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Sustainable Land-Use Planning to Improve the Coastal Resilience of the Social-Ecological Landscape

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Abstract: The dynamics of land-use transitions decrease the coastal resilience of the social-ecological landscape (SEL), particularly in light of the fact that it is necessary to analyze the causal relationship between the two systems because operations of the social system and the ecological system are correlated. The purpose of this study is to analyze the dynamics of the coastal SEL and create a sustainable land-use planning (SLUP) strategy to enhance coastal resilience. The selected study site was Shindu-ri, South Korea, where land-use transitions are increasing and coastal resilience is therefore decreasing. Systems thinking was used to analyze the study, which was performed in four steps. First, the issues affecting the coastal area in Shindu-ri were defined as coastal landscape management, the agricultural structure, and the tourism industry structure. Second, the main variables for each issue were defined, and causal relationships between the main variables were created. Third, a holistic causal loop diagram was built based on both dynamic thinking and causal thinking. Fourth, five land-uses, including those of the coastal forest, the coastal grassland, the coastal dune, the agricultural area, and developed sites, were selected as leverage points for developing SLUP strategies to increase coastal resilience. The results show that "decrease in the size of the coastal forest", "decrease in the size of the coastal dune", and "increase in the size of the coastal grasslands" were considered parts of a land-use plan to enhance the resilience of the Shindu-ri SEL. This study developed integrated coastal land-use planning strategies that may provide effective solutions for complex and dynamic issues in the coastal SEL. Additionally, the results may be utilized as basic data to build and implement coastal land-use planning strategies.

Keywords: resilience; systems thinking; casual loop diagram; coastal dune; coastal landscape; coastal landscape management; coastal green infrastructure

1. Introduction

Coastal regions are the interfaces where the land meets the ocean, comprising integrated systems with social and ecological landscapes [1]. Coastal regions near tidal areas are commonly used for navigation, sand mining, waterfront development, fishing, and recreation; they are experiencing high population pressure [2]. Each application is influenced by a unique landscape. Climate change can also have significant negative social-ecological impacts such as biodiversity loss, habitat destruction, and pollution [2].

Accordingly, coastal regions can be described as a social-ecological landscape (the SEL) in which a feedback relationship develops between the social landscapes and the ecological landscapes [3,4].

The water-food system is affected by the SEL. Water ecosystems can provide the landscapes that function as wildlife habitats, livelihoods, and irrigation, based on water resources. In addition, fisheries and agricultural activities from food ecosystems create the landscape. These components interact to create an SEL, which is affected by natural and physical disturbance. A natural disturbance is an unexpected large-scale disaster (for example, a flood or a typhoon) caused by climate change such as floods and typhoons, and related studies are being carried out to develop a strategy to adapt to that change. Physical disturbances mean land-use changes such as land reclamation, urbanization, and tourism development. These disturbances have focused on social benefits without considering the costs to ecological landscapes. Artificial development activities also disrupt the harmony of the entire local system by disturbing native wildlife habitats. The loss of the balance between social and ecological landscapes negatively affects the structure and function of the coastal SEL [4], leading to decreased coastal resilience.

To improve the coastal resilience of the SEL, many studies have been conducted; these studies have had three foci. First, some studies have focused on the "ecological resilience" of the SEL. Some case studies have proposed "ecological land-use complementation", which connects green infrastructures located close to each other to promote ecosystem processes such as seed dispersal, pollination, and wildlife movement [5]. In addition, De Vries et al. [6] noted that the resilience of soil ecosystems declines because of drought, and they proposed a method of managing grasslands by utilizing fungal-based soil food webs to improve ecological resilience [6]. Second, other studies have discussed the resilience of local communities near the coast, namely, the "social resilience" of the SEL. For example, several types of coastal community resilience have been proposed as they relate to hard resilience and soft resilience [7]. Previous works have focused on hard infrastructures, including artificial and green infrastructures, because coastal forests can protect the local community in the face of ecological disasters and increase the community's ability to recover. Some studies have created a questionnaire based on an understanding of coastal infrastructures and assessed the social resilience of the coastal SEL in six domains (leadership, collective efficacy, preparedness, place attachment, social trust, and social relationships) [8]. Third, other studies have proposed an integrated spatial planning that considers various types of resilience. For example, resilience has been classified into the following three categories: "geological resilience", which is the ability to return to the original coastal topography of the area; "ecological resilience", which is the ability to maintain biodiversity and the structure and function of the ecological network; and "social economic resilience", which includes economic effects such as flood prevention and recreational value [9]. By conducting a comprehensive analysis, some researchers have derived optimal land-use plans and classified resilience into three categories (local communities' resilience, economic resilience, and ecological resilience). They then presented a land-use planning strategy for allocating the components of coastal infrastructures, including both anthropogenic and green infrastructures, to enhance coastal resilience [10]. However, land-use planning studies that attribute significant weight to ecological resilience have limits because they lack effective strategies for implementing policies that would improve social resilience. Other studies that have focused on social resilience do not provide specific land-use planning measures. In contrast, the third type of study conducted to analyze coastal SEL regions can provide specific land-use planning strategies, leading to improved social-ecological resilience. From this perspective, sustainable land-use planning (SLUP), which has the goal of improving the coastal resilience, is a more effective solution in coastal regions that have experienced dramatic land-use changes caused by development activities.

Development activities in coastal regions (e.g., urbanization and tourism development) can lead to dramatic land-use changes, which can accelerate the decrease in coastal resilience and ultimately destroy a coastal SEL [9]. For example, most coastal forests were artificially created to protect social landscapes, including residential and agricultural areas, from sandstorms; in other words, the use of coastal forests can negatively affect the size of coastal dunes and coastal grasslands [11].

If coastal dunes increase extremely high wind stress, the coastal forest will be destroyed, decreasing its area [12]. However, the coastal dunes in Korea are gradually decreasing in area, and they must be protected [13]. Specifically, Shindu-ri has the largest sand dune coastal area, considers the coastal areas as an entity, and has closed those areas to residential development and tourism [13]. This region had experienced dynamic land-use changes such as housing development and highway construction [13]. Therefore, Shindu-ri must qualify the correlation of these phenomena through system modeling based on its land-use changes [14].

The effect is to diminish the function of the coastal dune as a habitat for animals and plants adapted to salinized soil, although they do store groundwater and freshwater [15–17]. In addition, coastal dunes protect social landscapes from coastal hazards, such as tidal waves and storm surges, both of which have become more prevalent because of climate change [9]. Moreover, coastal dunes not only create a stable ecological landscape but also protect a unique social landscape. However, the coastal SEL reacts sensitively to land-use changes such as the variation of coastal dunes because of their location on the boundary between marine and land environments [18]. As the prevalence of land-use changes, frequent conflicts can arise among residents, local governments, and associated governmental departments over the protection of the ecological landscape [19]. To alleviate these conflicts, the use of coastal dunes, coastal forests, and coastal grasslands has been progressively managed and planned as components of the ecological landscape because a decision maker cannot mediate differences among stakeholders regarding the best approach to land-use in coastal regions. Such a phenomenon can lead to imbalances in the coastal SEL, and integrated planning and management are necessary to protect and stabilize the ecological landscape. This approach can be achieved by SLUP and play an important role in improving coastal resilience.

To address the SLUP of coastal areas, Europe has proposed Integrated Coastal Zone Management (ICZM), which clarifies the roles and responsibilities of various organizations, including non-governmental organizations, governmental organizations, universities, and the European Union [20]. Although ICZM is interpreted in various ways, it can be understood as a tool for developing a common coastal region and policy [21]. In the 1980s, ICZM focused on resolving major disasters such as coastal erosion and pollution outfalls [20,21]. In the 1990s, there was a conceptual change that focused on sustainability and public participation [22], concepts that now include the improvement of coastal resilience [22].

In Australia, the Queensland coast comprises sandy beaches where individuals can participate in various recreational activities. Nonetheless, the coastal dunes in Queensland are simultaneously affected by tides and waves, and the local government has thus established integrated guidelines for sustainable coastal management [23]. In Portugal, efforts are being made to comprehensively plan and manage coastal regions based on a broad perspective that includes both natural landscapes, such as coastal dunes, coastal grasslands, and coastal forests, and social landscapes, such as residential and tourist sites [24].

Although such studies have been conducted to make coastal regions sustainable, they typically do not consider coastal resilience but instead focus on integrating stakeholders. Since coastal resilience in a landscape context is defined as a coastal SEL's ability to absorb disturbances and retain its structure and function [25–27], a coastal SEL with low coastal resilience is highly vulnerable and tends to collapse abruptly [3,28]. To protect from collapse and maintain the current SEL, SLUP is typically required, potentially enhancing coastal resilience by managing land-use changes as disturbances [29]. SLUP without coastal resilience can cause the collapse of a coastal SEL, in other words, SLUP based on coastal resilience is an important strategy for stabilizing the coastal SEL [30]. However, an understanding of SEL systems should be acquired before a decision maker charged with building bridges consults with stakeholders to conduct SLUP because coastal SEL systems are too complex and dynamic to adjust the balance between the social and the ecological landscapes. Therefore, systems thinking can play a key role in SLUP methodology by establishing strategies to increase coastal resilience. Systems thinking is a decision-making methodology that aims to solve problems by approaching certain issues and phenomena from a multilateral perspective, identifying the casual system relationships that change over time and examining them from a long-term perspective [31]. Systems thinking is a necessary decision-making tool to maintain balance in the SEL because it provides a tool for integrating coastal SEL systems and a lens through which to interpret the structure and behavior of a coastal SEL [32]. It is also capable of reinforcing the structure and function of the coastal SEL by building green infrastructures, such as coastal grasslands, because it can propose effective strategies based on the perspective of the social-ecological landscape. Based on the systems thinking process, this study aims to analyze the dynamics of the coastal SEL and to establish SLUP to improve coastal resilience in Shindu-ri, Korea. The results of this study identify the coastal SEL that can help improve both biodiversity and the residential environment.

2. Study Methods

2.1. Description of the Study Area

To analyze the structure and behavior of the SEL in coastal regions, areas involving social issues and conflicts over natural resources must be explored. In this study, the analysis of the SEL of the site was focused on the land cover classification. To that end, this study selected the Shindu-ri coastal region that is located at 36°49′–36°51′N and 126°10′–126°14′E and covers an area of approximately 1111 ha in the Taean-gun area of Chungchungnam-do Province, South Korea. This study categorizes land-uses of the Shindu-ri's coastal SEL based on a land cover map from South Korea's Ministry of Environment [33] (2014, with a scale of 1/25,000). The Ministry of Environment categorized the land cover map "Used area", "Agricultural land", "Forest", "Grass", "Wetland", "Barren" and "Water" in 30 m resolution [33]. When it applied land-use to Shindu-ri, we could reclassify the land cover map as "Used area", "Agricultural land", "Coastal forest", "Coastal grassland", "Wetland", "Coastal dune", and "Water" (see Figure 1).

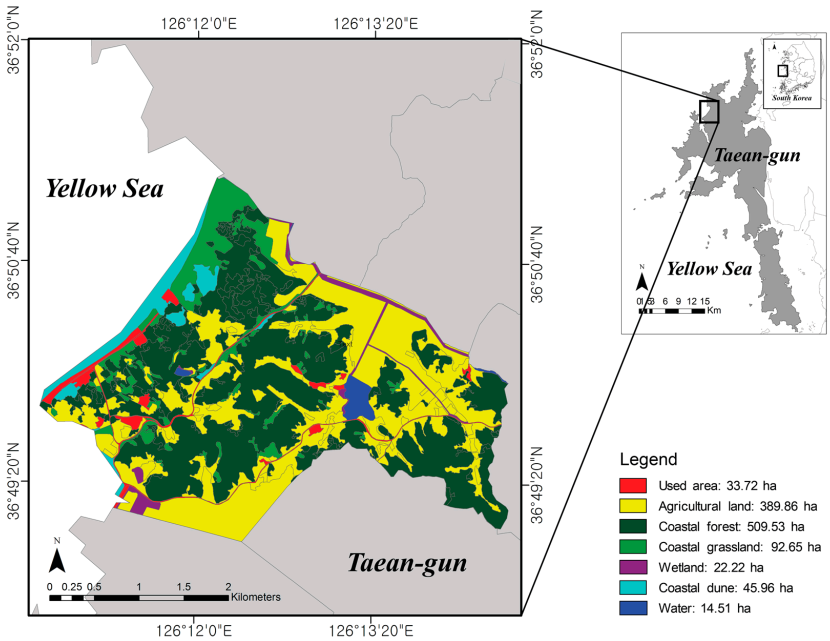


Figure 1. Location and land-uses in the Taean-gun Shindu-ri area. The land-use type consists of Used area (33.72 ha), Agricultural land (389.86 ha), Coastal forest (509.53 ha), Coastal grassland (92.65 ha), Wetland (22.22 ha), Coastal dune (45.96 ha), and Water (14.51 ha).

The Shindu Dune area has a unique coastal dune and is the largest dune in South Korea. The conservation value of natural resources in this area was recognized when the dune was designated as a natural monument and ecological landscape conservation area not only by the Korean government but also by the International Union for Conservation of Nature (IUCN) [34–36].

However, the Shindu Dune area is highly vulnerable to damage from ineffective coastal region management because the area is managed by various governmental organizations. For example, the Ministry of the Environment enforces the Natural Environment Conservation Act, laws on marine ecological system conservation and sustainable management, and the Wetland Conservation Act for coastal region management; the Ministry of Culture, Sports, and Tourism enforces the Cultural Properties Protection Law; and the Ministry of Land, Transport, and Maritime Affairs enforces coastal management laws.

Furthermore, the area of Shindu Dune and coastal forests has gradually decreased as Shindu-ri coastal regions have been subjected to continued land reclamation projects, which have been transforming the coastal region into agricultural sites since 1967 [13]. Thus, the area used for farmland has increased and the Iho Reservoir was constructed to secure water. Subsequently, with the goal of preventing drifting sand and preserving the coastal forest, residents of Shindu-ri launched a forestation project in 1991, which partially augmented the size of the coastal forest. Recently, the developed area of the Shindu-ri coastal region has been expanding, with the aims of invigorating the tourism industry by developing tourism-based infrastructure, including tourist packages from Shindu Dune, Duwoong Wetland, and Cheonlipo Arboretum [34,35]. Shindu Dune serves as a primary resource for ecotourism through the "Korean Ecological Tourism Development Project" sponsored by the Ministry of Culture, Sports, and Tourism. Simultaneously, ongoing projects are intended to monitor and restore the damaged coastal dunes [13]. However, most of these projects ignore the link between the coastal dunes and the coastal forest, resulting in a short-sighted coastal landscape management policy and creating an ironic phenomenon in which the overall size of coastal dunes and coastal forests in Shindu-ri coastal region is decreasing [3,36,37]. Moreover, several land-uses have formed complex connections with each other, resulting in land-use changes. This pattern of land-use changes is intensifying conflict among stakeholders (local government, residents, and the central government) over conservation and development.

2.2. Study Method

The study was conducted by analyzing the dynamics of the Shindu-ri coastal SEL according to the systems thinking process. This process includes a series of phases (dynamic thinking, causal thinking, closed-loop thinking, and discovering strategy) and can be used to analyze the structure and dynamics of complex systems [38,39] (Figure 2).

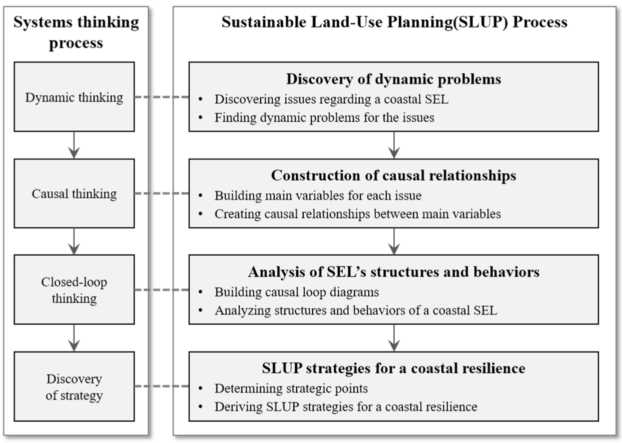


Figure 2. SLUP strategies process with systems thinking.

2.2.1. Discovery of Dynamic Problems and Construction of Causal Relationships

Researchers explore issues regarding the coastal SEL of the target site and derive relevant variables based on field study and literature reviews focusing on theses, research reports, and relevant news articles [40,41]. Field study was conducted using the four steps of the "coastal landscape guideline" promulgated by the Ministry of Land, Infrastructure and Transport [41], as follows. First, select the photograph point around the shoreline for landscape evaluation. Second, take photographs from the cardinal points of north, south, east, and west, including the coastal zone. Third, consider human eye level to be at a height of 1.6 m. Fourth, to avoid the influence of weather or the environment, take photography on a clear day, between 10:00 am and 4:00 pm, unaffected by sunrise and sunset. Fifth, the camera features a 50 mm lens similar to the human field of view. However, when it is difficult to photograph the target site at the angle of view, that angle may be either changed and photographed or replaced with a panoramic photo. Sixth, photographs should be taken to include both preserved and damaged landscapes. The literature review is used to identify issues and concepts, select the main variables, and prove causality among the main variables when structuring the dynamic problems of the coastal landscape, the agricultural structure and the tourism industry structure. Data on dynamic issues at the study site are collected from government agency policies, local government reports, and news articles.

2.2.2. Construction of Causal Relationships

After collecting the literature, the main variables are defined for each issue, and these variables are used to create a causal relationship. The research process of constructing the causal relationships stage is as follows. First, we derive main variables related to each issue. Second, we select the land-use types related to the main variables and consider the relationship among issues, the main variables, and related land-use types.

2.2.3. Analysis of the SEL's Structures and Behaviors

In the closed-loop thinking phase, researchers build each causal loop diagram based on the problematic issues and analyze the structures and behaviors of a coastal the SEL using Vensim PLE version 6.3 software (Ventana Systems, Harvard, MA, USA). Causal loop diagrams can be analyzed as system structures and behaviors based on systems thinking. Causal loop diagrams have control functions that are not depicted as distinct entities because they are in control loop diagrams [42]. Instead, the focus is on explaining the system variables and their influences on each other. In addition, feedback loops are not geometric structures used to specify functions or subsystems [42]. This approach shows the causal relationships between variables, which are specified textually using arrows that indicate the relationship, including positive (+), negative (−), and delay (//) relationships [42,43]. In this case, the feedback loops can be identified. A reinforcing loop (R_n) indicates a feedback relationship to the variable, reinforcing the initial deviation [43]. A balancing loop (B_n) is defined as the feedback relationship in which the loop returns an opposing deviation to the initial variable [43].

2.2.4. SLUP Strategies for a Coastal Resilience

Finally, in the discovery of strategy phase, individual causal maps are aggregated and analyzed to derive SLUP strategies that will improve resilience. In this phase, the "limitation of development" archetype of systems thinking is utilized [44], and SLUP strategies are derived using the following process: strategy target, strategy main agent, strategy intervention location, strategy intervention time, and redesign of the system.

3. Results and Discussion

3.1. Discovery of Dynamic Problems

Through a field study and a literature review of theses, research reports, and relevant news articles, we could deduce that the dynamic problems in Shindu-ri coastal region were related to three issues. First, the most controversial issue in the Shindu-ri coastal region concerns "coastal landscape management". In addition to coastal dunes, the Shindu-ri coastal landscape had abundant green infrastructures such as coastal forests and coastal grasslands, and there were separate measures to manage each type of land-use. However, there was no integrated system of coastal landscape management. Single-minded landscape management in Shindu-ri coastal region was considered an exclusive measure that prioritizes coastal dunes. This management was the result of overlooking the interplay between various land-uses and has resulted in a continued reduction in the area of coastal dunes, coastal grasslands and coastal forests over the long term. Second, another prevalent issue was the conflict between the conservation and the development of the coastal landscape based on the "agricultural structure" of the Shindu-ri coastal region. Agriculture is the main industry in the Shindu-ri coastal region, and residents of Shindu-ri pump out groundwater for agricultural use. However, excessive use of groundwater from the coastal region destroyed the equilibrium between freshwater and saltwater, resulting in the infiltration of high-salinity seawater into the farmland of the Shindu-ri coastal region. Furthermore, the biodiversity of the Shindu-ri coastal region had been maintained using livestock farming in coastal grasslands; however, under the pretext of protecting the natural monument, the implementation of a "no-grazing policy" has destroyed the wildlife food chain in the Shindu-ri coastal region. The third issue was the conflict between the conservation and development of the coastal landscape based on the "tourism industry structure." The local government's erroneous implementation of an ecotourism vitalization policy had led to over-expansion of the used area and has downgraded the quality of the Shindu-ri coastal landscape, which could ultimately destroy both the economy and the environment in various areas of Shindu-ri.

3.2. Construction of Causal Relationships

The causal relationships of coastal landscape management, agricultural structure, and tourism industry structure among the main variables were confirmed by many references (Table 1). These results were fundamental to the closed-loop thinking stage.

Table 1. Issues related to the Shindu-ri coastal region.

Issues	**Main Variables**		**Causal Link Mark**	**References** [1]
	Independent Variable	**Dependent Variable**		
Coastal landscape management	area of artificially planted herbage	number of sand fences	–	FS and GR
	number of sand fences	amount of eroded sand	–	FS and LR
	amount of eroded sand	coastal dune area	–	FS
	coastal dune area	area of artificially planted herbage	–	LR
	area of artificially planted herbage	coastal grassland area	+	LR
	coastal grassland area	sandy soil stabilization	+	LR
	sandy soil stabilization	amount of eroded sand	–	GR and LR
	coastal dune area	anti-erosion construction	–	FS and NA
	anti-erosion construction	link between terrestrial and coastal areas	–	RJ
	link between terrestrial and coastal areas	amount of eroded sand	–	LR
	coastal dune area	amount of sand added	–	NA
	amount of sand added	coastal dune area	+	GA
	coastal dune area	area of artificially planted trees	–	FS and GR
	area of artificially planted trees	average depth of tree roots	–	NA and GR
	average depth of tree roots	number of uprooted trees	–	GR
	number of uprooted trees	coastal forest area	-	RJ
	coastal forest area	area of artificially planted trees	–	GR
	number of uprooted trees	amount of eroded sand	+	GR

Table 1. *Cont.*

Issues	Main Variables		Causal Link Mark	References [1]
	Independent Variable	Dependent Variable		
Agricultural structure	amount of drafting sand	agricultural land	–	GR and LR
	agricultural land	amount of harvested crops and produce	+	GR
	amount of harvested crops and produce	agricultural revenue	+	GR
	agricultural revenue	local revenue	+	RJ
	local revenue	investment in coastal afforestation	+	FS and NA
	investment in coastal afforestation	coastal forest area	+	FS
	coastal forest area	amount of drafting sand	–	LR
	coastal forest area	salty wind	–	LR
	salty wind	amount of harvested crops and produce	–	FS and NA
	agricultural land	amount of water used for agriculture	+	FS
	amount of water used for agriculture	amount of groundwater	–	LR
	amount of groundwater	salinity of groundwater	–	LR
	salinity of groundwater	amount of harvested crops and produce	–	LR
	amount of drifting sand	coastal dune area	+	FS and NA
	coastal dune area	amount of drifting sand	+	LR
	coastal dune area	coastal grassland area	+	GR
	coastal grassland area	number of grazing cows	+	GR
	number of grazing cows	coastal grassland area	–	GR
	number of grazing cows	number of dung beetles	+	LR
	number of dung beetles	growth rate of herbage	+	LR
	growth rate of herbage	coastal grassland area	+	RJ
	number of dung beetles	soil fertility	+	LR
	soil fertility	coastal grassland area	+	LR
Tourism industry structure	tourism infrastructure	tourist site attractiveness	+	LR
	tourist site attractiveness	number of tourists	+	LR
	number of tourists	tourism revenue	+	FS and GR
	tourism revenue	local revenue	+	FS and GR
	local revenue	tourism investment	+	FS
	tourism investment	tourism infrastructure	+	FS
	tourism infrastructure	development site area	+	GR
	development site area	link between terrestrial and coastal area	–	FS and RJ
	link between terrestrial and coastal area	coastal dune area	+	GR and LR
	coastal dune area	quality of coastal landscape	+	RJ
	quality of coastal landscape	tourist site attractiveness	+	NA
	development site area	coastal forest area	–	RJ
	coastal forest area	quality of coastal landscape	+	NA
	development site area	coastal grassland area	–	RJ
	coastal grassland area	quality of coastal landscape	+	NA
	number of tourists	pressure for tourism activities in coastal zones	+	FS and NA
	pressure for tourism activities in coastal zones	vegetation of the coastal ecology system	–	GR and LR
	vegetation of the coastal ecology system	coastal grassland area	+	FS
	vegetation of the coastal ecology system	coastal forest area	+	FS
	tourism activity in Shindu Dune	pressure for tourism activities in coastal zones	–	FS and NA

[1] FS = field survey, NA = news articles, GR = government reports, LR = literature review, RJ = researcher's judgment.

3.3. Analysis of the SEL's Structures and Behaviors

3.3.1. Issue 1: Coastal Landscape Management

The coastal dune area management measures regulated by the Ministry of the Environment could be classified into three general categories: measures supporting sand accumulation by building sand fences and planting vegetation in dunes; measures supporting coastal dune creation by adding sand; and measures supporting protection of the coastal dune by designating it a protected area [45]. Among these measures, sand fences, which were temporary barriers erected to actively trap blowing sand, could be installed during any season and produce immediate results by trapping sand [17]. At the Shindu-ri coastal dunes, bamboo fencing was used as a sand fence; as the number of sand fences increases, sand erosion decreases and sand accumulation increases [13]. As the size of coastal dunes increased through the sand accumulation process, the need for sand fences decreases and eventually sand erosion also decreases. In other words, balancing loop B1, which demonstrated increasing sand erosion, is formed; based on the loop, an optimal coastal dune size can be maintained (Figure 3).

The management of coastal dunes by manually planting vegetation was a measure that increases sand accumulation using both topographical and ecological analyzed of the sand dune environment [46]. Sand dune vegetation not only trapped blowing sand but also stabilized the sandy soil and reduced sand erosion [46]. As a coastal dune increased in size because of reduced sand erosion, manual planting of vegetation was suppressed; this induces the process of coastal grassland reduction. In other words, by planting sand dune vegetation, the size of coastal dunes and coastal grassland could be maintained at an optimal level, as shown in balancing loop B2 (Figure 3). For convenience of management, however, most coastal regions tended to adopt artificial anti-erosion devices, such as seawalls, to prevent reductions in the size of coastal dunes [47]. However, this practice broken the link between terrestrial and coastal areas, preventing sand from accumulating in the coastal dune area and ultimately reducing the size of the coastal dune [48]. Furthermore, it created adverse effects as waves accelerate the deterioration of artificial construction and gradually reduce the amount of sand deposition, resulting in a receding coastal shoreline [47]. This type of reduction in coastal dune size brought about by the installation of artificial construction results in a scenario that promotes additional artificial construction to prevent erosion (Figure 3, reinforcing loop R1). This counterintuitive method of coastal dune management could be referred to as reinforcing loop R1, which was a vicious cycle that reduces the size of coastal dunes over time.

Beyond the Shindu-ri coastal dunes lied a large area of coastal forest. Because coastal dunes and coastal forests were spatially and functionally linked, coastal dune management and coastal forest management should be implemented simultaneously [49,50]. Coastal forest management of Shindu-ri adheres to the following guidelines from the Korea Forest Service: "Sustainable forest resources management guideline" and "Coastal disaster prevention forest creation guideline" [51,52]. However, the "Sustainable forest resources management guideline" did not include coastal forest management guidelines; thus, coastal forest conservation requires the additional process of designating the forest a conservation site. Moreover, the "Coastal disaster prevention forest creation guideline" did not contain sufficient information for coastal forest management. Thus, Coastal forest management has overlooked the conditions of the ecological systems in coastal regions and has implemented a forest management guideline solely for ecological systems in terrestrial zones. Under such inadequate coastal forest management, neither the landform and soil of coastal regions nor the characteristics of vegetation in coastal regions are examined or analyzed; instead, trees were planted indiscriminately. Manually planted trees did not form deep roots and could be uprooted by strong onshore winds because they have been planted prior to soil stabilization. As trees fall and fail to adapt to coastal regions, the size of the coastal forest was reduced, which resulted in tree planting by area residents; however, as time goes by, coastal forests decrease because of the poor establishment of roots, as shown in reinforcing loop R2 (Figure 3).

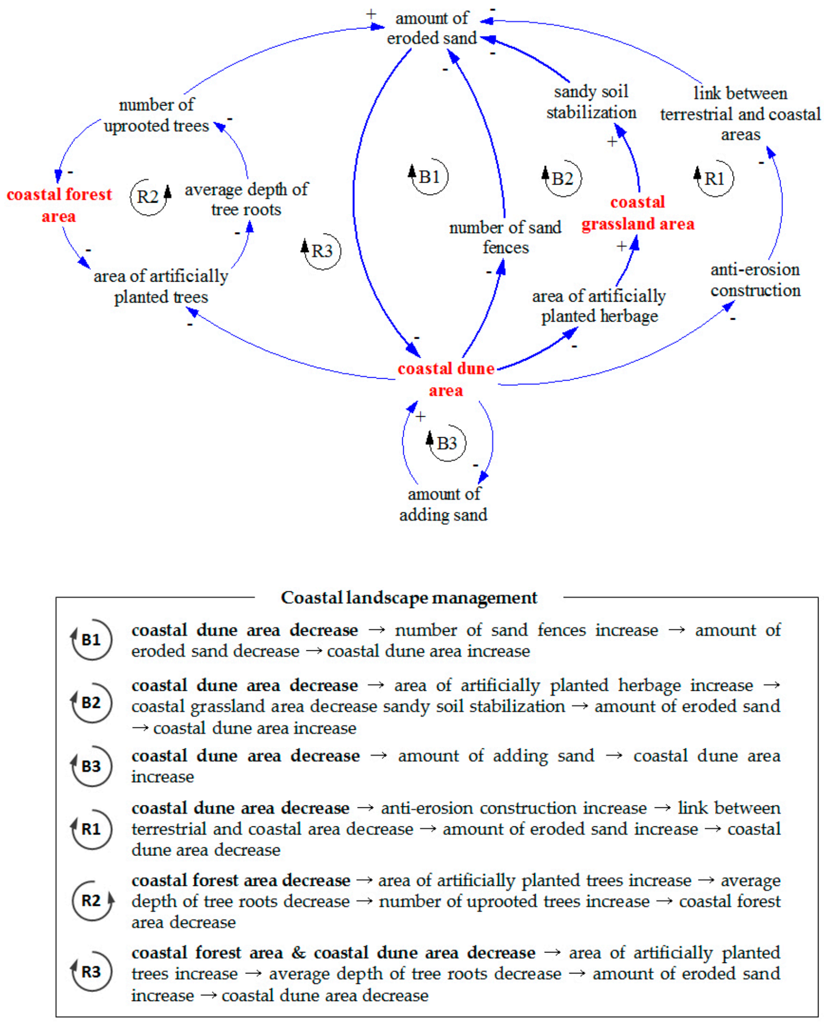
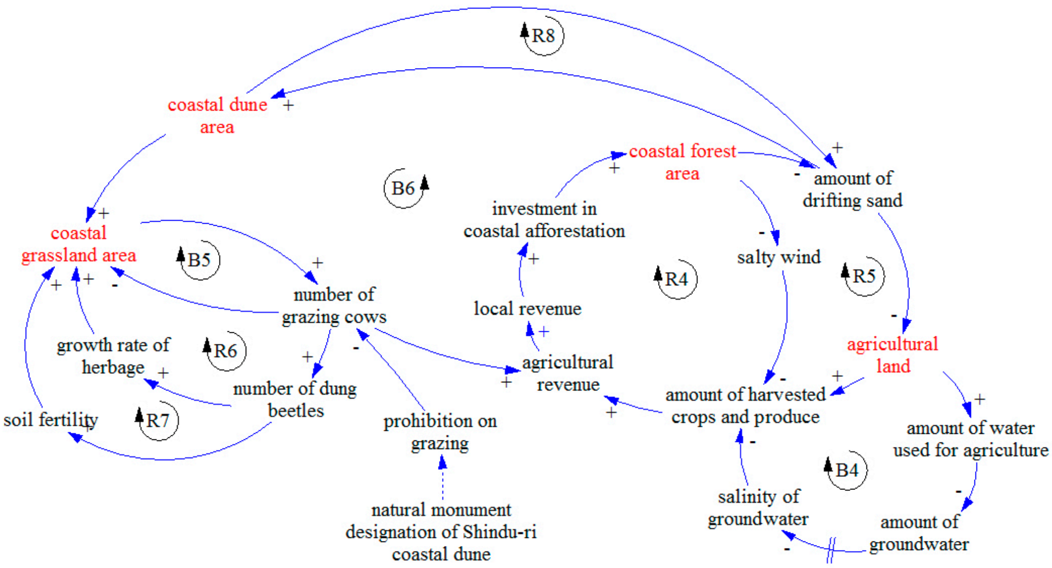


Figure 3. Causal loop diagram of coastal landscape resource management.

The increased number of uprooted trees caused by reinforcing loop R2 leaded to a reduction in the size of the coastal dune caused by increased sand erosion. Planting vegetation in the coastal dunes could be used to increase sand accumulation in the area [46,53]; in contrast, shrubs or tall trees could activate reinforcing loops R2 and R3, decreasing the size of both the coastal dune and the coastal forest. In other words, management that focused only on increasing coastal dunes caused a rapid reduction in the size of coastal forests. To improve the coastal resilience of the SEL, coastal region management required a strategy that considers both coastal forests and coastal dunes because the current management strategy has proven inadequate.

3.3.2. Issue 2: Agriculture-Related Conflicts over the Conservation and Development of the Coastal Landscape

Most Shindu-ri residents (more than 90%) engage in agriculture, which was the foundation of the Shindu-ri economy [13]. However, landward wind and the subsequent problem of drifting sand had negatively impacted agriculture. Consequently, since the 1970s the Shindu-ri area has continually built and managed a tree belt as a windbreak [13]. The tree belt has prevented a reduction in agricultural land induced by the accumulation of sand blown by strong landward winds on the west coast [11]. Retaining the area of coastal farmland using a tree belt helped secure steady revenues for farming households thanks to a stable harvest of crops and produce [11,51]. The Shindu-ri area's financial improvement enabled investment in coastal forest creation and management, potentially increasing the coastal forest area. Such an increased in the coastal forest forms reinforcing loops R4 and R5, which continuously improved the area's revenue. The increased area of agricultural land resulting from reinforcing loops R4 and R5 increased the amount of water available for agricultural use while decreasing the amount of groundwater [54]. Such a continual decrease in the groundwater level will increase the salinity of the groundwater over the long run and will eventually create an inadequate environment for growing crops [55,56]. These feedback phenomena could decrease the coastal resilience of the SEL. Poor food production decreased the revenue of farming households in the Shindu-ri area and could have an adverse effect on the local economy. This series of events could lead to negligence in coastal tree belt management, causing a decrease in the size of the coastal forest, and increases in drifting sand will turn agricultural land into sandy fields. The reduction in agricultural land increases the amount of groundwater because of decreased reliance on groundwater for agricultural use, but this process takes place over a significantly long period. Accordingly, it is anticipated that the structure of the agricultural industry area will collapse before the salinity of the groundwater begins to decrease (Figure 4, B4).



Agriculture structure in Shindu-ri coastal region

- **B4**: **agricultural land area increase** → amount of water used for agriculture increase → amount of ground water decrease → salinity of groundwater increase → amount of harvested crop and produce decrease → agricultural revenue decrease → local revenue decrease → investment in coastal afforestation decrease → coastal forest area decrease → amount of drifting sand increase → agricultural land area decrease
- **B5**: **coastal grassland area decrease** → number of grazing cows decrease → coastal grassland area increase
- **B6**: **coastal grassland area increase** → number of grazing cows decrease → agricultural revenue increase → local revenue increase → investment in coastal afforestation increase → coastal forest area increase → coastal forest area increase → amount of drifting sand decrease → coastal dune area decrease → coastal grassland area increase
- **R4**: **coastal forest area decrease** → sandy wind increase → amount of harvested crops and produce → agricultural revenue decrease → local revenue decrease → investment in coastal afforestation decrease → coastal forest area decrease
- **R5**: **coastal forest area decrease** → amount of drifting sand → agricultural land area decrease → amount of harvested crops and produce decrease → agricultural revenue decrease → local revenue decrease → investment in coastal afforestation decrease → coastal forest area decrease
- **R6**: **coastal grassland area decrease** → number of grazing cows decrease → number of dung beetles decrease → growth rate of herbage decrease → coastal grassland area decrease
- **R7**: **coastal grassland area decrease** → number of grazing cows decrease → number of dung beetles decrease → soil fertility → coastal grassland area decrease
- **R8**: **coastal dune area increase** → amount of drafting sand → coastal dune area increase

Figure 4. Causal loop diagram of the coastal landscape based on the agricultural structure.

In the past, Shindu-ri coastal dunes and coastal grasslands were used to pasture cattle. Over the years, cattle grazing in the coastal grassland had closely interacted with the coastal landscape and formed a unique coastal ecological system. In particular, coastal grasslands offer an abundant food resource, which allowed for an increase in the number of grazing cows; however, as the cattle graze on vegetation, the size of the coastal grassland decreases. The coastal grassland and the number of grazing cows form balancing loop B5, which indicated stabilization over time.

Excrement from cattle on coastal dunes could be used as a food source for the dung beetles that live in the Shindu Dune [53]; thus, an increase in the number of grazing cows lead to an increase in the number of dung beetles. The increase in dung beetles, in turn, can stimulate vegetation growth in the coastal grassland and improve the quality of soil in the dunes, which could help increase the area of coastal grassland [57]. However, in 2001, the Shindu-ri coastal dune was designated as a natural monument by the Cultural Heritage Administration; pasturing cattle on it was legally prohibited [34]. The prohibition on grazing, which was intended for coastal dune preservation, has eliminated the supply of cattle excrement on the coastal dunes and coastal grasslands, leading to a drastic reduction in the number of dung beetles. Thus, the prohibition on grazing has helped form reinforcing loops R6 and R7, creating a vicious cycle that has gradually reduced the size of the coastal grasslands (Figure 4). The causal loop diagram of the coastal landscape based on the agricultural structure showed that the short-sighted, preservation-focused coastal dune conservation policy destroyed the coastal landscape that had been formed by agricultural behavior (development).

3.3.3. Issue 3: Tourism-Related Conflicts over Conservation and Development of the Coastal Landscape

Previously, the Shindu-ri tourism industry expended substantial efforts to improve the attractiveness of the area to increase the number of tourists [34,58]. These efforts resulted in the construction of tourist amenities and a tourism infrastructure [59]. These improvements in the attractiveness of the Shindu-ri coastal area have indeed led to an increase in the number of tourists [59]. Because of the rapid increase in tourists, the area's tourism revenue has grown. Subsequently, investments in the tourism industry of Shindu-ri coastal area had also increased [60]. Investments in the tourism industry resulted in amenities such as coastal recreational facilities and the improvement of the tourism infrastructure [37], which over time has formed reinforcing loop R9. Concurrently, the number of tourists had been rapidly increased [37] (Figure 5).

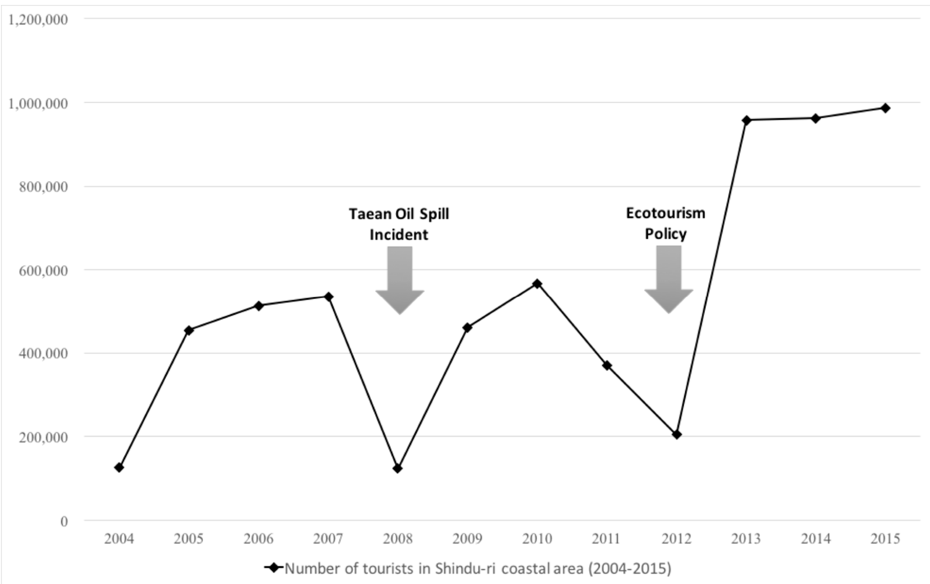


Figure 5. Number of tourists in the Shindu-ri coastal area [35].

The increased number of tourists drawn by the development of the tourism industry of Shindu-ri coastal area has had a positive economic effect, such as improved tourism attractiveness, enhanced tourism and local revenue, and increased tourism investment. However, it had also lowered the quality of the coastal landscape. Eventually, this degradation of the landscape weakened the structure of the tourism industry [44,59,61]. One factor in the destruction of the coastal landscape was the rapid increase in the number of tourist amenities and tourism infrastructure, along with the simple increase in the number of tourists [59]. The increased establishment of tourism amenities and tourism infrastructure by reinforcing loop R9 led to an expansion of the used areas. The growth of the used area utilized for tourism has weakened the link between the coastal region and the terrestrial area because the used area has primarily been developed between these two regions, blocking the sand movement cycle and destroying the topographic structure that could trap sand [3]. This outcome suggested a decline in sand accumulation and a reduction in coastal dunes [48]. In addition, most Shindu-ri tourist sites have arisen where once there was coastal grassland and coastal forest, and this land-use change has reduced the size of these two areas (Figure 6, B10, B11). The decline of the elements that comprise the Shindu-ri coastal landscape has reduced the quality of the coastal landscape. The depreciation of the coastal landscape, which is used as a Shindu-ri tourism resource, diminishes the attractiveness of the area as a tourist destination. If there is no policy to slow the depreciation of the coastal landscape and if the size of coastal dunes drops below a certain level, the number of tourists will drastically decrease and tourism amenities or infrastructure will cease to be built; eventually, Shindu-ri will not be able to attract tourists. Indeed, as shown in Figure 6, the destruction of coastal landscape caused by an oil spill incident and an inadequate ecotourism policy resulted in a decrease in the number of tourists visiting Shindu-ri. It appeared that this could become a vicious reinforcing loop that gradually destroyed tourism industry (Figure 6).

The increased number of tourists referenced by reinforcing loop R9 could harm the coastal landscape because of the increased pressure for coastal region tourism [44]. Despite banning cattle grazing for the conservation of coastal dunes, the reason for permitting tourism was that the department responsible for each activity was different and that inconsistent coastal dune policies have been implemented. Taean County Office, which oversees the tourism industry in Sinduri, has expanded the tourism industry using the coastal landscape, thus increasing residents' income [37]. For example, Taean-gun has hosted the "Korean Dunes Festival" in the Shindu-ri area to attract tourists. The large number of tourists who visited the area engaged in recreational events based on Shindu Dune tours. The increased pressure of tourism activity attributable to the large number of tourists who visited the coastal dunes could disturb the growth of vegetation in the coastal ecology system, which could reduce the major elements of the coastal landscape such as coastal grassland and coastal forest areas, depreciating the Shindu-ri coastal landscape (Figure 6, balancing loops B8, B9). This encourages Shindu-ri tourism stakeholders to invigorate the vicious reinforcing loop R9 while discouraging the invigoration of balancing loops B8, B9, B10, and B11, which are the feedback structures that will restore the coastal landscape. Ultimately, the repetition of this process will irrevocably damage the quality of the coastal landscape and destroy the Shindu-ri tourism industry.

The development of Shindu-ri tourism industry is based on the quality of its coastal landscape, which is composed of natural resources such as coastal grassland, coastal forest, and coastal dunes [37]. Therefore, negligence in natural resource management could cause a decrease in the quality of coastal landscape, leading to the collapse of the Shindu-ri economy and the destruction of the natural environment [61]. The tourism industry of Shindu-ri coastal area should consider the balance between development (Figure 6, R9) and preservation (Figure 6, B7, B8, B9, B10, B11), which were simultaneously considered and prioritized.

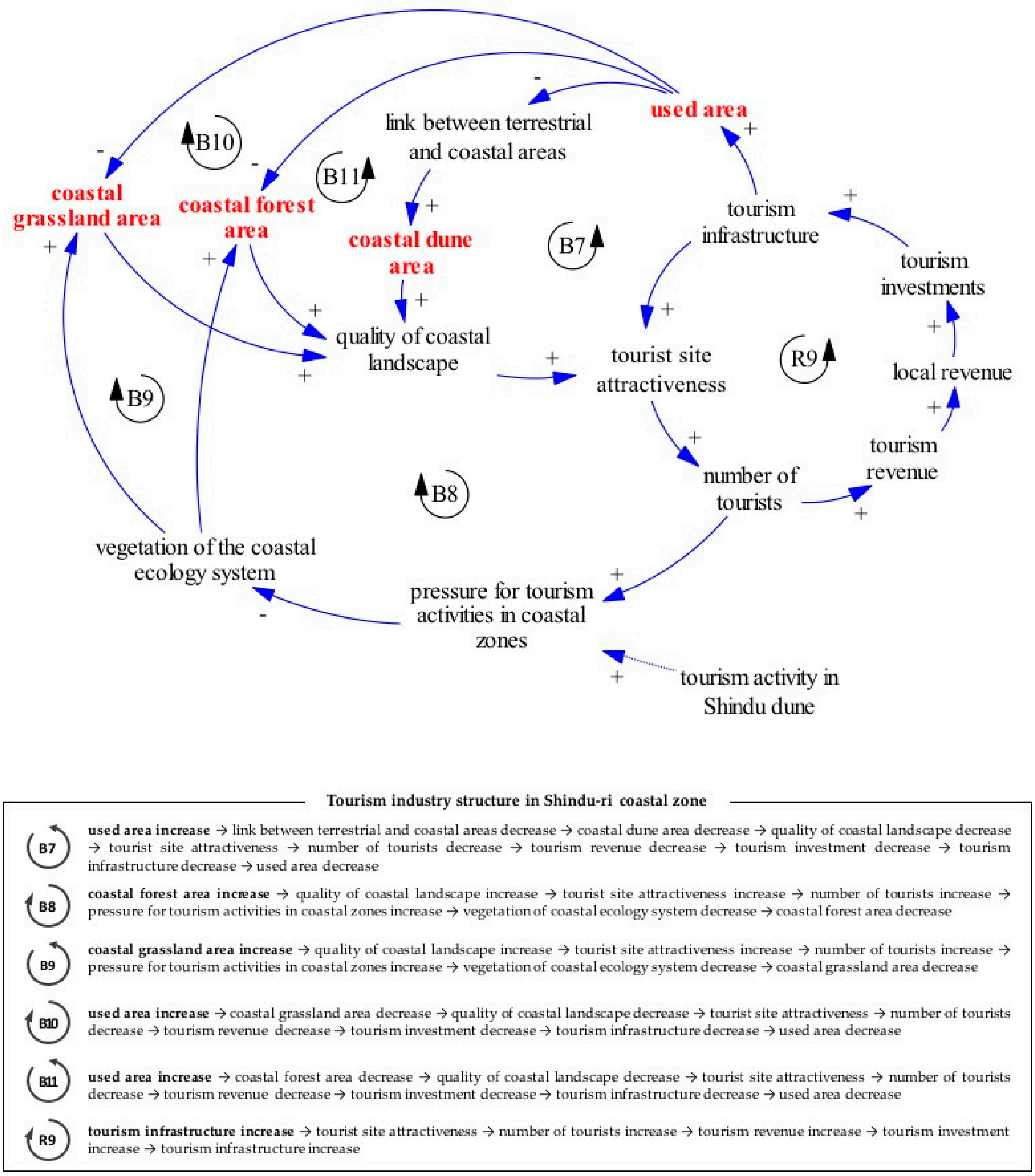


Figure 6. Causal loop diagram of the coastal landscape based on the structure of the tourism industry.

3.4. SLUP Strategy for Coastal Resilience

3.4.1. Strategic Points of the Shindu-ri Coastal SEL

An integrated causal loop diagram was created by combining the three causal loop diagrams of the studied coastal SEL. In these causal loop diagrams, an increase or decreased of land-use in Shindu-ri such as the coastal dune, the coastal forest, coastal grassland, the agricultural area, and the used area plays an important strategic role in the coastal SEL. The feedback loops involving the key variables of these strategic points could be described as the feedback structure prototypes of "limitation on development", as shown in Figures 7 and 8.

One predominant feedback structure of the SEL in a coastal region was reinforcing loop R_Lim1, which comprised factors such as the number of tourists and tourist site attractiveness (Figure 7). To maintain the virtuous cycle of this reinforcing loop, the quality of the coastal landscape should be constantly managed to improve tourist site attractiveness. However, meeting the increased tourism demands created by reinforcing loop R_Lim1 required the construction of tourism infrastructure such as accommodations, which led to changes in the landform and the quality of the coastal grasslands, coastal forests, and coastal dunes of the used area. These drastic land-use changes decreased the quality of the coastal landscape and hinder the improvement of attractiveness as a tourist site, slowing the increase in the number of tourists and hindering tourism-based growth. If Shindu-ri neglects the management of its coastal landscape ecological system, the areas of coastal grasslands, coastal forests, and coastal dunes will gradually turn into used areas, irrevocably changing the coastal region in the SEL. To prevent this, it is necessary to encourage a sustainable Shindu-ri tourism industry by balancing the used area with coastal grasslands, coastal forests, and coastal dunes.

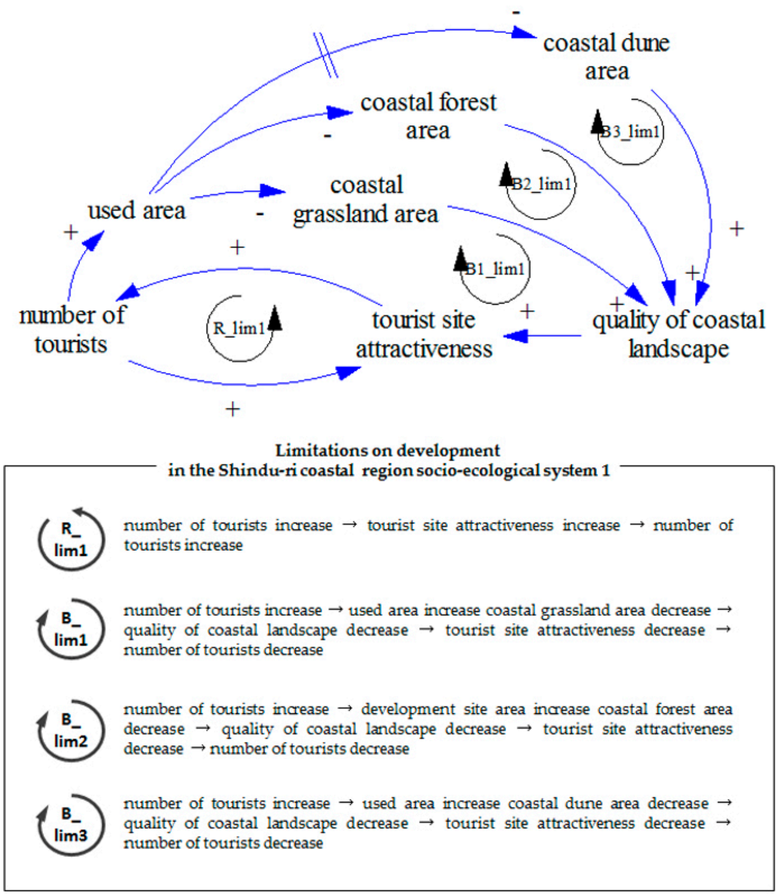


Figure 7. Limitations of development in the Shindu-ri coastal region's SEL.

Another prominent feedback structure of the Shindu-ri coastal SEL was reinforcing loop R_Lim2, which comprised factors such as local revenue and coastal forest area (Figure 8). As the area of coastal forest increased, the following changed occur: the amount of drifting sand decreases, agricultural revenue increases, the quality of the coastal landscape improves, revenue from the tourism industry increases, and overall revenue climbs of Shindu-ri. The increased area of coastal forest based on this reinforcing loop increases the area of agricultural land, which increased the utilization of water for agricultural use and caused a decrease in groundwater reserves, increasing the salinity of the groundwater, and leading to a decrease in the coastal forest area and initiates the vicious cycle of reinforcing loop R_Lim2. Therefore, to create the virtuous cycle of reinforcing loop R_Lim2, management of both coastal forests and agricultural land was required.

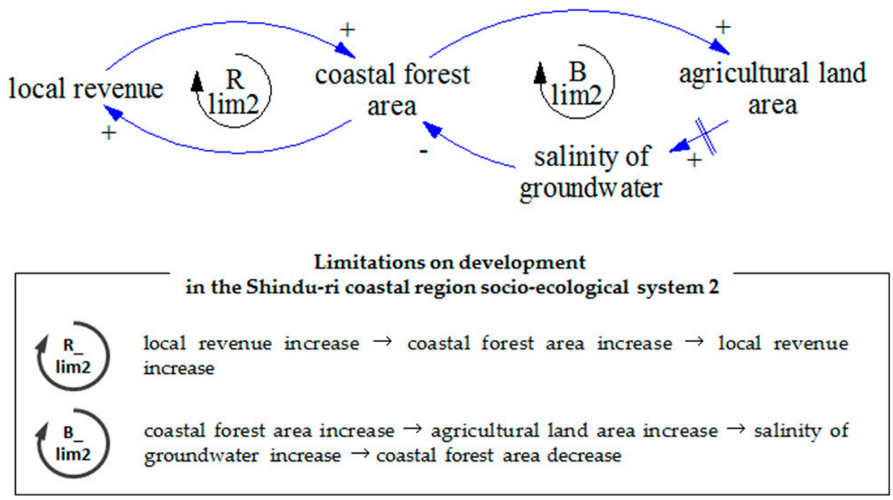


Figure 8. Limitations of the development in the Shindu-ri coastal region's SEL.

There were two prominent feedback loops that affect Shindu-ri coastal region, both of which were reinforcing loops: one consists of the number of tourists and tourism attractiveness, whereas the other consists of local revenue and coastal forests. These two reinforcing loops were controlled by various components of Shindu-ri coastal region land-use, including areas of coastal forests, coastal grasslands, coastal dunes, agricultural land, and used areas. In other words, land-use was considered the strategic point of the Shindu-ri coastal SEL; diverse land-use establishes the coastal SEL. However, anthropogenic development, which has increased in recent years, creates land-use change, and the sharp increase in land-use change weakens the coastal resilience of the SEL, challenging the system's normal restoration. Therefore, to assure the resilience of the Shindu-ri SEL, adequate SLUP that can handle disturbances must be established through scenario building based on the variables of the strategic point.

3.4.2. SLUP Strategies for Coastal Resilience

This study created 3 strategies: the decrease in coastal forests, the decrease in coastal dunes, and the increase in coastal grasslands. Based on the integrated causal loop diagram of the Shindu-ri coastal the SEL, the land-use change patterns were analyzed according to each scenario. The analyses were performed via the "discovery of strategy" approach, i.e., the final phase of systems thinking. In this study, strategies were analyzed as follows: first, in the integrated causal loop diagram composed of both anthropogenic phenomena and ecological phenomena, the feedback loop of ecological phenomena was first analyzed to predict land-use dynamics. Second, the feedback loops for each type of land-use were examined to show how different strategies result in land-use change. For example, coastal grasslands autonomously form either a reinforcing loop or a balancing loop with variables such as the number of dung beetles and the number of grazing cows. Third, the relationship among different land-uses was interpreted primarily based on the prominent loops. Each land-use is linked to many loops, but there is typically one feedback structure that dominates and accounts for certain phenomena. Therefore, this study analyzed land-use change strategies based on prominent loops for each issue.

First, the area of coastal forest forms a balancing loop with the areas of coastal dunes, used areas, and coastal grasslands. Thus, as the size of the coastal forest area decreases, the areas of coastal dunes and used areas become more stable after an established decrease while the area of coastal grasslands converges to a certain value after a period of enhancement. The increased in grasslands improved biodiversity because they provide habitats for cows as livestock and beetles as wild animals, promoting harmony with both the social and the ecological systems. Moreover, the strategy prohibits land-uses from increasing or decreasing indefinitely; thus, the SEL was stable in the end. Because of improved biodiversity and a stable SEL, adaptation to land-use changes is easier, and coastal resilience will be advanced.

Second, the decrease in the coastal dune area extends the areas of coastal forests, coastal grasslands, and agricultural lands, decreasing the size of used areas; however, growth slows over time. This strategy led to building a green infrastructure network with coastal forests and coastal grasslands. As the green infrastructure network developed, the ecological connection of Shindu-ri from the inland region to the coast alleviates habitat fragmentation and helps the coastal ecosystem processes evolve, e.g., through pollination and wild animal movement with enhanced coastal resilience. However, the decrease in sand dunes causes coastal hazards to negatively impact the social landscapes, e.g., agricultural lands and used area, leading to decreased coastal resilience in social landscapes. Therefore, the decision makers tasked with addressing land-use planning should attempt to maintain and conserve the existing coastal dunes. Coastal dune nourishment could be carried out not only by simple physical structures such as sand fences and anti-erosion construction but also by using computational software for complex sand movement models such as "the wave and morphology evolution model" or economic models with various scenarios [62,63].

Third, the area of coastal grassland forms a balancing loop with all land-uses that occur in the Shindu-ri coastal regions; the increase in the area of coastal grassland caused the increase in the areas of coastal dunes and used areas while decreasing the areas of coastal forest and agricultural land. In contrast, in the strategy that reduced the coastal dunes, the area of coastal dunes and used areas stabilize after a certain decrease; the areas of coastal forest and agricultural land converge to a certain level after a short increase. However, coastal forests could decrease in size depending on the indiscriminate utilization of groundwater after the area of agricultural land increases [55,56]. Therefore, it was important to establish alternatives that consider both political and economic factors by restoring coastal forests with increased local revenue from agricultural activities. To establish these alternatives, local farmers' awareness of the importance of both using groundwater and applying technologies of rainwater harvesting and utilization should be increased. It was also necessary to change intensive agricultural system of Shindu-ri into either an agroforestry system or an agricultural system that uses native vegetation.

4. Conclusions

This paper outlined challenges in issues of Shindu-ri coastal region. The coastal resilience of the SEL was discussed using causal loop diagrams and the systems thinking process. After analyzing the SEL, three issues were identified, and causal loop diagrams were created for different issues. First, a causal loop diagram was created to illustrate the phenomenon of a decline in coastal forests, coastal dunes, and coastal grasslands attributable to the absence of an integrated coastal landscape management plan. Second, a causal loop diagram was created to illustrate land-use changes resulting from various agricultural activities in the Shindu-ri coastal region. Third, a causal loop diagram was created to illustrate the collapse of the tourism industry caused by an increase in development and a decline in the quality of the coastal landscape based on recent tourism activities in Shindu-ri. The decline of the tourism industry leads to a decrease in local revenue, decreasing the financial resources available to restore coastal forests. Failure to restore coastal forests has a negative impact on agricultural structure by promoting migration to agricultural land. Based on these individual causal loop diagrams, an integrated causal loop diagram was created and analyzed; thus, land-use was derived as the strategic point for improving the resilience of the Shindu-ri coastal region's SEL. To establish land-use plans to improve coastal resilience, three strategies in the Shindu-ri coastal region were analyzed through the discovery of strategy approach. As a result, this study presented the possible alternatives of a "decrease in the size of coastal forests, a "decrease in the size of coastal dunes", and an "increase in the size of coastal grasslands" to establish SLUP in the Shindu-ri coastal region. Three strategies build green infrastructures to stabilize land-use changes and increase coastal resilience. However, because coastal dunes, which can attenuate waves and improve biodiversity, can rapidly shrink based on these three strategies, a measure for maintaining the area of coastal dunes is also required. According to the strategies of a "decrease in the size of coastal dunes" and an "increase in the size of coastal grasslands", a strategy to maintain both the areas of development and coastal forests at an adequate level must be established. The three strategies proposed in this study are expected to be utilized as baseline data for SLUP strategies to improve coastal resilience.

In conclusion, this study is also significant in that it breaks from previous single-minded coastal region management approaches and develops an integrated coastal region land-use planning strategy through systems thinking.

The current study incorporated three features of the social-ecological system interactions that have not been adequately considered by systems thinking and developed improved strategies to better understand dominant mechanisms linked with resilience. We introduced various theories and concepts discussed in the SEL literature that might also be useful in the emerging field of the SEL. Adopting these concepts will contribute a richer set of ideas and guidance to next-generation studies of the SEL. We also found two critical insights into the social-ecological resilience to disturbances. This study can contribute baseline data for future research to assess coastal resilience. In addition, this study utilized a qualitative study method, including a causal loop diagram analysis of the SEL, which proceeded in four steps from dynamic thinking to discovery of strategy. It is believed that follow-up studies can utilize land-use, the strategic point of this study, as a stock parameter to process other actors in anthropogenic, social, and natural environments as exogenous parameters and to conduct quantitative simulation using system dynamics. Such studies will help resolve complex issues involving the SEL of the Shindu-ri coast and will play a significant role in establishing numerical standards and implementing policy when creating an SLUP for resilience improvement. Although this study derived long-term land-use planning considering a time lapse, it did not adopt a spatial aspect approach. Future studies should propose a database through monitoring, survey or a resilience assessment index; in addition, they should establish SLUP measures through temporal and spatial modeling.

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Abbreviations

The following abbreviations are used in this manuscript:

IUCN	International Union for Conservation of Nature
ICZM	Integrated Coastal Zone Management
SEL	Social-Ecological Landscape
SLUP	Sustainable Land-Use Planning

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