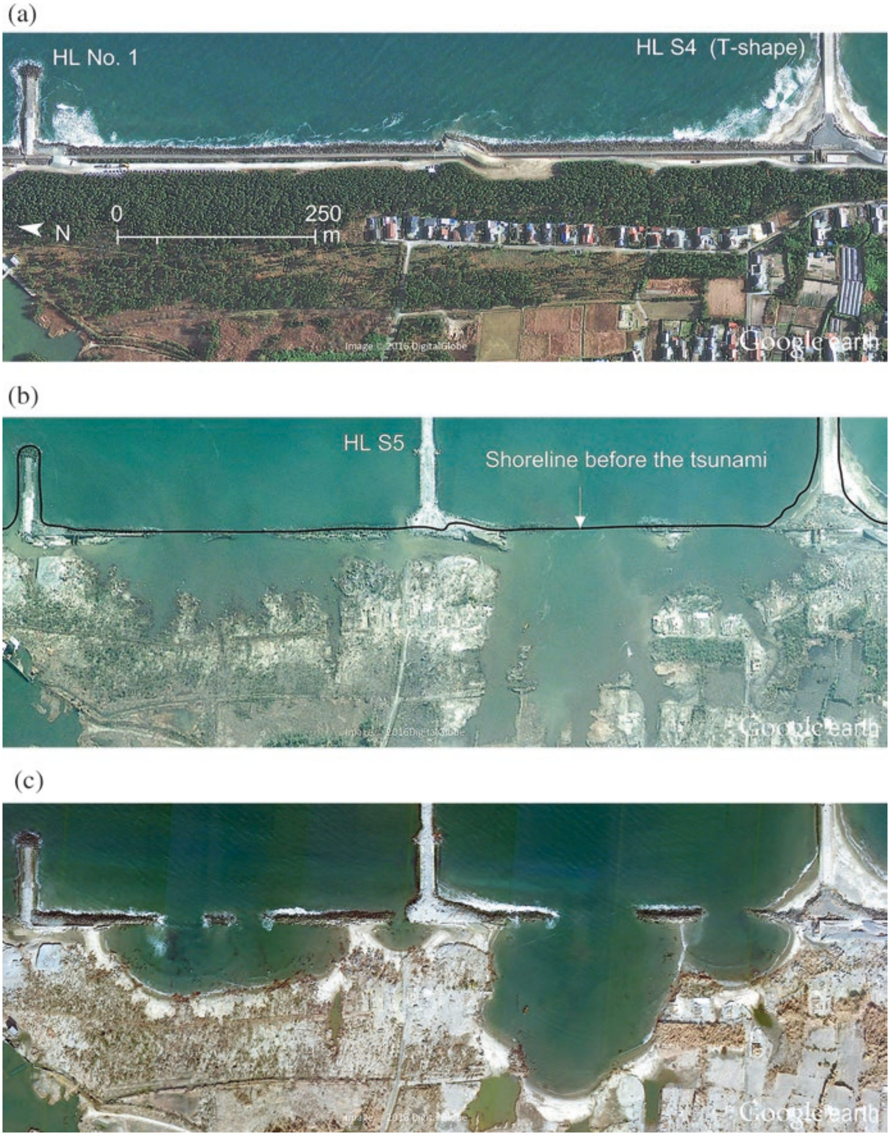


Fig. 22.5 Satellite images of Area C on the Yamamoto Coast (formation of tsunami embayment). (**a**) December 10, 2009. (**b**) March 14, 2011. (**c**) April 6, 2011. (**d**) May 24, 2011 (GSI). (**e**) April 12, 2012 (×: formation of tsunami embayment)

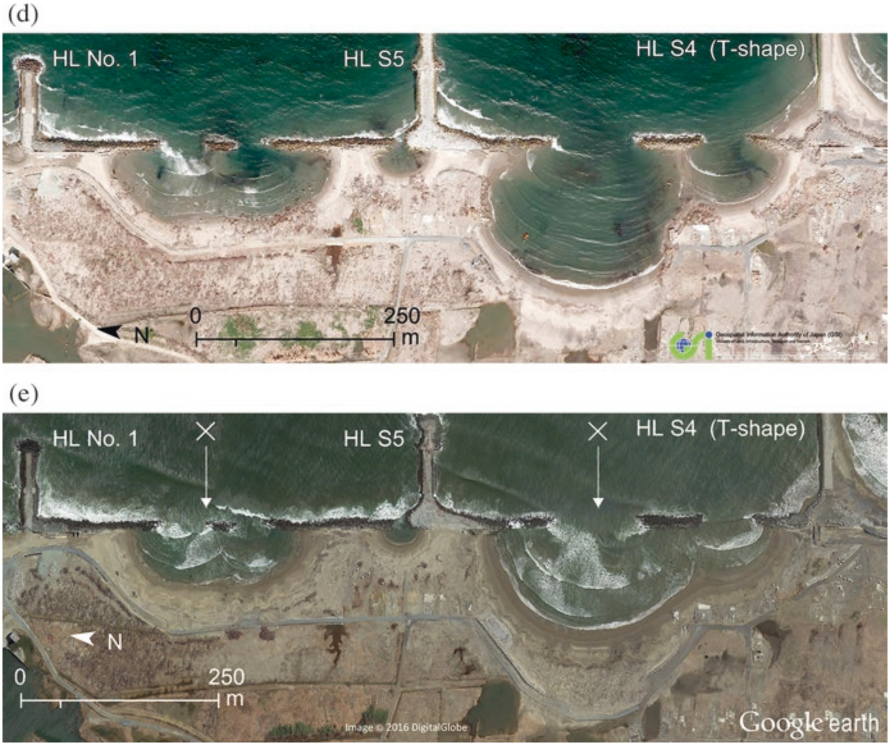


Fig. 22.5 (continued)

6–7 m in height above the MSL had been also constructed to protect the hinterland from storm surges and wind waves. Besides the damage of the sandy coast, the tsunami also broke the embankment at several places along the coast (Fig. 22.8b). The failure process and mechanism of the embankment on this coast were investigated by Iida et al. (2014). They reported that the destruction of the embankment was effected in two steps. At first, the surging bore of the leading tsunami waves broke the upper structure of the embankment, and, subsequently, the concentrated return flow expanded the erosion of the embankment. Due to its important role, the embankment has been reconstructed after the tsunami. Since the beginning of 2012, the reconstruction has been in progress. As shown in Fig. 22.8c, as of June 2014, almost the entire the embankment had been reconstructed except at two places of tsunami embayment. The aerial photograph shown in Fig. 22.8d, which was taken about 1.5 year later, indicates that the reconstruction of embankment at the tsunami embayment between headlands S2 and S5 was ongoing. The formation of tsunami embayment has forced reconsideration about the position and constructed progress of the reconstructed embankment. As a result, the reconstruction of the embankment at the places without and with formation of a tsunami embayment will be examined.

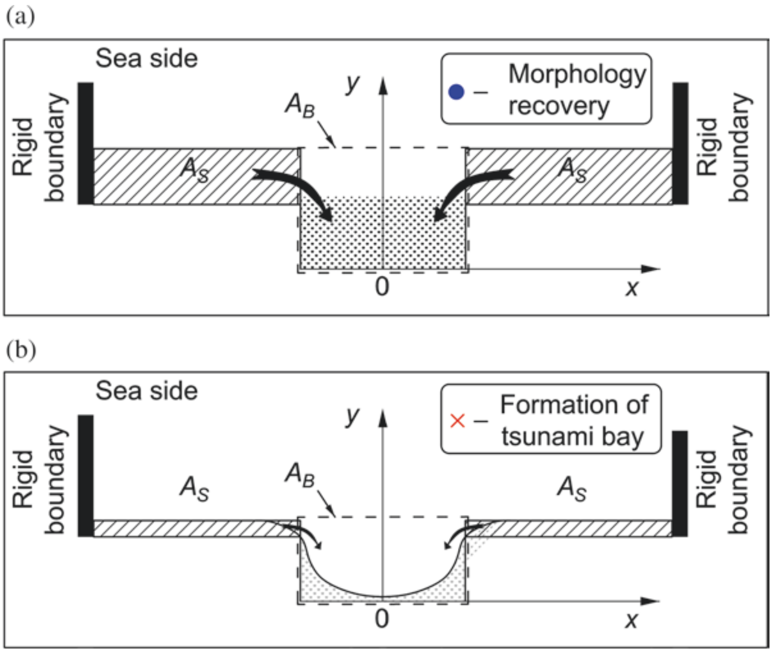


Fig. 22.6 Definition of the measured breaching area, A_B, and the area of adjacent sandy coasts, A_S. (**a**) Non-formation of tsunami embayment. (**b**) Formation of tsunami embayment

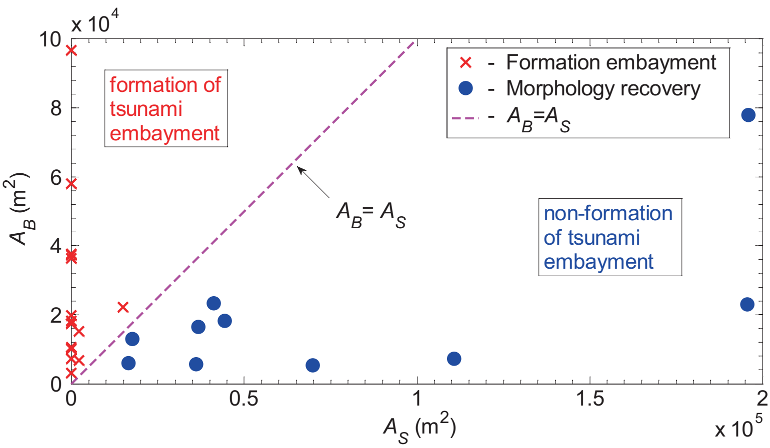
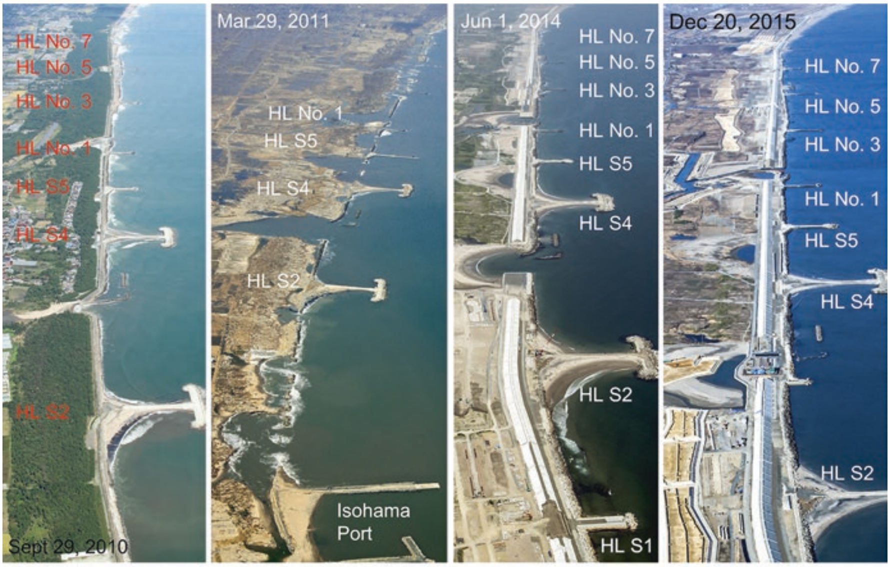


Fig. 22.7 Relationship between A_B and A_S (●: non-formation of tsunami embayment,: × formation of tsunami embayment)



(a) September 29, 2010 (b) March 29, 2011 (c) June 1, 2014 (d) Dec 20, 2015

Fig. 22.8 Aerial photographs of the coast before (**a**), right after the tsunami (**b**) and recent (**c**, **d**) (Tohoku Regional Bureau 2015a, b)

22.4.1 Reconstruction of the Coastal Embankment in Cases Without Setbacks

Figure 22.9a illustrates the cross section CS1 (Fig. 22.1) of the reconstructed embankment. This is the representative cross section of the reconstructed embankment from the left-hand side of HL No. 11 to HL No.5. The coastal morphology in this area has significantly recovered; therefore, the reconstructed embankment was elevated above the level at the same position of the previous embankment. The height of the reconstructed embankment is 7.2 m above MSL. According to Udo et al. (2015), this embankment height was determined by the sum of the mean spring tidal level, the maximum storm surge deviation, a 30-year return period of wave heights and allowance height. The tsunami debris is used as the banking material for the inner part of the embankment. Both values of seaward and back slopes are 1:20. These slopes are reinforced by concrete coating blocks. The reconstruction of embankment in the cases without setback started in January 2014 and completed in March 2015. Figure 22.10a is an oblique photograph of the embankment after the reconstruction. It was taken in between HL No. 11 and HL No. 9. According to that, a strip of sandy beach remained in front of the embankment.

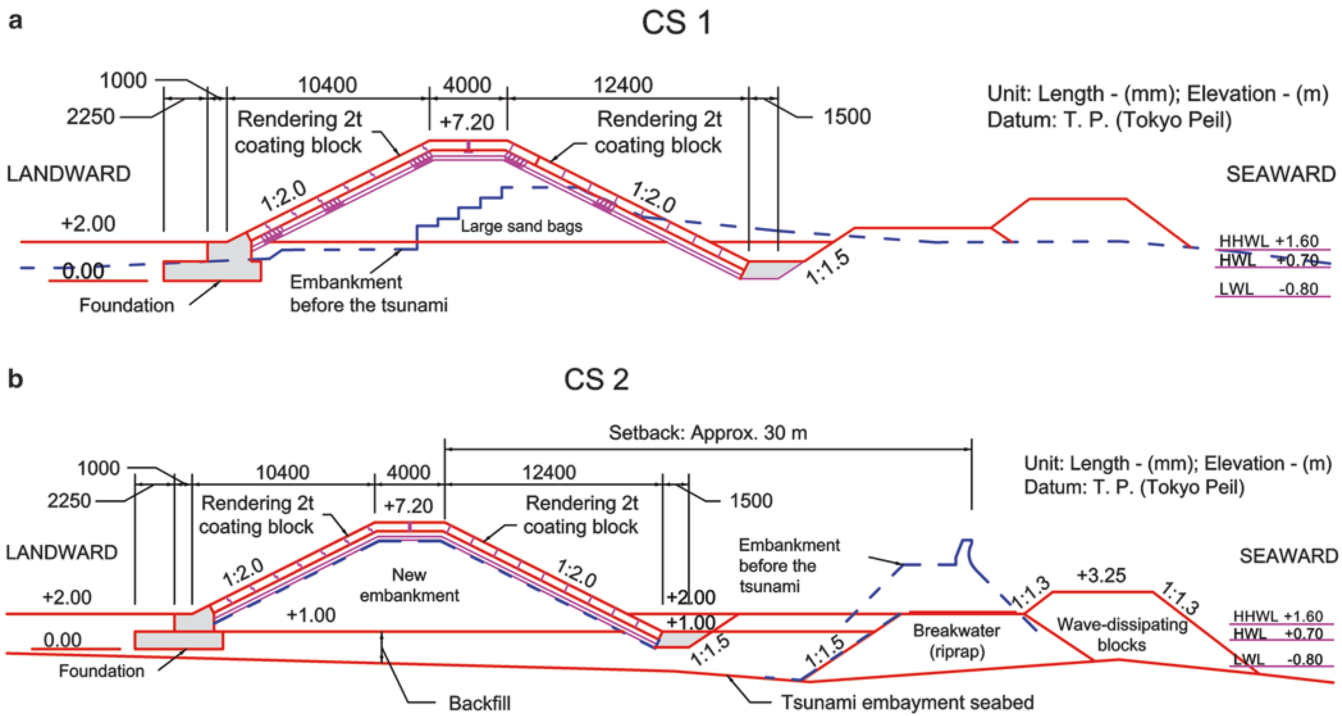


Fig. 22.9 Cross sections of the reconstructed embankment after the tsunami (Tohoku Regional Bureau). (**a**) Cross section of the reconstructed embankment at CS1 (without setback). (**b**) Cross section of the reconstructed embankment at CS2 (with setback)

Fig. 22.10 Oblique photographs of the reconstructed embankment in cases without and with setback. (**a**) Without setback (taken at the location between HL No. 11 and HL No. 9, looking southward). (**b**) With setback (taken at the location between HL S5 and HL S4, looking southward)

22.4.2 Reconstruction of the Coastal Embankment in Cases with Setback

The cross section CS2 (Fig. 22.1) of the reconstructed embankment is shown in Fig. 22.9b. This is the representative cross section of the embankment from HL No. 1 to HL S4, where the setback has been implemented. The design of the embankment in this case is the same as the one without setback. However, the position of the embankment has been assigned a setback of about 30 m from the position of the embankment before the tsunami. As mentioned previously, the embankment at the places of tsunami embayment can be the weak point due to large water depth, therefore the seaward side of the embankment is armored by wave-dissipating blocks. The reconstruction of embankment in the case with setback also started in January 2014, however, the completion was scheduled for March 2017. Figure 22.10b is an oblique photograph of the completed embankment of the case with setback. It was taken at the location between HL S5 and HL S4. According to this photograph, there is no sandy beach in the front of the embankment, instead, the ripraps and wave-dissipating blocks have been installed. Moreover, the embankment before the tsunami and the tsunami embayment are also pointed out in this figure.

22.5 Conclusions

This study investigated the morphological changes induced by the 2011 tsunami, the formation of tsunami embayment during the recovery process, and the reconstruction of coastal embankment along the Yamamoto Coast. The following overall conclusions have been made.

Coastal morphology on the Yamamoto Coast was severely damaged by the 2011 tsunami. A part of the coast has now significantly recovered, while the formation of tsunami embayment could be observed along the other one.

The mechanism of tsunami embayment formation is obtained through the relationship between the measured area of adjacent sandy coasts, A_S, and the measured area of breaching, $A_{B.}$ The formation of tsunami embayment takes place in the case where A_B greater than A_S and vice versa. Therefore, A_B=A_S is considered as the formation condition of tsunami embayment.

There are two types of cross sections of the reconstructed embankment. Due to the formation of tsunami embayment in several locations, a setback of approximately 30 m of the reconstructed embankment has been made. At the locations without the formation of tsunami bay, the reconstructed embankment is elevated above the level of the embankment before the tsunami.

Acknowledgement The data about design of the reconstructed embankment utilized in this study was provided by the Tohoku Regional Bureau, Ministry of Land, Infrastructure, Transport and Tourism, Japan. The authors would like to express their gratitude to the above for their support.

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Chapter 23
Challenges in Reconstruction and Strategies for Prevention and Mitigation of Coastal Disasters Five Years After the GEJE

Yoshimitsu Tajima

Abstract After the 2011 Great East Japan Earthquake (GEJE) and tsunami, the Central Disaster Management Council of Japan newly introduced the concept of two different levels of tsunamis for disaster prevention and mitigation strategies. Under this concept, in general, the height of the coastal dike is designed to prevent the inundation against the level-one tsunami. Against the higher level tsunami, on the other hand, the dike may allow overflow but should be designed to avoid fatal collapse and thus to reduce the damage level of the area behind the dike. The quantitative evaluation of such damage-reduction effects of dikes is, therefore, one of the key tasks because it affects land-use planning and other disaster-prevention or mitigation measures in the inundated area.

This chapter first discusses to what extent coastal dikes can reduce the extent of various coastal hazards against a tsunami flowing over the dikes. Based on a numerical study, the overall performance of coastal dikes is investigated by comparing the following three parameters: (i) volume of the overflow, (ii) inundation area and (iii) "*damaged area*", i.e., the area where the expected number of collapsed houses exceeds that of surviving houses. It was found through the analysis that coastal dikes show better performance in the reduction of the damaged area rather than in the other parameters and that these effects are practically diminished as the relative height of the dike decreases to below half of the tsunami height in front of the dike. The stability of the dike against an overflowing tsunami is also an important factor to ensure the damage-reduction effect of the dike; thus, a slope-type dike becomes one of the preferred designs for the dike. Such slopes of the dike, however, may reduce the dissipation effect of an overflowing tsunami and may thus sacrifice the damage-reduction effect in the inundated area. The influence of such a trade-off relationship is examined through laboratory experiments. The experimental results showed that the sloping-type dike clearly increases the overflow of a tsunami and

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V. Santiago-Fandiño et al. (eds.), *The 2011 Japan Earthquake and Tsunami: Reconstruction and Restoration*, Advances in Natural and Technological Hazards Research 47, DOI 10.1007/978-3-319-58691-5_23

has a significant impact on the damage in the inundated area. Finally, this manuscript outlines some other problems for the quantitative estimations of inundation characteristics, hazards and risks under various uncertain factors and discusses possible multi-disciplinary approaches to overcome these difficulties.

Keywords Coastal hazard • Coastal dike • Disaster mitigation • Uncertainties

23.1 Introduction

After the 2011 Great East Japan Earthquake (GEJE) and tsunami, the Central Disaster Management Council, Japan, introduced a new concept in the Basic Disaster Management Plan for disaster prevention and mitigation against tsunamis. This concept differs from the previous concept in that it accounts for two different levels of tsunamis. The level-one tsunami is defined as a tsunami with a return period of several decades to several hundred years, and coastal dikes, in general, should be designed to prevent inundation against this level-one tsunami. The level-two tsunami is defined as the highest possible tsunami in each region and has a return period of more than several hundred years to a thousand years. Under such a level-2 tsunami, the coastal dike may no longer be high enough to prevent the overflow; rather, the dike is expected to avoid fatal collapse to reduce the damage level in the inundated area. Each of the coastal regions then needs to develop various disaster-mitigation measures to minimize various risks against such a catastrophic tsunami event.

Under this concept, it is important to investigate how the integrated disaster-mitigation measures can be designed and implemented to address the various needs and constraints of regional communities, such as a limited budget, time and resources. Especially from the engineering view point, the determination of the optimum height and stability of coastal dikes is one of the most essential tasks because coastal dikes have a significant impact on the various damage levels in the inundated area, thereby determining the expected levels of other disaster-mitigation measures and land-use planning.

This chapter discusses various challenges found in the process of recovery and reconstruction, especially in the designs of coastal dikes that should be in harmony with the development of sustainable and disaster-resilient regional communities. The following sections discuss: (i) to what extent coastal dikes can reduce the coastal damage against catastrophic tsunami; (ii) the trade-off relationship between the stability and damage-reduction effect of dikes; and (iii) how various uncertainties affect the performance of coastal dikes.

23.2 Damage Reduction Effects of a Coastal Dike on a Catastrophic Tsunami

This section discusses to what extent various tsunami-induced coastal hazards can be reduced by coastal dikes using a numerical study with the assumption that all the coastal dikes suffer no fatal collapse during a catastrophic tsunami (Tajima et al. 2013).

23.2.1 Outline of the Numerical Study

Tajima et al. (2013) first validated their numerical models through comparisons of the computed and measured inundation characteristics at two selected case-study sites affected by the 2011 GEJE tsunami. Both of these case-study sites, the Sendai and Nakoso coasts, were devastated by the 2011 GEJE tsunami but have different geographic conditions. Tsunami propagation from the source, i.e., the initial displacement of the water surface, was computed based on a linear shallow-water equation discretized on the spherical coordinate system. The computed time-series of the water-surface fluctuations were then applied as the offshore boundary conditions for computations of the nearshore tsunami propagations and inundations based on a non-linear shallow-water equation discretized on a square coordinate system with a grid size of 20 m. The coastal dike was represented by a grid elevated to the designed crown height of the dike. The model accounted for the influence of the sudden change of the bed level around the crest of the dike by introducing a head loss for the sudden enlargement of the flow section in the momentum equations.

As listed in Table 23.1, the model was applied to several cases in which either the tsunami height or the crown height of the coastal dike was altered. In the table, S0 and N0 are the cases when all the coastal dikes were removed, and S1 and N1 are the cases with the actual dike conditions before the attack of the 2011 GEJE tsunami. Figures 23.1 and 23.2 demonstrate the overall reasonable predictive skills of

Table 23.1 Numerical study cases in Sendai (Miyagi Prefecture) and Nakoso (Iwate Prefecture). The height of the dikes is based on the Tokyo Peril

Case	Site	Dike	
S0	Sendai	–	
S1		5.0	
S2		6, 8, 10	
	Nakoso	Dike A	Dike B
N0		–	–
N1		4.2	6.0
N2		6.0	6.0
N3		5.1	5.1
N4		4.2	4.2

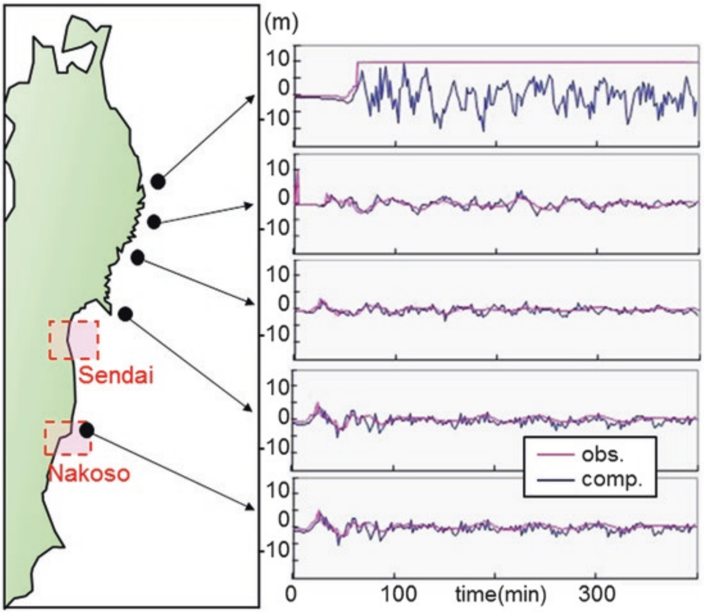

Fig. 23.1 Computed examples of the 2011 GEJE tsunami around the north-east coast of Japan

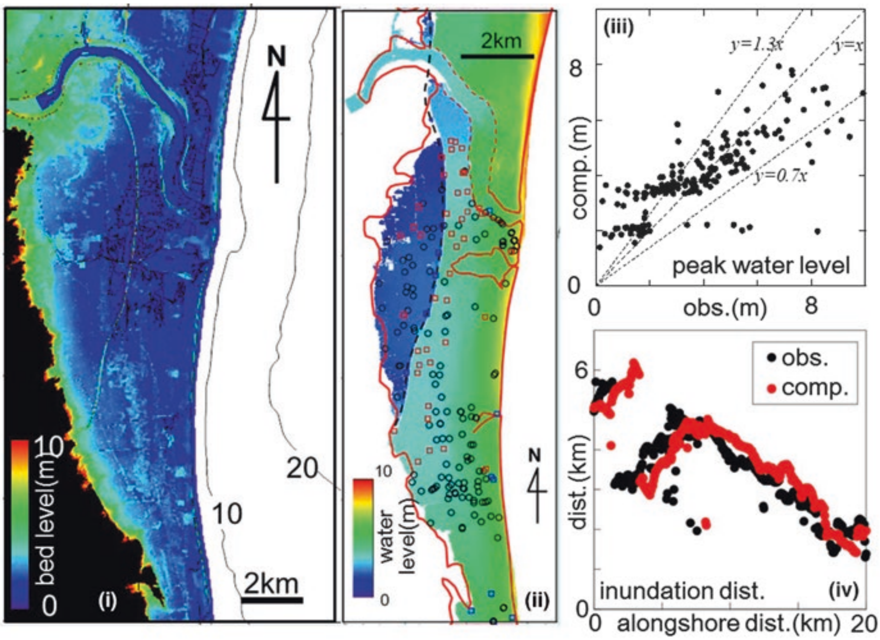

Fig. 23.2 Computed results around the Sendai coast: (**i**) bed level, (**ii**) inundation and comparisons of the computed and observed (**iii**) peak-water level and (**iv**) inundation distance

(i) the offshore water-surface fluctuations and (ii) the peak-water level and area of the inundation observed along the Sendai coast. Equally reasonable agreement between the computed and observed tsunami-inundation characteristics were also confirmed in the case of Nakoso.

23.2.2 *Findings and Discussions*

Tajima et al. (2013) investigated the effectiveness of coastal dikes by comparing two different parameters that may well represent the damage levels in the inundated area. The first parameter is the peak-water level, η_{max}, in the inundated area, and the second parameter is the peak value of $X = U^2h$, a product of the horizontal velocity, U, and the water depth, h; this parameter X represents the horizontal fluid force of the inundating tsunami. According to Hatori (1984), more than half of the total number of houses in the inundated area collapse when X exceeds 5.0 (m^3/s^2). Figure 23.2(i) shows X_{max}, the peak value of computed X in the case of S1. Figure 23.3(ii–iii) compares the differences of X_{max} and η_{max}, respectively, between the cases S1 and S0, i.e., with or without coastal dikes. In these figures, negative values, shown in blue, indicate that the computed values were decreased by the coastal dike.

The computed X_{max}, shown in Fig. 23.3(i), exceeds 5.0 (m^3/s^2) with even 1 or 2 km landside from the shoreline. The relatively large negative values of ΔX_{max}, shown in Fig. 23.3(ii), indicate that coastal dikes have significant reduction effects of X_{max} over the entire inundated area. In contrast to ΔX_{max}, the computed horizontal distributions of $\Delta\eta_{max}$ partially contain the area with positive values, i.e., the area where the peak-water level was elevated by the coastal dikes.

Figure 23.4 compares the time-series of the computed water levels at locations A, B, C and D indicated in Fig. 23.4(iii) in the cases of S1 and S0. As shown in the figure, coastal dikes decrease the peak water levels of the first and second waves near the coast, i.e., at locations A and B. In addition, coastal dikes also block the water flowing back to the sea and thus reduce the rate of the descending water level. As a result, coastal dikes increase the net amount of the water remaining in the inundated area when the third wave attacks the coast. The steep crest profiles of the first and second waves predominantly determine the highest water levels at A and B; these peaks are dispersed at locations C and D, whereas the net amount of water remaining in the inundated area predominantly determines η_{max}. As shown in these comparisons, the effectiveness of a coastal dike depends on the hydrodynamic features of the inundated area we focus on.

In contrast to the case in Sendai, which has a relatively low and flat plain with a long straight coast and uniform coastal dikes, Nakoso in Fukushima Prefecture has a narrower plain and coastal dikes with two different crown heights. Figure 23.5 shows the following computed results in the case of Nakoso: (i) X_{max}; and the difference of parameters, (ii) ΔX_{max} and (iii) $\Delta\eta_{max}$, between the cases of N1 and N4. The heights of dikes A and B shown in Fig. 23.5 are 4.2 m and 6 m, respectively, in N1,

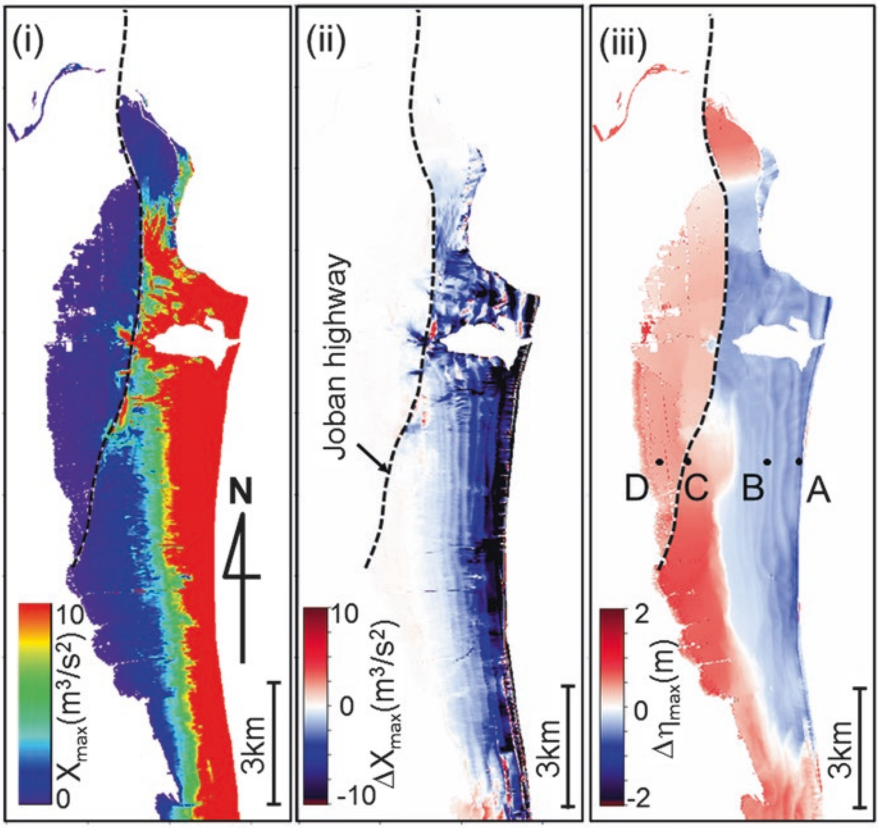

Fig. 23.3 Spatial distributions of the computed (**i**) X_{max}, (**ii**) ΔX_{max} and (**iii**) $\Delta\eta_{max}$ at the Sendai coast

and dikes A and B have the same height, 4.2 m, in N4. It is shown in these comparisons that an elevated dike B increases both η_{max} and X_{max} in the area behind the dike A, indicating that a partially elevated dike can enhance the hazard levels, e.g., the water level and flow velocity, in the surrounding area.

Finally, the overall effectiveness of coastal dikes for the reduction of a tsunami hazard was investigated through comparisons of following three properties: (i) overflow, i.e., the total volume flux of the water flowing over the dike; (ii) inundated area; and (iii) "damaged area", defined as the area where X_{max} exceeds 5.0 (m^3/s^2). These comparisons were performed for all the cases listed in Table 23.1, with various tsunami heights altered by simply applying the original water-level fluctuations at the offshore boundary multiplied by a proportional constant. Each of these three properties were compared with the values in the cases with no dike, i.e., S0 or N0, and Fig. 23.6 shows the reduction rate of these three properties as a function of the relative height of the dike, $Z=H_D/H_T$, with H_D, the height of the dike and H_T, the tsunami height. Here, H_T is defined as the maximum height of tsunami at the location

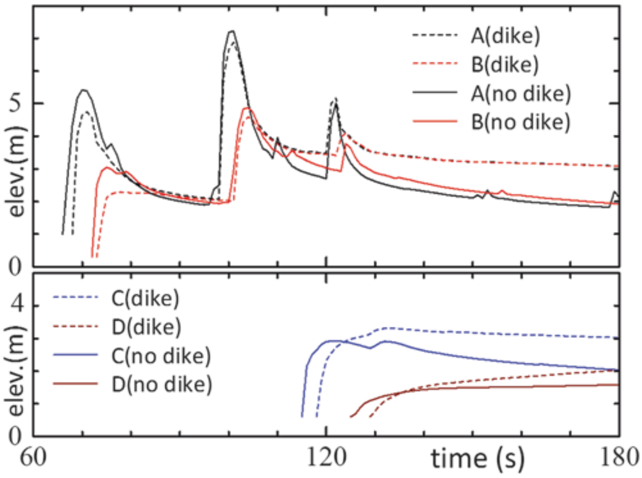

Fig. 23.4 Time-series of the computed water level at locations A, B, C and D shown in Fig. 23.3

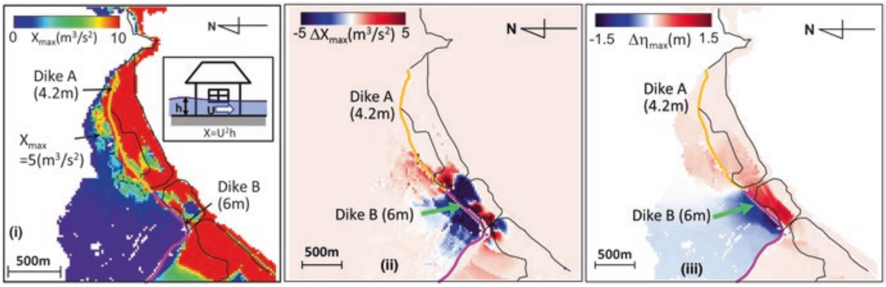

Fig. 23.5 Spatial distributions of computed (**i**) X_{max}, (**ii**) ΔX_{max} and (**iii**) $\Delta\eta_{max}$ at the Nakoso coast

of the coastal dike in the case of either S0 or N0. Because the computed tsunami height at the dike is increased by the presence of the dike, the tsunami overflows even if $Z = 1$. Reduction rate of each property, R, is defined by $R = (a_0 - a_i)/a_0$ with a_0 and a_i, computed properties of case 0 and case i (S1, S2, N1, N2 etc.).

As shown in Fig. 23.6, the reduction rates of all these properties decrease as Z increases, and the reduction rate of inundation area tend to be smaller than the others. A blank triangle in the table is the case of N1, in which dikes A and B have different heights, and the computed reduction rate is clearly smaller than the other cases with uniform dikes. The computed reduction rates were also found to be smaller in the case of Nakoso, which has relatively narrower hinterland behind the dike. The narrower hinterland tends to be quickly inundated, even with the relatively smaller volume of the overflow, and thus the effect of dikes quickly diminishes as Z decreases. This feature implies that the appropriate heights of the dike depend not only on the sociological or economic conditions but also on the topography of the hinterland. On one hand, in the region with relatively smaller hinterland, for

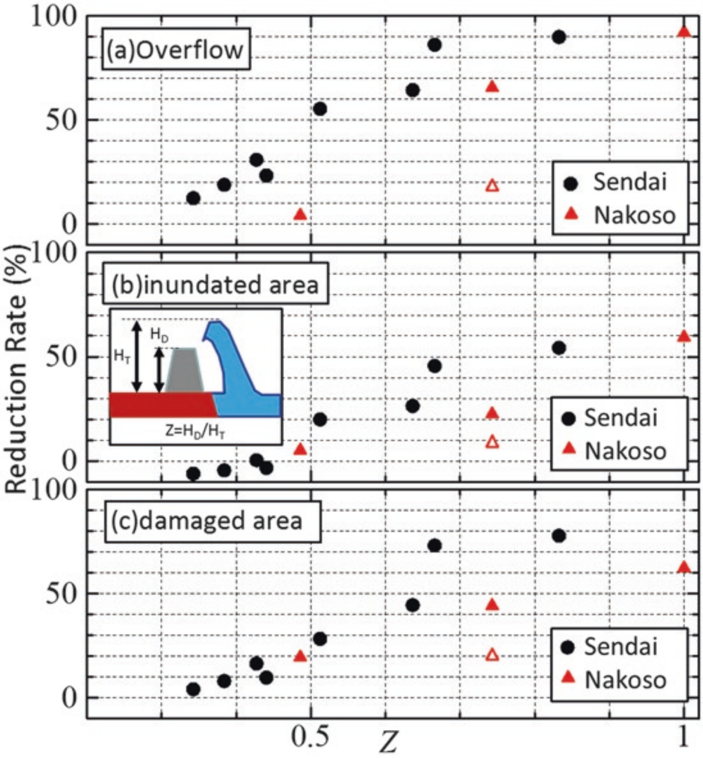

Fig. 23.6 Computed reduction rate of (**a**) overflow, (**b**) inundation area and (**c**) damaged area as a function of the relative dike height, Z

example, a smaller *Z* has little effect, and thus the priority in the design of new or reconstructed dikes should be placed on the height of the dike rather than the enhancement of the stability against a tsunami flowing over the dike. On the other hand, in regions with a relatively wider hinterland, a relatively smaller *Z* still has certain reduction effects on various damages, and thus the importance of the enhancement of the dikes' stability against an overflowing tsunami is highlighted.

23.3 Trade-Off Relationship Between Stability and Tsunami-Dissipation Effects of a Coastal Dike

The numerical study discussed in the previous section was based on the assumption that all the coastal dikes suffer no fatal collapse under tsunami attacks. In the case of the 2011 GEJE tsunami, however, a number of coastal dikes severely collapsed, and these collapsed dikes appeared to have little damage-reduction effects, while "survived" dikes without fatal collapse showed some damage-reduction effects in the inundated area. Following this lesson, the stability of coastal dikes against an overflowing tsunami is considered as one of most important factors in the reconstruction or reinforcement of coastal dikes, and a sloping face of dikes is considered as one of preferable options to enhance a dike's stability. Compared to a vertical-wall-type dike, however, such a slope-type dike may have fewer effects on the dissipation of an overflowing tsunami. This section briefly outlines laboratory experiments performed by Seto et al. (2015), who focused on such trade-off relationships between a dike's stability and the damage-reduction effect.

Figure 23.7 illustrates the experimental setups of Seto et al. (2015) and an example of measured time-series of the water level on the crest of the dike. As shown in the figure, dam-breaking waves, representing a tsunami wave, were introduced to six different types of dikes, each of which has either a vertical wall or different slopes on the landside or seaside faces, as illustrated in Fig. 23.7. The height of the tsunami was altered by changing the initial water-level difference, *H*, across the gate. Throughout the experiment, the time-varying water level and the horizontal velocity were measured at several locations, as shown in the figure. The total volume of the overflow was also obtained by measuring the water level in the overflow box, placed at 2.5 m on the landside of the dike.

Table 23.2 summarizes the results of the experiment of Seto et al. (2015). To investigate the overall damage-reduction function of dikes against an overflowing tsunami, the table compares the following four parameters: (i) total volume of the water flowing over the dike, Q_{ov}; (ii) arrival time, T_0, i.e., the time when the overflowing water first reached the overflow box; (iii) the first wave height, H_1, the water

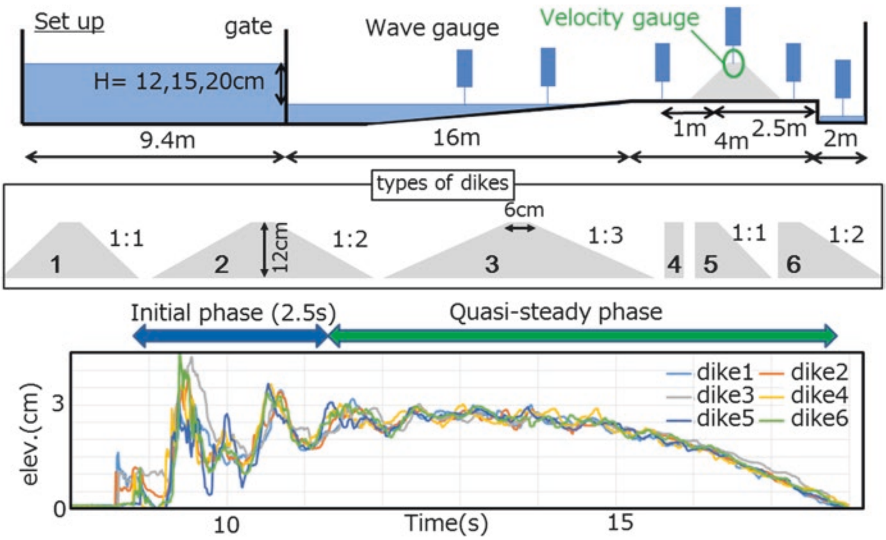

Fig. 23.7 Overview of the experiments of Seto et al. (2015): (**i**) layout of the experiment (*top*); (**ii**) six different types of dikes (*middle*); (**iii**) recorded time-series of water surface levels when an identical dam-break wave (H = 12 cm) was incident on six different dikes (*bottom*)

Table 23.2 Summary of the experiments of Seto et al. (2015)

H(cm)		Dikes					
		1	2	3	4	5	6
12	Q_{ov}	86	94	100	58	65	78
	T_0	1.5	0.9	0.0	2.9	2.5	2.1
	H_1	53	62	100	32	35	36
	X_{max}	93	88	100	78	62	89
15	Q_{ov}	88	100	100	79	80	84
	T_0	0.5	0.0	0.0	1.0	0.6	0.8
	H_1	68	77	100	43	58	61
	X_{max}	138	100	100	93	102	106
20	Q_{ov}	97	102	100	83	89	89
	T_0	0.4	0.0	0.0	0.9	0.7	0.6
	H_1	84	87	100	54	86	83
	X_{max}	83	87	100	94	92	106

The vertical dike (type 4) shows the best performance to reduce the tsunami overflow in all the cases. The unit of T_0 is in second

level when the first wave arrived at the wave gauge located 1 m landside from the dike; and (iv) the peak value of $X = U^2h$ at the same wave gauge. To enable the comparisons of different dikes, all these parameters except the arrival time, T_0, are respectively scaled by the values of the type-3 dike, which has the mildest slope on both sides of the dike. The arrival time, T_0, is expressed as the difference of the measured arrival time in each type of dike considered from that in the case of type-3 dike. In the case of $H = 12$ cm and the type-4 dike, for example, T_0 is 2.9 s, i.e., the arrival time of the first inundating water was delayed for 2.9 s by changing the shapes of the dike from type 3 to type 4. Assuming that the length scale of this experiment is 1/100 of the field scale, this time difference is equivalent to 29 s in the field scale; this difference is considered to be significant as a lead time for evacuation.

As summarized in Table 23.2, a vertical dike (type 4) showed the best performance to reduce the tsunami overflow in all the cases. The front vertical wall plays a significant role in the delay of the arrival time of the first tsunami in the hinterland because not only the type 4 dike but also the type 5 and type 6 dikes effectively delay the arrival time. The milder front slope significantly increases the overflow rate and the parameter, X, and advances the arrival time. The rear slope had relatively less impact but increases X in the hinterland. However, the influence of the dike's slopes tends to diminish when H, the relative height of the tsunami, increases.

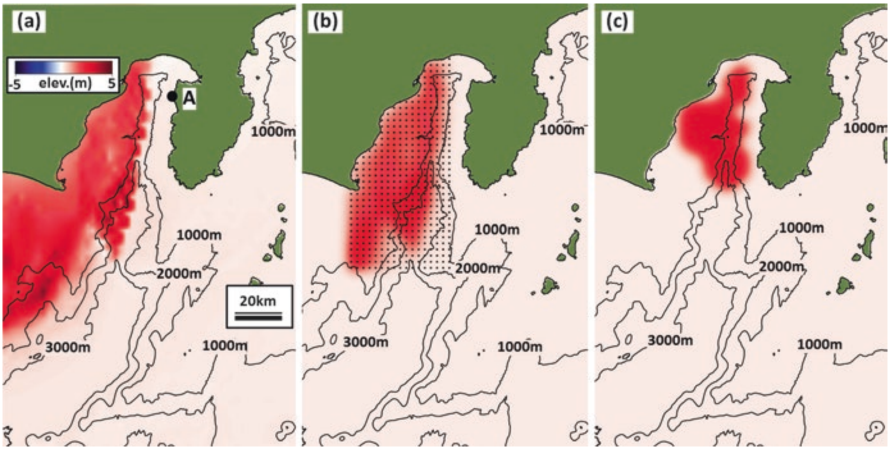

Fig. 23.8 Three different cases of the initial spatial displacement of the water surface level in Suruga Bay

23.4 Uncertain Factors in the Prediction of Coastal Hazards

To design the optimum height and stability of the dike under various constraints, such as a limited budget and other resources of each regional community, the disaster-mitigation effect of coastal dikes must be quantitatively estimated as a "benefit", so that it can be directly compared with the "cost" of the dikes in terms of construction, reconstruction or reinforcement, as well as other negative aspects, such as degradation of the environment. Because such effect of dikes should depend on different levels of tsunamis with different return periods, the estimation of the expected benefit of the coastal dike may require a stochastic approach. In addition to the estimation of the provability of the occurrence of each tsunami, various uncertain factors may have a significant impact on the evaluations of the effectiveness of coastal dikes. This section discusses some of these uncertain factors revealed through the post-disaster study of the 2011 GEJE tsunami.

23.4.1 Local Amplification of Tsunamis

Fujima and Hiwatashi (2013) applied the Gutenberg-Richter law (Gutenberg and Richter 1956) to estimate the return period of tsunami events with various magnitudes of the fault displacement. Through the computations of tsunami inundation with coastal dikes, this method enables us to evaluate the expected disaster reduction/prevention effects of a dike against various tsunami events. However, note that the coastal hazard level in each region depends not only on the quantity of the fault,

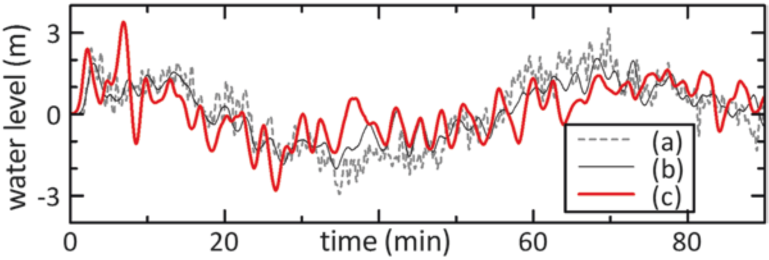

Fig. 23.9 Comparisons of the time-series of computed water level at A shown in Fig. 23.8 propagated from three different initial displacements

but also on the other factors, such as the locations and the spatial geometry of the fault displacement.

Figure 23.8, for example, compares the following three different cases of the initial displacement of the water level: (a) the combined displacement of five major earthquakes around the Tokai area, introduced by the Shizuoka Prefecture for estimations of a level-one tsunami around Suruga Bay; (b) the displacement is identical to (a), but is represented as linear combinations of Gaussian-type unit sources with a horizontal scale of 2.5 km; and (c) the displacement of the combined unit source that yields the locally concentrated high-water level at location, A, shown in Fig. 23.8(a). Here, each of the unit sources was aligned on square grids with intervals of 2.5 km, as shown in Fig. 23.8(b), and the tsunami propagation from each source was respectively computed based on the linear long wave theory. Figure 23.9 compares the time-series of the water-surface level induced by the initial displacements of (a), (b) and (c). Here, the computed results of (b) and (c) are obtained by linearly integrating the computed time-series from each source with the specified weight functions. As shown in Fig. 23.9, the computed profile of (b) reasonably represents that of (a), except that the computed (b) does not represent the high frequency fluctuations, which are not taken into account in each of the smooth unit sources. The profile (c) is also obtained through the integration of the unit sources but yielded a significantly high peak at the time of approximately 7 min after the initial displacement. Note that the initial displacement of (c) is equivalent to (b) in terms of the peak value and is approximately 60 % of (b) in terms of the total volume of displacement. This feature indicates that geometric conditions of the fault displacement also have a significant influence on the evaluations of the expected tsunami height in each region.

Figure 23.10 shows a picture extracted from the video taken by local residents when the 2011 GEJE tsunami struck the Shirahama Beach located at the inner part of the Ryori Bay in Iwate Prefecture. As shown in the picture, the water surface shows high fluctuations, which appear to enhance the fluid force acting on the coastal structures along the coast. Figure 23.11 shows the water-surface fluctuations at the steep slope of the cliff extracted from the video image. The figure also shows the computed fluctuations of the water level at the same location. The computation is based on the non-linear shallow water equations; although the model reasonably

Fig. 23.10 Snapshot of a recorded video image at Sahirahama Beach, Ryori Bay, Iwate Prefecture

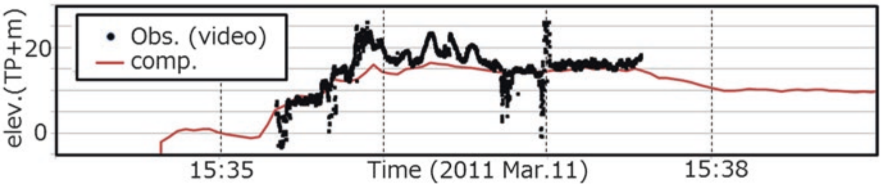

Fig. 23.11 Comparisons of the observed and computed water-level fluctuations at the cliff near Shirahama Beach

captures the overall profile of the tsunami, it fails to represent such high-frequency fluctuations. Yamanaka et al. (2013) indicated that wave fission around the tsunami front is one of factors that induce such high-frequency fluctuations and can be qualitatively explained by a non-linear dispersive wave model. This comparison indicates that a widely used non-linear shallow-water equation may potentially underestimate the influence of such high-frequency fluctuations, which may have a non-negligible impact on regional hazard levels. The significant impact of such high-frequency waves was also witnessed in the case of the storm-surge disaster induced by Typhoon Haiyan along the coast of Leyte and Samar, the Philippines, reported by Tajima et al. (2014, 2016a, b).

23.4.2 Various Uncertainties in Inundations

In addition to the uncertain factors of an offshore tsunami striking the coast discussed in the previous section, a variety of other factors of inundated areas should have a significant impact on the inundation characteristics. The presence of underground pipe lines, for example, is one such factor that increases the damage level in the inundated area. When the 2011 GEJE tsunami hit Nakoso in Fukushima Prefecture, for example, the initial inundation was observed at the vertical shaft of the underground pipeline located in the power plant. The shaft is approximately 200 m away from the coastal dike, and the inundation at the shaft started within 10 s after the tsunami hit the coastal dike. In approximately 1 min, the tsunami flowing over the dike reached the shaft. The abrupt inundation from the shafts of the sewer was also observed at Kesennuma, and such an inundation should have a significant impact on evacuations. Ground roughness, buildings and debris should also have a significant impact on the inundation characteristics and damage levels on the land. In the case of Otsuchi in Iwate Prefecture, devastated by the 2011 GEJE tsunami, for example, floating debris was concentrated along the foot of the hill behind the downtown area and caused a severe fire (Hokugo 2013).

23.4.3 Uncertainties in Changing Environmental Conditions

Determination of the properties of reconstructed coastal dikes, such as the height and locations of the dikes, was one of the first tasks in the process of recovery and reconstruction after the 2011 GEJE because these properties of dikes determine the safety levels and thus directly affect the other regional planning and disaster-prevention and mitigation measures in the area behind the dikes.

The challenges of this task are that all these properties must be determined based on various uncertain factors in different relevant aspects. Among those uncertainties, one of the most critical concerns in a scientific aspect may be the uncertainty in future coastal conditions, such as sea-level rise and coastal erosions. Figures 23.12 and 23.13 compares the shoreline changes around the Natori River in the Sendai coast before and after the impact of the 2011 GEJE tsunami. As shown in the figure, the shoreline on the northern side of the Natori River severely retreated after the event and has not recovered to the original locations, even 5 years after the event. A part of the original location of the coastal dikes is now exposed to the surf zone and requires special treatment to maintain sufficient stability against an overflowing tsunami and the attacks of daily waves. Because these works may also affect the ecosystem of the Ido-ura lagoon behind the dike, continuous monitoring is required to maintain the expected functions of the dikes and sustainable ecosystems in the lagoon.

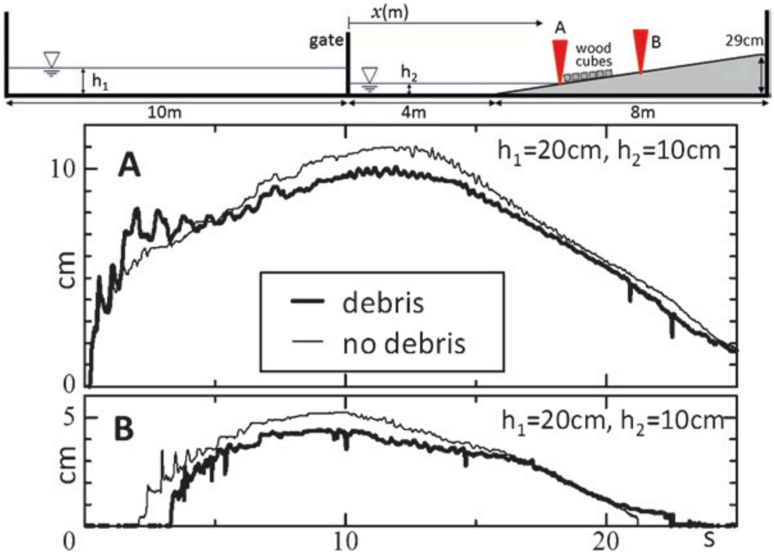

Fig. 23.12 Comparisons of the shoreline changes around the Natori River mouth before and after the 2011 event

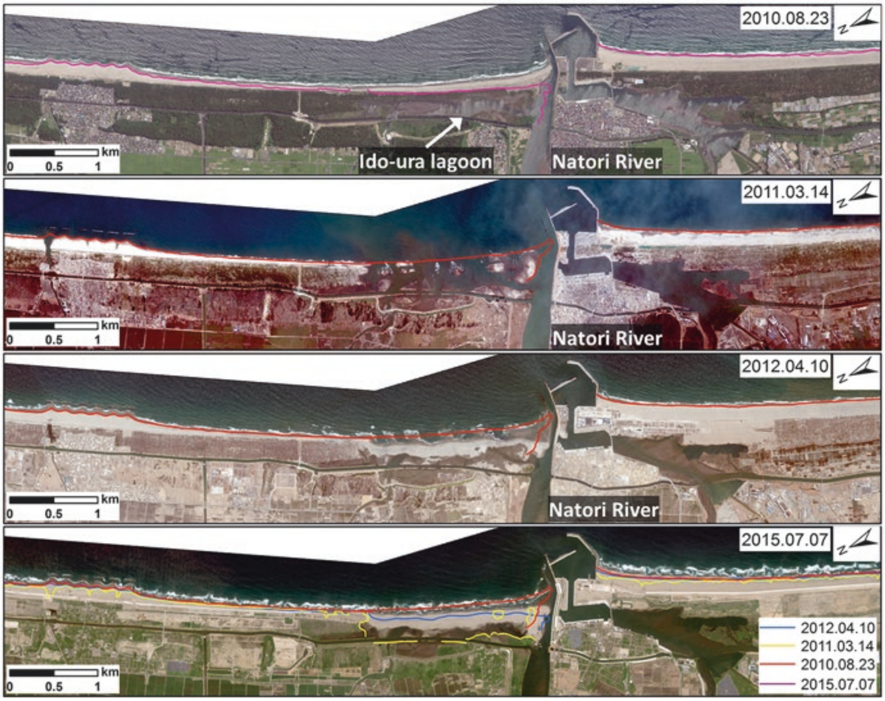

Fig. 23.13 Comparisons of the shoreline changes around the Natori River mouth before and after the 2011 event

23.5 Interdisciplinary Career Building

Although this chapter mainly focused on hydrodynamic aspects, evaluations of the overall effects of disaster-prevention and mitigation measures should also depend on other social aspects and thus require interdisciplinary view points and analysis. After the 2011 disaster, a number of efforts have been made for the cultivation of human resources in such interdisciplinary fields, with a focus on integrated disaster-mitigation strategies. The inter-disciplinary education program, "Disaster mitigation and recovery design," launched in the University of Tokyo after the 2011 event, is one example of such efforts; in this program, graduate students from various fields and various countries work together to explore and investigate hazards, risks and possible disaster-mitigation strategies at selected case-study sites. Through the interactions of students and faculty members from various fields and various countries and also interactions with local communities, this education program aims to allow students to explore and understand the needs of their own field in the context of interdisciplinary challenges toward the designs of integrated disaster-mitigation strategies.

23.6 Conclusions

This chapter discussed the challenges in the reconstruction process after the GEJE tsunami, especially for the designs of coastal dikes that are in harmony with sustainable and disaster-resilient regional communities. Coastal dikes with no fatal collapse showed damage-reduction effects in several aspects; however, such effects were diminished when the relative height of the dike is below half of the tsunami height. Enhancing a dike's stability against an overflowing tsunami was, therefore, considered to be one of the essential tasks; however, note that the stable profile of a dike may sacrifice the disaster-mitigation effect of the dike. In addition to such an uncertain trade-off relationship between stability and the effects of the dikes, this chapter also discussed various uncertain factors that significantly affect the extent of regional hazards and risks in the inundated area.

To realize the optimum integrated designs of regional disaster-mitigation strategies and measures, interdisciplinary career building is one of important future tasks. This chapter, as one example of such approaches, briefly introduced the newly launched interdisciplinary education program. Finally, as concluding remarks, the author hopes that the mutual interactions and feedback of such educational programs, academic studies, private and public sectors and local residents will bring forth sustainable and disaster-resilient regional communities. The lessons learned could also benefit other countries exposed to similar events.

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Chapter 24
Formation of Breaking Bores in Fukushima Prefecture Coastline Due to the 2011 Tohoku Tsunami: A Comprehensive Study Five Years After

Shinji Sato and Ohkuma Shohei

Abstract Tsunami effects on critical coastal structures were reanalyzed by combining laboratory experiments and numerical tsunami simulation, focusing on the formation of breaking bores and their large force to structures. Laboratory experiments demonstrated that nearshore tsunami is likely to form a breaking bore when the slope of the incident tsunami front is steep and the nearshore bed slope is mild. The impulsive pressure to coastal structures was found to increase with the steepness of the tsunami front. Based on these results, together with numerical simulation of tsunami, the formation of bores was discussed in relation to coastal topography in Fukushima Prefecture.

Keywords 2011 Tohoku tsunami • Breaking bore • Impulsive pressure • Coastal structures

24.1 Introduction

Many coastal structures were destroyed by the massive Tohoku Tsunami generated on March 11, 2011. Tsunami force exerted to coastal structure must be dependent on the type of structure as well as on the properties of incident tsunami as many studies reported large force generated by breaking bores (e.g. Sato and Ohkuma 2014). In Fukushima Prefecture, tsunami videos taken at Naraha located in the central part of Fukushima demonstrated that the incident tsunami formed a breaking bore resulting in catastrophic destruction of coastal structures (Fig. 24.1, Sanuki

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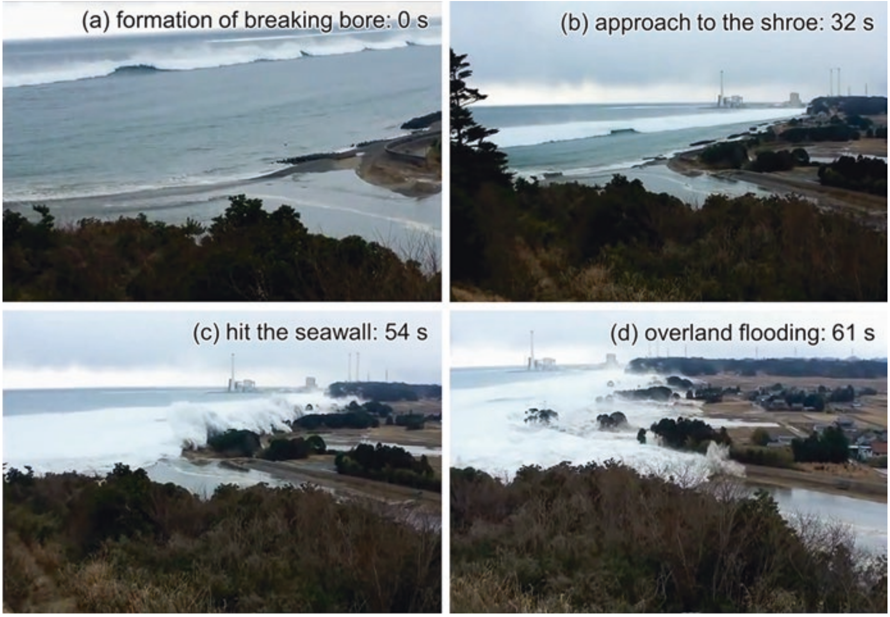

Fig. 24.1 Formation of a breaking bore observed at Naraha, Fukushima Prefecture (Sanuki et al. 2013. Pictures from a video footage provided by a local citizen allowing the author for their publication for scientific purposes)

et al. 2013). However, despite many studies done on the origin, type and behaviour of tsunami during the last past 5 years since March 2011, many uncertainties still remain in the nearshore and inland tsunami behaviours, such as dynamics of tsunami-induced flow (Lynett 2016), sedimentary processes represented by scour, erosion and tsunami deposit (Jaffe et al. 2016), and the interaction with structures (Yeh and Sato 2016).

In this study, we aimed at understanding the tsunami effect to coastal structures when the tsunami hit as a breaking bore. Laboratory experiments were conducted to describe the formation mechanism of the breaking bores and their large pressure to coastal structures. Based on these results, together with numerical simulation of tsunami, the tsunami damage concentrated to the central part of Fukushima was discussed in relation to coastal topography in Fukushima Prefecture.

24.2 Laboratory Experiments

Laboratory experiments were conducted in a 32 m long, 0.6 m wide wave flume as shown in Fig. 24.2. A hydraulically-driven gate is equipped at 9 m from one end of the flume. Sloping beds with s = 1/7 and 1/29 were placed. Tsunami was generated by abruptly opening the hydraulically-driven gate after raising the water level on the

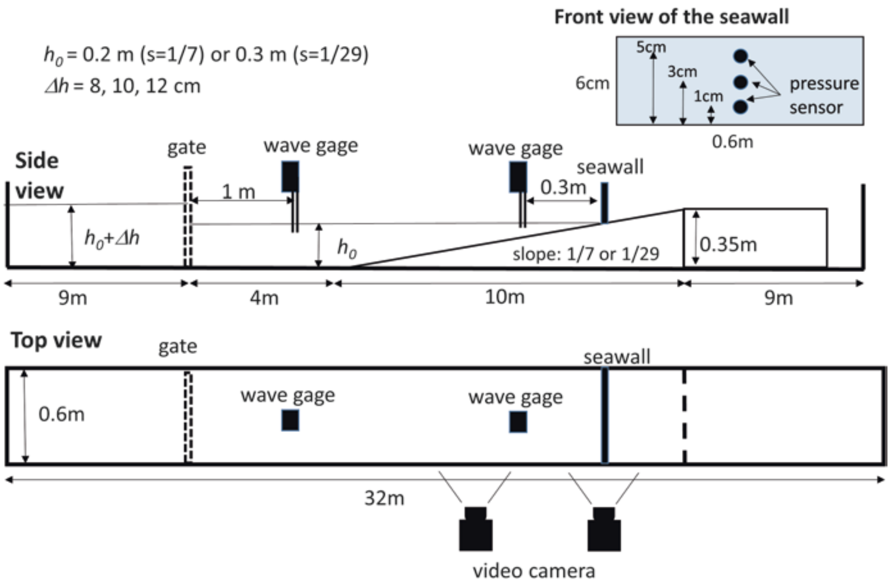

Fig. 24.2 Experimental layout details

offshore side. The profile of the incident tsunami was varied by adjusting the water depth h_0 (=0.2 m for s = 1/7 and =0.3 m for s = 1/29) of the flume, the water level difference Δh (=8, 10, 12 cm), the speed of the gate operation and the opening of the gate. The speed of the gate opening was controlled by the oil pressure of the system. The tsunami profile was measured by wave gages installed 1 m from the gate and 0.3 m from the shoreline. We firstly examined the formation of bores. The number of experimental runs was 17 for s = 1/7 and 40 for s = 1/29. Then the tsunami pressure to the seawall was measured for 18 runs with s = 1/29.

24.2.1 Formation of Breaking Bores

Breaking bores were formed when the front face of the incident tsunami was steep enough. Figure 24.3 illustrates a schematic diagram of tsunami profile measured at the offshore wave gage. The height $\Delta\eta$ of the incident tsunami and the time Δt for the water level rise were estimated from the offshore wave gage for every run of experiments. The time Δt was then converted to the horizontal distance Δx by the following equation based on the long wave theory:

$$\Delta x = \Delta t \times \sqrt{gh}$$

where h is the average water depth at the tsunami front defined by

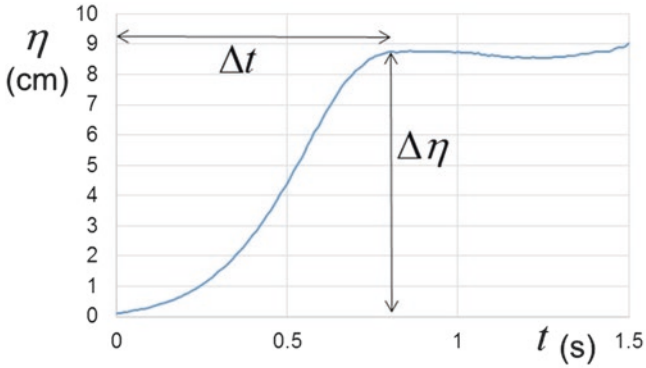

Fig. 24.3 Schematic diagram of incident tsunami profile recorded at the offshore wave gage

$$h = h_0 + \frac{\Delta\eta}{2}$$

The slope of the incident wave front $\Delta\eta/\Delta x$ was then estimated for every run of experiment. The still water depth h_b at the breaking point was estimated from the horizontal location of the breaking point identified from the video taken through the glass side wall.

Figure 24.4a, b shows the relationship between the breaker depth normalized by the incident tsunami height $h_b/\Delta\eta$ and the front slope $\Delta\eta/\Delta x$ of the incident tsunami. Marks 'x' represent for runs in which no bores were formed. For steeper slope (s = 1/7, Fig. 24.4a), bores were observed only on the offshore flat bed. No bores were developed when $\Delta\eta/\Delta x < 0.04$. On the other hand, for milder slope (s = 1/29, Fig. 24.4b), bores were observed on the slope as well as on the flat bed. The critical wave steepness for the bore formation on the milder slope was $\Delta\eta/\Delta x < 0.005$, which is one order of magnitude smaller than that for the steeper slope. It is confirmed that the formation of bores is dependent on the slope of incident wave front and that bores are more likely to be formed on milder beach slope. This is consistent with Goda (1975)'s analysis of periodic wave breaking which demonstrated smaller breaker height for milder slopes.

24.2.2 Pressure to Seawalls

A vertical seawall with height 6 cm was situated at the shoreline where wave pressure due to tsunami was measured by three pressure sensors installed at z = 1, 3, 5 cm from the bed. The sampling frequency of the pressure was set at 100 Hz since we confirmed the maximum pressure unchanged for higher sampling frequency.

Figure 24.5 illustrates a schematic diagram of typical tsunami profile and pressure variations observed at the wave gage 0.3 m seaward of the seawall. The pressure

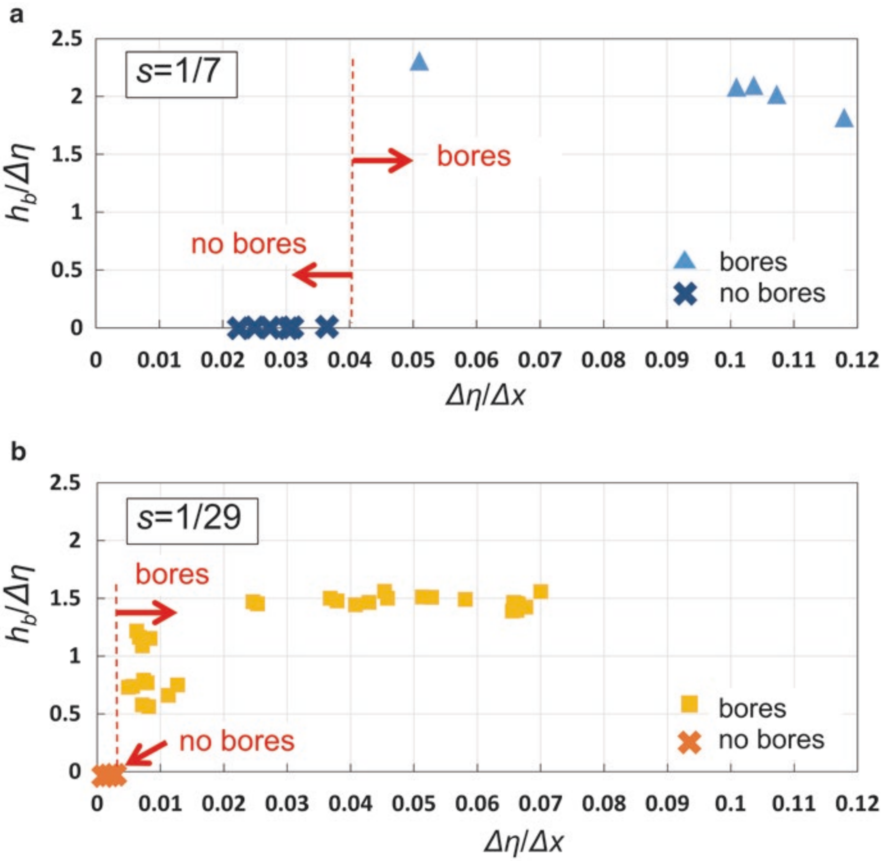

Fig. 24.4 (**a**) Relationship between the breaker depth and the front slope of incident tsunami; steeper slope. (**b**) Relationship between the breaker depth and the front slope of incident tsunami; milder slope

is composed of impulsive pressure with a duration of milliseconds and standing wave pressure with several seconds. The impulsive pressure was observed only when the tsunami formed a breaking bore. Figure 24.6 shows the relationship between the maximum pressure P_s due to the standing wave and the front slope $\Delta\eta/\Delta x$ of the incident tsunami. The pressure is normalized by the static pressure at the corresponding level due to the maximum water level. It is noticed that the maximum standing pressure is in the range from 1.0 to 1.5 times the corresponding static pressure. No dependency on the front slope is observed. The average pressure was estimated by 1.3 times the corresponding static water pressure.

Figure 24.7 illustrates the relationship between the maximum impulsive pressure P_i at $z = 1$ cm from the bed and the slope $\Delta\eta/\Delta x$ of wave front.

The impulsive pressure is normalized by the static water pressure corresponding to the maximum height of the progressive wave (see Fig. 24.5) since Asakura et al.

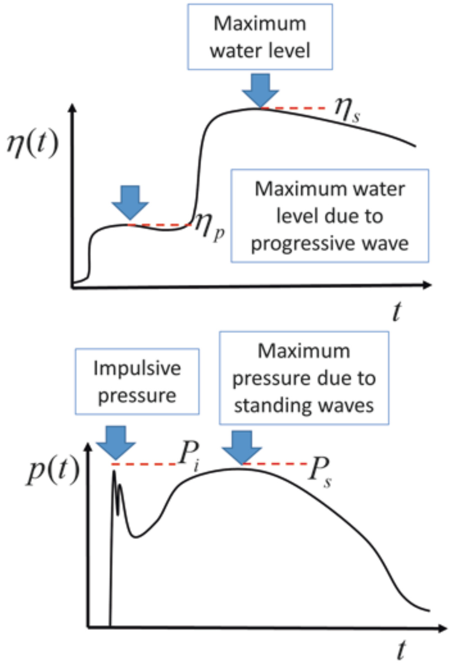

Fig. 24.5 Definition sketch of water level and pressure variation

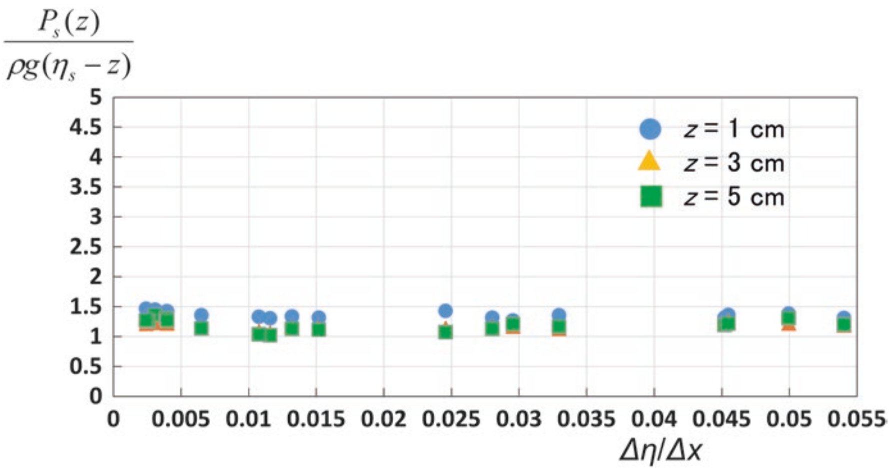

Fig. 24.6 Relationship between the maximum standing pressure and the slope of wave front

(2000) showed that the maximum impulsive pressure to a vertical wall can be three times as large as the hydrostatic pressure corresponding to the progressive wave. In contrast to the standing pressure, the maximum impulsive pressure was found to increase with $\Delta\eta/\Delta x$ until it reached three to four times as large as the hydrostatic

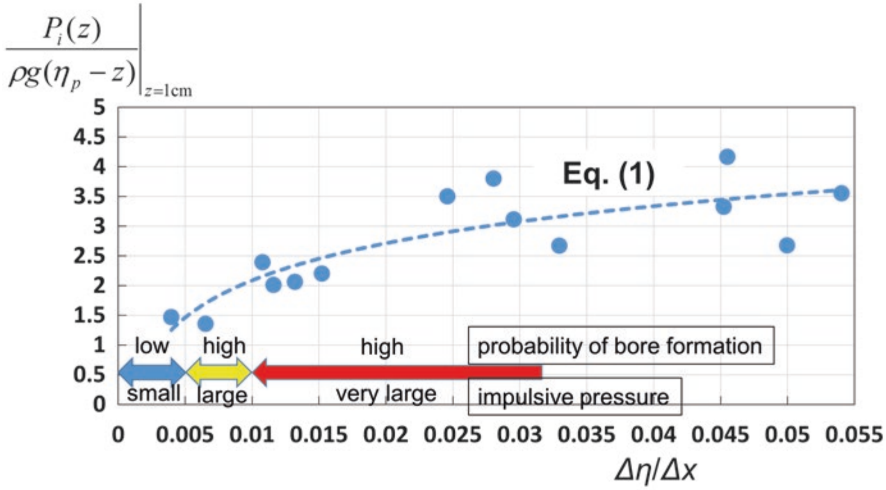

Fig. 24.7 Relationship between the maximum impulsive pressure and the slope of the wave front

pressure. The regression analysis yields the relationship expressed by the following equation:

$$\left.\frac{P_i(z)}{\rho g\left(\eta_p - z\right)}\right|_{z=1\text{cm}} = 2.1\log_{10}\frac{\Delta\eta}{\Delta x} + 6.2 \tag{24.1}$$

which is consistent with Asakura et al. (2000) when the slope of the wave front is in the range from 0.03 to 0.055. The ratio of the maximum impulsive pressure to the hydrostatic pressure decreases when the slope of the wave front is smaller than 0.03. The reason why the impulsive pressure becomes larger for steeper slope of incident wave front appears to be due to the large vertical acceleration developed in steep waves. The dependency of wave steepness on the flow structure in front of the seawall and thus on the large pressure exerted by bores is also confirmed in large-scale flume experiments conducted by Kihara et al. (2015). Such large pressure due to bores is observed in laboratory experiments by Asakura et al. (2000) and Arikawa et al. (2005). The 2011 Tohoku Tsunami is known to form a breaking bore in the central part of the Fukushima Prefecture as recorded in many videos as shown in Fig. 24.1. Sanuki et al. (2013) and Sato and Ohkuma (2014) investigated the massive destruction of seawalls there in relation to the flooding tsunami behaviour.

24.3 Numerical Simulation of Tsunami Propagation in Fukushima

Numerical simulation of tsunami propagation was conducted on the basis of the long wave equations. Tsunami source of Satake et al. (2012) was assumed. Tsunami propagation in deep water was calculated by the linear long wave equations in the global coordinate. The domain of the computation was from 140 to 146° in the eastern longitude and from 34 to 42° in the northern latitude. The grid size was 0.005° and the time step was 1 s. The total duration of the computation was 180 min from the earthquake. Nearshore and inland tsunami behaviour was computed by the non-linear long wave equations in the Cartesian coordinate in smaller domains situated in seven nearshore areas. The size of the domains was 20–40 km in north to south and 20–30 km in east to west. The time step was 0.1 s and the smallest grid size was in the range from 2 to 10 m. The numerical integration was conducted by the leap frog scheme. Additional mixing term due to breaking wave was not introduced. The topography were assumed from the bathymetry data of the Japan Oceanographic Data Center and the airborne laser profiler data obtained by the Ministry of Land, Infrastructure, Transport and Tourism before the 2011 earthquake.

We estimated the slope of the tsunami front from the profile of the surface elevation at 100 m offshore from the shoreline. The slope of the tsunami front was estimated for the largest and the second largest tsunamis by calculating the spatial slope in 40 m east to west horizontal distance. The larger slope was used in the following analysis. The east-west direction represents the cross-shore direction since the tsunami is incident from the east. Then the formation of breaking bores was judged from the slope of the wave front by using Fig. 24.4b. The ratio of the maximum impulsive pressure was estimated by using Eq. 24.1. It is noted however that the laboratory experiments were conducted only with slopes of 1/7 and 1/29 for a single tsunami. In the field, however, the actual bed slope in the nearshore area is about 1/50 and the effect of the preceding tsunami must be considered since the largest tsunami was mostly observed as the second or the third waves. The milder bed slope and the receding flow due to the preceding waves appear to decrease the critical slope of the wave front for the bore formation. By keeping this in mind, we attempted to classify the effect of bores in terms of $\Delta\eta/\Delta x$ as illustrated in the bottom of Fig. 24.7, that is, the formation of bores is highly probable for $\Delta\eta/\Delta x > 0.005$ and the maximum impulsive pressure is very large when $\Delta\eta/\Delta x > 0.01$, large for $0.005 < \Delta\eta/\Delta x < 0.01$ and small for $\Delta\eta/\Delta x < 0.005$.

Figure 24.8 shows the alongshore distributions of the largest tsunami water level (solid line) and the slope of the largest wave front (bars). It is noticed that both the tsunami level and the slope of wave front are large in the central part of Fukushima, which is consistent with Sato et al. (2013) which showed the large tsunami height developed in the central part of the Fukushima by the offshore bathymetry. The large tsunami height and the steep wave front suggest critical impacts in terms of flooding water level and tsunami force on structures. The slope of the wave front is

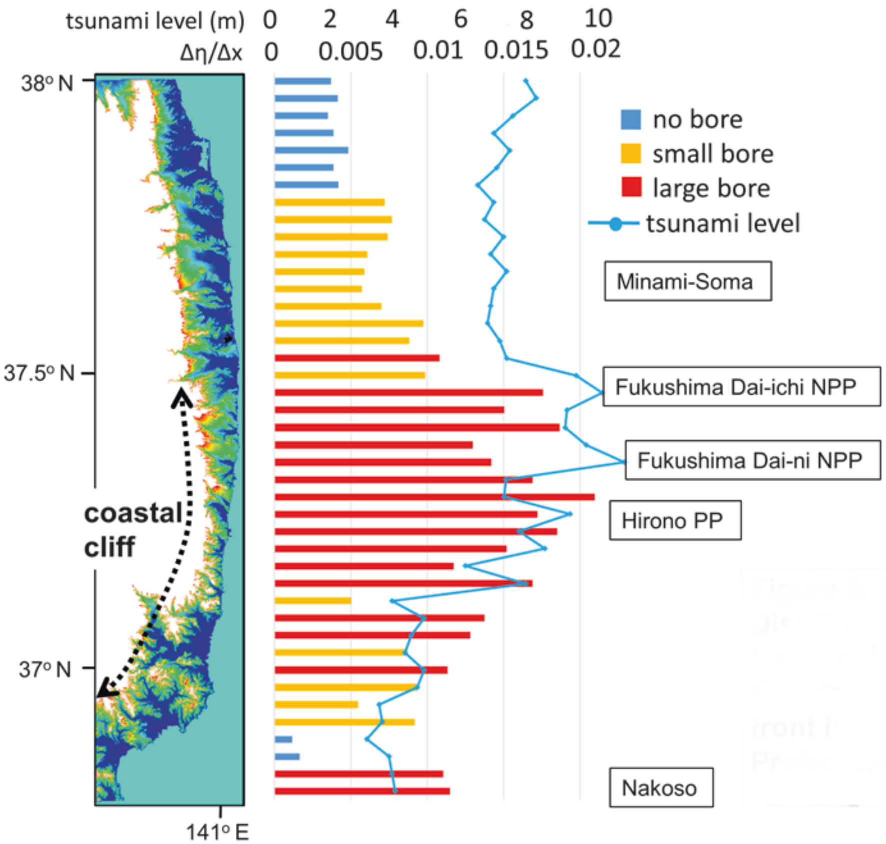

Fig. 24.8 Distributions of the tsunami level and the slope of wave front in Fukushima Prefecture

smaller in the area north to the Fukushima Dai-ichi Nuclear Power Plant although the tsunami level is as large as 7–9 m.

In order to understand the difference in tsunami properties observed in Fig. 24.8, we investigated the nearshore tsunami behaviour in the small computation domain including the Fukushima Dai-ichi Power Plant. Figure 24.9 shows the snapshots of tsunami level about 50 min after the earthquake when the largest tsunami approached to the domain. Time lag between the two figures is 65 s. Significant tsunami reflection is noticed in the southern area where coastal cliff is dominated. The height of the coastal cliff is about 20–40 m. On the other hand, in the northern area where a small plain is dominated, tsunami reflection is insignificant since the preceding tsunami develops flooding into inland. Such difference in the reflection may influence the deformation of the succeeding tsunami to develop different slope of the wave front.

Figure 24.10 shows the distribution of the slope of the water surface. The red zone represents steep slope facing the shore and the blue zone represents steep slope facing the offshore. It is confirmed that the steep slope of the wave front is devel-

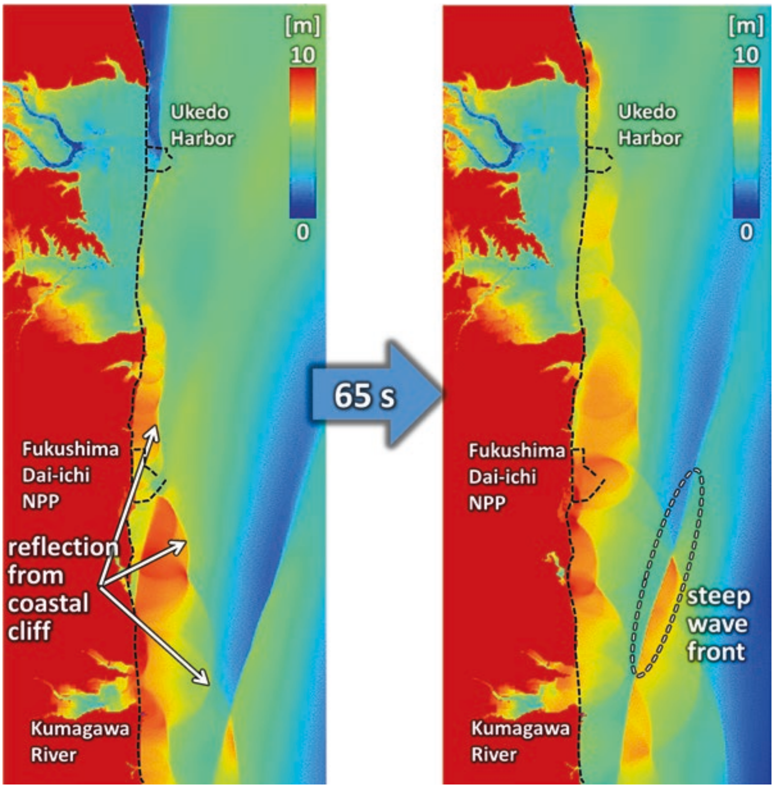

Fig. 24.9 Snapshots of the tsunami level around the Fukushima Dai-ichi Nuclear Plant (about 15:35 pm, March 11, 2011 JST)

oped in the offshore area of the Fukushima Dai-ichi Power Plant where reflection wave from the coastal cliff is dominant. It is suggested from Figs. 24.8, 24.9, and 24.10 that the formation of the breaking bore as well as the generation of the large impulsive pressure are highly probable in front of the coastal cliff where the slope of the incident tsunami can be increased as a result of the interaction with the reflected tsunami. The influence of the preceding tsunami is also reported by Tadepalli and Synolakis (1994) in which the runup height of the tsunami is increased when the negative tsunami preceded. The large tsunami height developed by the offshore bathymetry and the steep slope of the wave front enhanced by the interaction with the reflected tsunami from the coastal cliff must have enhanced the formation of the breaking bore and thus increased the tsunami force to coastal structures.

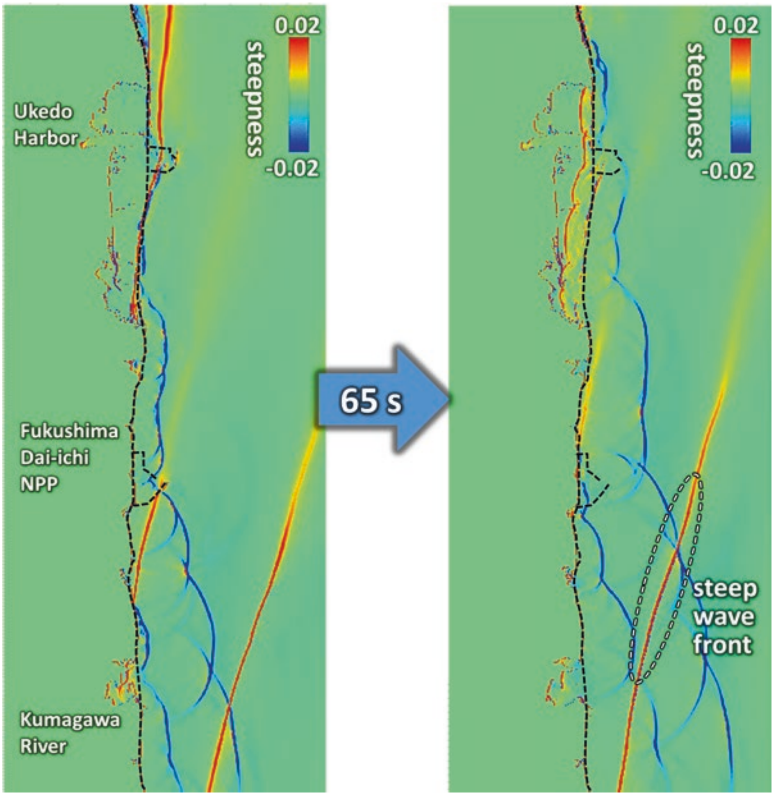

Fig. 24.10 Snapshots of the slope of the tsunami around the Fukushima Dai-ichi Nuclear Power Plant (about 15:35 pm, March 11, 2011 JST)

24.4 Conclusion

Laboratory experiments showed that the angle of the tsunami front was an essential parameter for the generation of breaking bores. Larger impulsive wave force was observed as the angle of the tsunami front became steeper. Numerical simulation revealed that such a steep tsunami was likely to be developed in the central part of Fukushima Prefecture, where the reflection of the preceding tsunami by coastal cliff appeared to enhance the steepness of the largest tsunami. It is therefore important to consider the steepness of the tsunami front in addition to the tsunami height and to pay attention to large impulsive pressure to coastal structures in these areas.

Acknowledgements A part of this study is financially supported by the GRENE Project, Ministry of Education, Culture, Science and Technology, Japanese Government.

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Chapter 25
The Role of Tsunami Engineering in Building Resilient Communities and Issues to Be Improved After the GEJE

Fumihiko Imamura, Anawat Suppasri, Shosuke Sato, and Kei Yamashita

Abstract Twenty five years have passed since the Tsunami Engineering Laboratory (TEL) was founded in 1991 after the re-establishment of the Disaster Research Group at Tohoku University, Japan. The TEL contributes to the safety of society and coastal communities by improving tsunami knowledge and technology and reducing damage, particularly in tsunami-prone regions. In 2010, the Japanese government reported an earthquake and tsunami probability of 99 % within 30 years at Miyagi in the Tohoku region. The TEL initiated a collaboration between residents, the local government and experts regarding tsunami engineering, forming the group who established countermeasures such as evacuation drills based on hazard maps, disaster planning, structural construction countermeasures and offshore tsunami observations using GPS sensors for the targeting earthquake and tsunami. Nevertheless, eastern Japan, particularly the Tohoku region, was hit by a massive M = 9.0 earthquake in 2011. The earthquake named the 2011 Great East Japan Earthquake (GEJE) generate a huge tsunami that caused large-scale damage to the eastern coast of Japan and resulted in an inundation area of more than 500 km^2 due to destructive wave forces. The Sanriku area was considered to be well prepared for tsunami disasters based on past damage experiences. However, following the 2011 tsunami, several issues need to be addressed. Researchers must determine why the large destruction occurred, what unrecognized factors contributed to the high vulnerability of the exposed area that must be reconstructed, and how the tsunami risk can be reduced in each region in the future. Reconstruction safety levels 1 and 2, which include comprehensive countermeasures related to creating tsunami-resilient communities, are just one example discussed in this study. The findings and issues also noted in this study will be valuable in improving future damage assessments in other high-risk areas throughout Japan such as the Nankai trough, and other tsunami-exposed coastal areas in the world.

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V. Santiago-Fandiño et al. (eds.), *The 2011 Japan Earthquake and Tsunami: Reconstruction and Restoration*, Advances in Natural and Technological Hazards Research 47, DOI 10.1007/978-3-319-58691-5_25

Keywords Tsunami engineering • Reconstruction • Hazard level 1 and 2 • Numerical simulation • HPCI simulation

25.1 Introduction

The Disaster Control Research Center (DCRC) at Tohoku University was established in 1990 by combining the Experimental Station of Earthquake Structures and the Experimental Station of Tsunami into one center with two laboratories: the Earthquake Engineering Laboratory (EEL) and the Tsunami Engineering Laboratory (TEL). In April 2000, the DCRC was re-started with three laboratories that were combined into the Disaster Potential Research Laboratory (DPR). The purpose of the center is to study the scientific principles underlying earthquakes, tsunamis and floods and to apply that knowledge to disaster control, i.e., minimizing damage by changing our activities, behaviors and awareness. The TEL is one of leading laboratories in the world, specially focusing on studies of tsunamis from an engineering point of view. In addition to studying modern and ancient tsunamis through field surveys and analysis of historical documents, the TEL has developed a numerical simulation of tsunamis, which is currently being used to develop highly accurate quantitative tsunami warnings and design characteristics of waterfront structures. The International Union of Geodesy and Geophysics (IUGG) and the Intergovernment Ocean Committee (IOC) joint project have conducted hazard and risk assessment using numerical simulations for tsunami-prone countries for the International Decade for Natural Disaster Reduction (IDNDR). The DCRC at Tohoku University, Japan, has acted as the center for the Tsunami Inundation Modeling Exchange (TIME) and transferred numerical techniques of tsunami simulation to countries that have experienced or may experience tsunami hazards. In 1997 the Manuals and Guides No. 30a was published by UNESCO/IOC (1997). This was the first effort to share tsunami modeling expertise and training throughout the world. As of January 2016, more than 48 institutes, in 24 countries including Japan obtained the computer programs and manuals developed and prepared by the DCRC through mail or direct training.

Not only numerical simulations but also field surveys are essential to investigate tsunamis at each region. Since 1992, when the Nicaragua and Flores Island (Indonesia) earthquakes and tsunamis occurred, the international tsunami community, specifically, the International Tsunami Survey Team (ITST), has conducted many field investigations immediately after the events. The included Nicaragua as well as Flores Island in 1992; Okushiri Island, (Japan) in 1993; East Java (Indonesia) in 1994; Shikotan Island (Russia) in 1994; Mindoro Island (Philippines) in 1994; Irian Jaya (Indonesia) in 1996; Indian Ocean in 2004; and GEJE in 2011 (Yeh et al. 1993; Synolakis et al. 1995; Imamura et al. 1997). Members of ITST need to decide that a field survey is necessary as soon as possible to try and determine the true value of the maximum run-up and to make accurately map the run-up distribution along the coast. Subsequent investigations by international and locally based scientists include onshore investigations by international teams (the First and Second International Tsunami Survey Teams; Kawata et al. 1999). Additionally, as part of the services provided by ITST, it has advised governments and survivors about coastline safety.

In 2011, the Tohoku region in Japan was hit by an earthquake (off the Pacific Coast of Tohoku, Japan, on March 11, 2011), which was followed by a huge tsunami that caused considerable damage to the eastern coast of Japan and other areas. Moreover, the Fukushima Nuclear Power Plant No.1 serious accident was in caused by the tsunami inundation in this facility. The event impacted the global supply chain that is a system of organizations, people, activities, information, and resources involved in moving a product or service from supplier to customer. The tsunami run-up height reached over 39 m in Sanriku, which was higher than any previous recorded run-up height (Mori et al. 2012). Historically, northeastern Japan has been hit by tsunamis that caused serious damage; therefore, the area has increased its tsunami preparedness, such as structural countermeasures and non-structural measures of awareness and education regarding earthquakes and tsunami mitigation, over a long-term period (Suppasri et al. 2013b), which however proved not be enough to mitigate the damage due to GEJE with the low frequency and high impact.

Having experienced the catastrophic disaster in 2011, Tohoku University founded the International Research Institute of Disaster Science (IRIDeS) in 2012 based on the interdisciplinary fields of natural, human, social and medical sciences for disaster risk reduction. The TEL is an integral part of IRIDeS. Together with collaborating organizations from many countries with broad areas of specialization, IRIDeS conduct world-renowned research on natural disaster science and disaster mitigation. Based on the lessons from the 2011 Great East Japan (Tohoku) earthquake and tsunami disaster, IRIDeS aims to become a world center of the study of these disasters and disaster mitigation by learning from and building upon past lessons in disaster management from Japan and around the world. IRIDeS will contribute to ongoing recovery/reconstruction efforts in affected areas, conduct action-oriented research, and pursue effective disaster management to build sustainable and resilient societies. IRIDeS will use previous research on catastrophic natural disasters from Japan and around the world to become a foundation of disaster mitigation management and science. The lessons learned regarding tsunami engineering could be summarized as follows:

- Risk evaluation and communication are important for disaster mitigation at the community level
- Emergency operation systems should be constructed prior to disasters
- Emergency communication, disaster information and management plans, including those of the tsunami warning system, should be conveyed in real time
- A new disaster mitigation plan for the twenty first century should be created based on the lessons learned from the past tsunami and hazard events including the GEJE.

25.2 Contribution to the Reconstruction and Classification of Tsunami Safety Levels

25.2.1 Damage Caused by the 2011 Tsunami and the Reconstruction Plan

The 2011 tsunami caused nearly every imaginable type of tsunami damage, including the destruction of coastal structures, tide/tsunami controls, forests, houses, buildings, and infrastructure due to flooding; topographical changes due to erosion and sedimentation; carrying rubble, offshore aquacultures, and ships to sea; spilling flammable materials that caused fires; damaging transportation networks such as roads and railways (including rolling stock); and affecting facilities such as nuclear and thermal power plants. We have obtained the results of field surveys, numerical simulations and satellite image analyses based on ground truth data to determine the extent of tsunami inundation and damage. Notably, seawalls and other protective structures had been constructed along the coast in Tohoku. Although the level of preparation/construction differed by region, we at IRIDeS must evaluate what role these measures played in reducing damage from the tsunami and their limitation as well. In addition, some robust structures, such as reinforced concrete buildings, suffered damage. Detailed investigations are necessary to determine the point in time soon after the tsunami generated when damaged occurred, as well as when the strong quake and liquefaction occurred (Latcharote et al. 2014; 2017).

After the GEJE, recovery/reconstruction are not only required in affected areas but also at the national level at which a general system for the development of tsunami-resilient communities should be discussed. In June 2011, the reconstruction plan was proposed by the Cabinet Office of the Japanese government (2011) and the Minister of Land, Infrastructure, Transport and Tourism (MLIT). The plan included relocation, on-site aggregation, raising land, on-site defense facilities and combinations of these strategies, as shown in Fig. 25.1. Five mitigation and land readjustment strategies have emerged as local requirement for destination of inundation zones and disaster area relocation zone:

(a) Relocation of residents and household to higher ground within the local authority area.
(b) Relocation and aggregation of existing housing units within the existing neighborhoods and the construction or heightening of sea walls in areas affected by the tsunami
(c) Raising land adjacent to low-lying areas and the strengthening of sea defense.
(d) A combination of the relocation of households and land rising.
(e) Repair of essential infrastructure allowing people to remain on the areas.

TEL at Tohoku University provided the expertise regarding past tsunami mitigation in Tohoku and damage data from 2011 GEJE, in addition to the numerical method used to estimate inundation areas under several scenarios for planning in each region. Finally, the MLIT published the guide to determining the potential

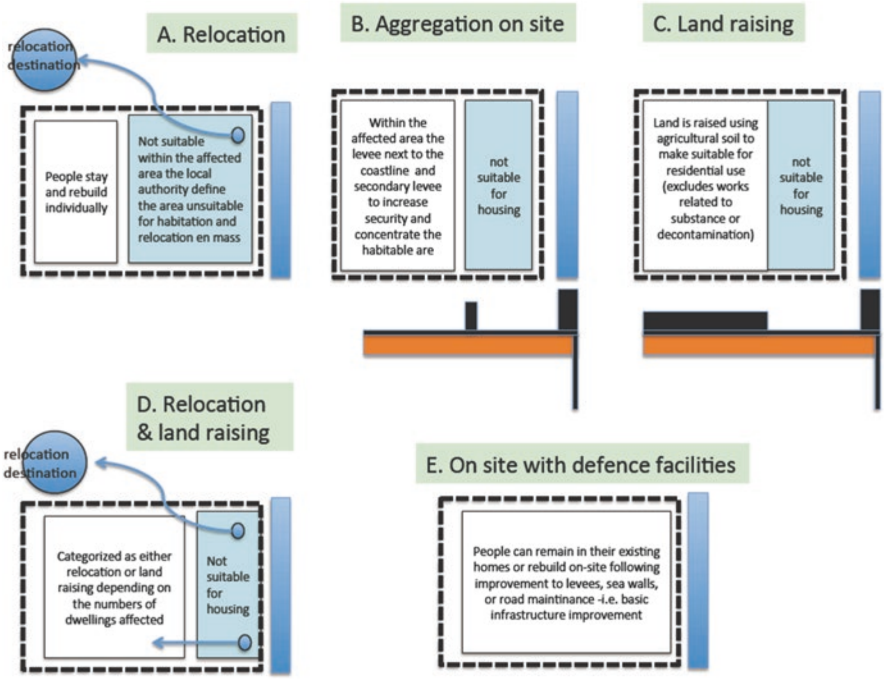

Fig. 25.1 Reconstruction plan for the each area; type (A)-(E), by MLIT (2012)

tsunami inundation (MLIT 2012), which was created with the help of tsunami experts.

25.2.2 Tsunami Level 1 and 2 for Tsunami Countermeasures

The Japanese government established guidelines for reconstruction based on the concepts of 'multiple defense' and tsunami hazard levels, which were used to build a disaster-resilient community (Cabinet office 2011). The guidelines were implemented as Act No. 123/2011, which mandated tsunami safety and required local governments to simulate the impacts of massive tsunamis when developing zoning policies. As the implementation of this concept, two types of areas have been proposed. Tsunami level 1 (structural protection) was defined as a high frequency but low impact level with a return period of 50–150 years. Tsunami level 2 (comprehensive countermeasure including evacuation) was defined as a low frequency but high impact level with a return period of more than several hundred or thousand years. Details of both levels are provided in Table 25.1.

The improved design of physical structures will minimize the impacts of tsunamis and save human lives and property in tsunami level 1 area. In tsunami level 2

Table 25.1 Levels of tsunami countermeasures

Tsunami level 1	Aim to ensure the protection of human lives, assets, national land at coast etc. against relatively frequent tsunamis (once every several decades or century) based on construction of coastal protection facilities
Tsunami level 2	Aim to prevent as much damage as possible at maximum tsunami levels by "integrated protection" that combines structural and non-structural measures such as land use regulation, building codes and emergency/evacuation procedures

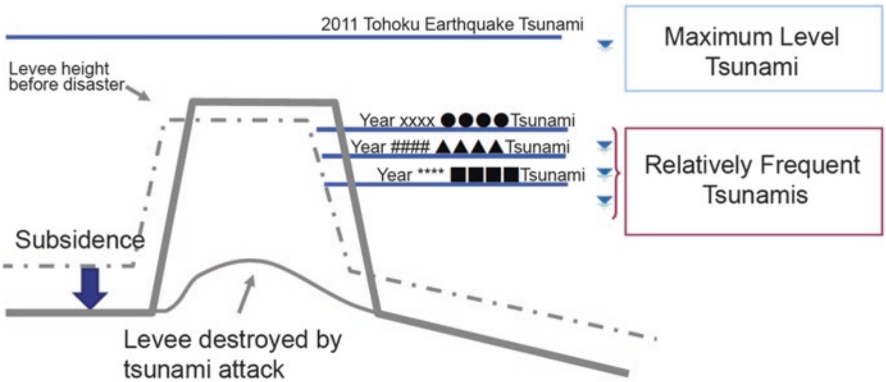

Fig. 25.2 Seawall/levee designs for levels 1 and 2 by using historical tsunami data and adding change of ground sue to an earthquake

areas, because the flood area is generally much larger, improvements to evacuation strategies and education are the major efforts suggested to save lives. Based on these two levels, reconstruction plans have been established in affected areas, including the design of seawalls and installation of breakwaters. Local governments determine the level, including the associated inundation, using numerical simulations based on historical tsunami data in each area.

The height of tsunami for Level 1 can be evaluated using the historical relatively frequent tsunamis in each target area. The height of a seawall/levee should be determined at the shoreline in level 1 areas and modified based on the subsidence due to the earthquake, environment, utilities, and landscape as shown in Fig. 25.2. The modifications of the heights are not unified because of many factors to be included. Therefore, local government must discuss it with the residents, government, experts and NGOs/NPOs to obtain the agreement in each community. It takes more time than the central government expected to obtain the agreement and make decisions because of divergence of discussions for the reconstruction in each community.

As of January 2016, 19 % of seawalls had been constructed along the 3,200 km coastline in the affected area of Tohoku, and 78 % were under way. However, 3 % were under discussion because agreements had not been reached between the residents and local government regarding the level 1 determination (Miyagi prefectural government 2016). In August 2016, the Miyagi prefectural government decided to revise the level 1 at Matsushima Bay from 3.3 to 2.1 m based on the recommendations of an academic advisory group that included TEL members. The group re-examined historical and 2011 tsunami data and performed numerical simulations to estimate the tsunami height in the area.

25.3 New Act for Tsunami-Resilient Communities

25.3.1 New Act and Guide for the Future

Preparing for a large-scale tsunami, such as the one induced by the 2011 event, requires a continued effort to develop tsunami-resilient communities with multiple protection strategies, such as combining both structural and non-structural measures. These efforts must be based on the concept of "disasters have no limit" and the priority of saving people's lives at all costs (Cabinet office 2011). Tsunami-resilient communities must be developed not only via the reconstruction of affected areas but also at the national level. This has led to the establishment of a general system for the development of tsunami-resilient communities, namely, the Act on the Development of Tsunami-resilient Communities (Act No. 123 of 2011).

Article 8, paragraph 1 of the Act on the Development of Tsunami-resilient Communities requires prefectural governments to determine the potential tsunami inundation, i.e., the area and depth of inundation deemed likely to result from a future tsunami, using numerical modeling based on UNESCO/IOC (1997) Manuals and Guides No. 30. The source, propagation and run-up processes of the 2011 tsunami were included in the guide (MLIT 2012). Paragraph 2 of the article states that prefectural governments may, when determining the potential tsunami inundation, ask the MLIT for information, technical advice, and other types of necessary support. Based on the abovementioned goals, this guide can be used as a reference to enable prefectural governments to determine the potential tsunami inundation. Since the guide will be updated as necessary with the participation of tsunami experts, the latest version and latest data should be used, and tsunami phenomena should be included in the guide to conduct analyses in a flexible and appropriate manner.

On July 6, 2011, the Panel on Infrastructure Development and the Transport System Subcommittee of the Panel on Transport Policy at MLIT invited TEL experts to present an urgent recommendation concerning the development of tsunami-resilient communities, which recommendation established the importance of future tsunami disaster reduction based on the following principles:

- Expect that a disaster as large as the 2011 GEJE as unexpected in the past can occur, and employ all structural and non-structural measures to mitigate such a disaster, with priority given to protecting human lives at all costs;
- Ensure that daily tsunami countermeasures are continued based on the concept of "disasters have no limit";
- Move from single-line protection using coastal levees, etc., to multiple protection strategies that use various structural and non-structural measures; and

Table 25.2 New acts and amendments supporting and strengthening tsunami countermeasures after the 2011 GEJE

2011	Act on the Promotion of Tsunami Countermeasures (No. 123)
	Act on the Development of Areas Resilient to Tsunami Disasters
2012	Amendment of the Disaster Countermeasures Basic Act
	Act for Establishment of the Nuclear Regulation Authority
2013	Amendment of the Disaster Countermeasures Basic Act
	Act on Reconstruction from Large-Scale Disasters
	Amendment of the Act on Promotion of the Earthquake-proof Retrofit of Buildings Amendment of the Flood Control Act and River Act
	Act on Special Measures for Land and Building Leases in Areas Affected by Large-scale Disasters
	Amendment of the Act on Special Measures for Promotion of Nankai Trough Earthquake Disaster Management (Amendment of the Act on Special Measures for Promotion of Tonankai and Nankai Earthquake Disaster Management)

considering the use of lowlands, instead of imposing uniform land use regulations, develop a flexible system that considers the safety of a location while reflecting the diverse characteristics and needs of the community and progressing toward the development/maintenance of protection facilities.

Along these lines, the need for developing a new legislative system was emphasized and new acts and amendments started as shown in Table 25.2 in order to mitigate only future tsunami disaster in Japan. The new system should include regulations on land use and building construction that consider, among other things, the expected area and depth of tsunami inundation determined from scientific knowledge, the creation and dissemination of a tsunami hazard map based on this determination, the details of the community, and safety procedures, which is improvement of tsunami countermeasure after the 2011 GEJE. This new disaster mitigation plan for the twenty first century should be created based on the lessons learned from the past tsunami and hazard events.

25.3.2 Tsunami Disaster Zoning Policy

The provisions of the act include the basic principles formulated by the MLIT (2012), the determination of potential tsunami inundation by prefectural governments, the creation of facilitation and land use plans by municipal governments, issues concerning the special measures applicable in areas designated in facilitation plans, matters related to city planning that concern collective facilities for the formation of tsunami-resilient areas, the management of tsunami adaptation facilities, the development of evacuation systems in tsunami disaster security zones, and measures concerning the regulation of certain development and building construction activities in the zones. This is the first policy for the tsunami zoning in Japan.

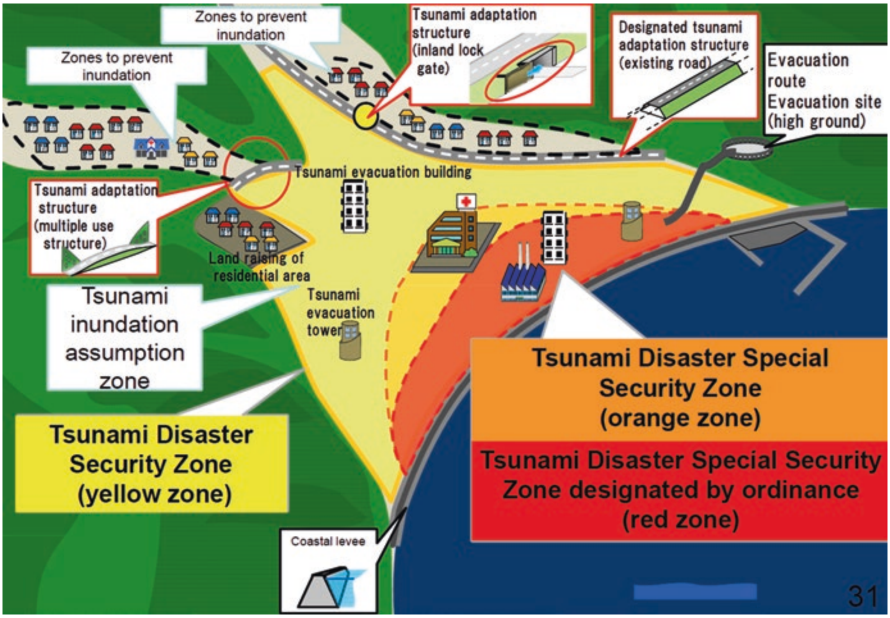

Fig. 25.3 Image of a tsunami-resilient area with zoning policy (MLIT 2012)

The basic guidelines by MLIT request that experts and related NGO should be involved to make advices and evaluate the plan. Tsunami inundation assumption to be set officially by central governments, and promotion plans to comprehensively promote tsunami-resilient area to be prepared by municipalities as local government. Then, "Tsunami Disaster Security Zones" with yellow zone: development of preparedness and evacuation procedures and "Tsunami Disaster Special Security Zones" with orange and red zones: land use regulation to be designated by governments.

The details of each zone on the map as shown in Fig. 25.3 are summarized as follows:

(a) Yellow zone where residents or others could lose their lives or be injured by tsunamis, the development of preparedness and evacuation procedures to escape from tsunamis.
(b) Orange zone where residents or others have high probabilities of losing their lives or being injured by tsunamis. Land use regulations should be done. As example, in hospitals and social welfare facilities, floor level should be above the tsunami water level.
(c) Red zone where people cannot evacuate smoothly or promptly when tsunamis occur, land use regulation are needed to reduce tsunamis damage.

So far the classification of tsunami zoning is done tentatively by tsunami inundation depth referring MLIT (2011) report taking account of tsunami damage and risk estimation. More reliable tool to evaluate the tsunami damage and risk is necessary.

25.4 Developing Numerical Simulations of Tsunamis and Damage Assessment

25.4.1 Recent Developments in Numerical Simulations and Fragility Analysis as a Tool for Zoning

Numerical tsunami simulations have been developed to evaluate tsunami behavior and its inundation, which is essential for the zoning. Many numerical models have been proposed to simulate tsunami wave propagation by applying linear long-wave theory in deep seas and nonlinear long-wave theory in shallow seas. After the 2011 tsunami, numerical tsunami simulations were verified with observed data and employed to investigate tsunami-induced impacts using numerical modeling codes, such as TUNAMI, MOST (Titov and Gonzalez 1997) COMCOT (Liu et al. 1994, 1995), NAMIDANCE (Yalciner et al. 2006), JAGURS (Baba et al. 2014), and NEOWAVE (Yamazaki et al. 2009). This section uses TUNAMI as an example of how a model was developed after the 2011 tsunami. TUNAMI was originally developed by Tohoku University in 1995 for the TIME project, which consisted of the TUNAMI-N1, -N2, and N3 series. For evaluating tsunami inundation for zoning, the tsunami model for simulation among the above listed should be carefully selected.

In the following for classification of tsunami zoning by taking account of tsunami damage and risk, their evaluation due to the future tsunami are needed. Understanding the damage mechanisms of earthquakes and tsunamis is important for evaluating future losses using the fragility damage function. The 2011 tsunami caused damage to various types of coastal properties; fragility analyses of tsunami characteristics such as tsunami height, flow depth and velocity have been performed in the context of human fatalities (Suppasri et al. 2013b) and damage to buildings (Suppasri et al. 2013a, 2015), fishing vessels (Suppasri et al. 2014; Muhari et al. 2015), pine trees and pedestrian bridges (Muhari et al. 2012). The human fatality ratio of the 2011 Tohoku tsunami was compared to those of other historical tsunamis. The fatality ratio on the Sendai Plain coast was as high as that on the Sanriku ria coast, even though the tsunami height on the Sanriku coast was much higher. This shows the importance of evacuations in reducing human losses caused by tsunamis. For buildings, a higher damage probability exists on the ria coast due to higher flow velocities at a given inundation depth. Additionally, Reinforced Concrete and steel buildings performed better than wood and masonry buildings. The performance of buildings with three or more stories is particularly significant. Buildings constructed after 1981 performed slightly better than buildings constructed between 1971 and 1981.

Damage was observed in fishing vessels when the tsunami height was greater than 2 m, and vessels were totaled when the height was greater than 5–10 m depending on the coast and vessels types. Fishery boats that were larger than 5 tons performed better. Tsunami flow depths larger than 2 m caused black pine trees to become inclined. Treetops were broken off when the tsunami depth reached 3–4 m, and trees were uprooted when the tsunami depth was greater than 5 m. Finally, pedestrian bridges were damaged by tsunamis when the flow depth was higher (1.5 times) than the bridge height or when the location of a pedestrian bridge relative to the shoreline was 1/10 of the maximum inundation. The results can be used to support decisions regarding the reconstruction of each topic discussed in tsunami-affected areas.

25.4.2 Sediment Transport Due to Tsunamis

The numerical modeling of tsunami sediment transport has been applied to explain bathymetric changes associated with past events, such as the 2004 Indian Ocean tsunami (Ranasinghe et al. 2013). Numerical models were originally proposed by Takahashi et al. (1999) to investigate tsunami sediment transport during tsunami flow and to explain the process of geomorphological changes. The 2011 tsunami caused massive morphological changes. After the 2011 event, numerical modeling of tsunami sediment transport was performed to investigate how modeled tsunami deposits and erosion corresponded with field observations (Sugawara et al. 2014; Yamashita et al. 2015). Recently, many studies in the sediment transport field have focused on specific aspects of these processes, such as the dynamic behavior of sediment transport and the factors that influence deposition, to improve the sediment transport models. In the sediment transport model, initial wave amplitudes, beach slopes and grain sizes have significant effects on tsunami deposit distribution. An expected ratio between tsunami deposits and the inundation distribution was developed as a way to estimate the inundation areas of future tsunamis by analyzing existing deposits from past tsunamis. In tsunami deposit simulations, forward and inverse modelings are two opposite approaches used to investigate tsunami sediment transport.

25.4.3 HPCI and Real-Time Tsunami Prediction

A high-performance computing (HPCI) technique has been developed to perform numerical tsunami simulations with high-speed calculations and improve tsunami early warning systems. There are two ways to utilize the HPC technique for tsunami early warning systems. The first is to simulate thousands of tsunami hazard scenarios from tsunami-induced sources and then store the resulting database of tsunami inundation simulations. The second is to perform tsunami inundation simulations for real-time tsunami prediction using real-time observational data. In reliable inundation simulations, a large computational time is required to solve nonlinear shallow water equations using high-resolution bathymetrical and topographical data. Therefore, a parallel programming code for tsunami inundation simulations must be implemented using parallel-processing computers. For two examples of parallel programming models, OpenMPI is used to enable parallel processing on Central Processing Units (CPUs), and CUDA is used to enable parallel processing on Graphics Processing Units (GPUs). Before the 2011 tsunami, a high-performance tsunami prediction system using General-Purpose Graphics Processing Units (GPGPU) with the CUDA application was developed based on TUNAMI-N1 using a large data set from a bathymetry file. For further improvement of numerical tsunami simulations, a parallel tsunami inundation simulation was developed and executed on the K computer at the Advanced Institute for Computational Science of RIKEN. The TUNAMI-N2 code was parallelized using a 1D/2D domain decomposition scheme, in which a load balance between the nested domain and the number of partitions in the x and y directions in each domain is a key to achieving high performance in real-time tsunami prediction (Oishi et al. 2015; Yamashita et al. 2015). In addition, accurate real-time prediction with tsunami inundation simulations using massively parallel high-performance computing will be fast enough to inform people of evacuation strategies in the near future (i.e., within 10 min or less). This development is very important in disaster mitigation.

25.5 Conclusions

The TEL is the major research laboratory that investigates tsunamis from an engineering point of view, and it provides relevant knowledge and data to the coastal community to design structures, create hazard maps and plan evacuations. The worst-case 2011 tsunami damage scenario required revised and improved tsunami mitigation plans, which were supported by the Act on Promotion of Tsunami Countermeasures (No. 123), setting up the policy of levels 1 and 2 as protective countermeasures against tsunami hazards. Conventional tsunami countermeasures have focused on the development of structures such as coastal levees/sea walls. Developing greater protection against large tsunamis such as the one experienced in 2011 requires basing the development of tsunami-resilient communities on multiple protection measures that combine structural and non-structural measures, as well as the concept of “disasters have no limit,” with priority given to protecting human lives at all costs. It becomes more important to select the appropriate tsunami policy for disaster risk reduction based on the safety level. Additional discussions and agreements, reliable and applicable numerical modeling including runup process for inundation and damage estimation are required and developed to simulate the multiple behaviors of tsunamis related to quakes, liquefaction, sediment transport, fires and so on.

Acknowledgements Research grant (A) No.17H01631, (B) No.15K06224 and (S) No. 24221010 of the Ministry of Education, Culture, Sports, Science and Technology (MEXT) project provided financial support for this research. We thank Prof. Koji Fujima of the National Defense Academy, who passed away in 2014, for his many helpful comments.

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Part VII
Coastal Modelling and Hazards Prediction

Chapter 26
Evolution of Numerical Modeling as a Tool for Predicting Tsunami-Induced Morphological Changes in Coastal Areas: A Review Since the 2011 Tohoku Earthquake

Daisuke Sugawara

Abstract Extensive datasets of the 2011 Tohoku Earthquake Tsunami, which include offshore records and onshore measurements, spatial distribution of erosion and deposition of sediments, as well as pre- and post-tsunami topography and bathymetry facilitated validation of developing tsunami sediment transport modeling. Case studies from Sendai Plain and Sanriku Coast have revealed detailed processes of tsunami-induced morphological change, and demonstrated the advantage of inclusion of sediment transport modeling to tsunami simulations. Modeling of morphological change is essential for accurate prediction of the inundation area in case topography consists of movable sediments. This paper reviews recent studies regarding the 2011 event and challenges for future research.

Keywords Tsunami • Sediment transport • Morphological change • Tsunami deposit • Numerical modeling

26.1 Introduction

The Mw 9.0 March 11 2011 off the Pacific coast of Tohoku Earthquake generated a gigantic tsunami that struck the Pacific coast of Northern Japan with a maximum height of up to 40 m in Sanriku Coast (Mori et al. 2012) and an extensive inundation more than 5 km in the coastal plain of Sendai Bay (Goto et al. 2012a). The earthquake and tsunami brought a complex disaster, namely the Great East Japan Earthquake, resulting in more than 18,000 deaths and missing, partial or total collapse of 400,000 houses and buildings as well as the fatal accident at the

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V. Santiago-Fandiño et al. (eds.), *The 2011 Japan Earthquake and Tsunami: Reconstruction and Restoration*, Advances in Natural and Technological Hazards Research 47, DOI 10.1007/978-3-319-58691-5_26

Fukushima-Daiichi Nuclear Power Plant (Fire and Disaster Management Agency 2013). The disaster includes erosion and deposition of massive amount of terrestrial and marine sediments and modification of the coastal geomorphology of the devastated areas, such as erosion and breaching of the sandy beaches and retreat of the coastline (Tanaka et al. 2012). Damages to the coastal infrastructure and property related with tsunami-induced sediment transport include ground scouring around coastal facilities such as engineered dikes (Mano et al. 2013), burial of waterways, channels and drainage systems by sediments and soil erosion and sand deposition in farmlands (Goto et al. 2011). Enormous amount of coasts have been expended during the last 5 years on the restoration works in the devastated areas, which include removal of tsunami deposits and debris and recovery of the lands that have been changed to the sea. Considering such post-disaster circumstances, quantitative prediction of tsunami-induced sediment transport and morphological change in the coastal areas will benefit pre- and post-disaster countermeasures, such as implementation of coastal protections and optimization of the restoration plans.

Attempt to predict tsunami sediment transport and morphological change has been taken for during the last two decades by means of coupled numerical models of tsunami propagation, inundation and sediment transport (e.g. Takahashi et al. 2000). The purpose of the numerical modeling is to predict infrastructural damage mentioned above, including bathymetric change of waterways and ports, deposition of sediments on land. The purpose also includes investigation of sedimentary processes of tsunami deposits and estimation of the size of paleotsunamis (e.g. Sugawara et al. 2014a). Researchers have dedicated efforts to improve our understandings on the mechanism of tsunami sediment transport and to enhance ability to predict tsunami-induced morphological change.

Validation is of the primary importance for numerical modeling. Benchmark data of flow depths and speeds, inundation distance, physical property and geometry of sediments are needed to validate the tsunami sediment transport simulations. Tsunamis are in general rare and destructive phenomenon and in-situ observation of tsunami sediment transport and morphological change is practically impossible. Until the emergence of the 2004 Indian Ocean Tsunami (IOT), benchmarks were quite sparse. Post-tsunami field survey of the 2004 IOT provided several benchmarks from Indonesia, Thailand and Sri Lanka (see review in Sugawara et al. 2014a). Comparison of the simulations with the benchmarks demonstrated advantages of the tsunami sediment transport simulations; nevertheless, validation has continuously been the central issue of the research. Uncertainties can be one of the reasons for making model validation difficult. To run numerical models, topography, bed roughness and physical property of sediments are specified as setups. Unconstrained setups likely affect to tsunami hydrodynamics, process of sediment transport, amount of erosion and deposition and morphological change. In particular, pre-tsunami topography and bathymetry data are indispensable for investigating tsunami sediment transport, given that the tsunami caused considerable change in the coastal geomorphology. In most cases, pre-tsunami topographies were poorly constrained (Sugawara et al. 2014a). No validation was made using pre- and post-tsunami topography data, and modeling results likely possessed wide range of uncertainties. With regard to bathymetry data, only two benchmarks were available until 2011 that include both pre- and post-tsunami data, namely the 1960 Chilean tsunami at Kesennuma Bay in Sanriku Coast (Takahashi et al. 2000) and the 2004 Indian Ocean Tsunami at Kirinda Harbor in Sri Lanka (e.g. Ranasinghe et al. 2013).

The emergence of the 2011 Tohoku Earthquake Tsunami drastically changed the situation. In Tohoku, regional data of the pre- and post-tsunami topography has been developed for the purpose of coastal management and emergence survey of the devastated areas (Udo et al. 2012, 2013). Dense field measurements of onshore tsunami height and additional information from the video footages from air and ground have been used for sophisticated validation of the tsunami hydrodynamics (e.g. Hayashi and Koshimura 2013). Onshore and offshore GPS instruments for detecting coseismic crustal deformation and tsunami waveforms provided constraints for the generation mechanism of tsunami (e.g. MacInnes et al. 2013). These groundbreaking data are facilitating researchers to run and validate the numerical models of tsunami inundation and sediment transport. Numerical case studies of the morphological change by the 2011 Tohoku Earthquake Tsunami, which have been published during these 5 years, investigated mechanism of the changes of coastal morphology and formation process and spatial distribution of tsunami deposits (Fig. 26.1 and Table 26.1; Sugawara and Takahashi 2013; Morishita and Takahashi 2014; Sugawara et al. 2014b; Imai et al. 2015; Yamashita et al. 2015). This paper reviews recent studies related to the numerical modeling of the sediment transport related to the 2011 Tohoku Earthquake Tsunami, and discusses further direction for the research. Note that methodological detail of tsunami sediment transport modeling is out of the scope of the present paper. Readers are recommended to follow a comprehensive review in Sugawara et al. (2014a) and references therein.

26.2 Modeling Morphological Changes by the 2011 Tohoku Tsunami

26.2.1 Background

Most numerical models for predicting tsunami-induced morphological change consist of a two-dimensional tsunami hydrodynamic model coupled with a sediment transport model. The nonlinear shallow-water theory is used for the governing equation of the hydrodynamic model. An important input parameter in the hydrodynamic model is bed roughness, which is typically calculated based on the assumption of the Manning's law. Choice of the Manning's roughness coefficient sometimes gives considerable effect to the hydrodynamic simulation, thus it can be a major source of model uncertainties (Jaffe et al. 2016). The sediment transport model is composed of transport formula for either bed- or suspension loads, advection-diffusion equation of suspended sediments and an exner-type equation for calculating morphological change. The sediment transport model requires far more input

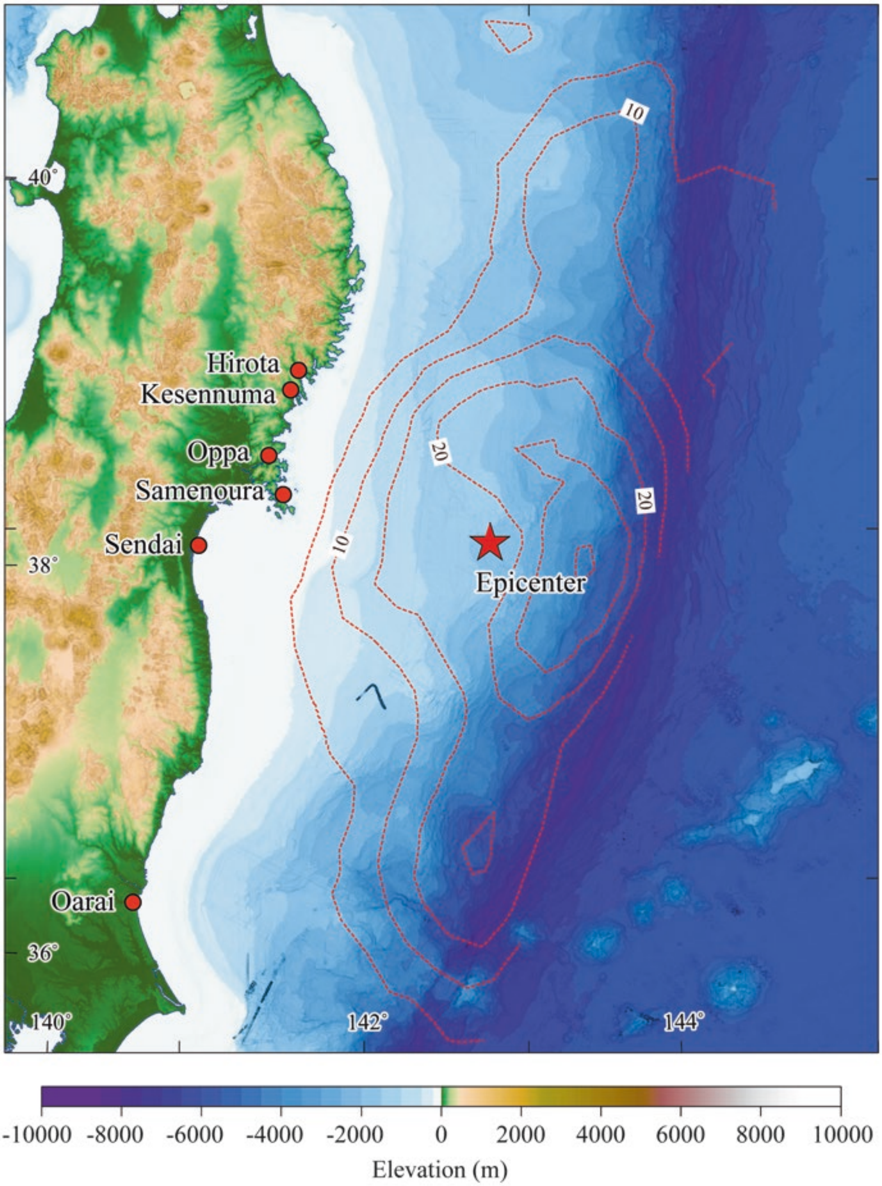

Fig. 26.1 Location map of case studies of numerical modeling of sediment transport and morphological change by the 2011 Tohoku Earthquake Tsunami. *Broken red line* shows the slip distribution of the earthquake estimated by Wei et al. (2012)

Table 26.1 Available benchmarks and case studies of the 2011 Tohoku tsunami

Location	Topography		Bathymetry		Tsunami record	Inundation area	Tsunami height	Flow speed	Video record	Tsunami deposit	References
	Before	After	Before	After							
Hirota Bay	H	H	L	H	✓	✓	✓		✓	✓	Yamashita et al. (2015)
Kesennuma Bay	H	H	H	H	✓	✓	✓	✓	✓	✓	Morishita and Takahashi (2014)
Oppa Bay	H		L	H	✓	✓	✓				Imai et al. (2015)
Samenoura Bay	H	H	L		✓	✓	✓			✓	
Northern Sendai Bay	H	H	L	H	✓	✓	✓	✓	✓	✓	Sugawara and Takahashi (2013) and Sugawara et al. (2014b)
Central Sendai Bay	H	H	L	H		✓	✓	✓	✓	✓	
Southern Sendai Bay	H	H	L	H	✓	✓	✓		✓	✓	
Oarai Port			H	H		✓			✓		Kuriyama et al. (2015)

H high resolution (~5 m), *L* low resolution (~50 m) parameters, such as sediment grain size and settling velocity, as well as choice of the transport formula (Sugawara et al. 2014a; Jaffe et al. 2016). There is variety of methods to measure the grain size and settling velocity. Most transport formulas include empirically-determined coefficients. Thus, the numerical simulation of sediment transport is affected from the choice of these parameters, and it again introduces uncertainties in the modeling.

Availability of topography and bathymetry data is essential to perform and validate sediment transport modeling. High-resolution topography data obtained by light detection and ranging (LIDAR) technique has been more common and it dramatically improved the resolution of tsunami inundation modeling. The LIDAR topography data that covers the Tohoku coasts has a typical resolution of 2–5 m. In Tohoku region, dataset of pre- and post-tsunami topography has been developed for the purpose of coastal management and emergent survey after the tsunami disaster (Fig. 26.1 and Table 26.1). Comparison of the pre- and post-tsunami topography data of Sendai Plain revealed the profound changes in the coastal morphology and quantified the volumes of sediment erosion and deposition (e.g. Udo et al. 2012, 2013). Considering the vertical error of the LIDAR data (typically plus or minus 0.15 m), quantitative assessment of thin (0–30 cm) tsunami deposit should be a difficult attempt (e.g. Sugawara and Takahashi 2013); nevertheless, the comparison of pre- and post-tsunami data that account for the coseismic subsidence has depicted complex spatial pattern of sediment erosion and deposition in Sendai Plain that implies effects from micro-topography, such as coastal dikes, embankments and channels (e.g. Udo et al. 2012; Sugawara and Takahashi 2013). Such results can be compared with tsunami sediment transport simulations (Sugawara and Takahashi 2013).

Pre- and post-tsunami bathymetry data have been obtained from some of the impacted sites of the Tohoku region, such as Sendai, Kesennuma and Hirota Bays (Fig. 26.1 and Table 26.1). For example, in Sendai Bay, bathymetric profiles of shallow sea were measured along survey lines with 0.2–1.0 km spacing. The bathymetric monitoring has been started much earlier than 2011. Udo et al. (2013) analyzed the bathymetry data to estimate tsunami-induced morphological change in the shallow sea. Their results showed local sediment deposition up to 1 m on the sea floor with a water depth of 2–15 m, which can be attributed to offshore transport of sediments by the tsunami backwash. In addition, more than half of the eroded terrestrial sediments were estimated to have been deposited in the shallow sea (Udo et al. 2013). Since sediment erosion and deposition on the sea floor can be much greater than the land, comparison of pre- and post-tsunami bathymetry will benefit quantitative validation of numerical modeling.

Use of appropriate input tsunami waveform is the necessary condition for the validating tsunami sediment transport modeling. In the case of the 2011 Tohoku tsunami, investigation of the tsunami source models are founded on the observation data of the tsunami waveform at many offshore and nearshore buoys, the coseismic crustal uplift or subsidence at tens of hundreds of GPS stations, as well as thousands of tsunami measurements in the inundation area (Mori et al. 2012). Variety of source models of the 2011 Tohoku tsunami has so far been proposed (e.g. MacInnes et al. 2013).

For example, Satake et al. (2013) suggested a model of combined rupture in the deeper and shallower place interfaces, based on inversion analysis of the nearshore and offshore tsunami records. The very deep large slip up to 25 m is responsible for the long wavelength of the tsunami that inundated the coastal plain of Sendai Bay, and the shallow huge slip up to 69 m generated the additional rapid increase of tsunami height in the offshore of Sanriku Coast. On the other hand, Tappin et al. (2014) proposed an alternative explanation for the generation mechanism of the large wave in the offshore of Sanriku Coast. Based on the analysis of seismic, geodetic and tsunami records, they suggested that the large wave was caused by a submarine mass failure in the slope of Japan Trench. The delayed submarine mass failure coincides well with the seismic record that lacks a rupture in the possible source of the large wave and both near- and far-field tsunami observations. Although the generation mechanism of the 2011 Tohoku Earthquake is so far controversial, use of tsunami generation models that simulate observed tsunami waveform near the coast will reduce uncertainty in the tsunami hydrodynamics and sediment transport.

26.2.2 Case Study of Sendai Bay

Sendai Plain is one of the best places to test the tsunami sediment transport simulations, because of the availability of datasets for running the model. In addition, a systematic field survey of tsunami deposits were carried out first in the plain, and many key findings were reported so far (e.g. Goto et al. 2011; Abe et al. 2012). Goto et al. (2012b) addressed two important questions regarding onshore deposits of the 2011 Tohoku Earthquake Tsunami in Sendai Plain; namely (1) limited extent of the sandy tsunami deposits compared with the inundation area and (2) faint marine signature in the onshore tsunami deposits. Sugawara et al. (2014b) investigated these questions by means of the conventional tsunami simulation coupled with sediment transport modeling (Fig. 26.2). Although Sendai Plain possesses natural sandy beaches, there are many artificial topographic features such as coastal dikes, embankments and pavements that limit the movement of sediments. In addition, part of these artificial features was destroyed by the tsunami. Therefore, use of the high-resolution pre-tsunami topography and land cover datasets was essential for detailed comparison of the observation and simulation. The LIDAR data obtained from the coastal area of Tohoku has a typical resolution of 2–5 m, by which most of the topographic features can be included in the model (Table 26.1). Spatial variability of the bed roughness and the extent of the sediment source were determined based on the pre-tsunami aerial photographs. The results of the modeling were compared with the in-situ tsunami deposit data obtained along three different survey lines. Although some of the model parameters, such as the bed roughness and saturation concentration of suspended sediments, had been identified as major sources of uncertainties, appropriate choice of the parameters was determined based on the comparison of the modeling results with the field data of the tsunami deposits.

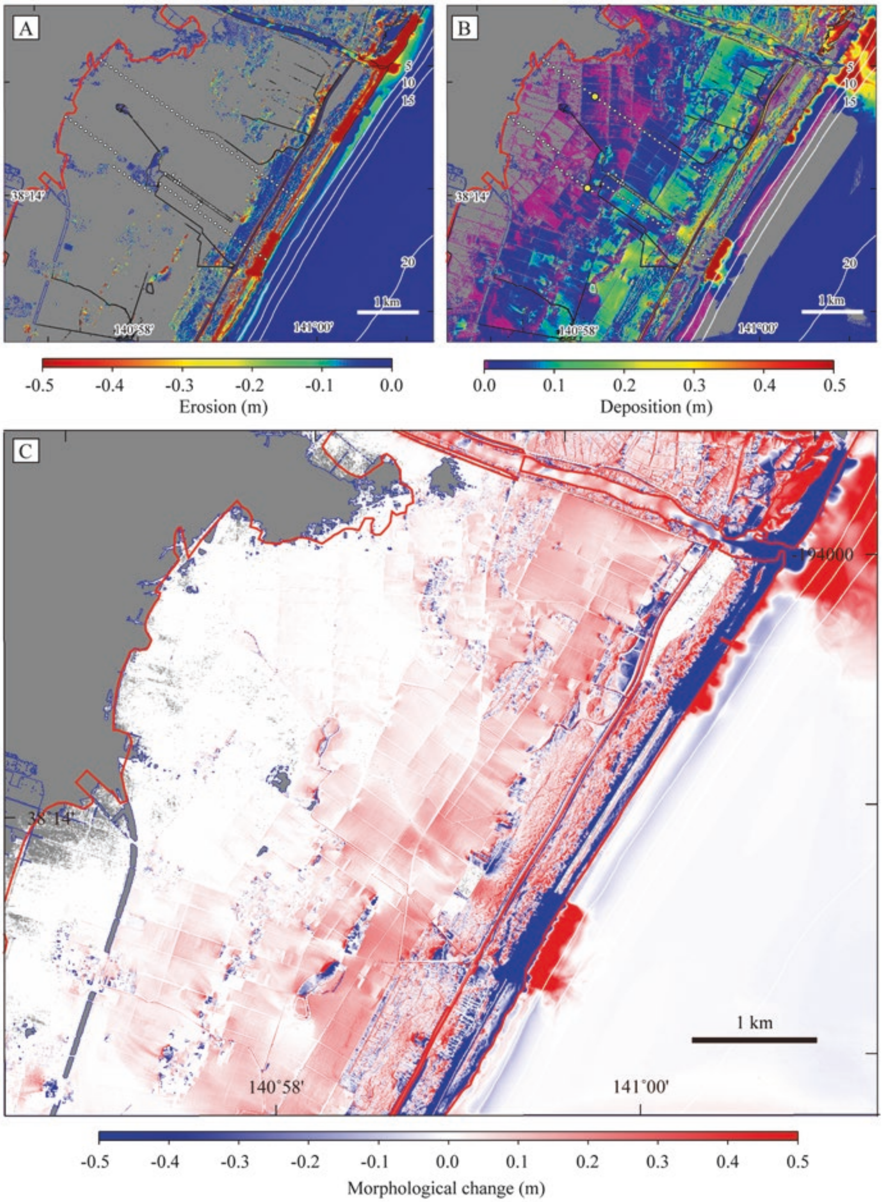

Fig. 26.2 Simulated erosion (**a**), deposition (**b**) and morphological change (**c**) by the 2011 Tohoku tsunami at the northern Sendai Plain (Modified after Sugawara et al. 2014b)

The simulation clearly demonstrated that (1) the coastal dikes limited the supply of sands from the beach to the inland paddy fields and (2) the artificial topography played an important role for limited transport of the sand (Sugawara et al. 2014b). These two factors were identified as important reasons for the gap between inundation area and inland extent of sandy tsunami deposits (Goto et al. 2011; Abe et al.

2012). Minimal marine material in the onshore tsunami deposit in Sendai Plain (Szczuciński et al. 2012) was attributed to the steep shoreface of the beach. The slope of the shoreface of Sendai Plain is around 1/30 and the still water depth increases more than 15 m at 500 m away from the coastline. The height of the main wave of the 2011 tsunami was 10 m on the coastline, thus the flow depth on the 15 m isobath might have been close to 25 m. Assuming that the Manning's law for estimating bed shear is applicable for this case, the flow thickness might have been too large to generate high shear stress to entrain the seafloor sediments. The simulation clearly depicted quite small amount of the seafloor sediments were suspended during the uprush of the first wave (Sugawara et al. 2014b). Faint increase of the entrainment of the seafloor sediments did not coincide with the passing of the tsunami front, and this can be an additional reason for minimal inland transport of marine materials. Assuming the Manning's law, a shallow and fast flow is required to generate high shear stress. Such a flow likely occurs during tsunami backwash, but in the case of the 2011 tsunami in Sendai Bay, the main wave did not accompany precedence backwash. These findings from the numerical modeling demonstrated that tsunami-induced sediment transport and morphological change are largely controlled by combination of topography, bathymetry and incoming tsunami waveforms.

26.2.3 Further Case Studies of Sanriku Coast

In general, higher tsunami run-up generates stronger backwash. The 2011 tsunami in Sanriku Coast ran up higher than that in any other areas (Mori et al. 2012), and the influences from the backwash and following waves are significant. The magnitude of sediment erosion and deposition and morphological change in Sanriku Coast has been found larger than that in Sendai Bay and other places. Recent researches showed that existing numerical models are capable of depicting the sedimentary processes of the 2011 tsunami in Sanriku Coast and predicting erosion and deposition of massive amount of sediments and extensive morphological change. Three case studies have so far been published regarding the tsunami impacts at Sanriku Coast, including Oppa, Kesennuma and Hirota Bays (Morishita and Takahashi 2014; Imai et al. 2015; Yamashita et al. 2015).

Processes of the morphological change in Oppa Bay in the southern Sanriku Coast were investigated by Imai et al. (2015). Oppa Bay has a length of 6 km and a width of 7 km, opening its mouth to the Pacific Ocean in ENE direction. A major river (Shin-Kitakami River) discharges into the bay from the west. A reclaimed land and a sandy beach were developed in the right bank of the river mouth, with a maximum length of 3 km and width of 2 km. The tsunami-induced change in the coastal morphology at Oppa Bay was one of the severest cases among the impacted sites. The tsunami height was measured up to 12–18 m from M.S.L. near the river mouth (Imai et al. 2015). The tsunami totally inundated the reclaimed land, and the tsunami ran up more than 50 km upstream of the river. Almost half of the reclaimed land had been changed into the sea because of the tsunami-induced sediment erosion as well as the coseismic subsidence that reached up to 0.8 m (Ozawa et al. 2011). On another half of the reclaimed, sands deposition reached up to 1 m in thickness. According to the post-tsunami survey, the erosion and submergence of the sand bar reached up to 3 m, and sediments of 0.5 m thick were deposited near the foot of the hills (Imai et al. 2015). In the simulation, the erosion of the sand bar and reclaimed land was explained by the uprush and backwash of the first wave (Imai et al. 2015). The uprush entrained sediments of the sand bar and transported them to the inland part of the reclaimed land, and the area of the erosion expanded during the backwash. They investigated the effect of grain size, because the actual grain size was not well constrained in their study. The parameter study demonstrated that the spatial distribution of erosion and deposition can be predicted using appropriate choice of the grain size.

At Kesennuma Bay, which is located in the south of Sanriku Coast, bathymetry of the inner bay (so-called Kesennuma Port) was measured both before and after the 2011 tsunami (Haraguchi et al. 2012). The bay has a length of 9 km along SSE direction and a maximum width of 2 km near the bay mouth, and is getting narrower toward its head. The tsunami arrived at the inner bay about 30 min after the earthquake and the observed maximum water level in the bay head reached 5–10 m from M.S.L (Mori et al. 2012). Comparison of the pre- and post-tsunami bathymetry data revealed that volumes of erosion and deposition in the bay floor reached at 674,000 m^3 and 928,000 m^3, respectively (Haraguchi et al. 2012). Deposition was found to be dominant in the inner bay. In addition, maximum depth of erosion near the bottleneck of the inner bay reached 7 m. The numerical modeling by Morishita and Takahashi (2014) reproduced gross volumes of erosion and deposition in the inner bay, which was calculated at 823,800 m^3 and 324,800 m^3, and which is about 124 % and 36 % of the observation, respectively. Erosion is quite dominant in the simulation, as opposite to the observation. To investigate the control factor to improve the simulation, they examined several model parameters, including (1) bed shear stress (Shields parameter), (2) grain-size dependency of transport formula, (3) saturation concentration of suspension load, (4) settling velocity of sand and (5) slope effect for bedload. The sensitivity analysis revealed that the factors (1–4) have significant effects to the model outputs. In the improved simulation, volumes of erosion and deposition and erosion were calculated at 354,000 m^3 and 296,000 m^3, respectively, in which erosion is less dominant. However, in terms of the volume, morphological change is considerable underestimation comparing to the observation.

In the case of Hirota Bay, volumes of morphological change were successfully reproduced in the numerical modeling (Yamashita et al. 2015). Hirota Bay is located in the northern next of Kesennuma Bay, having a length of 9 km and a width of 5 km, opening its mouth to the Pacific Ocean in SSE direction. A coastal deltaic plain is developed in the bay head. The plain had a sandy beach with 1.8 km in width and 0.3 km in depth, which was covered by some 70,000 of pine trees. Three pieces of submerged breakwaters are installed in front of the sandy beach to stabilize it. The tsunami-induced change in the coastal morphology was severest in the bay. The 2011 Tohoku tsunami arrived at the bay about 42 min after the earthquake (Ushiyama and Yokomaku 2012) and totally inundated the coastal plain. The run-up height reached to 20–25 m from the M.S.L (Mori et al. 2012). Post-tsunami aerial photo showed that most sandy beach has been washed away and the land had been changed to the shallow sea. According to the comparison of the pre- and post-tsunami bathymetry data (Kato et al. 2012), maximum depth of erosion was measured at 5–7 m. Deposition was evident in the shoreward of the submerged breakwaters, implying the sediments were derived from the sandy beach by the backwash and accumulated in the shoreward of the breakwaters. The gross erosion near the sandy beach was estimated at 1.9×10^6 m^3. Yamashita et al. (2015) compared the process simulated tsunami inundation with the estimated tsunami front by on-site photographs, demonstrating the flow speed is comparable between the simulation and observation. The simulation showed that the sandy beach was eroded both by the uprush and backwash of the first wave. They demonstrated that sediments up to few meters thick was eroded from the beach and transported inland. The sandy beach was further eroded by the backwash, creating gullies at the gaps between the submerged breakwaters, and sediments were accumulated in the shoreward of them. They showed the impact of the tsunami backwash is much greater than uprush, because of the depth of the coastal plain. According to their additional numerical experiments, a coastal plain with a depth of 2 km tend to generate largest near-shore flow speed by return flow and is most vulnerable to erosion of the coastline (Yamashita et al. 2015).

An important factor for successful result of the modeling of Hirota Bay is attributed to the distribution of the source of sandy sediments and the grain size. The pre-tsunami bottom survey revealed the original distribution of sandy sediments in the bay, which confirms the seafloor near the beach was covered by sand (Sanyo Techno Marine 2012). In addition, the grain size used in the modeling was given based on the pre-tsunami bottom survey and post-tsunami geological survey of onshore tsunami deposits (Naruse et al. 2012). In Kesennuma Bay, pre- and post-tsunami topography was much better constrained. In addition, terrestrial source of sediments can be excluded since the land was totally covered by pavements for the use of industrial and residential areas. This reduces complexity and uncertainty of the simulation. However, the simulated volume of morphological change was much smaller than observation (Morishita and Takahashi 2014). This can be explained by other source of uncertainties, such as distribution and grain size of the source sediments. The pre-tsunami bottom sediments were mainly composed of muds finer than 0.06 mm and the bottom sediments contained at most 10 % of sands coarser than 0.1 mm (Yamaoka et al. 2011). However, in the post-tsunami coring showed that tsunami sediments were composed of sand. There should be some unknown sources of sand from the inner bay. In addition, grain size for the modeling was not specified based on sedimentary data of the seafloor tsunami deposits. These examples strongly suggest the importance of information of initial distribution and physical property of sediments to be investigated by numerical modeling.

26.3 Application of Tsunami Sediment Transport Simulation

26.3.1 Advanced Tsunami Hazard Assessment

Conventional tsunami simulations do not include sediment transport modeling and cannot predict changes in the coastal morphology. However, if the coastal topography is composed mostly of movable sediments, the morphological change sometimes causes remarkable difference in tsunami heights or inundation areas. For example, increase in water depth due to seafloor erosion will permit more water to pass, resulting in extended tsunami inundation and higher run-ups. This also accelerates the speed of tsunami flooding. Imai et al. (2015) argued that tsunami erosion and deposition resulted in the change in the cross-sectional area of flow, and noted that the inclusion of sediment transport model resulted in higher water level of the tsunami invasion in the river. Yamashita et al. (2015) also argued that inclusion of sediment transport modeling to tsunami inundation simulation sometimes cause considerable difference in the hazard map. In the case of flat low-lying coastal plain with natural sandy beaches, considerable difference will appear in the tsunami inundation simulation due to the inclusion of sediment transport modeling. Before the 2011 Tohoku event, non-engineered sandy dike with a height of 5–6 m was installed on the sandy beach of the central Sendai Plain. Most part of the sandy dike was eroded by the tsunami and the elevation of the remaining part was decreased to 3 m (Sugawara and Goto 2012). To investigate the effect of the erosion of the sandy dike, tsunami simulations with and without the sediment transport model (STM) were compared using same input tsunami source model by Satake et al. (2013).

Numerical methods for solving tsunami hydrodynamics and sediment transport are same as Imai et al. (2015) and Yamashita et al. (2015). The inundation distance with STM reached 4 km from the coastline, which closely simulated the observed inundation area; meanwhile the inundation distance without STM changed up to 1 km shorter than that with STM (Fig. 26.3). Differences in maximum flow depth (Fig. 26.3a, b) and speed (Fig. 26.3c, d) were 1–2 m and up to 2 m/s, respectively. According to the post-tsunami damage survey and the numerical modeling of the 2011 event, flow depth of 2 m was identified as a threshold for increased rate of washing away of typical houses in Sendai Plain (Hayashi et al. 2013). Thus, use of a fixed tsunami scenario and numerical modeling without STM likely underestimate the tsunami hazards in the coasts with movable sediments. Although difference in the tsunami front was not significant at 1 h and 10 min after the earthquake, the flow depth was more than 1 m smaller in the simulation without STM (Fig. 26.4a, b).

At 2 h after the earthquake, maximum difference in the inundation distance appeared. In the simulation with STM, the tsunami reached 4 km from the coastline; meanwhile the simulation without STM showed much smaller (2–3 km from the coastline) inundation distance (Fig. 26.4c, d). Erosion of sandy dike resulted in an increase of the volume of incoming seawater (flux). This also increases the speed of tsunami propagation on land and likely reduces available time for evacuation. Considering the increasing performance of computers, systems for real-time tsunami propagation and inundation

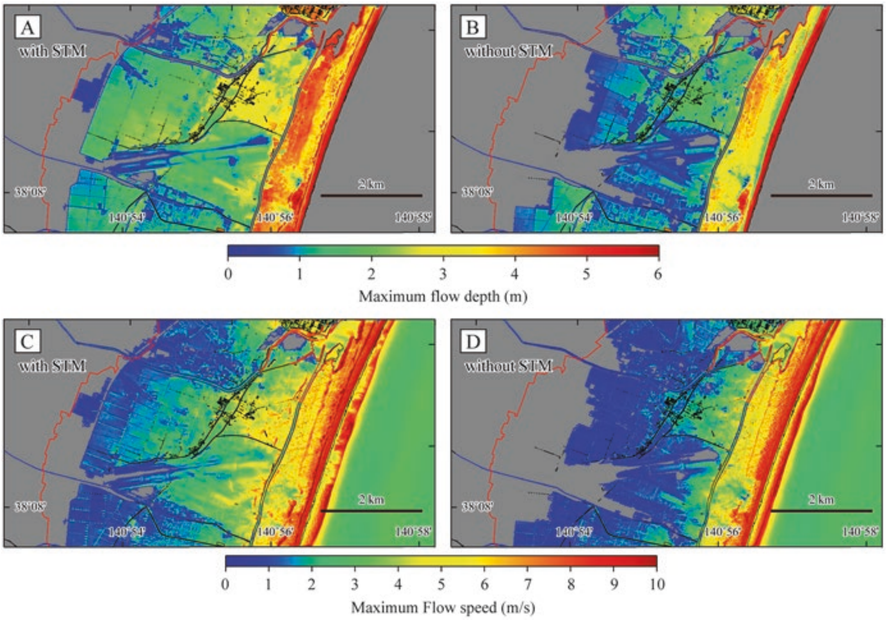

Fig. 26.3 Comparison of simulated flow depths (**a**, **b**) and speeds (**c**, **d**) by the 2011 Tohoku tsunami in the central Sendai Plain simulated with and without sediment transport modeling (STM)

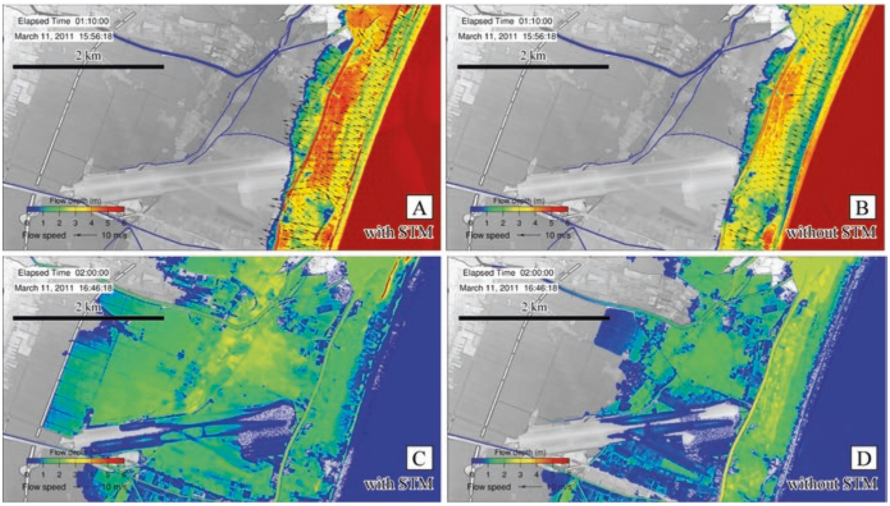

Fig. 26.4 Comparison of the inundation process of the 2011 Tohoku tsunami in the central Sendai Plain simulated with and without sediment transport modeling (STM). Instantaneous snapshots of flow depth and speed at 1 h and 10 min after the earthquake, considering (**a**, **c**) and neglecting (**b**, **d**) sediment transport and morphological change of the beach. Considerable difference in flow depth and speed appeared in the comparison of (**a**, **b**). At 2 h after the earthquake, the inundation area with STM reached 4 km from the coastline; meanwhile that without STM reached at most 3 km

simulation with sediment transport modeling will be possible in future. Such systems will provide improved real-time hazard map for evacuation.

26.3.2 Future Challenges

Validation of the simulations and analysis of the mechanism of tsunami sediment transport have been significantly improved with the groundbreaking datasets from the 2011 Tohoku event. Simulations with a resolution of an order of 5 m can reproduce general patterns of sediment erosion and deposition with a scale of greater than hundreds of meters (Sugawara and Takahashi 2013; Sugawara et al. 2014b; Imai et al. 2015; Yamashita et al. 2015). Nevertheless, challenges will arise with increasing resolution of the model. The 2011 Tohoku event demonstrated that the process of sediment transport and morphological changes are tightly related to the preexisting coastal facilities (Udo et al. 2013). Presence or absence of coastal dikes, embankments, channels and building makes considerable difference in the tsunami inundation process (Sugawara and Goto 2012). In the conventional models, the difference has been parameterized by means of roughness coefficient (Kotani et al. 1998). The Manning's law (friction term) in the governing equation of the tsunami hydrodynamic model is proportional to the square power of flow speed and inversely proportional to the 1/3 power of flow depth. It seems use of the Manning's law is not necessarily appropriate for calculating the resistance from the artificial features to the flow, since an increase of the flow depth results in a decrease of the resistance. The artificial features are likely damaged and destroyed during tsunami inundation. This means the flow field will be changed as a result of collapse of these coastal facilities during tsunami invasion, thus the dynamics of sediment erosion, transport and deposition will be altered. Requirements for quantitative prediction of the change in coastal morphology may include modeling of the damages to and destruction of the structures. In addition, since vertical motion of water is dominative for ground scouring behind elevated features, three dimensional modeling will be required to resolve the mechanism (e.g. Iwamoto et al. 2014). Existing three-dimensional numerical models can treat the detailed process of excavation and structural damage with relatively limited spatial scope. A question is whether damage and destruction of structures can be modeled and coupled with the conventional numerical models that treat the tsunami hydrodynamics and sediment transport. This can be one of key challenges to develop tsunami sediment transport simulations for more practical use.

26.4 Conclusion

The emergence of the 2011 Tohoku Earthquake has been a watershed for advancing numerical modeling of tsunami sediment transport, underpinned by well-constrained tsunami source models and pre- and post-tsunami topography data. Case studies have already been carried out regarding the impacted sites in Sendai Bay and Sanriku Coast. These studies demonstrated the numerical modeling is useful to investigate processes of tsunami sediment transport and predict changes in the coastal morphology. Inclusion of sediment transport modeling to tsunami inundation simulation will benefit improved assessment of future tsunami hazards. Datasets of tsunami-induced morphological change are available from many other sites from Tohoku region, and further research is needed to reveal the diverse nature of tsunami sediment erosion, transport and deposition. Although the groundbreaking data on tsunami source and topography reduced uncertainties in the numerical modeling, other factors such as initial distribution and physical property of sediments come to the front of the source of uncertainty. Modeling of damage and destruction of coastal facilities may be one of the important factors for improved prediction of morphological change.

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Chapter 27
Recent Process in Probabilistic Tsunami Hazard Analysis (PTHA) for Mega Thrust Subduction Earthquakes

Nobuhito Mori, Katsuichiro Goda, and Daniel Cox

Abstract A review of the progress of Probabilistic Tsunami Hazard Analysis (PTHA) for mega thrust subduction earthquakes after the 2004 Indian Ocean tsunami is presented. PTHA is used to quantify the tsunami inundation characteristics probabilistically, analogous to Probabilistic Seismic Hazard Analysis (PSHA) popularized since the early 1970s. The process of PTHA is briefly presented from frequency-intensity modeling, geometric fault parameter modeling, and synthetic slip distribution modeling. There are mainly three different approaches, i.e. historical records, a logic tree and random phase, to generate different slip distributions in PTHA. PTHA is useful for risk assessment, when combined with fragility models for probabilistic damage assessment. Moreover, PTHA provides a consistent framework that allows it to be integrated with probabilistic seismic hazard analysis (PSHA) for multi-hazard damage assessment.

Keywords Tsunami hazard assessment • Synthetic tsunami modeling • Probabilistic modeling • Inundation

27.1 Introduction

The 2004 Indian Ocean Tsunami renewed global interest in tsunami hazard assessment (e.g. McCloskey et al. 2008), and the 2011 Tohoku Earthquake Tsunami (e.g. Mori et al. 2011) has accelerated the progress in tsunami hazard research. In general, there are two approaches for tsunami hazard assessment, generally. The first is

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V. Santiago-Fandiño et al. (eds.), *The 2011 Japan Earthquake and Tsunami: Reconstruction and Restoration*, Advances in Natural and Technological Hazards Research 47, DOI 10.1007/978-3-319-58691-5_27

a more conservative deterministic approach which is based on the largest tsunami event and is often termed the "worst case" or "worst credible" tsunami. The second approach is probabilistic tsunami hazard analysis (PTHA) and is analogous to probabilistic seismic hazard analysis (PSHA) popularized since the 1970s after the pioneering work of Cornell (1968, see McGuire [2008] for a review of the early history of PSHA). The worst credible hazard assessment often requires less computational effort because the tsunami generation, propagation and inundation are based on a single scenario only. This approach is generally favored for evacuation planning where life safety is the primary consideration. On the other hand, it is not suitable to make risk-informed decisions, particularly with regard to the potential damage and loss in coastal areas, because the probability of the worst case event is typically very small and sometimes very difficult to quantify (Kagan and Jackson 2013). An accurate assessment of tsunami hazards and quantification of the uncertainty associated with the assessment are essential to mitigate and control disaster risk exposures effectively from a tsunami risk management perspective. Although this second approach is much more computationally intensive, PTHA provides the basis for risk-informed decision making, particularly when combined with fragility models for probabilistic damage assessment (e.g. Goda and Song 2016). Moreover, PTHA can be used for the basis of engineering design (e.g., Chock 2016), and provides a consistent framework that allows it to be integrated with PSHA for multi-hazard damage assessment (De Risi and Goda 2016). PTHA is one possible approach to identify tsunami source regions and corresponding scenarios that have major impact to a site of interest. This chapter focuses on PTHA, provides a summary of recent work in this area, and gives some thoughts on future work.

One of the major challenges for tsunami impact assessment is to predict the earthquake source characteristics of future tsunamigenic events (e.g., location, magnitude, and geometric slip distribution), and then to quantify the uncertainty associated with the variability in earthquake rupture (tsunami generation), tsunami propagation, and tsunami inundation processes (e.g., Burbidge et al. 2015). In particular, tsunami generation is influenced by the complex and nonlinear interaction of earthquake generation properties, while tsunami propagation, affected by changes in sea bathymetry, is generally considered as a 'solved' problem (Geist 2002; McCloskey et al. 2008; Løvholt et al. 2012; Goda et al. 2014).

Another major challenge is that tsunami inundation characteristics differ considerably in coast areas due to the nonlinearity of the phenomena. At municipality or sub-municipality levels, tsunami inundation depths and flow speeds depend on the complex interaction of the tsunami with the surrounding natural and built environment and will vary significantly due to local features. Because of this complexity and the computational challenges related to modeling tsunami inundation behavior, the state-of-the-practice for preparing tsunami hazard maps for coastal cities focuses on a few tsunami hazard parameters (e.g. maximum horizontal extent of the inundation and arrival time of the leading wave to the shoreline) considering a single (worst credible) scenario or a few scenarios based on, for example, far-field or near-field sources. This approach lacks information on uncertainties associated with hazard predictions, and thus hampers risk communication between tsunami analysts and local stakeholders. Consequently, users of tsunami hazard maps are unable to appreciate potential risks and their uncertainties under different conditions. For example, during the 2011 Tohoku Tsunami, more than 65 % of all fatalities in Kamaishi, Iwate Prefecture, Japan, occurred outside the areas that were designated as major inundation zones in the 2005 tsunami hazard maps used by the public for the previously-expected "worst case" scenario (e.g. Mori et al. 2013). The actual tsunami that was caused by the 2011 Tohoku event was beyond the historical records that were taken into account in preparing the 2005 hazard maps. Therefore, a set of tsunami inundation hazard maps for coastal cities and towns, corresponding to different tsunami behaviors and consequences, is useful for tsunami hazard preparedness, evacuation planning and long-term adaptation planning. Moreover, the use of worst credible scenarios limits the ability of engineers to design structurally sound facilities within the inundation consistent with other hazards (Chock 2016).

There are many scientific studies related to PTHA conducted worldwide (Table 27.1; excluding landside tsunami). The earliest study which considered the probabilistic nature of tsunami hazard was by Rikitake and Aida (1988). Although they did not consider a full PTHA, they used historical records and a typical earthquake fault model to estimate the probability of tsunami height exceeding a certain level at the shoreline. After the 2004 Indian Ocean event, there were several PTHA studies for other areas worldwide, including Australia (Burbridge et al. 2008), the Caribbean (Parsons and Geist 2009), Japan (Annaka et al. 2007; Yanagisawa et al. 2007), the Makran subduction zone at the northwestern Indian Ocean (Thio et al. 2007; Heidarzadeh and Kijko 2011), the Mediterranean (Tinti et al. 2005), Mexico (Geist and Parsons 2006), New Zealand (Power et al. 2007), the South China Sea (Liu et al. 2007), the US Pacific Northwest (Geist and Parsons 2006; Thio and Somerville 2009; Gonzales et al. 2009; Priest et al. 2010), US East Coast for landslides (Grilli et al. 2009), and elsewhere in the Pacific Ocean (Orfanogiannaki and Papadopoulos 2007). Since the 2011 Tohoku event, research on PTHA has accelerated worldwide, including studies in Canada (Leonard et al. 2014), Japan (Goda et al. 2015; Fukutani et al. 2015), Indonesia (Horspool et al. 2014), New Zealand (Power et al. 2013; Mueller et al. 2015), the Mediterranean (Grezio et al. 2010; Anita et al. 2012; Sorensen et al. 2012; Lorito et al. 2015), the South China Sea (Li et al. 2016), and the US Pacific Northwest (Park and Cox 2016). PTHA is basically formulated, with close similarity to PSHA, to estimate probabilistic tsunami height along the coast or inundation inland (e.g. Geist and Parsons 2016). However, there are several key underlying assumptions, model choices, and expert judgments to conduct PTHA. Therefore, it is important to summarize current knowledge of PTHA to understand similarities and differences of existing PTHA models for further development of tsunami hazard assessment. Section 27.2 outlines a general approach of PTHA. Section 27.3 provides some examples of PTHA results and discusses future development of PTHA.

Table 27.1 Summary of probabilistic near-field tsunami hazard analysis research from 1988 to 2016

References	Tsunami generation	Target country/area
Rikitake and Aida (1988)	Historical record	Japan
Burroughs and Tebbens (2005)	Historical record	Japan
Tinti et al. (2005)	Historical record	Italy
Geist and Parsons (2006)	Logic tree	US Pacific coast/Mexico
Annaka et al. (2007)	Logic tree	Japan
Liu et al. (2007)	Historical record	South China Sea
Orfanogiannaki and Papadopoulos (2007)	Historical record	Pacific Ocean
Power et al. (2007)	Random phase	New Zealand
Thio et al. (2007)	Logic tree	Northwestern Indian Ocean
Yanagisawa et al. (2007)	Random phase	Japan
Burbridge et al. (2008)	Random phase	Australia
Gonzalez et al. (2009)	Historical record	US Pacific coast
Parsons and Geist (2009)	Random phase	Caribbean
Thio and Somerville (2009)	Logic tree	US Pacific coast
Grezio et al. (2010)	Historical record	Italy
Priest et al. (2010)	Logic tree	US Pacific coast
Heidarzadeh and Kijko (2011)	Historical record	Northwestern Indian Ocean
Anita et al. (2012)	Historical record	Mediterranean Sea
Sørensen et al. (2012)	Random phase	Mediterranean Sea
Power et al. (2013)	Logic tree	New Zealand
Witter et al. (2013)	Logic tree	US Pacific coast
Horspool et al. (2014)	Logic tree	Indonesia
Leonard et al. (2014)	Historical record	Canada
Mueller et al. (2015)	Random phase	New Zealand
Fukutani et al. (2015)	Logic tree	Japan
Fukutani et al. (2015)	Logic tree	Japan
Goda et al. (2015)	Random phase	Japan
De Risi and Goda (2016)	Random phase	Japan
Li et al. (2016)	Random phase	South China Sea
Park and Cox (2016)	Logic tree	US Pacific coast

Random phase (modelling considering the random generation of a slip distribution) and Logic tree (weighted modelling slip distribution by expert judgment) see Fig. 27.3 and Subsects. 27.2.1 and 27.2.3

27.2 Probabilistic Tsunami Hazard Analysis (PTHA)

27.2.1 Outline of PTHA

The PTHA methods can be used to provide probabilistic estimates of tsunami heights along coasts, tsunami inundation depth or velocity within the inundation zone, and the upper limit of runup. Figure 27.1 is a brief summary of the PTHA methodology and outlines five steps that are usually used for PTHA. Step 1 is to

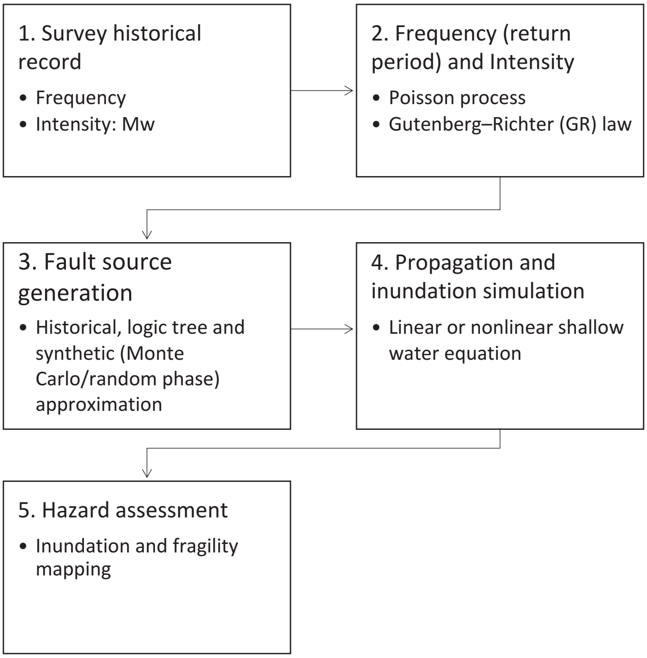

Fig. 27.1 Flowchart of probabilistic tsunami hazard analysis (PTHA)

estimate the frequency of occurrence of tsunamigenic earthquakes. In Step 2, the earthquake intensity for each frequency or the worst credible case is estimated. In Step 3, a synthetic fault model is used to simulate different configurations of tsunami generation and propagation. There are three approaches to consider variety of faults for PTHA that are commonly used: the first approach is to use a combination of historical or many source scenarios based on expert opinion (e.g. Gonzales et al. 2009). It is straightforward approach but number of events and variation of sources are limited, generally. The second approach is to use a logic tree based on a combination of slip scenarios and geometric slip parameters (e.g. Annaka et al. 2007; Horspool et al. 2014; Fukutani et al. 2015; Lorito et al. 2015; Park and Cox 2016). The third approach is to generate synthetic slip distributions by slip wavenumber spectra assuming a random phase (i.e. Monte Carlo method, e.g. Goda et al. 2014, 2015; Mueller et al. 2015; Davies et al. 2015). In Step 4, the propagation and inundation overland is conducted, usually by solving the linear or nonlinear shallow water equations. Tsunami propagation (Step 4) can be considered a solved problem, and, generally, there is no significant difference between the linear and nonlinear shallow water equations until very nearshore because of a weak nonlinearity of tsunami. For the inundation phase, tsunami models generally assume a 'bare earth' condition (no vegetation or buildings) and use a tunable friction factor to account for the surface roughness. In Step 5, the probabilistic hazard assessment is examined for variables of interest. These variables include the tsunami height at the shoreline, the inundation depth, speed or momentum flux in the inundation zone, or the total extent of inundation. The arrival time of the tsunami may be considered in a probabilistic sense; however, for evacuation the worst case condition shall be adopted.

Table 27.1 summarizes the major references of PTHA since Rikitake and Aida (1988). The number of research had increased after 2004 Indian Ocean Tsunami and 2011 Tohoku Earthquake Tsunami dramatically. While the use of the historical record was used initially for PTHA along with random phase and logic tree approaches, the use of the historical record has lost favor compared to the other two approaches. Additionally, the implementation of more detail of fault characteristics (strike and dip angles, top edge depth and etc.) depends on the researches which requires more detail of fault information and needs large number of ensemble. Furthermore, the some researchers combine other risks such as far field tsunamis and landslides but we focus on near field PTHA. The brief summary of PTHA will be presented following section.

27.2.2 Frequency-Magnitude Modeling

The frequency of tsunamigenic earthquakes needs to be estimated in the first step. If a mean occurrence rate λ of earthquakes having the moment magnitude Mw_0 or greater is known, the probability of exceeding that magnitude at least once in a time period T can be given assuming a stationary Poisson process (Geist and Parsons 2006):

$$P\left(Mw > Mw_0, T\right) = 1 - e^{-\lambda T} \tag{27.1}$$

The mean occurrence rate λ in Eq. 27.1 can be estimated by fitting the Gutenberg-Richter relationship to data and estimating the model coefficients a and b:

$$\lambda\left(Mw\right) = 10^{a+bMw} \tag{27.2}$$

The estimation of frequency for a given magnitude is site-specific based on the local historical records (Step 2).

Once the intensity of an event having Mw is given, the next step is to set up the fault model (Step 3). The synthetic fault modeling requires changing of the fault parameters, such as the fault geometry, the location of the peak slip, the mean and maximum slip, strike and dip angles, and the top-edge depth. The combination of these parameters should follow some constraints by accounting for the physical limitations of the fault. Typically, earthquake fault rupture modeling (e.g. geometry and slip distribution) is developed based on past major earthquakes, and results are summarized as empirical scaling relationships (e.g. Wells and Coppersmith 1994; Somerville et al. 1999; Mai and Beroza 2000; Papazachos et al. 2004; Blaser et al. 2010; Leonard 2010; Strasser et al. 2010; Murotani et al. 2013). For tsunamigenic earthquakes, scaling relationships for mega-thrust subduction zone events are important to know. The scaling relationships by Murotani et al. (2013) are specific to Japanese subduction earthquakes including the 2011 Tohoku Earthquake. Park and Cox (2016) extended the work of Murotani et al. (2013) to include recent subduction zone events outside of Japan.

Goda et al. (2016) presented all necessary parameters for stochastic source modeling, targeting an application to PTHA, by parameterizing the geometry, slip statistics, and spatial slip distribution based on a SRCMOD database of finite-fault earthquake rupture models (Mai and Thingbaijam 2014). SRCMOD is a comprehensive and growing on-line database of finite-fault rupture models. It includes inversion-based rupture models that have been published in the literature and is the largest public database of this kind, consisting of 317 rupture models from 155 earthquakes as of December 2015. Based on the analysis of the SRCMOD database for the source parameterizations, Goda et al. (2016) showed the different characteristics of tsunamigenic and non-tsunamigenic events for magnitude-fault dimensions, magnitude-slip, and magnitude-correlation length of slips. For example, Fig. 27.2 shows the fault width and length as a function of M_w by distinguishing tsunamigenic and non-tsunamigenic models (Goda et al. 2016). It can be observed that the magnitude-fault width scaling behavior for the tsunamigenic models differs from that for the non-tsunamigenic models, whereas the magnitude-fault length scaling behavior for the tsunamigenic models is similar to that for the non-tsunamigenic models. More specifically, for the same M_w values, the fault width for the tsunamigenic models is greater than that for the non-tsunamigenic models. This is because the fault planes of the tsunamigenic models dip more gently than those of the non-tsunamigenic models, and thus the fault plane can be extended along down-dip direction (note: the lower limit of the seismogenic layer of a subduction zone is typically constrained by the thermal condition). In Fig. 27.2, existing scaling

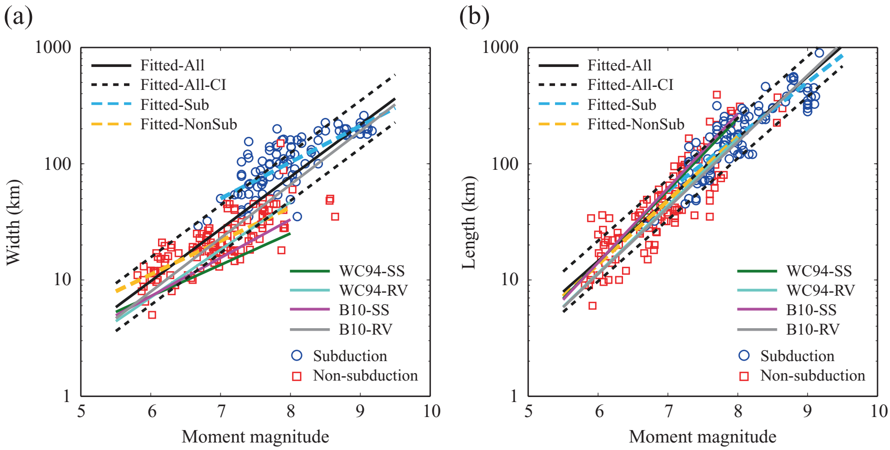

Fig. 27.2 Scaling of fault width, length and moment magnitude (Reprinted from Goda et al. (2016) with permission from World Scientific)

relationships by Wells and Coppersmith (1994, denoted as WC94 hereafter) and (2010, B10 hereafter) are also included. These results suggest that the non-tsunamigenic relationships for the fault width developed in this study are broadly consistent with the existing models that are available in the literature but the tsunamigenic relationships differ significantly from the existing ones. The differences may be attributed to the lack of mega-thrust subduction data in the previous studies. The scaling relationships will be improved by future mega-thrust subduction events, although there may be decades before the next event. Nevertheless, the generation part of PTHA should be improved with the progress of observations and the theoretical development.

27.2.3 Logic Tree and Random Phase Modeling for Fault

As mentioned previously, there are generally three methods for the fault generation. The first approach is to historical records or combine many source scenarios (e.g. Gonzales et al. 2009). This method generally relies on expert opinion and may be suitable only if there is a severe limitation of computational resources and is not discussed further. The second approach is logic tree modeling (e.g. Annaka et al. 2007), where typically several alternatives (i.e. branches in a logic tree) are considered for several main slip parameters (e.g. asperity and maximum slip location). An illustration of a logic tree in PTHA is presented in Fig. 27.3. The advantages of the logic tree modeling are simplicity of the source parameter selection and compatibility to existing hypothetical slip distribution(s), especially when there is an existing scenario-based hazard modeling. Moreover, PTHA based on the logic tree approach can be readily combined with PSHA using the same approach to create a probabilistic multi-hazard assessment. On the other hand, the logic tree approach has less flexibility to consider alternative hypothetical slip distributions and related characteristics due to nonlinear increase branches. Furthermore, a probability or weight needs to be assigned to each of the logic tree branches by expert judgment (see numbers in parenthesis in Fig. 27.3; the return period is obtained by geological records), which is not a trivial task to do in practice and is difficult to justify scientifically.

The third approach is random phase modeling (i.e. Monte Carlo simulation or stochastic tsunami modeling) and allows a more general synthetic source generation. The random phase modeling assumes the two dimensional Fourier amplitude spectra of the slip distribution in both strike and dip directions based on historical events at the target point. Then, a sufficient number of synthetic slip distributions are generated (typically 300–500 for each magnitude; see De Risi and Goda 2016) by changing the phase components of Fourier spectra (note: the Fourier amplitude spectra may be varied when the earthquake source parameters, such as correlation length, are treated as random variables; Goda et al. 2016).

Figure 27.4 shows an example of the computational procedure of the random phase modeling of the synthetic slip. A key to this random phase approach is the

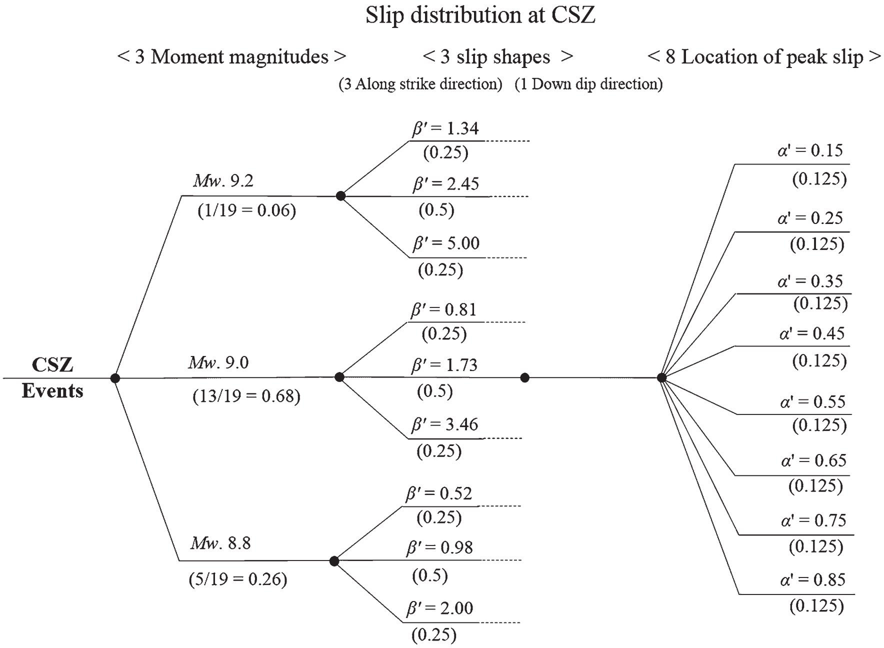

Fig. 27.3 Example of logic tree approach (Cascadian Subduction Zone in Oregon, USA)

generation of synthetic slips from slip spectra. Mueller et al. (2015) and Davies et al. (2015) assumed that the high frequency components of slip spectra follow k^{-2} where k is the wave number of the slip. Goda et al. (2014) proposed to estimate the slip spectra based on historical slip inversion results at a particular location. A more general approach has been developed by Goda et al. (2016). The random phase modeling can generate a large number of synthetic slips without the need for expert judgment in contrast with the first two approaches. On other hand, the results of random phase approximation require a historical event dataset or need to rely on empirical scaling relationships to estimate a coherent structure of the slip distributions. Additionally, the computational costs for the random phase approach are larger than for the logic tree approach due to the number of slips needed to establish statistical stability without expert judgment.

In summary, there are three approaches to generate multiple tsunami slip distributions for PTHA (Step 3). The first method, based on the historical record has decreased in use in favor of two other methods (logic tree, random phase). A historical record is often difficult or impossible to obtain in sufficient length to provide for a meaningful PTHA. The logic tree approach is widely used to be consistent and compatible with scenario-based modeling but needs expert judgment to estimate probability. The random phase approach can be justified scientifically if the regional earthquake rupture characteristics are well known and understood. Both approaches are still under the development and need to be validated against observed records.

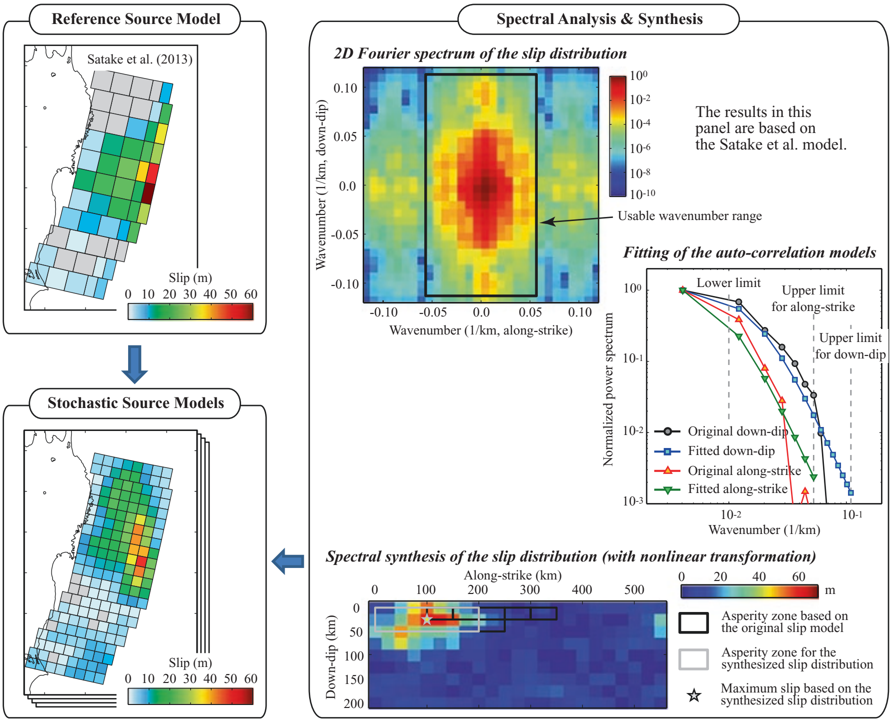

Fig. 27.4 Example of random phase modeling approach ((Pacific coast in Tohoku, Japan) (Modified from Mori et al. 2016)

27.3 Example of PTHA Results

The validation of synthetic tsunami source modeling is difficult due to a scarcity of observed tsunami events at particular locations. The sensitivity of coastal tsunami height or inundation characteristics to fault parameters is important to know. Figure 27.5 shows a set of tsunami simulation results for Sendai–Natori–Iwanuma (southern part of Miyagi Prefecture, Japan), obtained by changing fault parameters of top-edge depth, strike angle and dip angle for the 2011 Tohoku Earthquake Tsunami (the numbers in Fig. 27.5 indicate changed from the 2011 Tohoku event). Although the baseline simulation, hindcast simulation, is not shown here, the simulated and observed post-event survey data by the Tohoku Tsunami Joint Survey (TTJS) data (TTJS 2011; Mori et al. 2011; Mori and Takahashi 2012) are in good agreement. The results of the sensitivity analysis for the geometrical parameters shown in Fig. 27.5 indicates that the top-edge depth and dip parameters have major influence on the tsunami inundation, although the strike variations are less significant on the inundation characteristics in the Sendai–Natori–Iwanuma region (but this is not the case in other regions). The inundation areas for shallow water depth

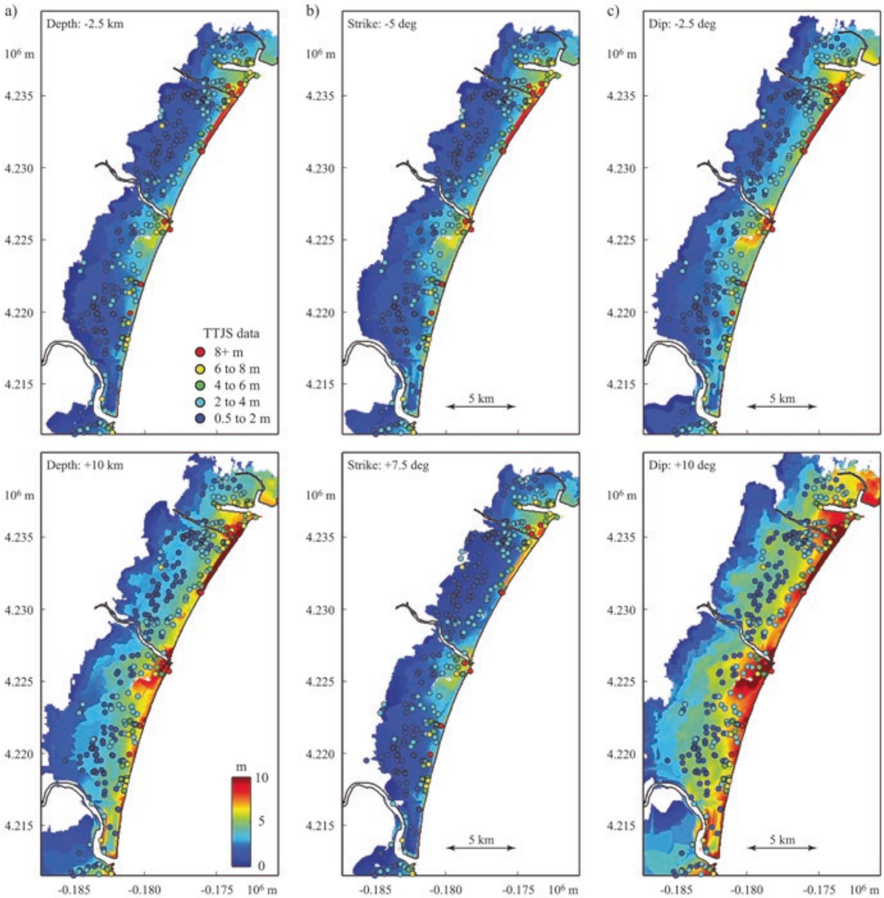

Fig. 27.5 Sensitivity of fault parameters to inundation depth for Sendai–Natori–Iwanuma in Japan based on the 2011 Tohoku Earthquake Tsunami. (**a**) top-edge depths of −2.5 km and +10 km, (**b**) strike angles of −5° and +7.5°, and (**c**) dip angles of −2.5° and +10° (Reprint from Goda et al. 2015 with permission from the American Geoscience Union (AGU))

thresholds are affected by variations of geometrical fault parameters rather than deep water depth thresholds. The flat terrain region, such as Fig. 27.5, is more sensitive to geometrical fault parameters than steep terrain (e.g. ria coast in the Sanriku region). Therefore, a random phase modeling is useful for searching a wide range of tsunami inundation characteristics.

Figures 27.6 and 27.7 are examples of probabilistic tsunami inundation results for the 2011 Tohoku Earthquake Tsunami ($Mw = 9.0$) by the random phase approach (Goda et al. 2015) and Seaside City, Oregon, USA (considering different values of Mw) by the logic tree approach (Park and Cox 2016), respectively. Figure 27.6 shows the ranked inundation extent based on the inundation areas above 1 m depth.

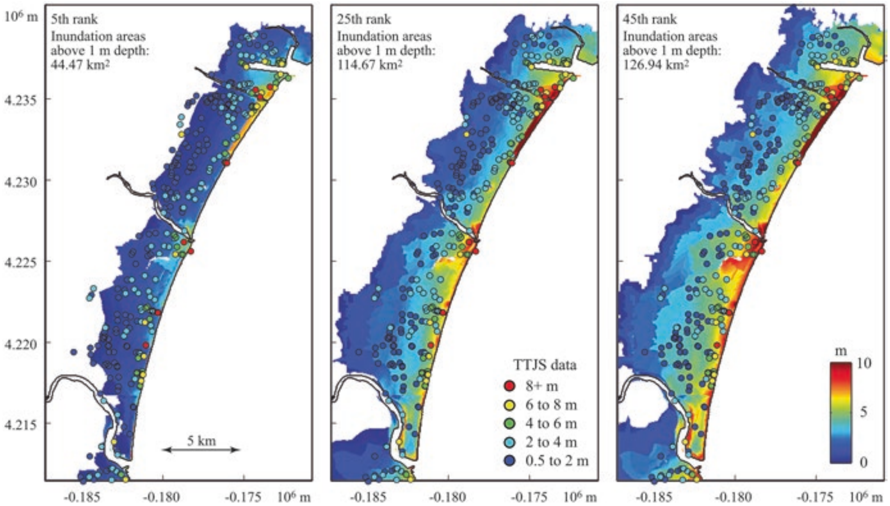

Fig. 27.6 Inundation depth contours for Sendai–Natori–Iwanuma: 5th rank, 25th rank, and 45th rank based on the inundation areas above one (1) meter depth of stochastic slip cases based on the 2011 Tohoku Earthquake Tsunami (Reprinted from Goda et al. 2015 with permission from Elsevier)

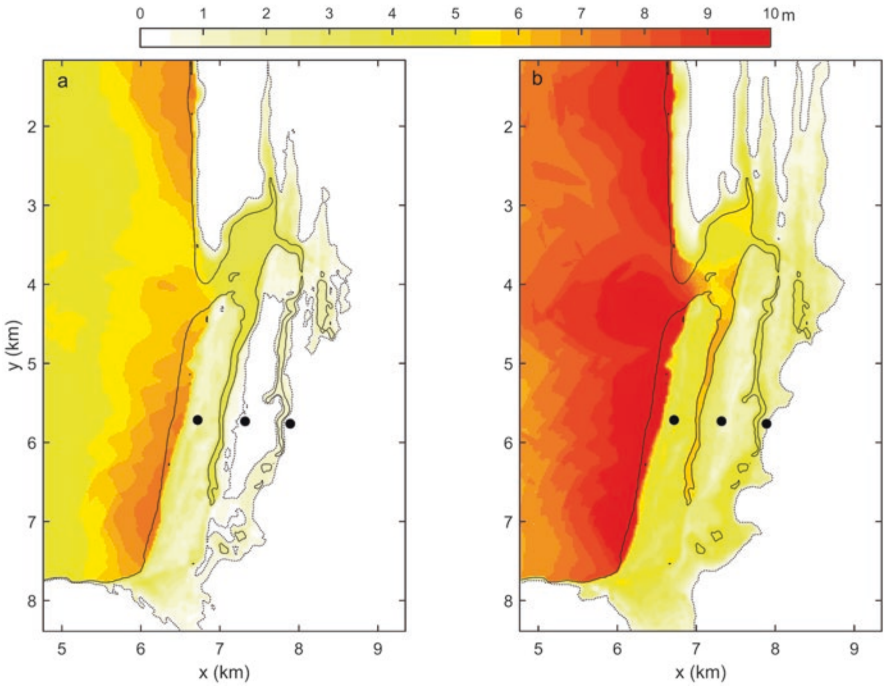

Fig. 27.7 Spatial distributions of inundation depth for 500 years (*left*) and 1,000 years (*right*) events in Seaside City, Oregon coast, USA (Reprinted from Park and Cox 2016 with permission from Elsevier)

It suggests that both spatial inundation extent and inundation depth increase as the considered scenario becomes more extreme. The results also indicates that the chance of experiencing similar tsunami inundation extent that was observed during the 2011 Tohoku Earthquake (i.e. TTJS data) can be considered as likely (more than 50 %) in a future *Mw*9 subduction earthquake in the Tohoku region.

Figure 27.7 shows the spatial distributions of the maximum inundation depth at Seaside, Oregon, based on the 500-year (0.002 %/year) and 1,000-year (0.001 %/year) exceedance probabilities, respectively. The solid line shows the mean high water to provide a conservative estimation of the scenario-based tsunami hazard assessment (Weibe and Cox 2014). The dotted line in each panel shows the maximum inundation limit, defined here as the contour line for which is $h = 0.3$ m. The inundation extent goes to bottom half of Fig. 27.7 (southern side) due to flat topography rather than top half of it due to flat topography in the southern side of the target domain. Moreover, the maximum inundation depth is somewhat uniform at about 5 m for much of the inundation zone. Although the makings of probabilistic inundation mapping are different by the random phase approach (Fig. 27.6) and the logic tree approach (Fig. 27.7), the inundation characteristics by large (rare) events change remarkably in flat terrain areas, depending on the probability level of interest. The above examples also show sensitivity of tsunami inundation characteristics to the fault geometric parameters (*Mw*, location, slip and etc.), demonstrating the usefulness of PTHA in quantifying the uncertainty of tsunami hazard assessments.

27.4 Conclusions

This chapter presents a brief review of the progress in probabilistic tsunami hazard analysis (PTHA) after the 2011 Tohoku Earthquake Tsunami. PTHA mainly is concerned with mega-thrust subduction earthquakes, which can trigger massive tsunamis. Through PTHA, probabilistic tsunami inundation characteristics can be evaluated. Currently, there are two different approaches, i.e. a logic tree and random phase, to generate different slip distributions in PTHA. It is noteworthy that PTHA can be extended to tsunami risk assessment when integrated with appropriate fragility models.

The future challenges of PTHA include validation of individual modeling results and comparison among different modeling results. As the target of PTHA is mega-thrust subduction earthquakes, an occurrence period of such large events is longer than 100 years. In such cases, the validation of PTHA is difficult due to the lack of historical records. The final outputs of PTHA are probabilistic hazard intensities but the estimation of these intensities involves many arbitrary choices and expert judgments. Therefore, comparison among different PTHA results at a particular location is also necessary in the future. It is also important to consider slow slip events in PTHA in the future. The extension of PTHA to multi-hazard analysis for different hazards (e.g. Leonard et al. 2014; Anita et al. 2015; De Risi and Goda 2016) particularly for the seismic hazard directly to the near-field tsunami hazards and also for uncorrelated hazards such as those driven by climate (high wind, elevated surge, or intense rain) is also important to develop to assess the natural hazard impact comprehensively.

Acknowledgements The authors appreciate for contributions to modeling and making examples by Professor P. Martin Mai (KAUST), Dr. Tomohiro Yasuda (Kansai University), Dr. Hyoungsu Park (Oregon State University), and Dr. Raffaele De Risi (University of Bristol).

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