Chapter 25

Coastal Community Preferences of Gray, Green, and Hybrid Infrastructure Against Tsunamis: A Case Study of Japan

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Abstract A decade has passed since the 2011 Great East Japan Earthquake and Tsunami struck. Despite increasing awareness that concrete-based coastal infrastructure, such as seawalls, is not sufficient to protect against unfathomable events, engineering structures still play a significant role in fortifying coastal communities. Meanwhile, purely nature-based approaches (i.e., coastal forests) also have limitations against cataclysmic waves, and there remain uncertainties regarding their ecosystem-based disaster risk reduction functions (Eco-DRR). In tackling these issues, hybrid infrastructure, which combines both gray and green components, has received growing interest. However, little research has been conducted to evaluate the economic values of coastal gray, green, and hybrid infrastructures under uncertainties in terms of people's preferences.

Therefore, in this study, we aimed to (1) quantify the economic value of coastal ecosystem services, including species richness, landscape, recreational services, and disaster risk reduction, under uncertainties through choice experiments; (2) clarify the differences in preferences for preparations against long-cycle tsunamis between those who reside in tsunami-prone areas and those who do not, using a conditional logit (CL) model; and (3) discuss the heterogeneities in coastal citizen perceptions by comparing the CL and mixed logit (ML) model. As a result, this study highlights the importance of considering the heterogeneity of preferences.

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Furthermore, our respondents in the tsunami-prone group (TPG) valued the coastal defense function offered by gray more highly than the non-TPG, demonstrating an especially large gap regarding seawalls against short-cycle tsunamis (willingness-to-pay (WTP) values of 11,233 JPY and 5958 JPY, respectively). However, there was no significance for coastal forests in the TPG, reflecting the importance of disaster prevention function offered by gray infrastructure. In addition, the hybrid landscape (seawalls + coastal forests) received higher positive responses, 71.1% with WTP of 8245 JPY, than the gray landscape (seawalls only) with WTP of −3358 JPY, as estimated by the ML model. These contradictions and heterogeneities in people's preferences may foreshadow the difficulties of applying hybrid approaches; hence developing synthesized both stated preference and other revealed preference methods is indispensable for providing strategic design of gray-green combined coastal defense and bolstering coastal realignment.

Keywords Seawalls · Coastal forests · Hybrid infrastructure · Eco-DRR · Choice experiments

25.1 Introduction

A decade has passed since the 2011 Great East Japan Earthquake and Tsunami occurred, which caused severe damages to both human life and socioeconomic properties both on the coast and in the hinterlands. After these events, artificial coastal defenses, including 10-m-high seawalls, have been constructed on some coastlines in Japan. The reliance on traditional defense methods continues despite increasing awareness that gray-based coastal infrastructure alone does not offer sufficient tsunami protection. Then, discussions regarding the reconstruction of higher and wider seawalls prompted coastal residents to rethink their coastal infrastructure because they both benefit from the ocean but also bear the brunt of natural hazards, such as tsunamis, windstorms, storm surges, and typhoons.

Over centuries, coastal design and planning have become an engineering discipline, initially for economic development, such as harbors and ports. Their spatial advantages have led to the development of human settlements, as coastlines provide resources, trading, and job opportunities, thus the global population benefits directly and indirectly from marine ecosystems (McGranahan et al. 2007). Moreover, population growth in coastal zones is accelerating, and more than half of coastal countries have 80%–100% of their population within 100 km of their coastlines (Martínez et al. 2007). Similarly, the intensity and frequency of natural hazards are increasing, implying that coastal zones are becoming more vulnerable. Thus, minimizing the impact of natural disasters is increasingly imperative. In particular, seawalls are considered to be the last line of defense and essential for maintaining residential livelihood (Reeve et al. 2018), as they have important roles in stabilizing the shoreline and protecting the coastal communities of Japan.

In parallel, *Pinus thunbergii* (black pine trees) has been traditionally afforested along coasts in Japan as a nature-based disaster mitigation method to collect

blown sand, mitigate wind speeds, and protect agricultural products and residential buildings. Moreover, coastal forests can be planted to attenuate wave velocity and stop drifts, thereby providing evacuation time when tsunamis occur (Harada and Imamura 2005). However, purely green measures have limitations against catastrophic events. Broadly, artificial coastal barriers (termed gray infrastructure, built infrastructure or hardened structures, encompassing seawalls, levees, culverts, bulkheads) ensure greater protection during extreme weather events than their nature-based counterparts, such as mangroves, coastal forests, dunes, and salt marshes, unless the intensities of natural hazards go beyond the infrastructure's capacity (Onuma and Tsuge 2018). Conversely, coastal armoring can exert negative or unexpected influences on coastal habitats and prevent them from restoring after disturbances (Borsje et al. 2011). Furthermore, the high cost of construction and maintenance poses a financial burden on municipality budgets. To overcome these issues, green infrastructure has been given increasing interest and is recognized as a nature-based approach that can serve disaster mitigation. However, the performance of ecosystem-based disaster risk reduction (Eco-DRR) varies because of coastal morphology and land use configuration (i.e., topography, soil conditions, and vegetation) (Irtem et al. 2009). Furthermore, Gedan et al. (2011) stated that unfathomable events, such as large tsunami waves and storm surges, can overwhelm the attenuation effects provided by vegetation and emphasized the necessity of combining man-made structures with ecological means of coastal protection. As such, hybrid infrastructure, which combines gray and green components, has also received growing interest. Sutton-Grier et al. (2015) summarized the characteristics of coastal gray, green, and hybrid infrastructure, evaluating their strengths and weaknesses. Tanaka (2012) investigated the effectiveness and limitations of coastal pine forests against large tsunami and concluded that their ability to attenuate waves is not better than that of seawalls, which does not necessarily mean their effect is negligible when a large tsunami overtops coastal armoring. In addition, it emphasized that other functions, such as trapping debris, provided by coastal forests should be considered, and gray-green integrated approaches should be applied to future coastal designs. Hence, the hybrid approach of seawalls and coastal forests that has long been utilized in some coastal regions in Japan may be a solution to the current reliance on gray-based coastal defense and the ambiguous effects of green infrastructure on coastal protection (Table 25.1). However, because of the multiple types of gray and green integrations (TCHGG 2018), there is a lack of economic analysis considering hybrid infrastructure that integrates seawalls and coastal forests. Furthermore, the uncertainties of disaster risk reduction (DRR) function provided by green infrastructure (Eco-DRR) hinder policymakers from performing cost-benefit analyses as it is difficult to understand how gray and green combined infrastructure can reduce hazard risks. (Hereafter, we use the term "DRR," which is the abbreviation of disaster risk reduction provided by either gray or green, but again, especially DRR function offered by green is termed Eco-DRR.) This financial challenge has an ongoing issue for green infrastructure (Sutton-Grier et al. 2015), which has also led to limited implementation and data regarding hybrid infrastructure as well.

Table 25.1 Coastal gray and green infrastructure strengths and weaknesses

Infrastructure	Strengths	Weaknesses
Gray (seawalls)	Greater level of protection	Coastal habitat loss
	– Alleviates speed of waves, tsunamis	– Has negative effects on other ecosystem services that coasts and surrounding areas, such as beaches, provide
	– Prevents erosion	Lack of capability and high maintenance cost
	– Withstands storm events soon after seawalls are built and performs stable protection for two to three decades	– Does not adapt to unforeseen events (e.g., tsunamis, sea-level rise)
	Greater understanding of techniques and effects	– Weakens the effects (built-in lifetime)
	– Can perform to cost–benefit analysis	Lack of ocean and community bond
	Significant engineering expertise	– Leads to safety misunderstandings and disaster risks
Green (coastal forests)	Many co-benefits	Ambiguous effects
	– Coastal protection	– Limited understanding regarding protection levels because of topography, vegetation, seasons, and soils
	– Recreational use	Time for mature forests
	– Coastal habitats with many species	– Requires approximately 20 years to mature for sufficient protection
	Lower cost	Pine wilt disease
	Adaptation to unexpected events	– Damaged by diseases and pests
	– Can keep pace with climate change, sea-level rise	Other societal disadvantages (crime, dumping)
Hybrid (gray + green: seawalls + forests)		– Requires appropriate maintenance
	Greater protection with other co-benefits	Little data and limited expertise
	– May require less space than natural approaches alone	– Requires more research regarding potential effects
	Innovative coastal design and planning	– May require more space to introduce both systems
	– Compatible with resilience and authentic value	

Sources: Based on Sutton-Grier et al. (2015) and Harada and Imamura (2005), edited by the authors

From an economic perspective, Costanza et al. (2008) evaluated the value of coastal wetlands for ecosystem protection against hurricanes in the United States and estimated the potential storm protection to be \$23.2 billion annually using a regression model. Barbier et al. (2011) evaluated the coastal ecosystem services (ESSs) in different natural environments, including coral reefs, seagrasses, salt marshes, mangroves, sand beaches, and dunes. However, these estimations of nonmarket values do not necessarily consider the trade-offs between ESSs in different coastal planning scenarios. Additionally, information regarding the potential values of coastal forests, especially *Pinus thunbergii*, is lacking. Thus, it is crucial to quantify the monetary values of ecosystem functions provided by concrete structures and natural measures. As there is a significant reliance on concrete structures, such as seawalls, and the uncertainties of DRR functions offered by coastal forests are still unclear, we considered seawalls as coastal gray infrastructure and coastal forests as green infrastructure (Fig. 25.1) in order to (1) evaluate the economic value of coastal ESSs, including species richness, landscape, recreational services, and DRR under uncertainties, (2) describe the preferences of coastal citizens regarding preparations against long-cycle tsunamis using economic models, and (3) discuss better combinations of gray and green infrastructure. In this project, we did not just aim at giving a monetary value of coastal ecosystem services but rather focused on how much coastal people understand the hazard risk and acknowledge the importance of coastal ecosystems; therefore, this study

Fig. 25.1 Example of gray, green, and hybrid approaches in Japan's coastal zone. *Source:* Based on Sutton-Grier et al. (2015), edited by the authors

identifies the reasons for which it remains difficult to build a consensus between municipalities and locals and promote hybrid approaches.

25.2 Survey Design

25.2.1 Data Collection

In this project, an online survey intended for people in their 20s to 60s in Japan was administered by Nikkei Research Inc. between March 6 and March 10, 2020. The subjects were randomly selected, and 955 responses were obtained. These data are summarized in Table 25.2. Note that the distances listed in Table 25.2 were calculated with open-source Geographic Information System QGIS 3.10 using

Table 25.2 Data collection

Gender		Distance (from the coastline: km)		Frequency of coastal use			
Female	466	(48.8%)	<5	295	(30.9%)	Almost every day	12 (1.3%)
Male	487	(51%)	5–10	146	(15.3%)	3–5 times/week	4 (0.4%)
Others	2	(0.2%)	10–15	129	(13.5%)	1–2 times/week	13 (1.4%)
			15–20	79	(8.3%)	1–2 times/month	61 (6.4%)
Age			20–30	80	(8.4%)	1–2 times/year	116 (12.1%)
20s	153	(16%)	30–40	51	(5.3%)	Vacation use	112 (11.7%)
30s	176	(18.4%)	40–50	36	(3.8%)	Seldom	345 (36.1%)
40s	242	(25.3%)	>50	45	(4.7%)	None	278 (29.1%)
50s	181	(19%)	Missing data	94	(9.8%)	Others	14 (1.5%)
60s	203	(21.3%)	Minimum value	0.1			
			Maximum value	102.7			
Income (million JPY)		Occupation					
<2	101	(10.6%)	Office workers	429	(44.9%)		
2–4	212	(22.2%)	Officials	33	(3.5%)		
4–6	218	(22.8%)	Association staff	22	(2.3%)		
6–8	163	(17.1%)	Self-employed	73	(7.6%)		
8–10	115	(12%)	Housekeepers	140	(14.7%)		
10–12	54	(5.7%)	Part-time jobs	141	(14.8%)		
12–14	29	(3%)	Retired	50	(5.2%)		
14–16	22	(2.3%)	No job	29	(3%)		
16–18	13	(1.4%)	Students	20	(2.1%)		
18–20	7	(0.7%)	Others	18	(1.9%)		
20–22	10	(1%)					
>22	8	(0.8%)					
Missing data	3	(0.3%)					

postal codes. Furthermore, answering postal codes was optional, and responders can type “9999999” or “0000000” in the questionnaires if they did not wish to provide.

25.2.2 *Experimental Design*

25.2.2.1 Review of Economic Evaluation

To evaluate nonmarket values, such as coastal ESSs, we employed choice experiments. The economic analysis of ESSs is essential for municipalities to conduct cost–benefit analyses for coastal planning. There are several methods to estimate the nonmarket values of coastal ESSs, including travel cost or hedonic methods, which are known as revealed preference. However, these methods are not applicable to coastal ESSs’ evaluations because of their far-reaching direct and indirect effects (Börger et al. 2014). Thus, in this study, we applied a conjoint analysis, which is a stated-preference method that enables researchers to understand individual respondents’ statements of ESSs and determine their preferences. For instance, Garber-Yonts et al. (2004) used choice experiments to estimate people’s willingness to pay (WTP) by changing the levels of biodiversity conservation under different conservation programs in the Oregon Coast. However, the public perceptions of ESSs’ benefits that both gray and green infrastructure offer, such as DRR function, richness, recreation, and landscape, are not well understood. To date, choice experiments have been conducted to investigate the preference of coastal citizens regarding seawalls and coastal habitat conservation (Imamura et al. 2016). Based on this, our choice experiments addressed citizen preferences by adding the DRR function attributes offered by either gray or green (or both) approaches. On the other hand, another challenge is that the estimates by stated-preference can be relatively stable over short periods of time, and the results for longer periods are likely to be unstable because of the environmental changes projected for 50–100 years into the future (Börger et al. 2014). Thus, we also included some future settings that coastal infrastructure might be presented with by changing different frequencies of tsunamis. Therefore, we are able to address these issues and reveal the changes in coastal citizens’ preference in various scales of tsunamis, and we explain the details of how these settings are generated in the following section.

25.2.2.2 Choice Experiments

A conjoint analysis using choice experiments provides concrete ecological information on a variety of coastal settings and evaluates trade-offs by jointly considering a number of important attributes for different hypothetical situations. It is therefore a useful tool for evaluating people’s perceptions of ESSs (Louviere 1988; Louviere et al. 2000). However, it requires careful descriptions of ESSs in the survey design in order to ensure the validity of the ecological data. In this sense, we considered four

coastal settings, including the status quo with the six attributes (Fig. 25.2): additional seawall height, coastal forest width, landscape, biodiversity, recreation, and annual tax, owing to ensuring that each attribute could be adequately understood without causing confusion (Bateman et al. 2002) (Table 25.3). The choice experiment was repeated eight times for each respondent, during which the levels of attributes changed. It is noteworthy that the additional seawall height and coastal forest width are associated with gray and green components, respectively, enabling the evaluation of DRR functions. The detailed explanations of the attributes and levels are provided in Sect. 25.2.3.

	Option 1	Option 2	Option 3
Additional seawall height	the preparation for one-in-100 year probability tsunami	storm surge (not well preparation for tsunami)	the preparation for one-in-10 year probability tsunami
Forest width	0 m	500 m	300 m
Landscape	seawall	coastal forest	both
Recreation	No recreational services	Camping & Walking	Camping, Walking & Fishing
Bird species	3 kinds of birds	10 kinds of birds	20 kinds of birds
Annual cost (JPY)	30,000	3,000	10,000
	↓	↓	↓
Most preferable	☐	☐	☒

Fig. 25.2 Example of question

Table 25.3 Attributes and levels of coastal settings

Attributes	Levels
Additional seawalls height (security)	±0 (for typhoons and storm surges)/ +1 m – +2 m (1-in-10 year tsunamis)/ +2 m – +5 m (1-in-30 year tsunamis)/ + over 5 m (1-in-100 year tsunami)
Forest width	0/100 m/200 m/300 m/500 m
Landscape	Coastal forest only/seawall only/both
Coastal recreation	Walking only/camping and walking/fishing only/ camping, walking and fishing/nothing
Coastal biodiversity (birds species)	3/10/20 kinds of birds
Annual tax (JPY)	1000/3000/5000/10,000/30,000

25.2.3 Attributes and Levels

25.2.3.1 Additional Seawall Height

Following the 2011 earthquakes and tsunamis, the MILT (2012) established new tsunami disaster risk management, in which tsunamis are classified into two different levels: Level 1 (L1) tsunamis, which have return periods ranging from approximately several decades to 100 years, and relatively low tsunami inundation depths; and Level 2 (L2) tsunamis, which are likely to occur for longer return periods, such as a few hundred to a few thousand years, and cause widespread damage to both the coast and hinterlands. This Japanese tsunami hazard management strategy further stipulated that the height of a coastal embankment should be designed in preparation of L1 tsunamis, whereas coastal structures are designed in preparation for L2 tsunamis in order to assure more time for evacuation. Then, seawall heights rely on prefectural decisions and computer simulations, causing some seawalls to be higher than 10 m in some coastlines. In our study, coastal gray infrastructure was categorized into four settings (Fig. 25.3), and then we assumed that the seawall with 2 m in height and 2000 m in total length has already existed (Fig. 25.4). First, as

Fig. 25.3 Seawall settings. (a) Present situation (storm surge, not well prepared for tsunami); (b) +1 m-less than 2 m (the preparation for one-in-10 year probability tsunami), total seawall height: 3–5 m; (c) +2 m-less than 5 m (the preparation for a one-in-30 year probability tsunami), total seawall height: 5–10 m; (d) + more than 5 m (the preparation for one-in-100 year probability tsunami), total seawall height: more than 10 m. *Note:* The material that was used in our questionnaires is not permitted to use for commercial uses, so we here display the similar image above

Fig. 25.4 The prerequisite of coastal land use. *Note:* Edited by the authors

shown in Fig. 25.3a (top left), there are no changes in a seawall with a height of approximately 2 m that already exists, providing effective protection from typhoons and storm surges. Second, as shown in Fig. 25.3b (top right), the additional height ranged 1–2 m will be constructed on the existing seawall in order to withstand a tsunami occurrence once a decade. Third, as shown in Fig. 25.3c (bottom left), a 2–5 m high seawall will be added to protect against 30-year probability tsunamis. Finally, a seawall that is over 10 m high will be built to protect against unexpected tsunamis (Fig. 25.3d). To increase responders' comprehension, various tsunami frequencies were assumed, and a total seawall height does not mean the height from the Tokyo Peil (T.P.). The Japanese datum of leveling is commonly used to express a seawall height.

25.2.3.2 Forest Width

Coastal forests, in which *Pinus thunbergii* is predominant, span the interface of beaches and terrestrial environments and are mainly observed on the main island of Japan. In other types of coastal forests, mangrove forests exhibit significant wave attenuation (Bao 2011) and play important roles in DRR, providing habitats for coastal creatures (Barbier et al. 2011; Morris et al. 2018). Although the effects of coastal forests on tsunami mitigation are not well established, Harada and Imamura (2005) examined the effect of coastal forests and observed a reduction in tsunami inundation depth and hydraulic energy behind the forests with increasing forest width, which denotes the cross-shore distance (Fig. 25.5). On the other hand, Tanaka (2012) investigated the tsunami-affected regions of the 2011 earthquakes and tsunamis and found that the forest width that can mitigate tsunamis is at least 200 m. This evidence was then applied to the government disaster management guidelines (MILT 2012). Specifically, if respondents selected coastal forests less than 200 m in width, they may prioritize protection from annual hazards such as wind storms rather than unexpected tsunami and wave attenuation, and if they select wider coastal forests, they desire a stronger protection level in both predicted

Fig. 25.5 Coastal forest scale. *Source:* Geospatial Information Authority of Japan, edited by the authors

and unpredicted natural disasters. Before beginning the choice experiment, we explained the positive and negative aspects concerning Eco-DRR, including that it has limitations and uncertainties in coastal protection (Onuma and Tsuge 2018). Then, we assume that coastal forests are afforested behind seawalls if they have already been constructed.

25.2.3.3 Landscape

Owing to increasing uncertainties in the face of multiple stressors, such as storm surges, typhoons, and coastal design for preparing against natural hazards, unforeseen events and several future scenarios must be considered. In this regard, coastal landscapes, also called “seascapes,” which are associated with land use planning adjacent to the coastline and ocean, that integrate existing structures and natural approaches are gaining increasing attention. As coastal zones provide significant economic, transport, residential, and recreational functions, all of which have foundations in physical characteristics, they should have appealing landscapes, natural resources, and terrestrial biodiversity (European Commission 2000). Perkol-Finkel et al. (2018) used ecologically sensitive designs and concrete technologies to minimize harmful impacts on marine flora and fauna. Concomitant to the growing threats of coastal hazards (Temmerman et al. 2013), anthropogenic changes in tourism and the development of residential districts are accelerating in coastal regions (Martínez et al. 2007). Subsequently, ecological engineering, which is relatively new discipline that combines engineering and ecology, has emerged to address these concerns (Chapman and Underwood 2011), and many studies regarding gray to green regime shifts and gray and green combined approach (hybrid) are available (Andersen et al. 2009; Cheong et al. 2013; Morris et al. 2018; Schoonees et al. 2019; Cooper et al. 2020), thereby augmenting coastal landscape architecture (Bergen et al. 2001; Pioch et al. 2018). Although interdisciplinary gray and green designs have been developed, there is limited information on how people value gray, green, and hybrid landscapes. Hence, to quantify gray and green coastal landscape from an economic point of view, our study placed landscape attributes

Fig. 25.6 Landscape photographs (a: gray, b: green, and c: gray + green). (a) Seawall. (b) Coastal forest. (c) Seawall and coastal forest. *Source:* The photo (c) was taken by researcher groups at Tokushima University

into choice experiments to explain the values of gray (seawalls), green (coastal forests), and gray + green (seawalls + coastal forests) landscapes. In addition, three photographs were provided during the choice experiment (Fig. 25.6).

25.2.3.4 Recreation

Recreation is an important ecosystem function and is a key element for evaluating estuarine and coastal ESSs (Barbier et al. 2011). Brenner et al. (2010) assessed the nonmonetary value of ecosystem functions provided by a coastal zone in Spain. They stressed the higher aesthetic and recreation values that contributed to the total coastal ecosystems. In previous studies, the direct uses of recreational benefits have been calculated via travel cost (Blackwell 2007; Ghermandi et al. 2009; Prayaga 2017). However, the indirect monetary value of recreational services is still not estimated, and the comprehensive understanding of recreational services offered by coastal pine forests is limited. Thus, our study classified coastal recreation into five cases: (a) a promenade provided for walking along coastlines, (b) fishing is permitted, (c) a promenade for walking and a space for camping near the ocean, (d) all three aforementioned activities are available, and (e) no recreation (Fig. 25.7).

25.2.3.5 Bird Species

Most marine flora and fauna reside in coastal areas; however, anthropogenic changes to coastlines are responsible for the loss of coastal habitats and associated ESSs

Fig. 25.7 Coastal recreation opportunities. (a) Walking. (b) Fishing. (c) Walking and camping. (d) Walking, fishing and camping. *Note:* As the material used in our questionnaires is not permitted for commercial use, we displayed a similar image above. The photos were provided only recreational activities are available for responders' understanding, but no recreation was reflected on the choice experiment (Fig. 25.2)

(Spalding et al. 2007). By accounting for the current ecosystems' values from human dimensions, some species are deemed more important than others. That is to say that the loss of some species at the peak of a food chain might have a very different effect than the loss of less charismatic species further down, which might support an entire ecosystem, called as a "keystone species" (Helm and Hepburn 2012). Thus, evaluating the monetary values of biodiversity is complex and difficult as it requires careful consideration from the perspectives of both human beings and animal conservation. Looking at the onshore environment, Sekercioglu (2006) stressed the ESSs provided by birds and avian ecological functions, such as predation, transportation, and excretion, which play significant roles in seed dispersal, pollination, controlling prey species populations, scavenging, and nutrient cycles. Canterbury et al. (2000) depicted the bird community as a useful tool for monitoring forest conditions. Thus, we regarded birds as keystone species in coastal zones using a scale of 3 to 20 kinds of birds, in accordance with Takagawa et al. (2011), who provided avian data in Japan. The small number of bird species indicated that *Columba livia*, *Larus crassirostris*, and *Corvus* (*Corvus macrorhynchos* or *Corvus corone*), which are generally seen in Japan, can be observed while a wide range of avian species is described as raptors and includes *Pandion haliaetus* and *Accipiter gentilis*, which are associated with higher consumers. These values are based on the annual number of average coastal birds to reduce migratory bird seasonal fluctuations.

25.2.4 Profile Design

To describe efficient settings in the choice experiments, we applied a D-efficiency for optimal profile design using Ngene (ChoiceMetrics 2018), which is a common and comprehensive tool utilized in economic analyses. Unlike an orthogonal design that is statistically uncorrelated in attributes, D-efficiency can consider the inter-attribute correlation and allow analysts to exclude “insignificant” alternatives and to place more weight on practical situations (Hensher et al. 2005).

25.3 Econometric Models

25.3.1 Conditional Logit and Mixed Logit Models

Discrete choice models are derived based on utility maximization, in which the decision-maker selects an alternative that offers the greatest utility. Let U_{ni} denote the utility that respondent n obtains from alternative i in choice set C_n as follows:

$$U_{ni} = V_{ni} + \varepsilon_{ni}, \quad (25.1)$$

where V_{ni} is a deterministic component and ε_{ni} is a random component, which are both assumed to be known to the individual, but unknown to the analyst. The probability that respondent n will choose i from alternative j in choice set C is the probability that U_{ni} is larger than U_{nj} as follows:

$$\Pr(i) = \Pr[U_i > U_j] = \Pr[V_i - V_j > \varepsilon_j - \varepsilon_i] \forall j \neq i, \forall j \in C, \quad (25.2)$$

where the index n is omitted for simplification. Note that U_{ni} depends on parameters that are unknown to the researcher and ε_{ni} is the unobservable portion that respondent n chooses alternative i .

This probability is a cumulative distribution as follows:

$$\Pr_i = \Pr(\varepsilon_j - \varepsilon_i < V_i - V_j \forall j \neq i) = \int I(\varepsilon_j - \varepsilon_i < V_i - V_j \forall j \neq i) f(\varepsilon) d\varepsilon, \quad (25.3)$$

where $I(\bullet)$ is an indicator function. Random utility models are obtained from different density specifications, which are then described as follows:

$$U_{ni} = \beta' x_{ni} + \varepsilon_{ni}. \quad (25.4)$$

When the utility is linear in β and x_{ni} is a vector of explanatory variables that are observed by the analysts and encompass the alternative attributes in a choice task, then $V_{ni}(\beta) = \beta' x_{ni}$.

The distribution of the random component (ε_i) is assumed to be a type I extreme value, and the probability that responder n chooses alternative i can be described in the conditional logit (CL) model as follows (McFadden 1974):

$$P_{ni} = \frac{\exp(\beta' x_{ni})}{\sum_{j=1}^J \exp(\beta' x_{nj})}, \quad (25.5)$$

where the preference parameter is assumed to be constant for all respondents (Train 2009). When assuming the heterogeneity of preferences that vary across individuals, mixed logit (ML) probabilities are the integrals of standard logit probabilities over density parameters in the following equation:

$$P_{ni} = \int L_{ni}(\beta) f(\beta|\theta) d\beta, \quad (25.6)$$

where $L_{ni}(\beta)$ is the logit probability evaluated at β and $f(\beta|\theta)$ is a density function, in which θ refers to the distribution. Thus, the ML probability takes the following form:

$$P_{ni} = \int \left(\frac{e^{\beta' x_{ni}}}{\sum_j e^{\beta' x_{nj}}} \right) f(\beta) d\beta. \quad (25.7)$$

ML is a mixture of logit functions that evaluate different β 's with $f(\beta)$ as the mixing distribution, wherein the utility (Eq. 25.4) takes a coefficient form (Train 2009), in which each of the coefficients is given an independent normal distribution with an estimated mean and standard deviation.

25.3.2 Estimation

The log likelihood for the model is described as follows:

$$LL(\theta) = \sum_n \ln P_{ni}(\theta). \quad (25.8)$$

Then, Eq. (25.8) is approximated by simulating for any given θ , in which the simulated log likelihood is determined by maximizing $LL(\theta)$; thus, Eq. (25.8) can be rewritten as follows:

$$SLL(\theta) = \sum_{n=1}^N \sum_j^J d_{nj} \ln \frac{1}{R} \sum_{r=1}^R L_{ni}(\beta^r), \quad (25.9)$$

where R is the number of draws and $d_{nj} = 1$ if responder n chooses j plan and $d_{nj} = 0$ if they do not. In the context of discrete choice models, Train (2009) explained

the superior coverage of Halton draws and its effectiveness, as compared with a random draw, stating that 100 Halton draws improve model accuracy. Thus, this study utilized the maximum simulated likelihood with 100 Halton draws applying to the ML model.

25.3.3 *CL Versus ML Model*

Next, we compared CL model with ML model of coastal residents' choices of coastal infrastructure. The limitation of the CL is that it assumes the same parameters for all responders. Thus, a CL facilitates interpretation when assuming that the same categories of responders have the same preferences. Therefore, we divided the data into two categories: a tsunami-prone group for the respondents that reside in the area where it is likely to be inundated by tsunamis (TPG) and others, using ArcGIS 10.3.1 and a tsunami inundation map is provided by Ministry of Land, Infrastructure, and Transport. Consequently, we obtained 105 TPG samples, which accounted for 11% of all responses. Meanwhile, the ML model enables us to consider the heterogeneities and elucidate the distribution of preferences.

25.3.4 *WTP*

WTP measures are useful for interpreting change in a given attribute and are employed for several reasons. Given the limited budgets in municipalities and the pressure of hydro-meteorological events (i.e., floods and windstorms), WTP can illustrate how much people value goods, properties, and services. Accordingly, our choice experiments assume that a respondent will pay an annual tax to improve the level of a given attribute when they understand the needs or the desirability of coastal designs. WTP is calculated as follows:

$$\text{WTP}_k = -\frac{\beta_k}{\beta_{\text{tax}}}, \quad (25.10)$$

where β_k is the parameter of attribute k and β_{tax} is the parameter of the tax.

25.4 Results

Table 25.4 lists the variables and definitions used in our analysis. Besides, Table 25.5 summarizes the estimation results of the CL model for the TPG and the others. As previously mentioned, the CL model assumes the same parameters for all respondents. In TPG, the attributes, except for forest, bird, and recreation, were found to be statistically significant at the 1% or 5% level. In contrast, for the non-

Table 25.4 Variables and definitions

Variables	Definitions
asc	A dummy variable representing respondents' answers for alternative 4 (choose nothing)
sea10	Whether alternatives including one-in-10 year probability tsunamis were chosen (0–1 dummy)
sea30	Whether alternatives including one-in-30 year probability tsunamis were chosen (0–1 dummy)
sea100	Whether alternatives including one-in-100 year probability tsunamis were chosen (0–1 dummy)
forest	Coastal forest width
bird	Species richness (the number of avian species)
landsc_sea	Whether alternatives including gray (seawalls) landscape were chosen (0–1 dummy)
landsc_both	Whether alternatives including hybrid (seawalls + coastal forests) landscape were chosen (0–1 dummy)
rec_walk	Whether alternatives including walking were chosen (0–1 dummy)
rec_fish	Whether alternatives including fishing were chosen (0–1 dummy)
rec_camp	Whether alternatives including camping were chosen (0–1 dummy)

Table 25.5 Estimation results

	Tsunami-prone sample			Others		
	Coef.	z	p-value	Coef.	z	p-value
sea10	0.4557	2.93	0.00	0.2230	4.1	0.00
sea30	0.5126	2.96	0.00	0.4292	7.14	0.00
sea100	0.4642	4.22	0.00	0.4134	10.7	0.00
forest	0.0020	0.08	0.94	0.0268	3.13	0.00
bird	−0.0061	−0.94	0.35	−0.0054	−2.35	0.02
landsc_sea	−0.2207	−2.02	0.04	−0.1137	−2.97	0.00
landsc_both	0.2273	2.2	0.03	0.2456	6.67	0.00
rec_walk	0.0706	0.53	0.60	0.0249	0.53	0.59
rec_fish	0.1350	1.35	0.18	0.0003	0.01	0.99
rec_camp	−0.0145	−0.11	0.91	0.0114	0.24	0.81
price	−0.0406	−5.42	0.00	−0.0374	−14.45	0.00
asc	−0.5868	−3.13	0.00	−0.4123	−6.3	0.00
Number of obs	3360			27,200		
Log likelihood	−1099.51			−9031.88		
Pseudo R2	0.056			0.042		

TPG group, which has less likelihood that their residences will suffer from tsunami inundation, most of the attributes were statistically significant, with the exception of recreation. Furthermore, Table 25.6 demonstrates the WTP results for both groups based on the findings listed in Table 25.5. Regarding seawalls, one remarkable finding was that the TPG had a higher WTP for short-cycle tsunamis than the non-TPG (11,233 JPY and 5958 JPY, respectively). Moreover, the highest WTP

Table 25.6

Willingness-to-pay (WTP)
estimation (JPY)

	TPG	Other	TPG-other
sea10	11,233	5958	5275
sea30	12,635	11,470	1165
sea100	11,441	11,046	395
forest	48	716	−668
bird	−152	−146	−6
landsc_sea	−5439	−3038	−2401
landsc_both	5602	6564	−962
rec_walk	1741	665	1076
rec_fish	3328	8	3320
rec_camp	−358	305	−663

values were estimated for the mid-term tsunami in both groups, reaching 12,635 JPY and 11,470 JPY for the TPG and others, respectively. In coastal forests, the WTP values/100 m was 716 JPY for the non-TPG, whereas it had no significance in the TPG. As for the number of bird species, both groups showed negative perceptions (−152 JPY in TPG and −146 JPY in others). Likewise, we observed negative WTP values for the gray-based coastal landscape in both groups. Simultaneously, the gray + green landscape had higher WTP values, at 5602 JPY for the TPG and 6564 JPY for the others.

Next, to consider preference heterogeneity, we applied all the data into both the CL and ML models for comparison (Table 25.7). Again, CL assumes the same parameters for all respondents, while ML assumes that individuals have different preferences. Thus, the former tends to overestimate the WTP. The normally distributed coefficients, estimated means, and standard deviations listed in Table 25.8 reflect the distribution of preferences. For example, the distribution of the seawalls with a 30-year-tsunami coefficient had an estimated mean of 0.44 and an estimated standard deviation of 1.19, such that 68.7% of the distribution was above zero and 31.3% was below. This indicates that two-thirds of the respondents view a seawall for a mid-term tsunami as a positive and prefer it, whereas one-third do not prefer it. Similarly, compared with seawalls for three different frequencies, seawalls for long-term tsunamis had an estimated mean of 0.12 and an estimated standard deviation of 1.88, implying 53.2% positive and 46.8% negative attitudes. A similar trend was observed for the short-term tsunamis with an estimated mean of 0.17 and a standard deviation of 1.19, implying 57.2% of respondents supported it and 42.8% did not. Regarding coastal forests, the results revealed that 60.3% of respondents accepted coastal defense by green infrastructure, whereas 39.7% did not. On the one hand, for landscape, gray + green (seawalls + coastal forests) obtained high positive responses (71.1% in positive and 28.9% in negative), while 61.3% of respondents showed negative perceptions toward gray landscape (seawalls only). Looking at bird species, 64.9% of responders had negative preferences regarding an increased number of birds. Conversely, regarding recreation, no significant results were obtained. Nevertheless, in the CL model, the recreation parameters were positive for various activities; however, the mean values of these ones in the ML model were

Table 25.7 Conditional logit (CL) and mixed logit (ML) model results

	CL					
	Coef.	z	p-value			
sea10	0.2485	4.85	0.00			
sea30	0.4380	7.72	0.00			
sea100	0.4188	11.50	0.00			
forest	0.0242	3.00	0.00			
bird	−0.0055	−2.53	0.01			
landsc_sea	−0.1252	−3.47	0.00			
landsc_both	0.2437	7.03	0.00			
rec_walk	0.0304	0.69	0.49			
rec_fish	0.0159	0.47	0.64			
rec_camp	0.0085	0.19	0.85			
price	−0.0378	−15.43	0.00			
asc	−0.4293	−6.95	0.00			
Number of obs.		30,560				
Log likelihood		−10135.66				
	ML					
	Mean			Standard deviation		
	Coef.	z	p-value	Coef.	z	p-value
price	−0.0459	−14.13	0.00			
asc	−0.9752	−11.35	0.00			
sea10	0.1718	2.21	0.03	1.1879	12.62	0.00
sea30	0.4430	5.29	0.00	1.1856	13.03	0.00
sea100	0.1187	1.49	0.14	1.8750	22.81	0.00
forest	0.0439	3.20	0.00	0.2128	11.12	0.00
bird	−0.0319	−6.49	0.00	0.1073	21.29	0.00
landsc_sea	−0.1540	−2.80	0.01	0.6796	8.90	0.00
landsc_both	0.3781	6.86	0.00	0.8967	12.91	0.00
rec_walk	−0.0839	−1.23	0.22	−0.7666	−11.38	0.00
rec_fish	−0.0551	−1.13	0.26	0.1370	1.27	0.21
rec_camp	0.0784	1.28	0.20	0.3985	4.04	0.00
Number of obs.		30,560				
Log likelihood		−8843.73				

contrasting, with the exception of camping. It is worth noting that the ML model can reflect the distribution of respondents' preferences (Fig. 25.8). Finally, the WTP results in each model showed significant differences regarding seawall variables. In particular, in seawalls for long-cycle tsunamis, the WTP calculated by the CL model was 8504 JPY higher than that in the ML model. However, it is not always the case that the CL model overestimates all attributes except coastal forests and landscape (gray + green) variables. Overall, we found that the CL model's overestimation is significant in gray infrastructure and that it is not easy to apply the stated preference method for long periods of time. Moreover, the average WTP/100 m of coastal

Table 25.8 Willingness-to-pay (JPY)

	Conditional logit (CL)	Mixed logit (ML)	CL-ML
sea10	6582	3747	2834
sea30	11,602	9662	1941
sea100	11,094	2590	8504
forest	642	957	−316
bird	−146	−696	550
landsc_sea	−3318	−3358	40
landsc_both	6455	8245	−1791
rec_walk	806	−1830	2636
rec_fish	420	−1202	1622
rec_camp	226	1710	−1484

Fig. 25.8 The distribution of willingness-to-pay (WTP). (a) Seawalls against one-in-10 year probability tsunamis, (b) seawalls against one-in-30 year probability tsunamis, and (c) seawalls against one-in-100 year probability tsunamis. (d) Graph with integrated (a), (b), and (c). WTP for (e) coastal forests, (f) species richness, (g) gray landscape, and (h) hybrid (gray + green) landscape. (i) Graph with integrated (g) and (h)

forests was estimated to be 957 JPY by the ML, while that of the hybrid landscape was 8245 JPY. Conversely, species richness showed a negative value of -696 JPY with an increasing number of bird species.

25.5 Discussion and Conclusion

The analysis presented in this study supports a number of issues, including the trade-off relationship between ESSs, the monetary values of coastal functions, and the preferences for long-term settings using the stated preference method. However, before discussing our results, we must determine the restrictions of this study. To investigate whether the responders live in areas that are susceptible to tsunamis (TPG), we first specified coordinates using zip codes applied for geocoding. However, the points identified by coordinates do not necessarily indicate their precise location. In particular, zip codes apply to large areas, making it likely that there are higher and lower tsunami risks (Fig. 25.9). Moreover, as 213 respondents hesitated to supply their zip codes, we used their answer to the TPG-related question to group them, as shown in Fig. 25.10. Thus, this process depends on the reliability of their answers. Furthermore, the CL model assumes the same parameters for all respondents, implying that the TPG and the non-TPG each have their own

Fig. 25.9 Precision limitations. *Note:* The polygon represents the typical location identified by the zip codes, and the line depicts a municipal boundary. As the polygon does not identify specific respondents' addresses, it covers both tsunami-prone and lower areas. Hence, there exists a limitation in identifying the respondents in the tsunami-prone areas

Q33
(Choose one)

Do you live in the area (tsunami-prone area) where it is likely to suffer from tsunamis?

(q33)=1 ☐ Yes

(q33)=2 ☐ No

(q33)=3 ☐ N/A

Fig. 25.10 Example question

parameters. Based on the comparisons between the TPG and the non-TPG, the former provided higher WTP values for the DRR function offered by gray than the latter. In particular, the difference in preferences against a short-cycle tsunami was significant (11,233 JPY and 5958 JPY for the TPG and others, respectively). In addition, increasing the scale of coastal forests/100 m in width had no significance in the TPG. This is probably because of the unstable Eco-DRR effects and the fact that expanding coastal forests may overlap with their residences. Then, more birds were not preferable for the TPG. Despite the economic importance of biodiversity (Martínez et al. 2007; TEEB 2010), for which the bird community is a useful tool for monitoring the onshore environment (Canterbury et al. 2000; Sekercioglu 2006), birds may be associated with negative images of bird droppings, and the drawbacks of certain ESSs, known as ecosystem disservices. Thus, evaluating the economic value of biodiversity remains challenging. Also, only animals in the peak of a food chain should not be spotted, so we need to pay attention to the underestimation of other fauna and flora and to consider the way of evaluating coastal biodiversity in both onshore and offshore environments as well. Regarding landscape, both groups had negative attitudes toward gray-based landscape, especially the TPG (−5439 JPY), whereas TPG had a higher WTP for gray + green landscape (5602 JPY). Considering the understanding of the DRR functions of gray, the negative response toward gray landscape reflects the difficulty of coastal disaster management and installation of hybrid infrastructure. Furthermore, the visual image can affect the responders' decision-making; hence, further development of questionnaire design is necessary.

Meanwhile, the heterogeneities in preferences can be examined using the estimation results from the CL and ML models. Regarding additional seawall height, little attention was paid to low-probability tsunamis, in which a WTP of 2590 JPY was estimated by the ML model. This indicates the importance of considering the individual preferences in comparison to the CL model (11,094 JPY). However, the large gap between CL and ML results in long-cycle tsunamis demonstrates the complexity of predicting people's preferences for future settings (Fig. 25.8d). The coastal forest data suggest that respondents expect coastal forests to function as Eco-DRR, despite the presence of uncertainties. Although the WTP for the

DRR function of coastal forests is 957 JPY, which is lower than that for gray, ecosystem multifunctionality, encompassing biodiversity, landscape, and recreation, the approximately 60% of positive answers from respondents must be considered. Overall, a perceived increase in the proportion of coastal disaster reduction in the gray and green infrastructure was shown to attract higher WTP values. As the goods and services resulting from ecosystems are prone to be underestimated (Heal 2000; Beaumont et al. 2008), economic valuation techniques have been developed to capture monetary terms. Moreover, coastal ecosystem functions commensurate with other vegetation (i.e., sand dunes and coral reefs). However, as we have focused on only the onshore environment, only coastal forests were applied in our choice experiments. Chávez et al. (2021) mentioned that coastal green infrastructure encompasses the multi-scale processes of recovery and maintenance, and then it can encourage local people's engagement. Silva et al. (2017) categorized green infrastructure by applying the degree of naturalness ranging from natural to hard engineering and stressed that coastal green infrastructure can be regarded as a series of natural to artificial components. Thus, we need to address how the economic values of coasts in both onshore and offshore environments as a whole can be evaluated. Another thing that needs to be explored is that recreational services were not significant in either model. In order to value coastal recreation and landscape services for cost-benefit analysis, the careful descriptions are required. These economic and ecological constraints have long been a subject of debate. Finally, the ML model demonstrated that the hybrid landscape had over 70% of positive responses, whereas the gray landscape had approximately 60% of negative perceptions. Therefore, our study highlighted the recognition of coastal protection offered by gray and green infrastructure, but the question of whether seawalls prevent people from enjoying ocean views remains. Furthermore, even though the hybrid approach is preferable for coastal citizens, identifying the best locations and practice of coastal designs that optimizes gray, green, and hybrid approaches is inevitable (Conger and Chang 2019).

All in all, the results of the TPG and others clarified that the former valued protection function provided by the gray infrastructure. However, the estimated values in the ML model were lower as the scale of seawalls increased for low-probability tsunamis. In addition, the Eco-DRR of coastal forests was not significant in the TPG, but the ML model showed the necessity of its multifunctionality. Furthermore, hybrid seascapes received positive attention in both groups in both models. These paradoxical views of coastal infrastructure and the heterogeneities of people's preferences may foreshadow the challenges of building a consensus among multiple stakeholders and implementing hybrid approaches. As there is no one-size-fits-all coastal design, it is important to explore long-term resilience planning at regional and local levels from risk reduction socioeconomic and ecological perspectives. In the future, we will examine the risk preferences of people that reside in or will move to hinterlands and higher places where they are less likely to be affected by tsunamis. As their DRR function values may reflect their locations, the hedonic pricing method will be useful. Therefore, the synthesized both stated preference and revealed preference data will help coastal communities provide

strategic and long-term coastal planning through the interdisciplinary design stage of gray-green combined coastal defense for DRR while simultaneously enhancing the quality of life.

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Appendix

The questionnaire is provided.

By accounting for the explanations above, please choose the most preferable coastal plans for you. If Plan 1–3 are not preferable, please click "Choose nothing." If the plan has both seawalls and coastal forests, forests are basically located behind seawalls.

Q17T01

Please choose the most preferable coastal planning for you.
If Plan 1–3 are not preferable, please click "Choose nothing."

[You can check the images of situations. Please click here.](#)
[You can check the images of situations. Please click here.](#)

(Choose one)

	Plan 1	Plan 2	Plan 3	
Additional seawall height	Prepared for one-in-30 year probability tsunami	Prepared for one-in-100 year probability tsunami	No changes	Choose nothing
Coastal forest width(m)	200	0	500	
Landscape	Seawall	Seawall	Coastal forest	
Recreation	Fishing	Fishing	Walking	
Bird species	3 kinds of birds	10 kinds of birds	10 kinds of birds	
Annual tax (JPY)	30,000	3,000	3,000	
	Plan 1	Plan 2	Plan 3	
	↓	↓	↓	↓
	☐	☐	☐	☐

Note: The choice experiments were introduced in Q17T01–Q17T08 in the questionnaire.

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