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Maladaptation, fragmentation, and other secondary effects of centralized post-disaster urban planning: The case of the 2011 "cascading" disaster in Japan

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ABSTRACT

Previous studies have documented the negative impacts and unexpected secondary effects of post-disaster housing development. Here, we build on this tradition to explore how post-disaster urban planning and risk mitigation measures affect internal migrations after a major disaster. In the aftermath of the 2011 Great East Japan Earthquake and Tsunami, the Japanese government put forward significant efforts to provide safe housing and land in more than 20 cities. We used GIS spatial analysis to identify urban footprint changes, which proved to be reliable indicators of internal migration. Our results reveal the secondary effects of planning interventions, and more specifically, how the maladaptation measures triggered rapid urban sprawl and increased risks of landslides and vulnerabilities in mountainous areas. We also find increased urban fragmentation, both socially and spatially. Maladaptation, urban fragmentation, and rapid changes in urban footprints emerged as the consequences of centralized government-mandated planning and housing development. We conclude that the uncertainty surrounding dynamic recovery processes requires incremental adaptive action. Planners and local authorities must recognize and remain attentive to the cascading effects of centralized planning decisions.

1. Introduction

1.1. Cascading hazards and cascading effects

The 2011 Earthquake and Tsunami struck 474 cities in northern Japan, claimed approximately 22,252 lives [1], and caused 157.5 billion USD in damages [2]. This disaster, and the recovery process that followed, are notable for their large-scale and long-term consequences, complexities, and cascading effects. As a matter of fact, the 9.0 magnitude earthquake generated a subsequent tsunami that devastated the Tohoku coastal region, 500 km along the Pacific Ocean, and caused the meltdown at the Fukushima Daiichi Power Plant. The massive and cascading destruction induced massive displacement between regions and the internal migration of people seeking to settle in a safer place. As this paper will demonstrate, urban responses to the disaster eventually triggered unprecedented urban sprawl.

Post-tsunami mitigation and reconstruction measures to provide secured land were implemented by the government through several key decisions, including designating hazardous zones, heightening coastal levees, elevating roads, ground raising, and developing collective relocation areas. The government's *White Paper of Disaster Management* recognised the importance of "Building Back Better" [3]. The response was characterized by authorities' strong planning intervention that attempted to quickly rethink land use and resettle survivors. Land-use control and mitigation measures that were taken in Japan had two objectives: reducing exposure to tsunami risk and supporting people's housing reconstruction in a safer place.

This paper explores the secondary effects of urban planning efforts put in place by the Japanese government after the 2011 disaster, and ultimately, seeks to answer the following questions: What are the consequences of the mitigation measures taken to "Build Back Better" in the Tohoku region? How did post-disaster urban planning and risk mitigation measures affect internal migrations in coastal cities after the tsunami? What do these impacts tell us about post-disaster urban planning and recovery?

To answer these questions, we focused on tsunami-affected coastal

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cities in the Miyagi and Iwate Prefectures, where we investigated changes in urban footprint patterns. We divided the built-up area of two cities into five zones categorized by planning interventions and housing reconstruction patterns. The first section of the paper explains the context of post-disaster urban planning and risk mitigation measures after disasters. The second section examines urban footprint changes in two case study cities and unpacks people's reconstruction decisions and overall satisfaction. Post-disaster planning interventions and urban footprint changes constitute the two constructs of our theoretical framework applied to the empirical cases (Fig. 1). Finally, the secondary effects of post-disaster urban planning are discussed in terms of tensions, gaps, and missing links between urban planning decision-making and residents' well-being.

Fig. 1 shows the analytical framework adopted for this study. The main objects of analysis are urban footprints and secondary effects of post-disaster urban planning. In this way, we focus on documenting urban changes: "Monitoring of recovery indicators is both a way to document the recovery process for improving models, as well as to mark the recovery process in real time so as to apply and evaluate interventions" [4]. Urban footprint changes following the tsunami are explored through two primary drivers: 1) planning interventions by the Japanese government in its attempt to provide safe housing and land through land-use regulations; and 2) people's decisions to relocate after the disaster. Pre-disaster conditions and people's decisions regarding housing reconstruction become crucial contextual factors in these empirical cases. Aging and depopulation in the Tohoku region and other coastal communities, for instance, are significant challenges that affect livability after a tsunami occurs. It is worth noting that Japan is one of the world's most rapidly aging societies: the number of people aged 65 or older reached 23.1% in 2010. Its population also began to shrink in that same year [5]. Both population decline and aging were previously considered in several municipalities' planning document before the tsunami, and affected the recovery process (see Fig. 1).

This paper understands post-disaster recovery as a process to enhance and ensure "sustainability, livability, resilience, and equity," all of which will be used as key concepts to evaluate the empirical data obtained. Resilience is often defined as the system's ability to absorb shocks, bounce back, adapt to uncertainty, and evolve to deal with changing circumstances and threats [6,7,9]. But Cutter and other authors have claimed that achieving resilience entails—above anything else—the principles of equity, fairness, and access to resources. The elusive concept of resilience begs two questions: resilience to what, and resilience for whom? [10]. Cutter and others therefore refuse to accept an intrinsic value in resilience, and consider that its pertinence depends on the fit between problems and solutions in a given context and time, where conflicting interests and objectives might emerge.

1.2. Controversies around post-disaster urban planning

A common consequence of internal migration following disasters is urban sprawl and footprint changes [11]; [12]. Urban planning interventions are, therefore, increasingly framed in terms of urban sustainability, livability, and resilience. For key decision makers, disaster recovery represents a window of opportunity to alter land-use patterns and reshape existing social, political, and economic urban conditions [13]. However, previous studies have documented the unexpected secondary effects of post-disaster interventions [14]. "The pressure to urgently address complex, difficult decisions can result in reactive policies that may increase the long-term vulnerability of affected populations," states Ingram [15]. Paraphrasing Gotham [7], vulnerability is a condition that encompasses the features of exposure, susceptibility, and coping capacity. Vulnerabilities can therefore be created while trying to address objectives of resilience and protection. A measure can reduce exposure to a certain risk, while increasing people's susceptibility to be affected by another sudden or ongoing threat. Other researchers have found, for instance, that "the emphasis on using market-centered approaches for urban recovery and rebuilding in New York [after 9/11] and New Orleans [after Hurricane Katrina] should be seen not as coherent or sustainable responses to urban disaster, but rather as deeply contradictory restructuring strategies that are intensifying the problems

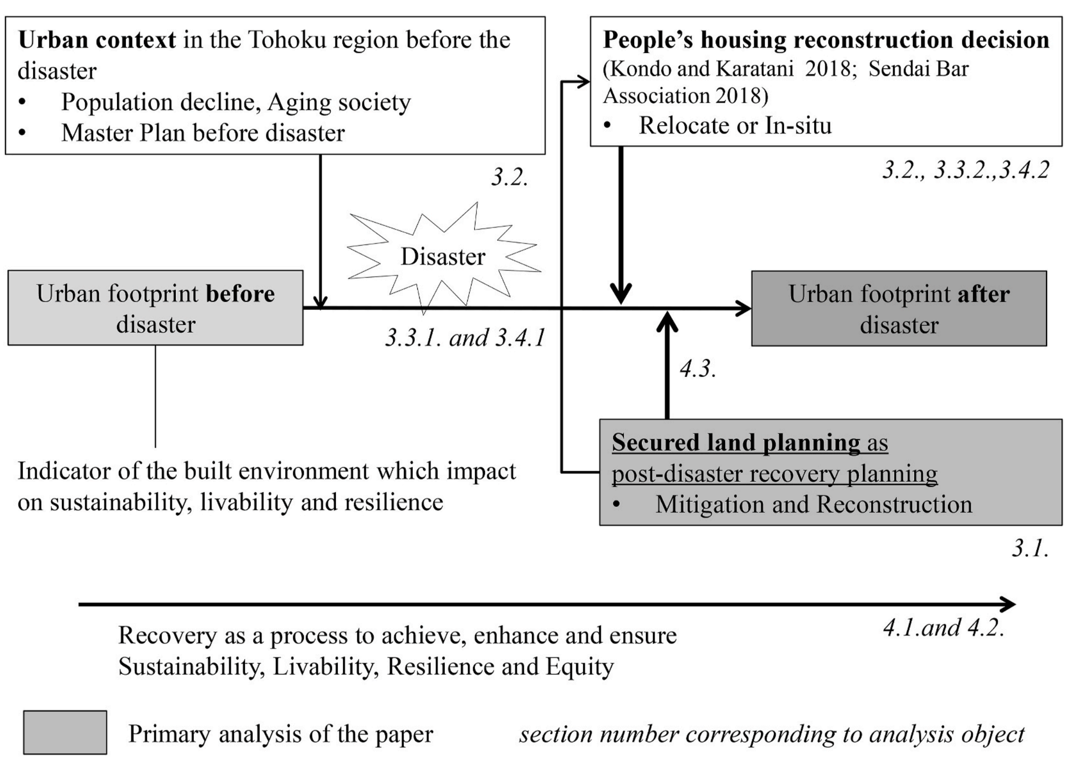

Fig. 1. Constructs adopted in the analytical framework.
(Source: authors)

they seek to remedy" [16]. This article builds on a tradition of urban disaster scholarship to explore how post-disaster urban planning and risk mitigation measures affect risks related to internal migration and displacement.

The 2011 disaster is one of the rare cases in Japan where post-tsunami urban planning emphasized substantial changes in land use to facilitate resettlement. "Since the Meiji period, the [Japanese] government has consistently preferred to use specific projects rather than the development of a regulatory system that controls private development activity," argues Sorensen [17]. And the measures proved to be controversial. According to Iuchi, "only minimum efforts had been made to manage space for resilient development until the 2011 Japan disaster" [18].

1.3. The link between urban footprint changes and internal migration

Urban footprint changes can be linked to internal migration and displacement after disasters [19]. People's free or induced decisions to relocate can exacerbate urban footprints, contribute to urban sprawl, and affect the overall recovery process. In fact, Smith and Wegner [13] define disaster recovery as "the differential process of restoring, rebuilding, and reshaping the physical, social, economic, and natural environment through pre-event planning and post-event actions." It is often argued that urban footprints have a significant impact on urban sustainability, livability, and resilience [20,21]. Rapid urban sprawl is typically considered unsustainable, as it increases ecological footprints and results in high infrastructure development and management costs. Jabareen suggests that "the ideal sustainable urban form is that which has a high density and adequate diversity, compact with mixed land uses, and its design is based on sustainable transportation, greening, and passive solar energy" [22]. Appropriate urban density is essential for survivors' livelihood restoration and urban livability following the disasters [23,24]. Urban density and design affects survivors' quality of life, largely because these factors determine accessibility to services, jobs, and public facilities. Relocation can also disrupt community networks [25]; another reason why managing urban footprints through land-use planning is imperative for building disaster-resilient communities and reducing their exposure to hazards [26].

2. Methods: Zoning analysis of urban footprints

Yin suggests that researchers often use the case study method when seeking to address *how* and *why* questions, especially when the boundaries between the phenomenon and its context might be blurry [27]. This research employs an embedded multiple case study design based on Yin's approach to qualitative research [27]. Fig. 1 shows our primary embedded units of analysis (in grey), and the multiple data sources that were triangulated to understand the consequences of the post-disaster recovery process. The primary analysis focuses on planning interventions, urban footprint changes, and their interrelationships. We explored the post-disaster recovery processes through qualitative case study methods, including a questionnaire survey, interviews about people's housing reconstruction decisions and satisfaction, analysis of previous report [28,29], and more than 50 field visits conducted between 2012 and 2019 in the Tohoku region. This methodological triangulation helped us distill the causes and consequences of urban planning decisions, and strengthened the construct validity of the case study. The empirical research followed a five-step analysis:

2.1. Analysis of post-disaster urban planning and land zoning

We analysed the process of post-disaster urban planning in detail, exploring mitigation measures to designate hazardous zones, the design of coastal levees, plans for ground raising, and collective relocation initiatives taken by the government. We classified the built-up area of cities into five zones focusing on post-disaster urban planning, and housing reconstruction patterns in each zone. The hypothesis was that urban footprint changes and secondary effects of urban planning varied between zones, according to patterns of relocation and displacement.

2.2. Selecting case study cities

We selected two cities to be treated as detailed case studies: Ishinomaki city in the Miyagi Prefecture and Rikuzen-Takata city in the Iwate Prefecture. Coastal shape affects the run-up height and inundation depth in the case of tsunamis, and so, largely determines possible damages [30]. The criteria for selecting these cities were predicated on the severity of damages experienced by the tsunami, as well as their different coastal shapes, topographies, and urban forms, which allowed us to determine patterns of post-disaster urban planning [31]. As the results section shows, the two cities followed different secured land zoning patterns. Fig. 2 highlights the locations of two selected cities in Tohoku: the Ria coast runs through the Aomori and Iwate Prefectures, from Rikuzen-Takata city down to the Oshika Peninsula in the Miyagi Prefecture; the coastal plain ranges from Ishinomaki city to the south of the Miyagi prefecture.

2.3. Analysis of urban footprint changes

Here, we analysed urban footprint changes through two indicators: post-tsunami housing construction and post-tsunami vacant lots. We refer to post-tsunami housing as a residential building constructed between 2.5 and 6 years after the tsunami, on what used to be a vacant lot a year prior to the disaster. A post-tsunami vacant lot is a parcel where housing was located a year before the tsunami, but was demolished within 2.5–6 years following the disaster.

We used the Arc GIS 10.6.1 software Geoprocessingtool—including the selected layer and overlaying building footprint data in 2010, 2013, and 2017—and then "inverted" the results to identify the non-intersecting layers of building footprints (Fig. 3). As illustrated, post-tsunami housing units (2013) were identified by setting "input feature layer" in a 2013 map, "select feature layer" in a 2010 map, "relationship" as "intersect," and by inverting the spatial relationship. Post-tsunami vacant lots (2013) were identified by setting "input feature layer" in a 2010 map, "select feature layer" in a 2013 map, "relationship" as "intersect," and by inverting the spatial relationship (see example in Fig. 3). We then obtained residential building footprint data from ArcGIS Geo Suite maps, the main data source of ESRI Japan, which

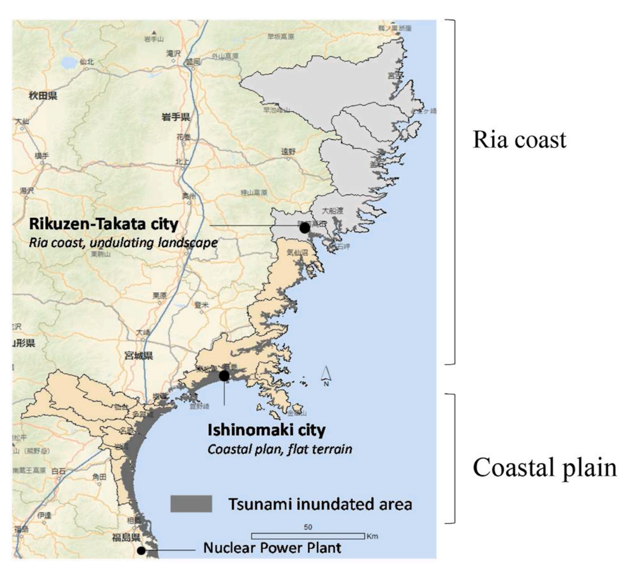

Fig. 2. Tsunami inundated coast and location of the case study cities. (Source: authors based on tsunami inundation GIS data from the MLIT)

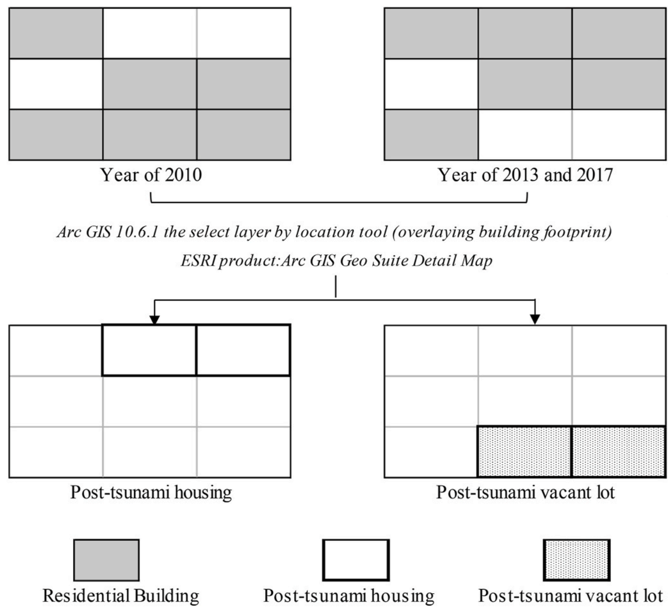

Fig. 3. Datasets and methods used for urban footprint analysis (Source: authors).

was developed based on residential maps made by Zenrin Co., Ltd (the company that provides the data for Google Maps in Japan), and the geospatial land map of the MLIT.

2.4. Overlaying urban footprint changes with pre-tsunami land-use and landslide-prone areas

We overlaid the post-tsunami housing and post-tsunami vacant lots (as identified in step 3) with secured land zoning, pre-tsunami land-use types, and landslide hazard areas to better understand the characteristics of urban footprint changes. We also conducted a survey [28] among 823 residents to address people's motivations for relocating or staying in zones that experienced urban footprint changes, and the kinds of problems they faced. These surveys included a questionnaire distributed in 2014 and 2016 among people who relocated voluntarily (that is, not through collective relocation initiatives) to inland and mountainous regions within the tsunami-affected cities. Another survey was conducted in 2018 by a Lawyers Association [29] among people who opted for in-situ housing reconstruction in low-lying areas hit by the tsunami. As much as 81.7% of respondents were elderly living in housing with unfinished repairs.

2.5. Analysis and synthesis

Empirical evidence from case studies of urban footprint change and secondary effects was analysed first. Then, we drew cross-case comparisons and conclusions from the individual case reports. The results provide both practical and theoretical implications, and demonstrate contrasting patterns, as explained in the discussion section. We finally reviewed several articles on post-disaster urban planning processes and housing recovery, and compared previous patterns with our own empirical findings. This is how we were able to generalize about the Japanese case and posit suggestions around planning and policy.

3. Results – Understating cascading effects after post-disaster urban planning

3.1. Secured land planning

After the 2011 disaster, the national government classified tsunamis into two categories: Level 1 for those tsunamis with a possible return period of 100 years, and Level 2 for gigantic events with a return period of 1000 years, such as the 2011 tsunami. The idea is that Level 1 tsunami damage can be prevented by engineering solutions such as coastal levees, whereas Level 2 tsunami risk requires more comprehensive mitigation measures, including land-use regulation.

By the end of 2011, most of the heavily damaged cities in the Iwate and Miyagi Prefectures unveiled reconstruction plans. The levee height is a precondition for local secured land planning. The total distance of coastal levees along the Tohoku region is 431 km, with construction only expected to be completed ten years after the tsunami [32].

Managing future tsunami risk has been a consistent theme of prefectural-level reconstruction planning [33]. While the municipality was the primary stakeholder in post-tsunami urban planning, the national government held a strong influence in two ways. The Ministry of Land, Infrastructure, and Transport (MLIT) took the immediate initiative, creating a "Recovery Pattern Inquiry." The MLIT [31] presented the following five reconstruction strategies: 1) relocation, 2) construction in areas protected by an elevated road as a second levee, 3) construction with ground raising, 4) a combination of relocation and ground raising, and 5) in-situ rebuilding protected by a coastal levee. "Most of the disaster-stricken municipalities had drawn up recovery plans, based on the MLIT-led inquiry and recommendations" [34]. The other influence derives from the fact that recovery funding was dominated by national funding sources, so municipalities could only really secure land planning by "selecting" urban redevelopment projects legislated by national law. A total of 118 billion U.S. dollars were spent on mitigation projects in the Tohoku region that shared approximately 40% of the total reconstruction budget, 320 billion U.S. dollars [35].

3.1.1. Designating hazardous zones

Land-use regulation in Japan is an exclusive, non-engineering measure for secured land that reduces exposure to tsunamis in tandem with collective relocations. This zone is specified in Article 39 of the Buildings Standard Law of Japan; municipalities have the authority to designate a hazardous zone by their local ordinance. In the hazardous zone, new residential building reconstruction was prohibited, with the exception of housing repairs. Coastal levee heights had a strong influence on hazardous area designation: higher levees make hazardous zones smaller [36]. But how did municipalities designate hazardous zones? Matsumoto and Ubaura conducted an interview survey of 25 municipalities and found that the topographic signature, damage, and the will of survivors (with respectful consideration of where they wanted to reconstruct their housing), were all taken into account [37]. Most municipalities conducted a questionnaire survey in the early stages of post-disaster recovery planning. Thus, the designation process was not only based on tsunami risk simulation, but also served as housing resettlement support for homeowners.

3.1.2. Elevated road construction as a second levee

An elevated road was built to reduce the impact of a Level 2 tsunami. This mitigation measure was applied to the coastal plain in the southern part of Miyagi prefecture, which does not have a steep terrain behind the urban area. An elevated road therefore divides the coastal area in the hazardous zone and a residential area beyond the second levee. It cost 297 million U.S. dollars to employ the 6-m-high elevated Tobu Fukkou Road, which opened to traffic in November 2019, to prevent the tsunami from reaching the urban areas that run 10.2 km along the Sendai plain. During its opening ceremony, the Mayor of Sendai praised the road for "protecting our lives" [38].

3.1.3. Ground raising

Plans to raise the ground level were devised to enlarge areas for residential and commercial use. "The height of the mound up is designed according to the 2-2 rules. Many tsunami-affected municipal governments prohibit residential land use where the result of Level 2 tsunami simulation shows an inundation depth of over 2 m and current velocity of over 2 m/s" [39]. The total area of land readjustment in the Tohoku region is 1,532 ha [40], which is the same size as Letchworth Garden City in England. Ground raising was also applied to build new housing in the city center. Ground raising in Japan is not often implemented by the land readjustment initiatives, although there was a special provision put in place to address the 2011 tsunami-affected areas. Land adjustment was also used to reorganize urban structures and land patterns in concurrence with expropriation. The primary mechanism for land readjustment implementation was replotting, which refers to changes in forms and areas of several plots of land [41]. The project reorganized land use and provided replotted parcels to landowners regardless of whether they wanted to reconstruct their homes or start their business in the ground-raised area.

3.1.4. Collective relocation to inland and mountainside areas

Collective relocation aimed to reduce exposure to tsunami risk along with hazardous zone designation. There are 31 districts with 7 cities in Iwate Prefecture, and 73 districts with 12 cities in Miyagi Prefecture, both of which conducted collective relocation [42]. MLIT categorized patterns of collective relocation based on a combination of relocation promotion zones and resettlement areas [31], including the construction of a mixed-use settlement and aggregating new residents into urban areas.

The specific scheme of the project required municipalities to purchase residential lots in hazardous designated zones, to bring services and infrastructure to new lots in relocation areas, and then sell or lease them to survivors. When acquiring new lots or building new homes, survivors could get a reimbursement for certain relocation expenses, such as moving costs and the buyout price of the land designated a hazardous zone. This initiative was originally a mitigation measure used to reduce disaster risk, but was later adopted in the post-disaster phase to support survivors. Municipalities often combined land readjustment and collective relocation with new housing reconstruction. As opposed to the land readjustment initiatives, the scale of collective relocation was determined by the survivors' needs. The MLIT whitepaper shows that this initiative had been adopted to relocate 1,834 households since it was first established in 1972, until 2006, mostly due to landslides, with each project averaging 53 households [43]. The initiative then reemerged in 2011 with the aim of increasing tsunami risk reduction [44]. The volume of collective relocation after 2011 reached a total of 30,536 households in the Tohoku region [45]. While more than ten housing units were required to incorporate collective relocation in 1972, the restriction was eased to 5 units for the Great East Japan Earthquake. Ground raising and collective relocation development for just one parcel exceeds 600,000 U S. dollars [46].

3.1.5. Zoning by secured land planning

We classified the built-up area of a city into five zones, defined by characteristics of urban planning and housing reconstruction patterns in order to examine the different effects of planning intervention on urban footprint changes. This zoning was not designed by municipalities but by authors, based on tsunami inundation, hazardous zones, reorganizing land use, and securing land mitigations, all of which can influence people's housing reconstruction (Table 1).

Zone A is the hazardous zone where new housing reconstruction was prohibited. Zone B experienced tsunami inundation but was secured by two levees: the coastal levee and the elevated road, which enabled in-situ housing reconstruction. Zones C and D refer to the areas where the government reorganized land use by ground raising and collective relocation development. The difference between Zone C and D is that, while the former experienced tsunami inundation, the latter is far from coastal areas (Table 1 and Fig. 4). The rest of the four zones are external areas that did not have any government planning intervention.

3.2. Planning processes, population shift and housing reconstruction patterns found in the case study cities

Table 2 shows the massive scale of damage in two case study cities among 19 other coastal cities in the Iwate and Miyagi prefectures, with severe damages to more than 500 residential buildings. The relative destruction in these two cities was high, which made it challenging for survivors to remain in place. As we shall see below, this eventually led to massive internal migration. Fig. 5 shows the internal migration pattern beyond municipality limits [47,48]. As illustrated, the migration moved inland and concentrated on Sendai city, the largest city in the Miyagi prefecture. Almost all municipalities' population recovery rates are still low, except for the cities of Sendai and Natori, where an important immigration process had started before the tsunami. The population recovery rate of Ishinomaki-city is 88.7%, which is higher than that of Rikuzen-Takata city, which is 80.3% [49–52].

The Population Census data helps explain three patterns of housing reconstruction in each city: 1) in-situ housing reconstruction or no damage, 2) relocation within the city, and 3) relocation beyond municipality limits. Fig. 6 shows that more housing relocations were found in Rikuzen-Takata city and more in-situ housing reconstructions in Ishinomaki city [5,53]. The patterns of internal migration and population decline beyond municipality limits (shown in Fig. 5) and housing reconstruction patterns (shown in Fig. 6) lay the basis for the urban footprint analysis described in Step 3.

Seven years before the tsunami, the Iwate Prefecture [54] stated in the urban development policy of Rikuzen-Takata city, that the Takata-district (a city center commercial area that went through ground raising after the tsunami) had been "experiencing urban decline, depopulation, and aging." It was recommended that "the city should strengthen its urban function by networking within surrounding cities on a regional scale." The same document argues that "it is unlikely to have an increase in the population so that it is unnecessary to set the boundary between an urbanized area and an urbanization-restricted area." This designation aimed to avoid urban sprawl under the Urban

Table 1
Five zones classified by post-disaster urban planning and housing reconstruction patterns.

	Zone A	Zone B	Zone C	Zone D	External Zone
Location	Low-lying and Coastal area	Low-lying and Coastal area	City center	Inland and Mountainside	Inland and Mountainside
Tsunami inundation	Yes	Yes	Yes	No	No
Hazardous zone	Yes	No	No	No	No
Reorganizing land use by planning	Yes	No	Yes: replotting, expropriation	Yes: subdivision	No
Secured land planning	No/Outside	Coastal levee & elevated road	Land raising	Collective resettlement※	No
Housing reconstruction pattern	In-situ O Repair × Reconstruction	In-situ O Repair O Reconstruction	Relocate × Repair O Reconstruction	Relocate × Repair O Reconstruction	Relocate × Repair O Reconstruction

(Source: authors)

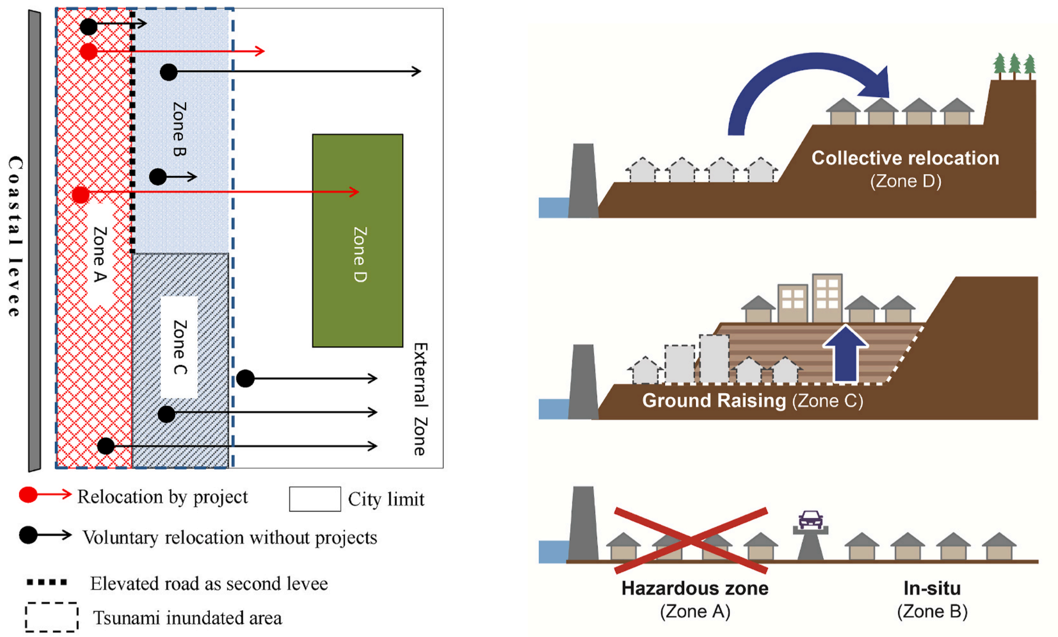

Fig. 4. Zoning by secured land planning: 2D diagram and section plan.
(Source: authors)

Table 2
Relative damage of case study cities among 19 coastal cities that experienced severe damages to more than 500 residential buildings in Miyagi and Iwate Prefectures.

	Human loss		Severe Housing Damage		Tsunami inundated	
	Number of deaths	% out of total population[a]	Building	% out of total housing[b]	Size (ha)	% out of built-up area[c]
Rikuzen-Takata city	1,806	7.8%	3,806	49.4%	1,320	42.9%
Average of 6 cities in Iwate Pref.	5,037	3.1%	18,572	25.6%	4,591	29.3%
Ishinomaki city	3,972	2.5%	20,039	35.1%	5,654	45.7%
Average of 13 cities in Miyagi Pref.	11,739	0.7%	81,376	12.1%	29,053	30.9%

[a] (dead and missing) [1]/population in 2010 [55].
[b] (severe damage) [1]/total housing stock in 2010 [5].
[c] Inundated area [56]/built-up area in 2010 [56].
(Source: authors)

Planning Act of Japan. The number of people aged 65 or older reached 34.9%, and the population decrease between 2000 and 2010 was 9.3% (compared to the national average of 0.3%) [5,55].

The post-disaster recovery plan of Rikuzen-Takata city launched in December 2011. The local government initially developed a plan to regenerate the Takata-District through ground raising. However, after conducting a questionnaire among its citizens, the authorities added six collective relocation areas around the ground-raising zone. As many as 14.3% of survivors wanted to rebuild their homes in-situ, whereas 53.0% of them preferred a collective relocation within Takata-district [57]. The idea was to build a compact area for an aging, depopulated city. The national and prefectural governments determined the height of the coastal levee to be 12.5 m from Tokyo Peil (T.P.), to account for dangerous tsunamis in the future. This 81.6ha ground-raising area, which includes a 12 m high (T.P.) embankment, is the largest in the Tohoku region [58]. By July 2018, when the collective relocation (Zone D) was complete, all lots were handed over to landowners. Ground raising (Zone C) will, nonetheless, continue until the end of March 2021. Rikuzentakata is the only city in Iwate Prefecture in which a secured land project is still ongoing (as of 2020).

Similarly, there is notable depopulation (−8.0% between 2000 and 2010) and urban decline in the city center of Ishinomaki City [59]. Aging is also a problem there: the proportion of people aged 65 or older has reached 27.3%, which is slightly higher than the national average. A high-density building footprint without open space is a significant challenge in low-lying areas (Zone B). On the other hand, a suburban residential development (in the inland zones) is attracting the population toward the interchange of the highway that leads to Sendai city. National and prefectural governments determined the height of the coastal levee to be 7.2 m, to protect the area from a Level 1 tsunami—with an elevated road (3.5 m, T.P.) that serves as a second levee. The area between the coastal levee and the second levee was designated a hazardous zone (Zone A) for industrial use and parks, whereas residential areas protected by the levees were zoned as housing reconstruction areas (Zone B). The areas for inland collective relocation (Zone D) are some of the largest in the Tohoku region. Fig. 7 shows the different combinations of secured land projects and zoning in the two cities. Takata district in Rikuzen-Takata city is divided into Zones A, C, D, and the external zone. The western part of the urban area in Ishinomaki city is divided into Zones A, B, D, and the external zone. The cross-sections indicate the different topographic signatures that influence secured land planning.

The scale of planning intervention for severely damaged housing also differs in the two locations. The portion of secured land subdivision in ground raising and collective relocation is four times larger in Rikuzen-Takata city than in Ishinomaki city—see Table 3 [60]. However, the proportion of disaster public housing units [60] and severely damaged housing [1] is almost the same.

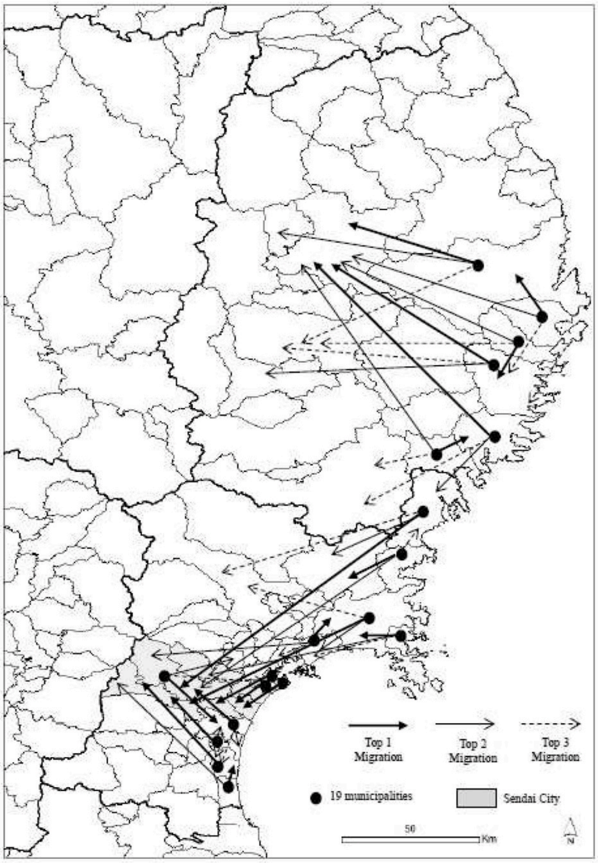

Fig. 5. Internal migration beyond municipality limits.
(Source: authors)

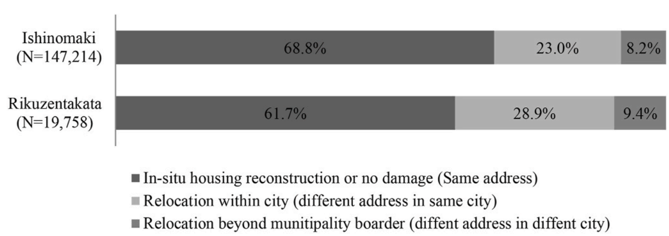

Fig. 6. Housing reconstruction patterns in two case study cities.
(Source: authors)

3.3. Case study 1: Rikuzen-Takata City, Iwate Prefecture

3.3.1. Urban footprint changes

Fig. 8 shows the spatial distribution of post-tsunami housing and post-tsunami vacant lots. Post-tsunami housing in the external zone is low density, scattered, and situated on a higher ground of a steep terrain. A more significant number of post-tsunami vacant lots can be found in Zone C. Post-tsunami housing is sprawled beyond Zone D with low density. It is important to note that Rikuzen-Takata city conducted a questionnaire survey for Zone C landowners regarding their plans for using their lots. More than 60% of landowners did not have any plans to construct their housing or start their businesses in Zone C [61]. Future housing reconstruction will determine the urban footprint in Zone C after the completion of ground raising, which is expected to be finished by 2021, though the landscape has been deserted since 2019 (Fig. 9).

In Fig. 10, we overlaid the pre-tsunami land use (2010) and post-tsunami housing patterns to understand the characteristics of post-tsunami residential construction. Post-tsunami housing development in the external zone converted forest and agricultural land into built-up areas. The urban footprint significantly changed after the tsunami and long-term reconstruction process, due to internal migration, relocation within the affected city, and government-led planning interventions.

Fig. 11 shows the crossover of landslide hazardous zone and post-tsunami housing. Post-tsunami housing is found in the landslide hazardous zone. The prefectural level designates the zone under the Landslide Prevention Act of 2000. Rikuzen-Takata city selected a collective resettlement (Zone D) area by considering the landslide hazardous zone; however, there was little control over development by individual housing reconstruction and private housing builders in the external zones [62]. The author's field visit confirmed that the quality of the retaining wall and drainage work in the external zone is inferior to that of Zone D, which was developed by the government.

3.3.2. People's decisions on housing reconstruction and government support

Why did people decide to relocate to the external zones? Kondo and Karatani [28] conducted two questionnaire surveys for households that relocated to the external zone in the years 2014 and 2016, across 9 municipalities in Miyagi and Iwate Prefectures. The objective was to reveal residents' decision-making process for relocation—and the problems they encountered—to assess their overall satisfaction. The survey shows that most people sought to "reduce tsunami risk" and avoided housing construction in Zone C due to the speed of construction in external zones and the feeling of unease and uncertainty of tsunami inundation in that zone [28]. Although respondents remained concerned about their financial situation and feelings of isolation in resettled areas, they were generally satisfied with the fact that they could rebuild fast in external zones.

Rikuzen-Takata city also rolled out initiatives that were not found in other municipalities, including subsidies for water, sewage, and road construction in external zones [63]. The funding for these initiatives came from the national government, through a special tax for the prefectural government and recovery bonds, to enable municipalities to conduct special reconstruction programs. The national government intended to support collective relocation outside of hazardous zones [64].

3.4. Case study 2: Ishinomaki City, Miyagi Prefecture

3.4.1. Urban footprint changes

Fig. 12 shows the location of post-tsunami housing and post-tsunami vacant lots. Post-tsunami vacant lots can be found in Zone B, where the government expected people to stay, given that the coastal levee and elevated road were supposed to secure the area. The post-tsunami housing located next to Zone D is more concentrated than in Rikuzen-Takata city. Similarly, the share of post-tsunami housing constructed in residential land is far more significant than that of Rikuzen-Takata city (Fig. 13). In particular, the vacancy rate in collective relocation areas of Ishinomaki city is 24.4%, which corresponds to 342 out of 1401 lots [65], a figure that is higher in Zone C in Rikuzen-Takata city.

Much of the post-tsunami housing is concentrated in the external zone beside Zone D, which is the largest collective relocation development in the Tohoku region. Post-tsunami housing is, essentially, infilled development, and forms a high-density residential area between Zone D and the external zone. Before the tsunami, the external zone next to Zone D was considered the city center, marked by public residential subdivision and private commercial development. It is close to major hospitals, railroad stations, and the commercial shopping malls surrounding Zone D.

Landslide risk assessment was not conducted in Ishinomaki city because of its flat terrain (Fig. 7).

3.4.2. People's decisions on housing reconstruction and government support

Why did people opt for in-situ housing reconstruction in Zone B? Zone B suffered a 2.0 m tsunami inundation, and the inland from Zone B

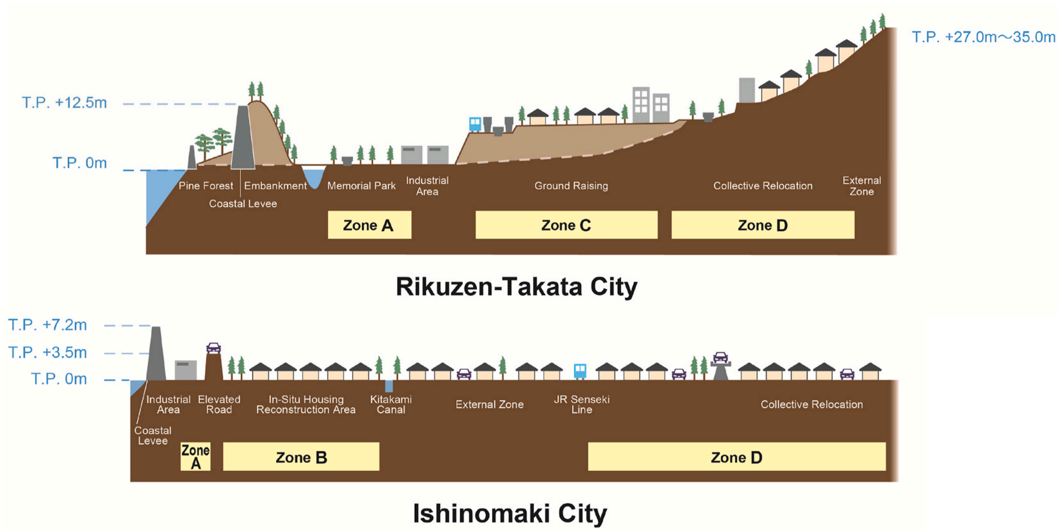

Fig. 7. Cross-section of land secured zones in two case study cities.
(Source: authors, altitude calculated by the Geospatial Information Authority of Japan's drawing application)

Table 3
Scale of planning intervention for mitigation and housing reconstruction.

	Rikuzen-Takata City	Ishinomaki city
Disaster public housing (units)	895	4,456
Disaster public housing/severe Housing (%)	23.5%	22.2%
Government-provided secured lot (units) by ground raising and collective relocation area	1,954	2,626
5eerred lot/Severe housing (%)	51.3%	13.1%

(Source: authors)

(External Zone in Fig. 7) experienced 1.0–2.0 m. MLIT categorizes Zone B as a "major and partially damaged area" [66]. Fig. 13 shows that many post-tsunami vacant lots are found in Zone B, even though this area was designated an in-situ housing reconstruction zone protected by coastal levees.

During the emergency phase, thousands of residents stayed in their houses to avoid entering overcrowded temporary shelters. They were referred to as "at-home victims" by mass media, government sectors, and non-profit organizations. But the language also evolved: "at-home victims" changed from being "self-sheltered people" in the emergency phase to "people living in housing with unfinished repairs" in the recovery phase. To better support these survivors, the Ishinomaki-city surveyed about 4,000 households in Zone B, that experienced significant housing damage. In 2019, the government found that 60% of them had not finished their housing repairs, and had been living in unrepaired housing since the tsunami [67]. The Sendai Bar Association conducted door-to-door aid services for 305 households, on consignment from the municipality. The association discovered that 81.7% of respondents were elderly, and their common struggles included: 1) unfinished housing repair (42.6% of respondents); 2) government assistance gaps among survivors (28.6% of respondents); 3) anxiety about their daily lives (28.2%), and 4) neighborhood issues (7.8%), including isolation, strained relations with neighbors, and neighborhood rebuilding [29].

"At-home victims" qualified to receive a subsidy for their housing reconstruction under the Disaster Relief Act. However, this subsidy could not fully support their housing reconstruction, and several residents were ultimately excluded from getting enough government support [29]. Only survivors who lacked a place to live due to severe

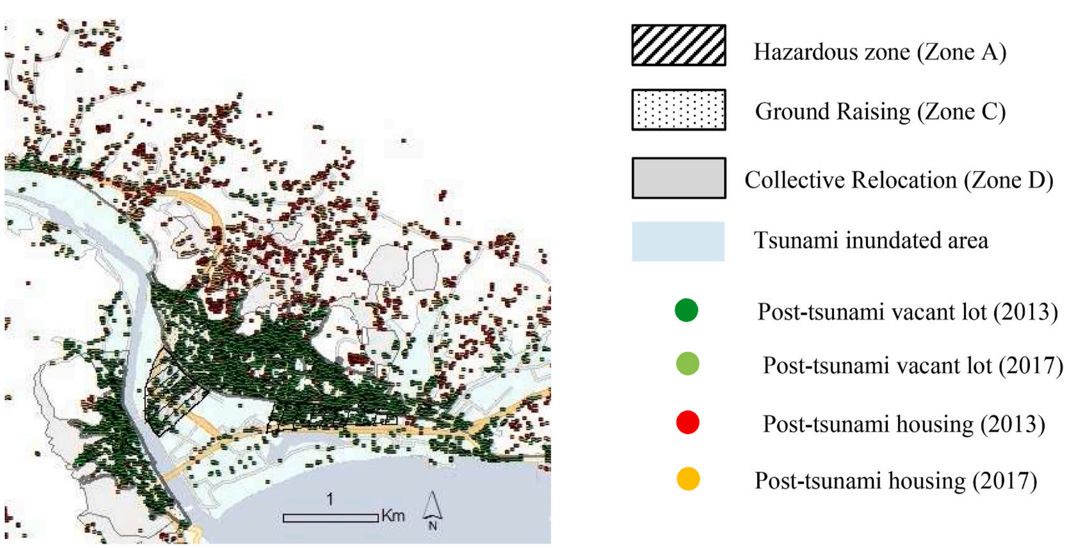

Fig. 8. Location of post-tsunami housing and post-tsunami vacant lots in Rikuzen-Takata city.
(Source: authors)

Fig. 9. Vacant lots in Zone C in Rikuzen-Takata city (the signboard reads ‘Lot for Sale’).
(Source: authors)

housing destruction could apply to live in temporary housing under the Disaster Relief Act. Homeowners who had used subsidies for their housing repairs were excluded from disaster public housing as they could not satisfy either condition: not having a place to live (under the Disaster Relief Act), and not being in dire need of housing (under the Public Housing Act).

4. Discussion: Maladaptation, urban fragmentation, and other cascading effects

In the previous section, we identified the secondary effects of post-disaster urban planning on locations of post-tsunami housing and post-tsunami vacant lots. This section offers an interpretation of the secondary effects of post-disaster urban planning on the urban transformation from the perspective of sustainability, livability, and resilience. We also examine the influencing factors of secondary effects in two cases that can predict similar results in other case studies [27]).

4.1. Maladaptation

Secondary effects of post-disaster urban planning found in Rikuzen-Takata city can be seen as problems of “maladaptation.” Juhola defines maladaptation as the “result of an intentional adaptation policy or measure directly increasing vulnerability for the targeted and/or external actor(s), and/or eroding preconditions for sustainable development by indirectly increasing society’s vulnerability” [68]. UNEP suggests that maladaptation is “the absence of evolvability”. It is futile in the way that it damages resources, which narrows future options, worsens the problem for vulnerable populations, passes the responsibility for finding solutions on to future generations, and violates both sustainable development and social equity—burdening the most vulnerable [69]. Why can the Rikuzen-Takata city case be interpreted as a maladaptation?

First, the mitigation, reconstruction, and adaptation measures in the ground-raising zone had negative effects on external zones and citywide urban structures. There was as much as sixty percent of unoccupied land in the ground-raising zones. Low-density development in the external zones expanded citywide urban land coverage, damaged natural resources (such as agricultural land and forests in mountainside areas), increased the infrastructure management cost, and passed on the responsibility for maintenance of all this new infrastructure to future generations. Urban sprawl is an unsustainable footprint pattern in a depopulated city: “Urban sprawl and low-density developments frequently come with hidden costs and disadvantages, ranging from car dependency to loss of agricultural space and the risk of social isolation” [23]. Second, people living in external zones saw their exposure to landslides increased in exchange for tsunami risk reduction. Urban sprawl might also negatively affect the livability of elderly people resettled in external zones, especially those who don’t drive a car. Poor mobility is likely to reduce people’s livability in external zones, mostly in terms of deteriorating their health, increasing isolation, and weakening community networks. Mobility is not only essential for enabling people to access necessary services but to adapt to changes in their lives at an advanced age. Livability might decline without people’s “coping capacity” to new threats and environmental changes.

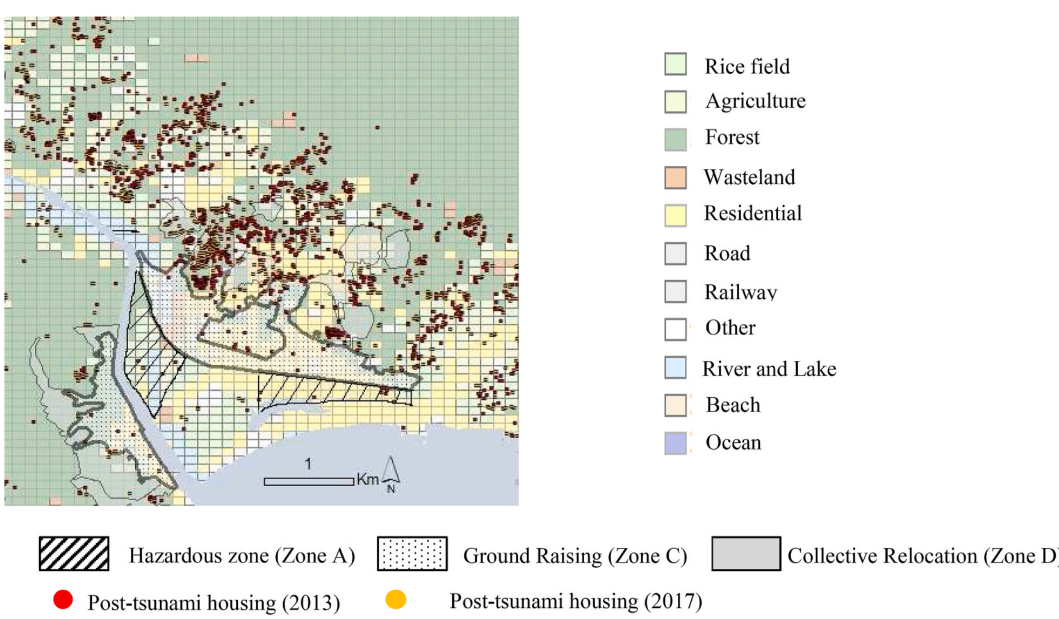

Fig. 10. Pre-tsunami land use and post-tsunami housing in Rikuzen-Takata City.
(Source: authors, pre-tsunami land-use data is from MLIT)

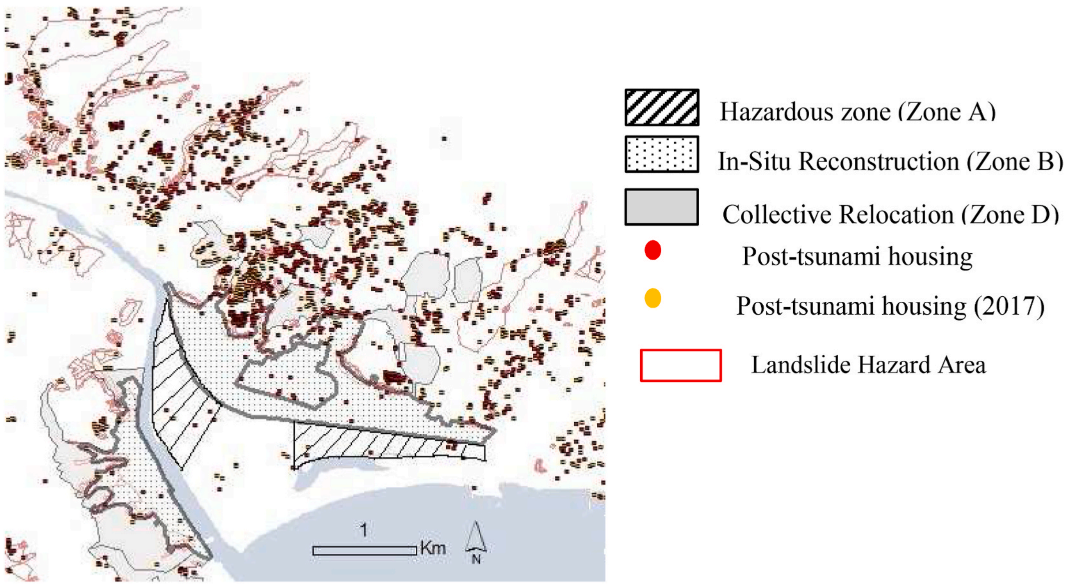

Fig. 11. Landslide hazard area and post-tsunami housing.
(Source: authors, Landslide hazard area is from MLIT).

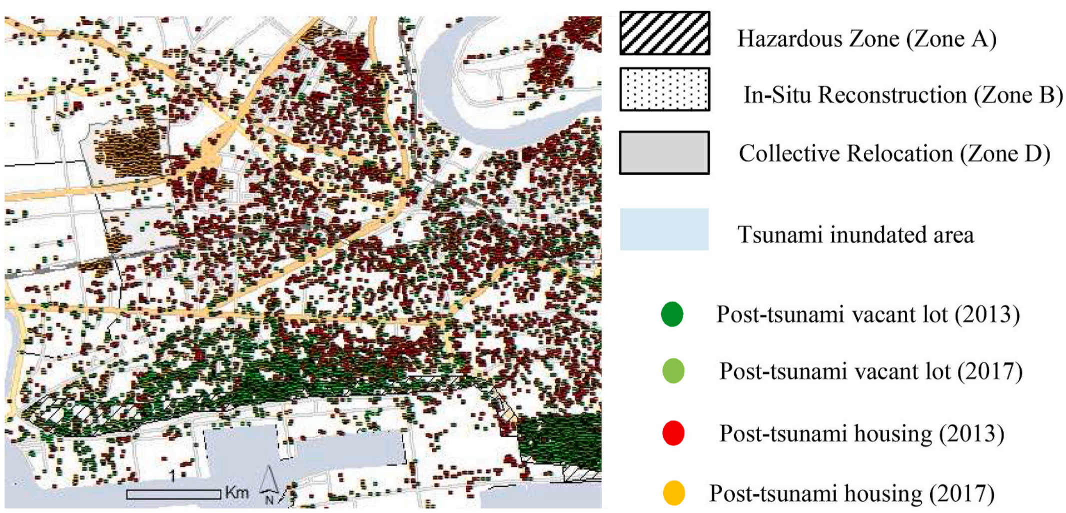

Fig. 12. Location of post-tsunami housing and post-tsunami vacant lots in Ishinomaki city.
(Source: authors)

4.2. Urban fragmentation between people and places

Post-disaster planning in Ishinomaki city has led to fragmentation between places and people. There is now higher inequity between spaces and the people who occupy them. In fact, thousands of people stayed in homes without proper repairs, surrounded by vacant lots, and in neighborhoods that have generally decreased their quality of life. If vacant lots are not managed correctly, the situation can only worsen. On the other hand, collective relocation prompted surrounding areas to develop and become second city centers that attracted people who could afford to buy new housing and lots.

To be sure, urban fragmentation had started before the tsunami, but accelerated quickly after it. Contrary to physical fragmentation, social fragmentation between people only emerged following the disaster. Inequity and injustice rose between people in low-lying areas and those in resettled inland areas. Survivors felt a feeling of inequity in government reconstruction assistance. In the in-situ housing reconstruction zone protected by coastal levees, people were concerned about "neighborhood issues" [29]. The large number of vacant lots implied that residents lost relationships with neighbors and felt isolated. What made affected cities so fragmented, immediately after the disaster, was the tsunami inundation borderline; however, fragmentation is now caused by post-disaster urban planning during the recovery process.

Fig. 14 summarises the cascading effects and the emergence of maladaptation and urban fragmentation. Post-tsunami mitigation and reconstruction measures to provide secured land did reduce exposure and vulnerability in the face of tsunamis and restored urban conditions after damages. However, they also triggered secondary effects, notably in terms of urban and social fragmentation, inequity among beneficiaries, increased exposure to landslides, and reduced sustainability and livability in urban contexts. The measures taken by the Japanese government lacked adaption to specific local conditions and flexibility to mitigate or avoid these secondary effects.

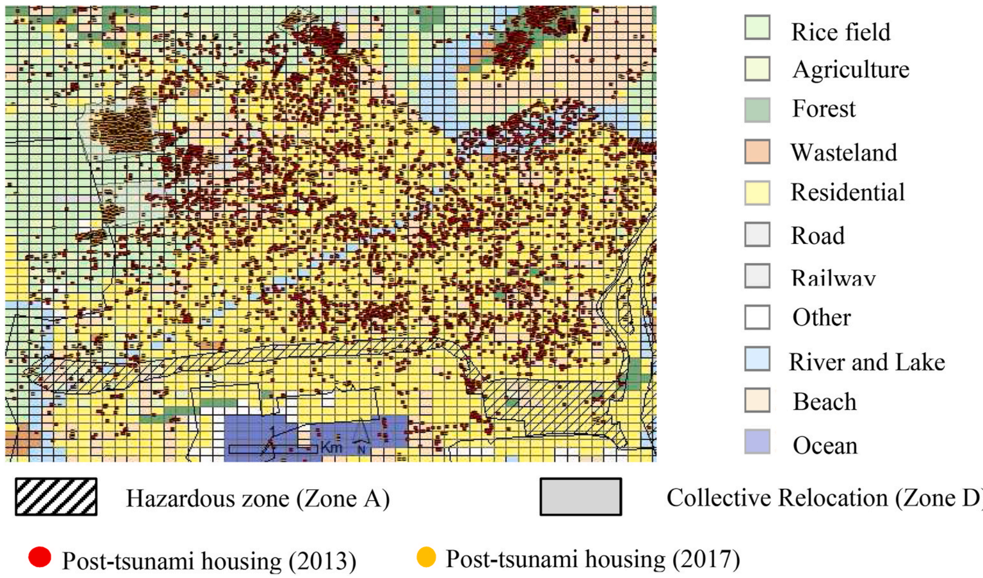

Fig. 13. Pre-tsunami land use and post-tsunami housing in Ishinomaki city.
(Source: authors, pre-tsunami land-use data is from MLIT).

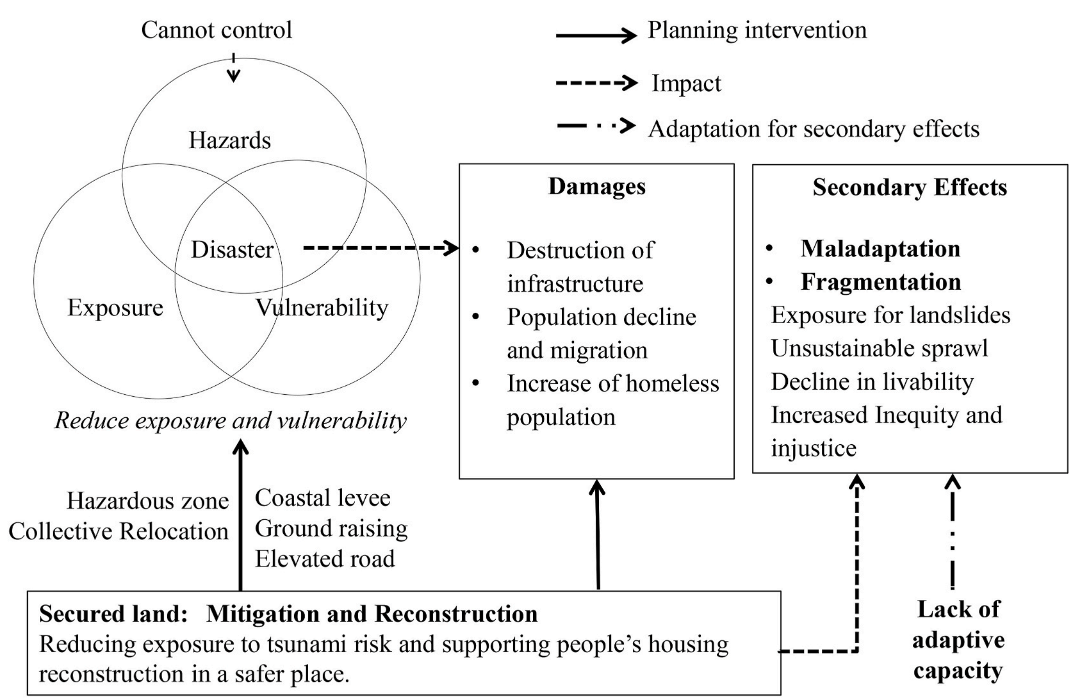

Fig. 14. Secondary effects of post-disaster urban planning after the 2011 disaster in Japan.
(Source: authors)

4.3. Driving factors affecting maladaptation and fragmentation

What were the man-made impacts on maladaptation and urban fragmentation? And under what conditions were they found? Here, we argue that four factors played a significant role in changing urban patterns in Japan. These factors are not totally surprising. As a matter of fact, this study is positioned as part of post-disaster urban planning and housing recovery studies, which explore the ways in which planning intervention affects urban footprint changes, and people's housing reconstruction decisions.

4.3.1. Large-scale and long-term mitigation projects

Large-scale and long-term mitigation projects induced withdrawal from the ground-raising zone and increased voluntary relocation to external zones. "Threats from maladaptation would likely escalate as the scale of the action increases" [69]. Rikuzen-Takata city needed a large-scale, ground-raising zone to regenerate the old city center due to the rias-coastal shape, which cannot reduce tsunami damage with coastal levees.

4.3.2. Assistance programs

Housing reconstruction assistance programs served as a trigger for maladaptation, expanding the urban footprint in the external zone of

Rikuzen-Takata city. The municipality designed this program by recognizing that housing construction in the external zone, nonresidential land use, could not be implemented without the development of utility piping and road construction. It also prevented out-migration in the city, which had experienced a severe population decline before the tsunami. We can find a trade-off between helping housing reconstruction in the external zone, maintaining population, and expanding the urban footprint.

4.3.3. National recovery policy and rules

Exclusion from the national recovery program prevented people from relocating inland and moving to temporary or disaster public housing in Ishinomaki city, which led to urban fragmentation. Japanese housing recovery policy's emphasis on "equality of opportunity," rather than the "equality of results called equity" induced inequality of the built environment between the in-situ housing reconstruction zone and the collective relocation zone. This characteristic can also be applied to the national government housing assistance program for the external zone, which is unqualified to join collective relocation, to ensure equality between the inundated hazardous zone and outside the zone [64].

4.3.4. People's perception of insecurity living in the tsunami-inundated area

People's perception of insecurity living in the tsunami-inundated area—the ground-raising and in-situ housing reconstruction zones—affects not only maladaptation but also urban fragmentation. The different risk perceptions between remaining residents and relocated residents increased post-tsunami vacant lots in the two zones. Differences in risk perception between citizens and the municipality enlarged the gap between what planning was expected to be rebuilt through in-situ housing reconstruction and the phenomenon of demolished housing.

4.4. Relationships between empirical findings and previous research results

We reviewed a number of articles on the post-disaster urban planning and housing recovery processes introduced in "Urban Planning after Disasters" [4]. By bringing together selected papers on the essential topic of planning after a disaster, and the "Handbook of Disaster Research" [13]—an interdisciplinary collection of disaster research—we highlighted key findings in post-disaster urban recovery studies and used these previous patterns to generalize about the Japanese case and posit implications around planning and policy.

4.4.1. Recovery process and secondary effects

Post-disaster recovery is a process [70]; Rubin, 1985 [4,13,71], that is directly associated with secondary effects [71,72]. Quarantelli points out that "the recovery process sometimes ignores or downplays the secondary of ripple effects of disaster" [71]. Our analysis in Japan confirms this pattern. Alesch suggests that disaster is exacerbated as secondary and tertiary consequences, triggered by the initial event and the initial consequences, cascading through the community and beyond [72]. Arendt and Alesch [73] classify these consequences into five types of effects that disturb the functions performed by the built environment. Secondary effects in coastal cities, which affect urban footprint distortion, are organized using the following framework: 1) Initial consequences: 9.0 magnitude earthquake and massive tsunami, 2) immediately following consequences: tsunami fires, nuclear power plant meltdown, 3) systemic community consequences: internal migration and relocation within tsunami-affected cities, 4) ripple effects beyond the community: outflow migration to non-affected regions, urban sprawl beyond the tsunami inundated zones, landslide risk increase in the non-tsunami inundated zones, urban fragmentation between tsunami-affected and non-affected zones, 5) ripple reverberations returning to the initial community: not identified yet in this article. Our analysis demonstrates that planning intervention in a certain place can have negative effects on the citywide urban transformation, which manifests as maladaptation and urban fragmentation.

4.4.2. Sustainability, livability, and equity in the recovery process

Past research shows that concepts of hazard mitigation, sustainability, and equity should be applied to the recovery process [13,74]. Although we showed that the long-term recovery process after the 2011 tsunami reduced the risk of other tsunami, it has not yet achieved sustainability and equity. Several articles in the U.S. case studies exhibit that housing recovery cannot remedy the inequity that emerges throughout the recovery process [75–80]. Peacock, for instance, suggests that the inequalities in long-term housing recovery are often determined by damage and pre-disaster social vulnerabilities [78]. But our case studies prove that inequity was also induced by the Japanese government planning intervention, which gave priority to reducing risk. Post-disaster recovery typically includes three different transitions: restoration, betterment, and adaptation [4,70,71,81–83]. The results show that, while physical mitigation measures are nearly complete, this is not the case for restoration of livability. Post-disaster recovery in Japan has strived to achieve compact urban footprints and livable cities for depopulated and aging regions, and yet, there is a gap between these plans and reality; urban sprawl has emerged.

Cutter argues that there is often indifficient understanding of how dynamic pressures influence the spatial and temporal patterns of vulnerability and resilience [84]. Our results explore spatial and temporal patterns of vulnerability through urban footprint analysis and connects them to urban planning decisions, showing how measures in urban transformation and disaster risk reduction can lead to unintended consequences that create new risks.

4.4.3. Adapting decisions to uncertainty and specific local urban conditions

Besides, public intervention in Japan missed the possibility of adaptation for negative secondary effects. Adaptation is necessary to complete restoration and achieve betterment. Quay argues that the "traditional planning paradigm predict-and-plan approach" [81] is inadequate to address the highly complex and uncertain issue of climate change, and that social institutions must embrace "anticipatory governance" to explore uncertainty. Adaptive thinking is crucial to the recovery process, with the aim of removing the built environment from harm's way (to the extent possible) and restoring and improving its economic situation [82]. We suggest that the concept of adaptation in public intervention is essential to address the uncontrollable cascading effects in the long-term recovery transformation which "does not proceed along predetermined paths or on a predetermined schedule" [85]. Land use planning is often one of the measures that contribute to resilience [9]. But in Japan, large-scale, long-term, and robust tsunami mitigation projects affected people's decision to relocate to mountainside areas. This might have contributed to increase resilience to tsunami hazards but created vulnerabilities to landslides and other threats.

4.4.4. Limitations

The main limitation in our study is that the post-tsunami housing and post-tsunami vacant lot analyses could have a margin of error due to the ground movement caused by a gigantic tsunami, which can result in the difference of geographic coordinate systems (between pre-tsunami and the post-tsunami). It is difficult to identify the degree of error; however, we recognize that these indicators surely showed the hotspots of new housing construction and demolition. More importantly, our analysis does not demonstrate the "cause-and-effect relationships" between public intervention and urban footprint change, nor does it "model the performance of urban systems" [87]. We infer that public intervention is one of the drivers that affects internal migration. This claim is supported by Kondo and Karatani [28]; who observe that a large number of survivors' decisions on housing relocation have not been affected by the post-disaster recovery plan developed by local governments. Finally, we did not compare the impact of primary and secondary effects, which include reduced exposure and vulnerability to tsunami. Successful policy outcomes are likely to have negative effects in varying degrees [68]. For instance, collective relocation projects can be an effective way to sustain communities. Comparative analysis is needed following housing reconstruction in the ground-raising and collective relocation areas.

5. Conclusion: High uncertainty in long-term recovery needs incremental adaptation

This article explores how internal migration has impacted urban transformations, which manifests in urban fragmentation and maladaptation measures. Developing original indicators—post-tsunami housing and post-tsunami vacant lots—and classification of secured land use planning have enabled us to demonstrate citywide unsustainable urban sprawl and other secondary effects triggered by land use. We were able to identify spatial and temporal vulnerability and resilience patterns and the process that led to them, including the increased exposure to landslide risk and inequity between beneficiaries.

Even the most well-intended mitigation measures can pose the risk of deteriorating other places and cause citywide urban fragmentation. Centralized post-disaster urban planning in Japan failed to exercise adaptive capacity, one of the essential resilience components. High uncertainty surrounding the dynamic recovery process requires incremental adaptive action to remedy the distortion of sustainability, livability, and equity, all of which have emerged from interactions between people and planning throughout the long-term recovery process. Planners and local authorities must accept and remain attentive to the cascading effects of planning decisions that do not proceed along a predetermined trajectory.

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Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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