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Post-Disaster Health Status and Coastal Infrastructure Reconstruction After the Great East Japan Earthquake and Tsunami

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To understand adaptable strategies in mitigating disaster risk and protecting human health, this study aims to examine the effects of grey or green infrastructure (GI) on human health in disaster-affected rural areas. The study included four disaster-affected municipalities that were historically prone to coastal natural disaster events (e.g., tsunami, typhoon, and high tide), so that residents constantly faced disaster-related public health recovery. We firstly analysed coastal vegetation changes with special attention to coastal infrastructure conditions using Geographic Information System, then conducted an ecological study of regional, health statistics, including stress, metabolic syndrome, self-rated health, exercise habits, and obesity. For each municipality, we compared these statistics from before and after the Great East Japan Earthquake and Tsunami in 2011. This study found different mitigation strategies associated with the infrastructure conditions caused by coastal environmental changes. Also, the natural coastal environment encompassing GI was found to be more positively associated with human health than environments without GI during the post-disaster recovery phase. This study concludes that, during the post-disaster recovery phase, a coastal infrastructure encompassing green infrastructure provides a more effective and comprehensive approach to health promotion than grey costal infrastructure.

Keywords: green infrastructure; post-disaster reconstruction; coastal environment; human health; great east Japan earthquakes and tsunami

I. INTRODUCTION

Natural disasters affect human health. Therefore, the adaptability of people and their communities to natural disasters is a crucial issue for population health. People in coastal areas, including much of Japan, which is prone to natural disasters, are vulnerable to disaster-related human health risks. However, in rural areas in Japan, the impact of coastal environment degradation on human health has been little studied (World Disaster Report 2014).

Traditionally, the public sector has focused only on responding to human life emergencies and has paid little attention to the relationship between natural landscapes and human health or the implications of these factors for disaster mitigation strategies (Chiabai *et al.*, 2018; Coutts and Hahn 2015; Karen *et al.*, 2015; Meerow and Newell 2017). The ongoing challenge is to broaden the focus of disaster recovery beyond response to more proactive and holistic approaches, emphasizing prevention and mitigation of disaster risks through community development and green recovery.

To suggest adaptable public health strategies for a coastal ecological environment engaged in disaster recovery, this study focuses on the effect of coastal green infrastructure (hereafter referred to as GI) on human health in coastal rural areas that are vulnerable to tsunamis and high tides. Grey infrastructure, which includes manmade infrastructure like concrete and steel, is regarded as effective at protecting offshore and coastal areas from waves, tides, and breakwaters. GI, in contrast, refers to natural features and infrastructure that can accompany or replace grey infrastructure, like forests, wetlands, parks, and sandy

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beaches. GI can not only reduce disaster damage but also contribute to ecosystem resilience and provide human benefits through ecosystem services (Demuzere *et al.*, 2014). Some studies indicate that GI mitigates climate change and supports human health (Clark and Kerr 2017; Derkzen *et al.*, 2017). Other empirical studies suggest that GI plays an important role in preparing for and recovering from natural disasters (American Planning Association 2014). GI uses vegetation, soil, and other elements to restore some natural processes that mitigate high tide, enhance water drain management, and create healthier green environments for humans. The effects of green spaces on human health are considered essential for planning (Elbakidze *et al.*, 2017). Despite all this existing literature, evidence for GI's impact on human health in a post-disaster recovery phase is still scarce.

So far, the application of GI has generally been limited to urban, rather than rural, areas (Shackleton *et al.*, 2018). In Japan, GI studies have focused on measuring the impact of engineering that utilizes urban GI for floodwater management and developing a disaster prediction model for climate change (Natsuhara, 2018). In contrast, this study aims to examine the possibilities of rural GI, which integrates coastal greening into post-disaster reconstruction to support human health recovery.

Disaster mitigation planning has accentuated international public health emergency preparedness. However, there are few examples of local planning in which connections have been made between disaster resilience and GI objectives, though GI planning is becoming more widespread as the ecological and human benefits provided to communities by open space, parkland, and other protected natural areas become clearer. Thus, this study focuses on how intentionally created coastal land use changes cause problems for human health in the form of post-disaster reconstruction. Careful design and implementation of GI have attracted increased attention because GI can contribute to natural disaster adaptation (Matthews, Lo, and Byrne, 2015). Following the occurrence of the Great East Japan Earthquake and Tsunami (GEJET) on 11 March, 2011, several coastal communities in the Tohoku region started constructing grey infrastructure, including sea walls and jetties, while others designed 'disaster prevention' forests that functioned like sea walls (without raised banks) (Ohta 2012). The green coastal environment of GI provided natural protection from wind and sand as well as a barrier against erosion and flooding for coastal communities. Grey and green infrastructure are not mutually exclusive. Road and railways, domestic gardens, and landscaping around commercial infrastructure are examples of GI combined within a grey infrastructure.

However, the vital function of GI is to provide a framework that can guide future land development. By focusing on land to protect community assets and natural resources, GI helps the community plans for both land conservation and development in a way that satisfies the needs of nature and human health (Derkzen *et al.*, 2017). In this sense, GI is expected to protect us from a tsunami and improve the quality of life, simultaneously. In the Tohoku region, some community members deeply connected with nature, particularly the sea, through fishery-based occupations and community activities. The residents' reliance on grey infrastructure has understandably instilled in them a sense of separation from nature because the main economic activity in these areas is marine product industry and people have coexisted with coastal nature as well as grey infrastructure. After the construction of grey infrastructure along the coast in the wake of the disaster, this connection to nature diminished, resulting in a decline in resident's recognition of nature's healing role (e.g., ability to manage stress and improve emotional and psychological well-being and ecotherapy) (Bloomfield, 2017).

The GI approach can close the gap with coastal nature, facilitate conservation activities in a community, and foster support for funding green space conservation and management (Tashiro and Sakisaka 2015; Byrne and Jianjun 2015). This study investigates the effects of GI on health outcomes and health behaviours during the post-disaster recovery phase in rural coastal towns that were affected by the Great East Japan Earthquakes and Tsunami (GEJET) in 2011.

II. MATERIALS AND METHOD

A. Study Area

This study involved four sites in the Tohoku region that constructed either green or grey infrastructure in disaster-affected coastal areas. The sites were a) Rikuzentakata City in Iwate Prefecture; b) Minamisanriku Town in Miyagi Prefecture; c) Iwanuma City in Miyagi Prefecture; and d) Minamisoma City in Fukushima Prefecture (Fig. 1). We selected these municipalities because they were severely damaged by the GEJET in 2011 and were rebuilt with different types of infrastructures – grey vs. green.

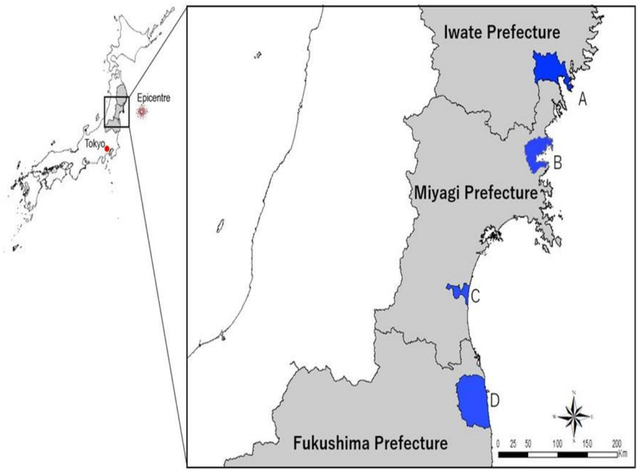

Figure 1. Map of the study sites: A, Rikuzentakata City; B, Minamisanriku Town; C, Iwanuma City; D, Minamisoma City

B. Source of Data

To study changes to the coastal environment and to understand coastal infrastructure construction in the post-disaster phase at each study site, we referred to the five-year basic environmental plans published by each municipality. (Table 1).

Furthermore, to capture changes in land use and vegetation in the coastal areas before and after 2011, we used land-use and land cover data (LULC) from the geographic information system (GIS) provided by the Biodiversity Centre of Japan (2010, 2014), Ministry of the Environment. For the change of LULC, we examined the relationship with health using municipal aggregated health reports (e.g., stress, metabolic syndrome, self-related health (SRH), exercise habits, and obesity). The reports, which included all residents 20 years or older, were obtained from an earlier municipal study on the residents' health before and after 2011 (Table 1).

Table 1. Data sources for each municipality

	Municipality	Health statuses		Coastal environmental survey		Coastal infrastructure
		Pre	Post	Pre	Post	
		Before or during GEJET[b]	After GEJET	Before or during GEJET	After GEJET	
A	Rikuzentakata City	Rikuzentakata (2011)	Kiyomi S. (2016) Rikuzentakata (2016a)	Rikuzentakata (2013)	Rikuzentakata (2016b); Rikuzentakata (2017)	Grey infrastructure
	Survey period	2011	2012–2015/ 2013–2015	2012–2013	2016/ 2016–2017	
B	Minamisanriku Town	Minamisanriku (2010)	Minamisanriku (2016)	Minamisanriku (2011)	Minamisanriku (2016)	Ecological infrastructure
	Survey period	2009	2014	2009–2010	2015–2016	
C	Iwanuma City	Iwanuma (2011a)	Iwanuma (2018a)	Iwanuma (2011b)	Iwanuma (2018b)	Hybrid: green-grey infrastructure
	Survey period	2010	2014	2009–2010	2017	
D	Minamisoma City	Minamisoma (2013)	Minamisoma (2017a)	Minamisoma (2011a)	Minamisoma (2016) Minamisoma (2017)	Green infrastructure
	Survey period	2009-2010	2017	2010	2015–2016/ 2016–2017	

[a]Stress, metabolic syndrome, self-related health, exercise habits, and obesity.
[b]GEJET, Great East Japan Earthquake and Tsunami. Parenthetical numbers indicate the year of a report for municipalities.

C. Measures / Variables

We collected statistics on residents' health statuses in the relevant municipalities, as shown in Table 1. We then conducted the chi-square test for independence of frequency distribution to compare health statuses before and after the GEJET for each health indicator at the municipal level. We set the significance level as P = 0.05. The test was for adults and not adjusted by sex, age, or other demographic variables due to the lack of detailed information in published municipal reports. Because the total number of subjects is not included in municipal reports, we reported this as not applicable (n/a) in the testing results. Indicators of health status in this study were defined as the percent of persons with better or poorer results for the following health outcomes and behaviours:

i. Stress: Residents answered the question, 'Do you feel stress or anxiety now?' with 'strongly feel' or 'feel'. For Rikuzentakata City alone, the Kessler Psychological Distress Scale (K6) ≥ 5 was used to assess stress.
ii. Metabolic syndrome: According to the criterion of Japan-specific metabolic syndrome (J-MS), abdominal obesity: waist circumference at umbilical level ≥85 cm in men and ≥90 cm in women is obligatory plus any two of the following three abnormalities must be observed as a diagnosis of J-MS: hyper triglyceridemic and/or low high-density lipoprotein cholesterol; hypertension; hyperglycaemia (Matsuzawa, 2005).
iii. Good self-rated health (SRH): Residents answered the question 'How do you feel about your current health status?' with 'very good' or 'good.'
iv. Regular exercise habit: This is defined as exercising for more than 30 minutes, at least two times a week.
v. Obesity: BMI of 25 or more.

III. RESULT

A. Changes in Coastal Vegetation

Fig. 2 shows the changes in land use and vegetation in the coastal environments of the four study sites, including the process of coastal construction before and after GEJET. In Rikuzentakata City, the urban area was spread over the coastal plains before GEJET, whereas approximately 80% of the locality's homes were submerged during the disaster. Numerous lives were disrupted, the lifestyles and the social system were damaged, and the natural coastal environments were destroyed. For a long time before the disaster, the Takata Matsubara coastal pine forests and willows (*Pinus thunbergii* plantation) were cultivated by the city as an essential, nationally designated place of scenic beauty. However, the huge tsunami destroyed approximately 70,000 pine trees, leaving only one tree standing after GEJET. Because the function of the trees since the 17th century had been to protect the shoreline from erosion and deposition caused by tsunamis, the local community has expanded, managed, and passed down the forest over many generations. However, following GEJET, development spread over the forest area. People relocated residential areas to higher elevations, and no one was left to manage the coastal vegetation. Therefore, the deteriorated urban area became vacant lots overgrown with weeds (Fig. 2-A). Currently, grey infrastructure (comprising sea walls and industry buildings) is being constructed along the coastal area. Minamisanriku Town has rich fishery resources and approximately 18,000 residents. In this town, the tsunami-induced damage to aqua-cultural facilities has become a major concern because the fishing industry forms the backbone of their economy. The tsunami inundated approximately 52% of the town's area and destroyed 3,301 houses. Before GEJET, the bamboo forest along the coast protected the shoreline from erosion and the spread of paddy weeds near the coastal area. Following the tsunami, the bamboo forest disappeared, and the lowland weed transformed into stripped topsoil (Fig. 2-B). However, local people had a marine symbiotic relationship with the natural environment' without losing any content. They cherished coastal vegetation as ecological infrastructure for the coastal environment.

Before GEJET, Iwanuma City was famous for its beautiful coastline. The tsunami killed 180 residents; damaged 5,542 houses; and inundated 48% of the land area. After the disaster, the mayor implemented a GI project called '1,000-year Kibonooka Project' to revive the affected area. The project officials decided to go against the nationwide trend of building ever higher seawalls and opted to repair existing seawalls and replant huge sections of the forest. Before the disaster, vegetation, including *Pinus thunbergii*, was spread across the coastline. However, the tsunami swept away all types of vegetation from the coastline. The project facilitated the gradual recovery of seaside vegetation, which currently functions as a green barrier to disasters, an emergency shelter, and a place where children regularly come to learn about safety (Fig. 2-C).

Minamisoma City is well-known for Kitaizumi beach, a beautiful surfing and swimming spot. The beach has been popular for both surfers and families with children. In addition, Kashimaku, with its fishing harbour, provides access to fresh seafood, a great resource to enrich the diet of locals. In the city, the tsunami killed 1,121 residents; damaged 8,306 houses; and inundated 10% of the land area. As shown in Fig. 2-D, before the disaster, a saltmarsh with vegetation was located near the Uno promontory and Japanese black pine trees covered the coastal lands. Although the tsunami destroyed Minamisoma's disaster prevention forest, the municipality utilised GI and initiated tree-planting along the coastlines to redevelop the coastal disaster-prevention forest (comprising Japanese black pines and broadleaf trees) after the disaster, like the case of Iwanuma. Accordingly, the coastal vegetation increased slight, although it cannot be discerned in the GIS data.

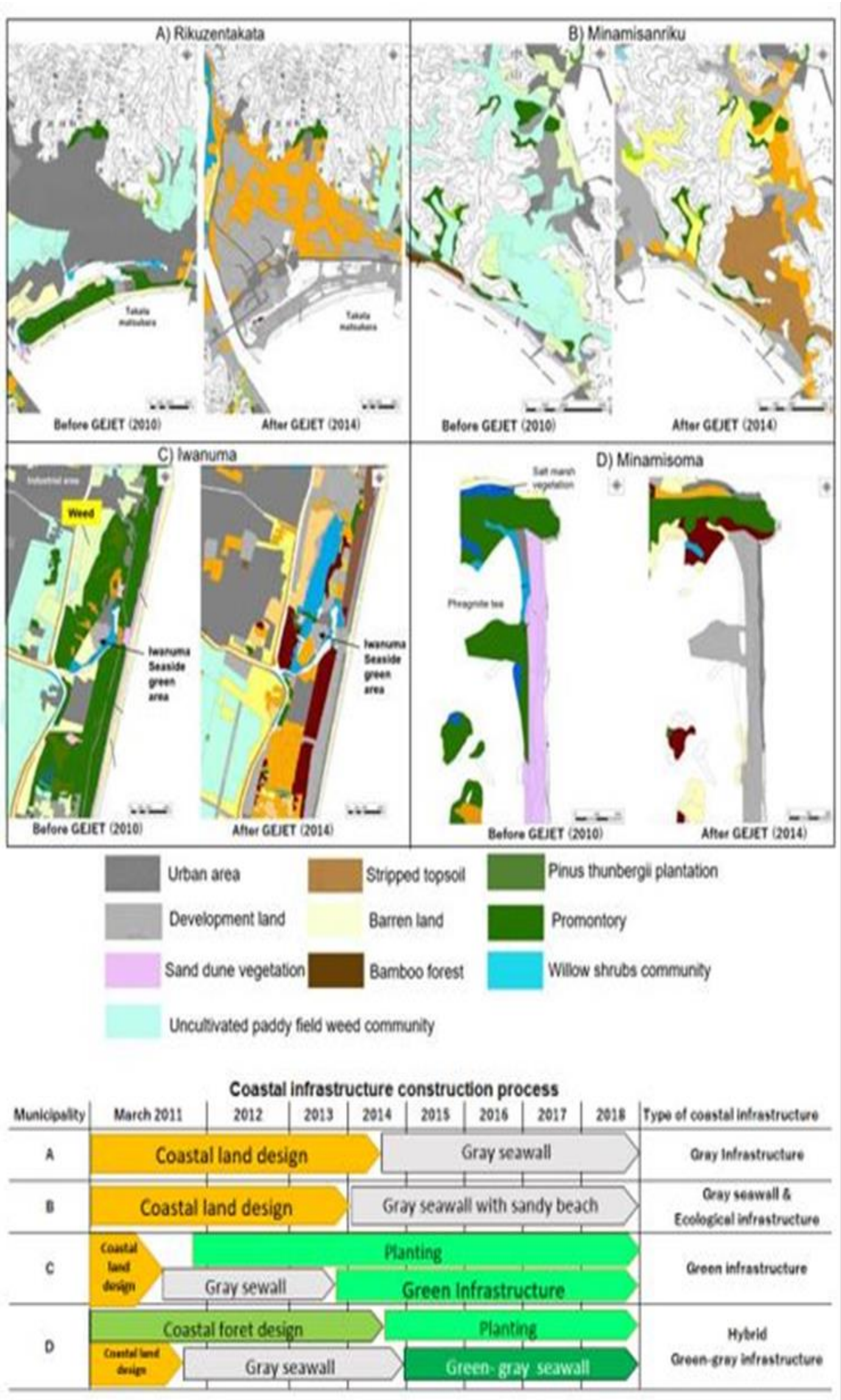

Figure 2. Changes in land use and vegetation in the coastal environments. GIS data was reproduced from the Biodiversity Centre of Japan (2010) and the Biodiversity Centre of Japan (2014)

B. Change in residents' health

Table 2 shows changes in residents' health after GEJET. The table demonstrates that Rikuzentakata City and Minamisanriku Town underwent both positive and negative health changes. In Rikuzentakata City, the positive change was that stress decreased. In contrast, the metabolic syndrome increased by 24% and good SRH declined by 4% after GEJET. In Minamisanriku Town, the negative changes were that stress and metabolic syndrome increased by 12% and 13%, respectively. Good exercise habits declined by 12%. In contrast, good SRH increased by 23%.

Iwanuma and Minamisoma Cities underwent relatively positive health changes. In Iwanuma City, the proportion of stress decreased by 10% and that of good SRH increased by 8%. Good exercise habits also increased by 5%, though the chi-square test was not applicable. Moreover, metabolic syndrome increased by 1%. In Minamisoma City, the one negative change was that the proportion of good SRH decreased by 4%. The positive changes included an increase in good exercise habits by 9% and a decline in obesity by 5%.

Table 2. Change in residents' health statuses after GEJET

	Stress (%)			Metabolic syndrome (%)			Good SRH (%)			Regular exercise habits (%)			Obesity		
	pre	post	p-value	pre	post	p-value	pre	post	p-value	pre	post	p-value	pre	post	p-value
A	42 (4940)	24 (3143)	↓ ***	35 (4908)	59 (3143)	↑ ***	90 (4953)	86 (3143)	↓ ***	22 (4953)	25 (3143)	↑ *	30 (4953)	31 (3075)	0.25
B	66 (447)	78 (457)	↑ ***	38 (2063)	36 (457)	0.53	58 (447)	81 (457)	↑ ***	37 (421)	25 (457)	↓ ***	23 (419)	36 (457)	↑ ***
C	72 (672)	62 (1079)	↓ ***	30 (n.a.)	31 (1079)	N/A	75 (672)	83 (1079)	↑ ***	41 (n.a.)	46 (1079)	N/A	30 (n.a.)	29 (1079)	N/A
D	76 (979)	60 (635)	↓ ***	32 (979)	32 (4900)	0.84	80 (1628)	82 (n.a.)	N/A	41 (n.a.)	50 (1079)	↑ ***	33 (1628)	28 (635)	↓ *

Pre-post period: pre: before or during GEJET; Post: after GEJET based on Table 1.
*:$P<0.05$, **:$P<0.01$, ***:$P<0.001$. N/A: not applicable due to the absence of data on the sample size.
Parentheses indicate the sample size of each category.

IV. DISCUSSION

To date, most studies have emphasised the importance of GI on human health relationships in urban areas not impacted by disasters (Artmann *et al.*, 2019; Elbakidze *et al.*, 2017). In contrast, this study provides valuable insight into the possible impact of coastal GI construction on human health in disaster-affected rural areas.

This study revealed that the tsunami had damaged coastal vegetation, causing spatial vegetation inequalities in disaster-affected areas (Fig. 2). Moreover, our results showed that the ecosystem service of GI improved health status. In the two municipalities where GI was implemented, Iwanuma and Minamisoma Cities, residents' health was higher after GEJET than before. In contrast, in the other municipalities where GI was not implemented, Rikuzentakata City and Minamisanriku Town, deteriorating health conditions were identified among the residents.

This study provides lessons from the experiences of the Tohoku region. These lessons indicate that GI construction in disaster-affected areas satisfies the human need to maintain close relationships with nature and that GI positively affects not only our physical needs – protecting from coastal natural hazards -- but also our health. In this sense, our study provides the new insight that incorporating GI into post-disaster recovery efforts can help local communities promote human population health and become more resilient to future disasters.

As for limitations, this was an ecological study; it is not able to establish a causal relationship between GI and human health. We could not fully examine the corresponding relation between the ecological health data and coastal construction process of GI before and after GEJET. Thus, for future research, the relationship between GI and health outcomes need to be ascertained using individual data and preferably longitudinal designs. This will help generate more robust evidence on the link between GI and health. To move toward a better understanding GI's benefits for human health, further study is needed to identify how to assess potential trade-offs between disaster risk reduction in the case of hazard events like GEJET and enhancing the quality of life though GI.

However, our findings suggest that by launching a coastal environmental improvement project with GI, coastal shorelines were restored to more natural conditions and positive health changes were observed at the population level, as compared to the changes seen in areas with grey infrastructure.

V. ACKNOWLEDGEMENT

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