Ph.D. Dissertation of Engineering

Integrating Ecosystem Services and Connectivity for Prioritizing Conservation Areas in Jeju Island, Republic of Korea

제주도의 우선보호지역 선정을 위한 생태계서비스 및 연계성 통합 분석 연구

August 2023

Graduate School of Seoul National University
Interdisciplinary Program in Landscape Architecture Integrated Major in Smart City Global Convergence Program

Jihwan Kim

Integrating Ecosystem Services and Connectivity for Prioritizing Conservation Areas in Jeju Island, Republic of Korea

Advisor: Youngkeun Song

A dissertation submitted in partial fulfillment of the requirements for the Degree of Doctor of Philosophy in Interdisciplinary Program in Landscape Architecture and Integrated Major in Smart City Global Convergence Program in Seoul National University

August 2023

Jihwan Kim

Approved by Thesis Committee

Chair	(Seal)
Vice Chair	(Seal)
Examiner	(Seal)
Examiner	(Seal)
Examiner	(Seal)

Abstract

Integrating Ecosystem Services and Connectivity for Prioritizing Conservation Areas in Jeju Island, Republic of Korea

Jihwan Kim
Interdisciplinary Program in Landscape Architecture and
Integrated Major in Smart City Global Convergence Program in
Seoul National University
Graduate School of Seoul National University
Supervised by Professor Youngkeun Song

This dissertation presents a comprehensive approach for identifying priority conservation areas to achieve sustainable conservation, delving into the interrelationship among ecosystem services, biodiversity, and land ownership along with their collective influence on the ecological landscape of Jeju Island. In an era marked by rapidly changing environmental conditions, the study aims to augment our understanding of conservation dynamics through an in-depth exploration of changes in land use and land cover over a 47-year period. The analysis reveals discernible impacts on Jeju Island's ecosystem services. Due to an apparent decline in their ecological value, coastal regions are specifically identified as areas of significant concern that require immediate, effective conservation measures. This observation requires discussion on the ways land use and cover changes influence ecosystem services, thereby aiding in the plans for relevant conservation strategies. Drawing attention to the transformative influence of forest restoration policies implemented in the 1970s and 1980s, the study credits these initiatives for substantially bolstering Jeju Island's ecological stature, and thus, its conservation value. This work adds depth to the discourse on sustainable ecosystem management, particularly in the context of volcanic island ecosystems. Furthermore, it introduces the concept of ecological connectivity into conservation management planning, suggesting that improved connectivity fosters biodiversity. It identifies notable pinch points and disconnects, specifically between coastal and mid-mountain regions, thereby offering vital insights for future conservation priorities. This nuanced understanding highlights the significance of ecological connectivity in managing conservation strategies. By illustrating the complexity of conservation planning, the study also examines the land ownership aspects. The findings underscore the challenges of conservation activities on private land due to the potentially higher associated costs, advocating for effective public–private collaborations. In an effort to tackle the challenges posed by limited protected areas, this study introduces the use of Other Effective area-based Conservation Measures as a novel and effective solution. It stresses the need for a balanced approach to conservation, considering both quantitative and qualitative aspects of protected area expansion, with a strong focus on ecosystem services and network characteristics. In conclusion, this dissertation presents an integrative framework for sustainable conservation planning, demonstrating the relevance of multidimensional analysis for informed conservation decision-making. Although this study focuses on Jeju Island, the principles and strategies discussed here are universally applicable for similar ecosystems worldwide. By adopting integrated, context-specific strategies that consider local conditions and stakeholder interests, this study concludes that it is possible to strike a balance between conservation, cost-effectiveness, and long-term sustainability of natural resources.

Keyword: Conservation management, Ecological planning, Protected areas, Ecological connectivity, UNESCO heritage, Jeju Island
Student Number: 2019-30345

Table of Contents

Chapter 1. Introduction 1

Chapter 2. Complex spatiotemporal changes in land-use and ecosystem services in the Jeju Island UNESCO heritage and biosphere site (Republic of Korea) 5

2.1. Introduction 5
2.2. Materials and methods 8
2.3. Results 10
2.4. Discussion 16
2.5. Conclusion 21

Chapter 3. Integrating Ecosystem Services with Ecological Connectivity for Spatial Conservation Prioritization in Jeju Island, South Korea 22

3.1. Introduction 22
3.2. Study area and methods 26
3.3. Results 32
3.4. Discussion 39
3.5. Conclusion 43

Chapter 4. Prioritizing Conservation Areas on Jeju Island, South Korea: An assessment of Ecosystem Services and Land Ownership 44

4.1. Introduction 44
4.2. Study area and methods 48
4.3. Results 55
4.4. Discussion 61
4.5. Conclusion 66

Chapter 5. Conclusion 67

Supplementary 69

Bibliography 85

List of Figures

Figure 1.1. Study flow of this dissertation 4

Figure 2.1. 2019 map of Jeju Island, Republic of Korea (33° 10′ – 33° 34′ N, 126° 10′ –127° E) 8

Figure 2.2. (a) Proportional changes in total area by land type from 1973 to 2019, (b) differences in area of land use and land cover (LULC) changes in the coast area, (c) differences in area of LULC changes in the mid–mountain area, and (d) differences in area of LULC changes in the mountain area. 12

Figure 2.3. Spatial distribution of changes in ecosystem services from 1973 to 2019: (a) habitat quality (index: 0–1); (b) carbon stock (tonnes/pixel) 14

Figure 2.4. Cryptomeria japonica seedlings being planted during the National Forestation Plan, afforestation, and current status. a) seedling transplant, b) seedling trampling, c) seedling digging, d) seedling temporary planting, e) afforestation of Nori–oreum in 1973, f) current Nori–oreum, g) afforestation of Buk–oreum in 1973, h) current Buk–oreum. Oreum is local dialect for a formation "created by small volcanic activity.". from Jeju Province (2006) Jeju Forest 60 Years History. Jeju: Jeju Province. Image reused with permission. 20

Figure 3.1. Map of Jeju Island, South Korea (33° 10'–33° 34'N, 126° 10'–127° E) in 2020. 27

Figure 3.2. Spatial distributions of ecological services (ES) and protected areas on Jeju Island. ES evaluation results are not mean absolute values, but relative values for the target area. Habitat quality and carbon stock showed similar patterns, whereas seasonal water yield distribution differed. The bottom right panel shows a large protected area (green shading) concentrated in central Jeju Island, with a river network (blue lines) connecting the central and coastal areas. 33

Figure 3.3. Spatial patterns of ecological source and resistance surface values. 34

Figure 3.4. Spatial distribution of normalized current flow. (a) Results of overall EC analysis of the study site. Mid−mountain and mountain areas are densely heterogeneous. (b–d) Regions showing connections between coastal and mid−mountain areas. (e) Regions where high resistance surface and high ecological source values are interconnected 36

Figure 3.5. Spatial distribution of SCP ranks (left) and overlap between SCP areas and protected areas (right) 37

Figure 3.6. Summary of overlap (% area) between SCP areas and existing protected areas for four land use types 38

Figure 4.1. Land−use and land−cover map of Jeju Island, South Korea. The administrative cities of Jeju and Seogwipo are located to the north and south of the island, respectively. DEM, digital elevation model; PAs, protected areas. 48

Figure 4.2. Spatial distributions of land price, ecosystem services, and species richness. (a) Public land price (m^2/USD). PAs consist of nationally designated PAs and PAs designated by the Jeju Island administration. The latter category principally includes Hallasan National Park and areas with high ecological protection value. PAs + OECMs signify areas that, beyond currently protected zones, exhibit potential for OECM designation. (b) The four ecosystem services and species richness results that were used to derive the conservation prioritization areas. 55

Figure 4.3. Spatial representation of protected area (PA) scenarios across the study area. (a) Scenario for a 17% target in existing PAs under the three penalties. (b) Scenario for a 30% target in existing PAs under the three penalties.....................................56

Figure 4.4. Spatial representation of other effective area−based conservation measures (OECMs) scenarios across the study area. (a) Scenario for a 17% target in existing protected areas (PAs) + OECMs under the three penalties. (b) Scenario for a 30% target in existing PAs + OECMs based on the penalty................................ 57

Figure 4.5. Comparison of land cover and ownership area (km^2) across scenarios based on the solution. (a) Land use and land cover (LULC) by ownership in the protected−area (PA) scenario,

and (b) LULC by ownership in the OECM scenario 58

List of Tables

Table 2.1. Land use and land cover transition from 1973 to 2019 (km2) 12

Table 2.2. Ecosystem changes on Jeju Island, Republic of Korea, during 1973–2019. Habitat quality (HQ) and carbon stock (CS) were divided into coast, mid−mountain, and mountain areas. Water yield (WY) was calculated as the amount of annual water produced over the entire study site. 16

Table 3.1. Geographical regions (% area) of Jeju Island classified by flow type, indexed according to flow variation. SD, standard deviation. 35

Table 3.2. Summary of overlap (% area) between SCP areas and existing protected areas. 38

Table 3.3. Landscape pattern indices for each geographic region and the entire study area 39

Table 4.1. Summary of planning cost, area, and boundary length with respect to ownership. Cost refers to the total price of land as officially announced in the study area, expressed per 1,000 US dollars. Boundary length represents the length of the boundaries for the proposed solutions under each protected area (PA) and other effective area−based conservation measures (OECM) scenario. Shorter boundary lengths indicate less fragmentation. 60

Publications

Please note that some part of this dissertation proposal was written as stand-alone paper (see below), and therefore there are some repetition in the methods and results. Portions of this dissertation have been reprinted with permission, from previously published materials. Chapters 2 have been reprinted from Environmental Conservation,

1. **Kim, J.**, Choi, H., Shin, W., Yun, J., & Song, Y. (2022). Complex spatiotemporal changes in land-use and ecosystem services in the Jeju Island UNESCO heritage and biosphere site (Republic of Korea). *Environmental Conservation*, 49(4), 272-279.

2. **Kim, J.**, & Song, Y. (2023). Integrating Ecosystem Services with Ecological Connectivity for Spatial Conservation Prioritization in Jeju Island, South Korea. *Landscape and Urban Planning*. (Minor Revision)

Chapter 1. Introduction

The decline of biodiversity has various impacts on human life, including climate change adaptation and mitigation, food security, and quality of life (Bawa et al., 2021; Thomas et al., 2013). Despite efforts worldwide to increase biodiversity, expand conservation areas, and reduce carbon emissions, uncontrolled development for urbanization is gradually becoming more severe (Le Saout et al., 2013; Strassburg et al., 2020). As intensive development due to rapid urbanization and biodiversity conservation conflict, coordination between urbanization and ecosystem conservation is increasingly crucial (Li et al., 2013; Qian et al., 2015).

As human intervention expands, there is now a discussion on how to efficiently select and manage protected areas (Carroll et al., 2021; Dawson et al., 2021). The discussion includes not only quantitative expansion of protected areas but also the enhancement of their functional aspects (IUCN, 2017; Snäll et al., 2016). To expand protected areas, it is necessary to approach the issue not only from a global scale but also from national and regional levels in order to realistically present solutions (Donaldson et al., 2021; Maxwell et al., 2020). In addition, it is important to consider where and how to conserve in the process of selecting protected areas (Cameron et al., 2022). The location and cost of selecting conservation areas should be considered along with the potential ecological benefits, as well as the economic gains and losses (Carroll et al., 2021).

To expand the quality of ecosystems at the local level, it is important to establish protected areas that take into account ecosystem functions (Cimon-Morin et al., 2013; Kukkala & Moilanen, 2017). Ecosystem services are a sub-concept of ecosystem function, and considering the functional connectivity between ecosystem services and reducing fragmentation can efficiently enhance the overall function of the ecosystem (Hong et al., 2017; Luo et al., 2021). The purpose of this study is to identify priority protected areas that consider ecosystem services and connectivity, and to propose conservation prioritization areas to maximize ecosystem services. This study was conducted by selecting Jeju Island as the research subject. Jeju Island is the largest island in Republic of Korea and is a region abundant in biodiversity, selected as a biosphere reserve, a global geopark, and a world natural heritage site due to its excellent natural assets (Kim et al., 2022). However, due to the over 10 million tourists visiting each year to utilize these ecosystem services, rapid urbanization is occurring, and various environmental issues are arising.

To achieve the objectives of this study, the paper is structured into three main topics (Fig 1.1). This research will provide information on the distribution and changes in ecosystem services in Jeju Island, as well as propose management strategies for spatial conservation prioritization (SCP) areas to enhance ecological planning.

● Sub-theme 1: Complex spatiotemporal changes in land-use and ecosystem services in the Jeju Island UNESCO heritage and biosphere site (Republic of Korea)

● Sub-theme 2: Integrating Ecosystem Services with Ecological Connectivity for Spatial Conservation Prioritization in Jeju Island, South Korea

● Sub-theme 3: Prioritizing Conservation Areas on Jeju Island, South Korea: An assessment of Ecosystem Services and Land Ownership

The first sub-study identified the dynamics of land use and land cover (LULC) change and change of ecosystem services for 47 years on Jeju Island. The study area of this paper Jeju Island, where conservation value is high, encountered massive changes related to land cover over the last about 50 years but there has not been much research conducted related to the change. Throughout the extensive implementation period of National Greening Program, the forest area increased dramatically, and it was confirmed that this incident carried out great influence on the current ecosystem services of Jeju Island. However, after the restoration program, the increase in crop land and urban land led to a quantitative decrease in ecosystem services. In particular, land use change differs depending on policy making. Thus, for sustainable development, active discussions on land use and ecosystem service management plans should be considered beforehand.

In second sub-study, development and conservation conflict with each other as human social activity increases due to rapid urbanization. To introduce effective conservation measures, it is imperative to identify areas that need to be protected first. Ecological connectivity (EC) considering ecological functions is crucial in prioritization. The three main objectives are 1) identifying primary pinch points through EC analysis using ecosystem service (ES) evaluations- habitat quality, carbon stock, and seasonal water yield; 2) recognizing where conservation and restoration are appropriate according to EC model results; and 3) discussing conservation strategies that can enhance EC within Jeju Island. Pinch points showed heterogeneity in the mid-mountain area, and it was confirmed that the coastal and mid-mountain areas were disconnected. In particular, about 80% of newly identified SCP areas were presented in the mid-mountain area and were mainly distributed in agricultural land and artificial grassland. Based on this study, I can intuitively identify new SCP areas based on existing protected areas and provide policymakers with a plan to manage the mid-mountain area. This study is meaningful in that it suggests a new approach based on ES and EC at an island scale.

In the third sub-study, following the second sub-study, we identified priority conservation areas using ecosystem services and biodiversity indices to determine the conservation priority areas. The 2022 Convention on Biological Diversity COP15 raised the conservation target from 17% to 30% after the Aichi Targets, requiring a different conservation strategy. Therefore, this study identified the optimal conservation areas at conservation targets of 17% and 30%. The results of the analysis indicated that priority protected areas for both the 17% and 30% conservation targets were located around Mt. Hallasan in Jeju Island, especially in areas with high concentrations of Oreum in the eastern part of the island. Furthermore, while public areas were the primary focus for the 17% conservation target, the expansion to 30% resulted in a substantial increase in the number of private areas, resulting in higher conservation management costs. This study could help to develop conservation management strategies from an ecological planning perspective for Jeju Island.

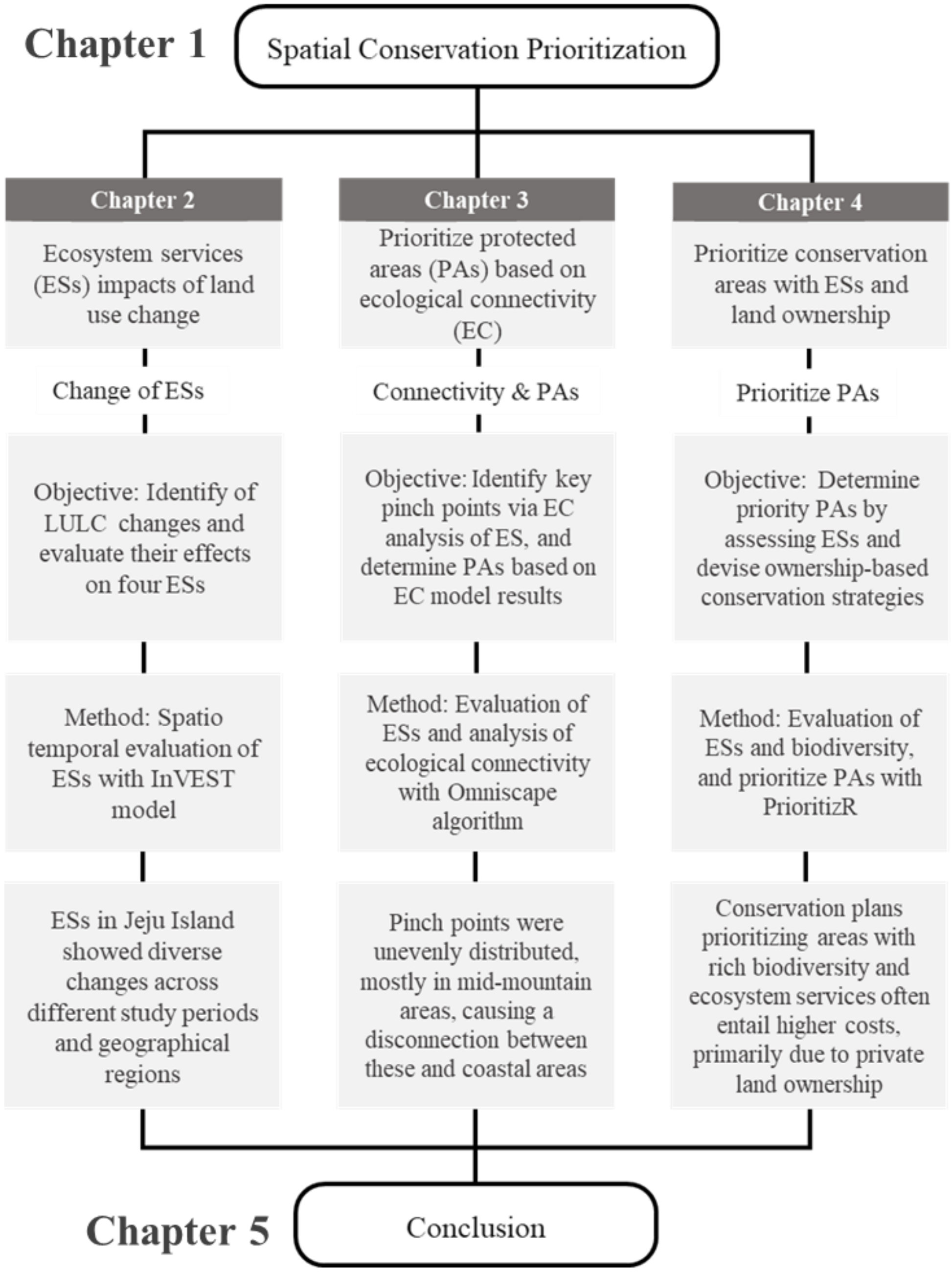

Fig 1. 1. Study flow of this dissertation.

Chapter 2. Complex spatiotemporal changes in land−use and ecosystem services in the Jeju Island UNESCO heritage and biosphere site (Republic of Korea)

1. Introduction

Human demand for ecosystem services has recently increased, imposing continuous threats upon natural environments (MEA, 2006; Xu et al., 2019; Yohannes et al., 2021). The number of tourists using ecosystem services is consistently increasing world-wide, particularly in areas rich in natural resources (Deng & Bauer, 2002; Barr & Choi, 2016; You et al., 2017). With the aim of revitalizing local economies and tourism, indiscreet development is increasingly rampant. Land use and land cover (LULC) changes, such as tourism development and urbanization, can lead to declines in the value of ecosystem services (de Groot et al., 2010; Gao et al., 2017). To better manage ecosystem services, resource managers need to implement long-term plans and develop sustainable management policies in areas rich in natural resources. These efforts should be approached from a long-term perspective beyond simply expanding the quantity of ecosystem services. To this end, it is necessary to first identify changes in land use from the past to the present as well as the resulting changes in ecosystem services (Nelson et al., 2009).

Changes in LULC can strongly alter ecosystem services (Nelson et al., 2009; Polasky et al., 2011; Crossman et al., 2012; Haase et al., 2012; Capitani et al., 2019; Xu et al., 2019). Assessments of ecosystem services are now needed to inform policymaking (Daily et al., 2009; Bagstad et al., 2013; Ruhl et al., 2013). LULC changes resulting from urban expansion are affecting ecosystem services (Verburg et al., 2009; Zhai et al., 2020);

however, most existing studies have focused on protected areas or areas where abrupt urbanization has occurred (Kim et al., 2015; Paudyal et al., 2019; Berta et al., 2020). Sustainable management plans generated from quantitative evaluation of LULC and ecosystem service changes over the long-term can critically inform policy decision making.

Jeju Island (Republic of Korea) is a region formed by volcanic activity, harboring an outstanding natural landscape and world heritage site. Jeju Island has achieved a triple-crown in the field of Natural Sciences at the United Nations Educational, Scientific and Cultural Organization (UNESCO), which includes designations of Biosphere Reserve in 2002, World Natural Heritage in 2007, and Global Geopark in 2010 (Kim et al., 2019). In addition, the island is also home to two intangible UNESCO cultural heritages, the Chilmeoridanggut Intangible Cultural Heritage (ICH) and Jeju Haenyeo ICH, as well as Jeju Batdam, a world agricultural heritage site designated by ICH and the Food and Agricultural Organization of the United Nations (FAO) (You et al., 2017). Thus, Jeju Island not only has high protection value but is also vital in terms of ecosystem, cultural, and tourism resources. The island has undergone many changes in land use over the past 50 years (Hong et al., 2021). Due to the forest rehabilitation policy promoted throughout the Republic of Korea, forest land increased for about 20 years after 1973, but LULC has changed rapidly due to increases in crop land and urban land since the 2000s. Local livelihoods rely mostly on agriculture and tourism, and income is earned from tourists who seek natural environments, such as natural heritage sites. Due to the outstanding natural scenery, the number of tourists visiting Jeju Island in 2019 was 13 million (Jeju Tourism Association, 2020), which is more than 130 times higher than in 2006. There is continuous development pressure on the region due to the influx of visitors (Barr et al., 2016).

Despite these recent trends (Polasky et al., 2011; Kim et al., 2019;

Sun et al., 2019b; Xu et al., 2019) and Jeju Island's status as a place of high ecological and cultural value, understanding of LULC changes over time, ecosystem service management, and long-term planning has been inadequate. The consequences of LULC changes and management for ecosystem services need to be quantitatively assessed (Han et al., 2019; Sun et al., 2019b; Sharp et al., 2020). However, it is important to not only evaluate ecosystem services but also to comprehensively identify the causes of LULC changes as well as the corresponding changes in ecosystem services. To identify these causes, it is necessary to examine the policy background of the study site. There are several tools to evaluate ecosystem services; Artificial Intelligence for Ecosystem Services (ARIES), and the Toolkit for Ecosystem Service Site-based Assessment (TESA), but the Integrated Value of Ecosystem Services and Trade-offs (InVEST) tools are particularly useful, as they utilize land cover and other spatially explicit data at the site to evaluate ecosystem services (Posner et al., 2016; Sun et al., 2019a; Sharp et al., 2020).

In the present study, we identified LULC changes on Jeju Island, evaluated their effects on four ecosystem services, and examined the dynamics among these services, which were habitat quality (HQ: supporting service), carbon storage (CS: regulating service), water yield (WY: provisioning service), and cumulative viewshed (CV: cultural service). The main objective of our research was to examine the dynamics of land use and ecosystem service changes on Jeju Island over the 47 years from 1973 to 2019. The investigation of such long-term LULC changes provides the opportunity to examine the cause of alteration in ecosystem services. In Jeju Island, discussions are continuously being suggested to prevent severe development pressure and to increase biodiversity and ecosystem services (Kim et al., 2019; Hong et al., 2021; Jun et al., 2021). Hence, the study is crucial to provide decision- and policymakers with a long-term perspective and a fundamental data to improve land use and ecosystem services management.

2. Materials and methods

2.1. Study area

Jeju Island is a volcanic island located in the Republic of Korea, with an area of 1842 km^2 and a population of 697,349 in 2021 (Fig. 2. 1). The administrative district is centered on Mt Hallasan in the middle of the island, Jeju-si in the north, and Seogwipo-si in the south. Jeju Island is divided into three regions and is managed accordingly: the coast (altitude: 0–200 m), mid-mountain (altitude: 200–600 m), and mountain (altitude: >600 m). Based on land cover, the coast includes large areas of urban land and crop land, the mid-mountain area is primarily grass land, and the mountain area harbors most of the forest land, including Mt Hallasan in the center of the island. Jeju Island also has the unique Gotjawal Forest, characterized by a combination of irregular rocky areas, forests, and bushes, created by lava that erupted during eras of volcanic activity (Kim et al., 2018).

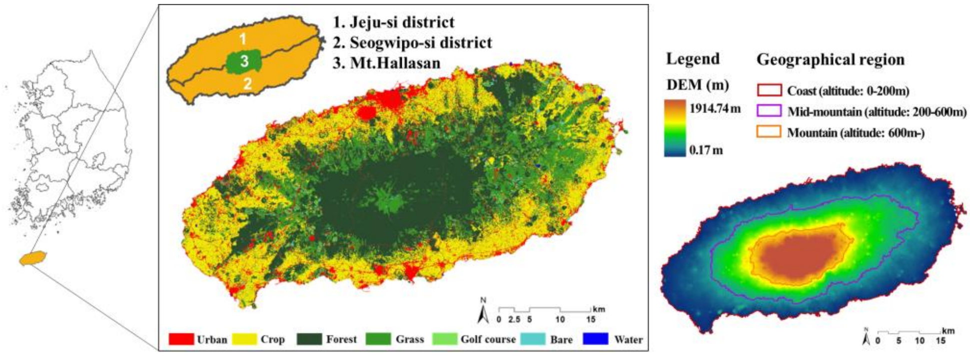

Fig. 2. 1. 2019 map of Jeju Island, Republic of Korea (33°10′-33°34′ N, 126°10′-127° E).

2.2. Data acquisition

We analyzed land-cover data from 1973 to 2019, divided into five periods. The dataset was constructed by digitizing the entire site based on a paper map published by the government in 1973 (National Construction Research Institute, 1973), which became the first digitized land cover for Jeju Island. Data from 1989 to 2019 were set using the land cover level-1 map at a resolution of 30 m (Korea Environment and Space Information Service; http://egis.me.go.kr).

2.3. Ecosystem services assessment

Changes in the four types of ecosystem services (MEA, 2006; Başkent, 2021) related to LULC changes were assessed using the InVEST model consisting of: HQ, CS, WY estimation modules (version 3.9.0), and CV in order to evaluate the ecosystem services. The HQ model represents an indicator of biodiversity as a model for evaluating supporting ecosystem services (Sun et al., 2019a; Sharp et al., 2020). The value of the habitat was assessed by distance from the threat and sensitivity affected by the threat factor (Sharp et al., 2020). Based on the previous study, the threats and sensitivity table obtained through LULC was selected (Kim et al., 2015). The value of the habitat ranges from 0 to 1, with values closer to 1 representing higher habitat quality.

The CS model was used to evaluate a regulating ecosystem service. CS is affected by aboveground biomass, belowground biomass, soil, and dead organic matter (He et al., 2016; Sharp et al., 2020). More carbon is stored in the terrestrial ecosystem than in the atmosphere, and LULC change through forest restoration can act as an important factor in carbon storage (Sharp et al., 2020).

The WY model was used to estimate the average annual quantity and value produced by reservoir hydropower to evaluate a supporting ecosystem service. Because the study site is an island, Jeju residents depend solely on groundwater for their drinking water sources. Water supply through groundwater is more important than in any other area (Redhead et al., 2016; Sharp et al., 2020).

The CV analysis refers to the frequency at which one point can see other points (Wheatley, 1995), and also functions to draw a line of sight between the observation point and the target point using numerical geographical information to determine whether to block the visible area (Jeung et al., 2018). At the study site, random extraction of 1000 points for each urban land, forest land and grassland was practiced, and urban parks by time period were set as points. In the case of terrain height, a digital surface model was constructed based on the building data at the time, along with a digital elevation model (DEM). The points were extracted based on the LULC of the administrative district for ease of analysis because the center of Jeju Island cannot be seen across the mountain due to Mt. Hallasan (Fig. 1). Because Mt. Hallasan reaches high altitudes in the center of Jeju Island, the administrative areas of Jeju-si and Seogwipo-si were analyzed separately.

3. Results

3.1. Land use and land cover change over 47 years on Jeju Island

Land-use status is presented in Figures S1 and 2.2. Three types of LULC, namely crop land, forest land and grass land, changed rapidly between 1973 and 1989 and between 1998 and 2009 (Fig. 2.2-a). Between 1973 and 1989, crop land fell by 8.18%, while forest land increased by 27.76%, and grass land decreased by 19.93% (Table S1). The forest land increase and grass land decrease occurred mainly in the coast and mid-mountain areas, respectively (Fig. 2.2-b, c). Between 1998 and 2009, crop land increased by 23.4% (431.53 km^2), while forest land decreased by 21.29% (392.86 km^2) (Fig. 2.2-a, Table S1). These changes occurred primarily in the coast area, and 399.94 km^2 of forest land was converted to crop land (Fig 2.2-b, Table 2.1).

Changes in grass land between 1973 and 1989 were closely related to changes in forest land. In terms of LULC changes over time, large areas of grass land transitioned into forest land (Table 2.1). Grass land accounted for the largest area in 1973, with 42.12% of the total area; however, in 1989, crop land comprised 222.99 km^2, and 322.51 km^2 of grass land had shifted to forest land, increasing the proportion of the latter to 50.14% (Table 2.1, S1).

This general trend of decreasing grass land and increasing forest land occurred on Jeju Island until 1998. In 1973, grass land was mainly distributed in coast and mid-mountain areas, but over time, the area of grass land declined in the coast area (Table S1). Grass land decreased by 19.93% in total area between 1973 and 1989, and most of the reduced area was shifted to forest land. Grass land decreased by 123.04 km^2 (12.43%) in the coast area, 218.71 km^2 (37.14%) in the mid-mountain area, and 22.12 km^2 (9.02%) in the mountain area (Table S2). Although no significant changes in area occurred for bare land and water; urban land increased by 10% from 2009 to 2019, and golf course area increased approximately five-fold from 2.39 km^2 to 12.33 km^2 by 2009.

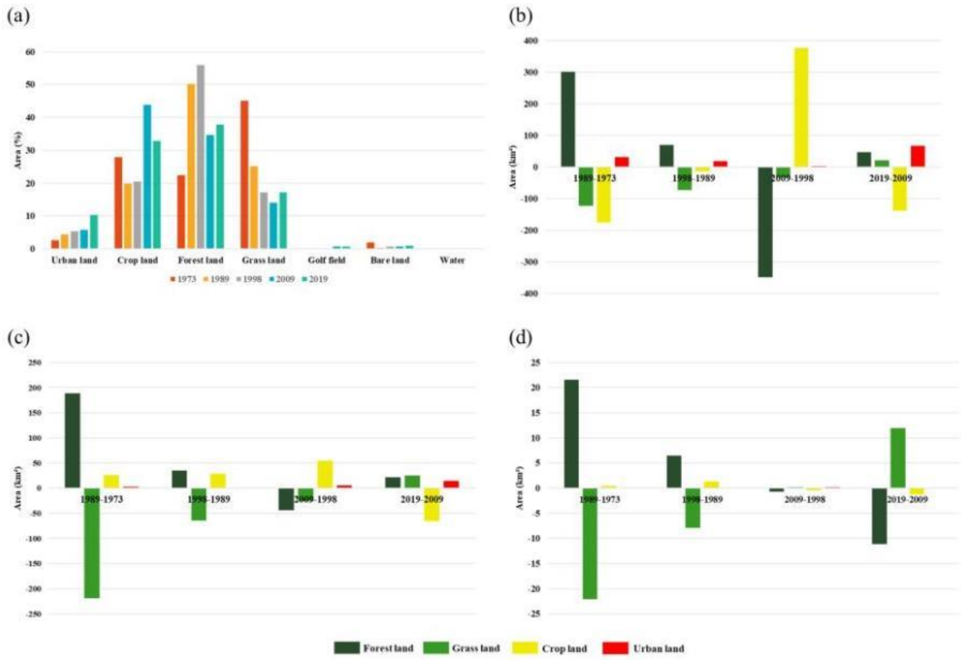

Fig. 2. 2. (a) Proportional changes in total area by land type from 1973 to 2019, (b) differences in area of land use and land cover (LULC) changes in the coast area, (c) differences in area of LULC changes in the mid-mountain area, and (d) differences in area of LULC changes in the mountain area.

Table 2. 1. Land use and land cover transition from 1973 to 2019 (km^2).

		1989						
		Urban land	Crop land	Forest land	Grass land	Golf course	Bare land	Water
1973	Urban land	30.35	8.54	7.33	0.72	0	0.23	0.05
	Crop land	35.19	200.77	222.99	50.65	0.01	1.8	0.24
	Forest land	3.92	29.21	349.54	26.3	0.02	0.4	0.04
	Grass land	7.26	114.89	322.51	378.96	1.02	1.45	0.09
	Golf course	0	0	0	0	0	0	0
	Bare land	2.87	8.58	16.57	5.78	0	0.3	0.03
	Water	0.07	0.1	0.07	0.01	0	0.04	0.33
		1998						
		Urban land	Crop land	Forest land	Grass land	Golf course	Bare land	Water
1989	Urban land	47.58	21.57	9.83	1.05	0	1.2	0.01
	Crop land	29.95	182.51	102.68	43.58	0.2	4.74	0.02
	Forest land	15.27	74.11	789.47	39.57	0.4	1.84	0.04
	Grass land	3.97	95.36	128.82	232.42	0.73	1.28	0.01

	Golf course	0	0	0	0	1.05	0	0
	Bare land	1.3	2.29	0.42	0.74	0.01	1.43	0.03
	Water	0.06	0.13	0.1	0.01	0	0.14	0.38
					2009			
		Urban land	Crop land	Forest land	Grass land	Golf course	Bare land	Water
1998	Urban land	85.77	12.9	0.24	0.22	0.04	0.27	0.05
	Crop land	10.94	344.81	8.88	10.16	1.11	1.85	0.26
	Forest land	6.27	399.94	606.09	13.33	4.06	1.6	0.57
	Grass land	2.19	49.87	23.8	235.46	4.69	1.01	0.39
	Golf course	0	0	0	0	2.39	0	0
	Bare land	1.53	2.5	0.1	0.12	0.04	8.35	0.08
	Water	0.08	0.02	0.02	0	0	0.03	0.53
					2019			
		Urban land	Crop land	Forest land	Grass land	Golf course	Bare land	Water
2009	Urban land	101.89	2.03	1.14	1.1	0	0.46	0.07
	Crop land	65.09	594.54	67.51	74.35	0	6.42	0.42
	Forest land	8.44	4.96	563.67	59.64	0.31	1.59	0.17
	Grass land	7.28	3.99	62.98	180.78	0.22	3.81	0.15
	Golf course	0	0	0	0	12.33	0	0
	Bare land	3.72	0.21	0.92	1.25	0	4.87	0.12
	Water	0.46	0.02	0.21	0.18	0.01	0	0.95

3.2. Changes in ecosystem services over 47 years

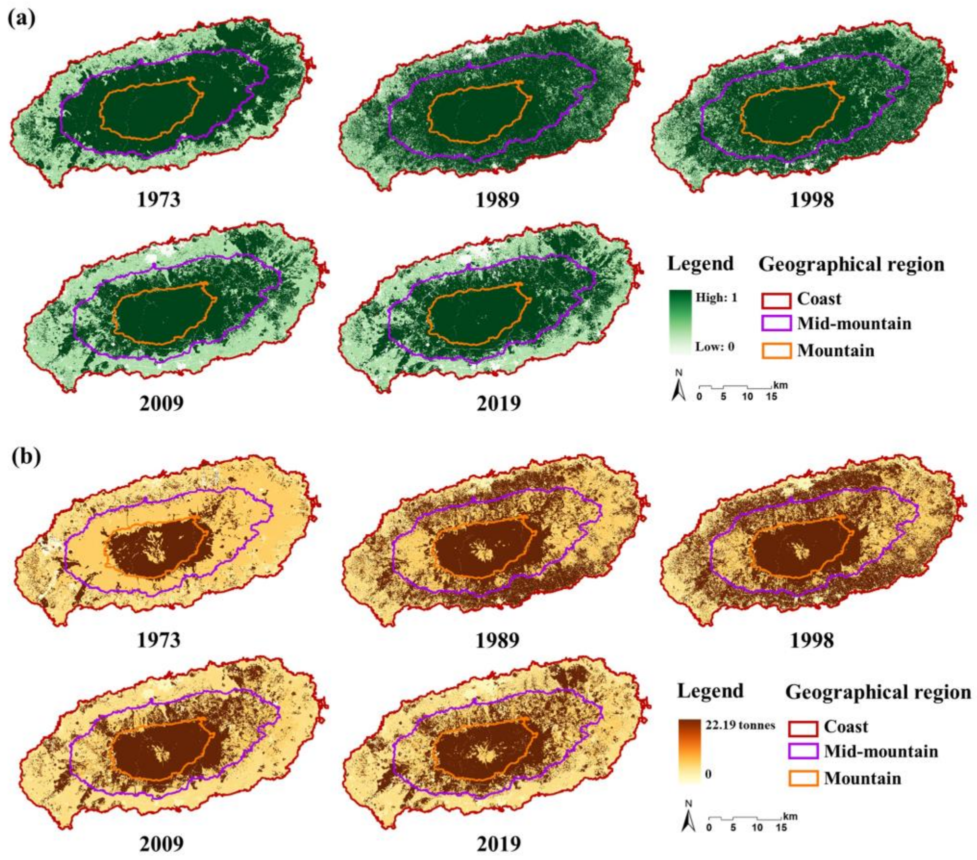

Fig. 2. 3. Spatial distribution of changes in ecosystem services from 1973 to 2019: (a) habitat quality (index: 0-1); (b) carbon stock (tonnes/pixel).

Many gains and losses of ecosystem services occurred depending on time and region (Fig. 2.3, Tables 2.2 and S3). The trend of increases and decreases in HQ and CS over time were similar (Table 2). In terms of the relationship between LULC change and ecosystem services, the percentages of HQ and CS increased due to increases in forest area, but the rate of increase in LULC change was larger than the increase in ecosystem services. In 1989 compared to 1973, HQ index values in the range of 0.25–0.5 decreased by 11.21% in the coast area, while values ranging from 0.75–1.0 increased by 9.57%. Between 1973 and 1989, forest land in the coast area increased by 29.98%, crop land decreased by 17.75%, and grass land decreased by 12.41%. Subsequently, no meaningful changes in HQ occurred until 1998. However, in 2009, crop land in the coastal area increased by 37.36% (377.2 km^2), while forest land decreased by 34.48% (348.55 km^2). During the same period, HQ's 0.75–1.0 range decreased by 20.37% in the coast area. In the mid-mountain area from 1973 to 2009, the 0.25–0.5 range of HQ continued to increase and then decreased in 2019. The 0.75–1.0 range of HQ was highest in 1973 at 30.51% but decreased to 25.86% in 2019. However, with changes in LULC, forest land increased by 31.99% between 1973 and 1989, and grass land decreased by 37.14% in the mid-mountain area (Table S2). Forest land then increased to 54.59% by 1989, but decreased to 50.89% by 2019, in the mid-mountain area (Table S2). Compared to the coast area, the mid-mountain area experienced small changes in crop land, leading to little change in HQ over time. In the coast area, CS increased to 2.9 million tonnes in 1989 and to 3.0 million tonnes in 1998, but decreased to 2.3 million tonnes in 2009, due to increased crop land and decreased forest land.

Unlike HQ and CS, WY peaked in 2019, and was at its lowest level in 1973 (Table 2.2). These dynamics appear to have been affected by precipitation, because out of the five time periods, the lowest average precipitation (1001.7 mm) was in 2009 and the highest was in 2019 (2102.3 mm) (Table S8). Between 1973 and 1998, average precipitation increased from 1448.03 mm to 1739.82 mm.

Changes in CV are presented in Table S3. The 0–5% range of CV indicated that Jeju-si was higher than Seogwipo-si, and no meaningful changes occurred over time. For the 5–50% range of CV, Seogwipo-si was high, but Jeju-si was high for the 50–100% range (Table S3, Figure S2).

Table 2. 2. Ecosystem changes on Jeju Island, Republic of Korea, during 1973–2019. Habitat quality (HQ) and carbon stock (CS) were divided into coast, mid-mountain, and mountain areas. Water yield (WY) was calculated as the amount of annual water produced over the entire study site.

HQ		1973	1989	1998	2009	2019
Region	Index	Percentage	Percentage	Percentage	Percentage	Percentage
Coast	0–0.25	2.39	4.13	5.03	5.14	8.65
	0.25–0.5	28.32	17.11	16.51	36.89	29.56
	0.5–0.75	0.04	0.03	0.07	0.1	0.13
	0.75–1.0	23.68	33.25	33.02	12.5	16.24
Mid-mountain	0–0.25	0.17	0.31	0.32	0.63	1.44
	0.25–0.5	1.51	3.17	4.72	8.09	4.78
	0.5–0.75	0	0.01	0.01	0.04	0.02
	0.75–1.0	30.51	28.64	27.02	23.3	25.86
Mountain	0–0.25	0.03	0.03	0.03	0.04	0.05
	0.25–0.5	0	0.04	0.11	0.13	0.08
	0.5–0.75	0	0.01	0.01	0.01	0.01
	0.75–1.0	13.39	13.33	13.22	13.19	13.25
Total	0–0.25	2.59	4.47	5.38	5.81	10.14
	0.25–0.5	29.83	20.32	21.34	45.11	34.42
	0.5–0.75	0.04	0.05	0.09	0.15	0.16
	0.75–1.0	67.58	75.22	73.26	48.99	55.35
CS (tonnes)		1973	1989	1998	2009	2019
Coast		8,759,757	14,028,753	15,107,271	8,887,143	9,514,804
Mid-mountain		6,385,710	9,405,548	9,924,058	9,096,225	9,455,462
Mountain		5,350,450	5,705,454	5,808,873	5,794,736	5,609,732
Total		20,495,917	29,139,755	30,840,202	23,778,104	24,579,998
WY (10^8 m^3)		1973	1989	1998	2009	2019
		1.917	1.958	2.497	2.167	3.165

4. Discussion

4.1. Spatiotemporal variations of LULC and ecosystem services

LULC changes occurred over 47 years on Jeju Island and these strongly influenced the ecosystem services (Fig. S1, Table 2.2). Similar to previous studies of the effects of changes in land use on ecosystem services (Nelson et al., 2009; Crossman et al., 2012; Haase et al., 2012; Polasky et al., 2011; Xu et al., 2019), our findings confirmed that increases and decreases in ecosystem services were driven by changes in threat factors. In the present study, threat factors affecting ecosystem services were considered to be urban land, crop land, and industry (Table S5). Between 1973 and 1998, concomitant increases in forest land and grass land as well as decreases in crop land led to sharp increases in ecosystem services (Fig. S1, Table 2.2, Table S1). These findings suggest that declines in ecosystem services can be accelerated if crop land and urban land increase rapidly as forest land and grass land decrease.

The changes in LULC on Jeju Island can be divided into two categories: increased forest land and increased crop land. Between the 1970s and 1980s, grass land sharply declined while forest land increased, and between 1998 and 2009, crop land greatly increased. Consequently, both HQ and CS increased until 1998 and then decreased in 2009, which was prominently centered in the coast area (Fig. 2.3). On Jeju Island, overall ecosystem services increased due to a governmental forest restoration policy implemented in the 1980s. However, ecosystem services sharply decreased in the 2000s, due to the rapid increase in crop land. LULC was converted to urban land and crop land in the coast area, because the steep slopes at altitudes above 400 m are unsuitable for crop land, leading to changes in ecosystem services. In addition, Jeju Island's agriculture was in the form of self-sufficient agriculture before the economic growth in the 1990s, but after the period, the area of crop land increased as it changed to high-income commercial agriculture such as tangerines, vegetables, and flowers (Lim, 2013; Kim & Kang, 2015). Locations where the slope is lower, ecological degradation can occur due to high human intervention such as urban development and agricultural land reclamation (Peng et al., 2018). Jeju

Island could easily be converted into crop land because the coastal area has a relatively low slope. Similarly, Upadhaya & Dwivedi (2019) found that HQ decreased due to increases in crop land and blueberry arable land in a mountainous area. On Jeju Island, Mt Hallasan occupies most of the mountain area, and it was designated as a Natural Reserve in 1966 and as a National Park in 1970, severely restricting development activities. Thus, depending on which policies are adopted by the government, LULC changes can convert forest land and grass land into crop land or urban land, which can substantially impact ecosystem services in the region. However, LULC changes did not have much effect on cultural services. This would not affect CV as LULC has changed mainly to cropland in the mid-mountain area, although the urban area development occurred in the coast area. This study is limited in that it is a macro-analysis for all of Jeju Island; however, the macro-analysis makes it possible to derive more efficient management measures if areas experiencing changes in LULC and ecosystem services have been rapidly degraded.

4.2. Restoration intervention on Jeju Island

Forest restoration is an extremely important factor in supplying ecosystem services (Rodríguez et al., 2016; Chazdon, 2008; Chazdon et al., 2017; Huang et al., 2018; Paudyal et al., 2019) and on Jeju Island also, in the 1970s and 1980s it strongly affected the current level of ecosystem services. We observed a dramatic increase in forest land from 1973 to 1989, concomitant with a rapid decrease in grass land (Fig. S1, Table S1). These changes were driven by increased forest land through a National Greening Program implemented throughout the Republic of Korea from 1973 to 1997. On Jeju Island, the National Forestation Plan was implemented extensively from 1973 to 1988, and primarily *Cryptomeria japonica*, *Chamaecyparis obtusa*, and *Pinus thunbergii* were planted throughout grass land and bare land (Jeju Province, 2006; Bae et al., 2012; Park & Lee, 2014). Fig. 2.4

shows growing seedlings in 1973 through the seedling transplant and seedling digging work. For 16 years (1973–1989), forest land expansion more than doubled from 409.83 km^2 to 920.95 km^2 due to afforestation and successional processes, resulting in a quantitative expansion of ecosystem services.

Because afforestation is advantageous, some areas experience increases in the value of ecosystem services as large areas are converted into forest land, while other areas, such as grass land, are developed in response to socio-economic demands such as tourism (Bengtsson et al., 2019; Schirpke et al., 2017). On Jeju Island, grass land was mainly converted to forest land (Table 1), but because grass land accounts for close to 30% of the mid-mountain region, it may be exposed to development risk (Table S2). The forest restoration policy of the Republic of Korea succeeded in vastly increasing forest land (Bae et al., 2012; Le et al., 2012; Park & Lee, 2014). Although ecosystem services were quantitatively expanded through afforestation, Jeju Island harbors the highest proportion of grass land ecosystems in all of the Republic of Korea, at 48.15%, which are otherwise uniquely scarce in terms of ecosystem diversity (Dolezal et al., 2012; MAFRA, 2021). Grass land can also provide various functions such as carbon storage, food mitigation, and water erosion in terms of ecosystem services (Bengtsson et al., 2019; Zhao et al., 2020). In implementing restoration measures, not only forest restoration, but also grass land restoration should be considered. As crop land was originally converted from grass land, this phenomenon exposes the risk of affecting ecosystem changes such as biodiversity degradation and soil carbon loss (Bengtsson et al., 2019; Tang et al., 2019; Bardgett et al., 2021). Therefore, it is important to consider the biodiversity level of the restoration area and to implement policy to improve ecosystem services in the decision-making sector (Rizvi et al., 2015; Sabogal et al., 2015; Bengtsson et al., 2019). Therefore, it is important to consider the biodiversity level of the restoration area and to prepare measures to improve ecosystem services in the decision-making sector (Rizvi et al., 2015; Sabogal et al., 2015; Bengtsson et al., 2019).

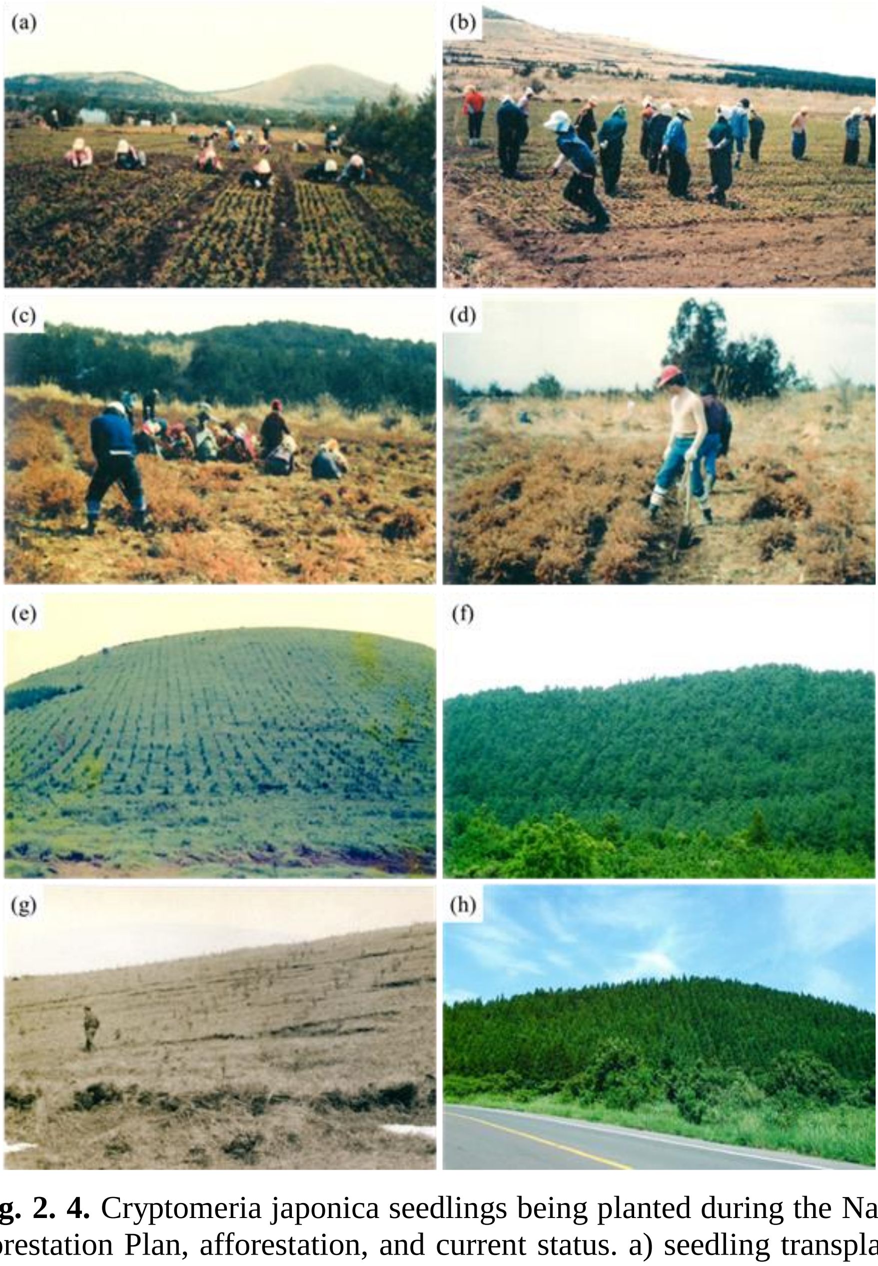

Fig. 2. 4. Cryptomeria japonica seedlings being planted during the National Forestation Plan, afforestation, and current status. a) seedling transplant, b) seedling trampling, c) seedling digging, d) seedling temporary planting, e) afforestation of Nori-oreum in 1973, f) current Nori-oreum, g) afforestation of Buk-oreum in 1973, h) current Buk-oreum. Oreum is local dialect for a formation "created by small volcanic activity.". from Jeju Province (2006)

Jeju Forest 60 Years History. Jeju: Jeju Province. Image reused with permission.

5. Conclusion

This study of 47 years of changes in LULC and ecosystem services on Jeju Island highlights the importance of balancing the demands of humans and supply in terms of ecosystem service management. Supporting and regulating ecosystem services increased sharply in the 1980s and 1990s due to increases in forest land, while ecosystem services fell sharply in the 2000s due to increases in crop land. In particular, ecosystem services decreased rapidly in coastal areas, and in future research. Hence, measures to improve ecosystem services should be implemented more on ecological planning by utilizing future scenarios. One novel aspect of the present study is that the dynamics of LULC and changes in ecosystem services were studied together through a long-term analysis over 47 years from 1973 to 2019. Jeju Island has a high conservation value due to its characteristics as a volcanic island, and the region has been well maintained by the successful implementation of ecologically valuable forest restoration policies in the 1970s and 1980s. The results of this study showed various changes in ecosystem services according to the period and geographic region of Jeju Island. Overall, we are expecting this study could provide valuable guidance for policy decisions or for scientific information to stakeholders and decision makers by highlighting the restoration and conservation of ecology in specific areas such as the coastal area in Jeju Island.

Chapter 3. Integrating Ecosystem Services with Ecological Connectivity for Spatial Conservation Prioritization in Jeju Island, South Korea

1. Introduction

Increasing development pressure on designated natural heritage areas poses a significant threat to biodiversity and ecosystems (Ng et al., 2013). Urbanization and deforestation exacerbate this pressure, making it essential to prioritize conservation measures in protected areas (Le Saout et al., 2013; Liang et al., 2018; Peng et al., 2018b; Strassburg et al., 2020). Thus, balancing intensive development with biodiversity conservation is a critical step towards achieving ecological sustainability, and requires coordination between urbanization and ecosystem conservation (Li et al., 2013; Peng et al., 2018b; Qian et al., 2015). Effective biodiversity conservation requires an understanding of the concepts of ecosystem services (ES) and ecological connectivity (EC) (IUCN, 2017; Mitchell et al., 2013; Snäll et al., 2016; UNEP, 2015).

EC is the degree to which species or resources disperse and interact across landscapes (Kukkala & Moilanen, 2017; Mitchell et al., 2013; Ng et al., 2013); it affects ecosystem function and biodiversity, and is presumed to influence the supply of ES (Fahrig, 2003; Mitchell et al., 2013). Thus, EC has long been a focus of conservation scientists (Harris, 1984), as it enhances the sustainability of regional ecosystems by promoting interactions between ecological sources and stabilizing ecosystem dynamics (Hong et al., 2017; Luo et al., 2021; Peng et al., 2018a). EC is crucial to ecological functions, which form the basis of ES (Cimon-Morin et al., 2013; Kukkala & Moilanen, 2017; Snäll et al., 2016). Therefore, EC management measures based on ecosystem functions and landscape patterns can lead to effective oversight of protected areas and local living environments (Peng et al., 2018a). The implementation of conservation measures through an integrated ecosystem management approach represents a new paradigm for ecological governance that recognizes ecosystem complexity, in contrast with isolated ecosystem control (Kukkala & Moilanen, 2017; Peng et al., 2018b). EC strengthens the supply of ES and improves ecosystem functions, while enhancing connections among ES. As organic matter and materials move through the landscape, ecosystem functions are either disrupted or enhanced depending on the degree of EC (Lundberg & Moberg, 2003; Mitchell et al., 2013). EC analysis considering ES has been recently studied as a method to analyze ecological security patterns (Fu et al., 2020; Peng et al., 2018b) or ecological corridors (Dong et al., 2020; Wang et al., 2022; Xiao et al., 2020). Thus, integrated management strategies that promote EC through methods that reflect ES are anticipated to improve ecosystem functions and enhance biodiversity.

Several methods have been developed to evaluate EC by identifying core areas; however, such areas are typically selected simply based on natural and key habitats or designated biodiversity conservation areas (Huang et al., 2020; Li et al., 2020; Peng et al., 2018a). A few studies that integrated ES and EC have applied these core-based approaches at broad scales (Fu et al., 2020; Peng et al., 2018a; Peng et al., 2018b; Wang et al., 2020). However, defining the connecting areas can be problematic, particularly in studies that consider various ecological functions. This difficulty is compounded when trying to estimate EC among ES over large regions, where the complexity and scale of the area may impose limitations (An et al., 2020; LaRue & Nielsen, 2008; McRae et al., 2016; Phillips et al., 2021). To overcome these challenges and improve EC predictions, several methods have been proposed. These include circuit theory models (Peng et al., 2018b), least-cost path analysis (LaRue & Nielsen, 2008), resistance kernel analysis (Dong et al., 2020), and network analysis (Phillips et al., 2021). In analyzing ES and EC across an entire study area, it is important to consider all pixels within the focal geography as potential sources of ES (Landau et al., 2021). Such an approach can provide a more comprehensive understanding of the relationship between ES and EC (Kukkala & Moilanen, 2017). Circuit theory is used to analyze ecological restoration areas by predicting movement patterns within complex landscapes and between isolated patches (McRae & Beier, 2007; Peng et al., 2018b). The Omniscape algorithm, which is based on circuit theory, is a useful method for creating maps of broad-scale connectivity using a moving window method (McRae et al., 2016; Phillips et al., 2021). It eliminates the need to divide the landscape into a binary representation of matrix habitat and core areas to be connected, which are arbitrary allocations that can strongly influence connectivity modeling results (Landau et al., 2021). This approach allows the definition of connected features, while retaining a core-free connectivity modeling approach (McRae et al., 2016). However, relying solely on EC results can make it difficult for spatial planners to implement appropriate protected area or landscape management measures (Babí Almenar et al., 2019; Jalkanen et al., 2020a). Although numerous EC studies have considered ecosystem functions, effective protection or restoration measures remain inadequate. Previous studies have emphasized core connectivity based on the minimum cost path (Dong et al., 2020; Fu et al., 2020). However, it can be challenging for policymakers to determine which areas should be prioritized for protection based on EC assessment results (Cameron et al., 2022). Therefore, it is important to efficiently identify areas that require protection on a priority basis to ensure the continuous supply of ES related to land use and landscape patterns and minimize negative impacts on biodiversity (Almenar et al., 2019; Hodgson et al., 2011; Jalkanen et al., 2020a).

Spatial conservation prioritization (SCP) is a method of identifying regions where EC requires protection; it selects important conservation areas, assigns biodiversity offsets and habitats for restoration, and identifies areas that must avoid economic development impacts (Kukkala & Moilanen, 2017). Because it is challenging to determine how to allocate limited resources in regions requiring active EC conservation (Cameron et al., 2022; Kukkala & Moilanen, 2017; Lehtomäki & Moilanen, 2013), identifying SCP areas that efficiently utilize resources while considering ES and interactions among landscape elements is crucial for prioritizing conservation measures (Jalkanen et al., 2020a; Kukkala & Moilanen, 2017).

Jeju Island, the largest island of South Korea, was designated a UNESCO Natural World Heritage site in 2007 (Kim et al., 2022). Thus, in addition to rapid urbanization, increased agricultural development, and intense land use changes, Jeju Island now has more than 10 million tourists visiting each year. Therefore, SCP areas on Jeju Island should be designated considering ES and EC in the context of ecological planning. Due to the geological and ecological characteristics of the island, limited resources can be introduced from outside, and these are ecologically fragile (Balzan et al., 2018). Like similar islands, Jeju Island is vulnerable to anthropogenic modification due to its isolation, limited size, and high demand for natural resources (Guzmán-Colón et al., 2020; Vitousek et al., 1997). Because these conditions can easily lead to the degradation of ecosystem functions, EC management, which reflects ecosystem functions, should be a primary consideration (McRae et al., 2012). Therefore, in this study, we identified SCP areas of Jeju Island and performed an island-scale EC assessment in the context of ecosystem functions. The main objectives of this research were to identify primary pinch point areas through EC analysis in terms of ES and determine where conservation and restoration are needed according to the EC model results. Finally, we discuss conservation strategies that may enhance EC on Jeju Island.

2. Study area and methods

2.1. Study area

Jeju Island is the only island province of South Korea, with an area of 1,846 km^2 (Fig. 3.1). Its population was approximately 680,000 in 2022, and it was designated as a United Nations Educational, Scientific and Cultural Organization (UNESCO) Biosphere Reserve in 2002, a Natural World Heritage site in 2007, and a Global Geopark in 2010. Mount Hallasan, in central Jeju Island, is strictly protected as a national park and cultural property, with subtropical to temperate vegetation and unique geological characteristics due to past volcanic activity (Kim et al., 2020). The outstanding natural heritage of Jeju Island has led to intensive tourism, with visits increasing from 4 million in 2001 to 15 million in 2019. Among these visitors, 13 million were Koreans, representing more than 30% of the South Korean population (Jeju Tourism Organization, 2020). A surge in visitors in the late 2000s significantly influenced urbanization, with a rapid increase in road development for tourists, which led to discussions on the preservation of the environment of Jeju Island. In response, the Jeju administration divided the island into three regions according to altitude: coastal (altitude: 0–200 m), mid-mountain (200–600 m), and mountain (> 600 m). Development is forbidden in mountain areas, and high-rise buildings cannot be constructed in mid-mountain areas. The major cities Jeju and Seogwipo are located in the north and south coastal areas, respectively, where cultural land is generally distributed. Forests and grasslands are distributed in mid-mountain areas, and most mountain areas comprise forested land. Slopes are steep toward the interior of the island, whereas the coastline has a low, belt-shaped slope, and the mid-mountain areas link the coastal and mountain areas.

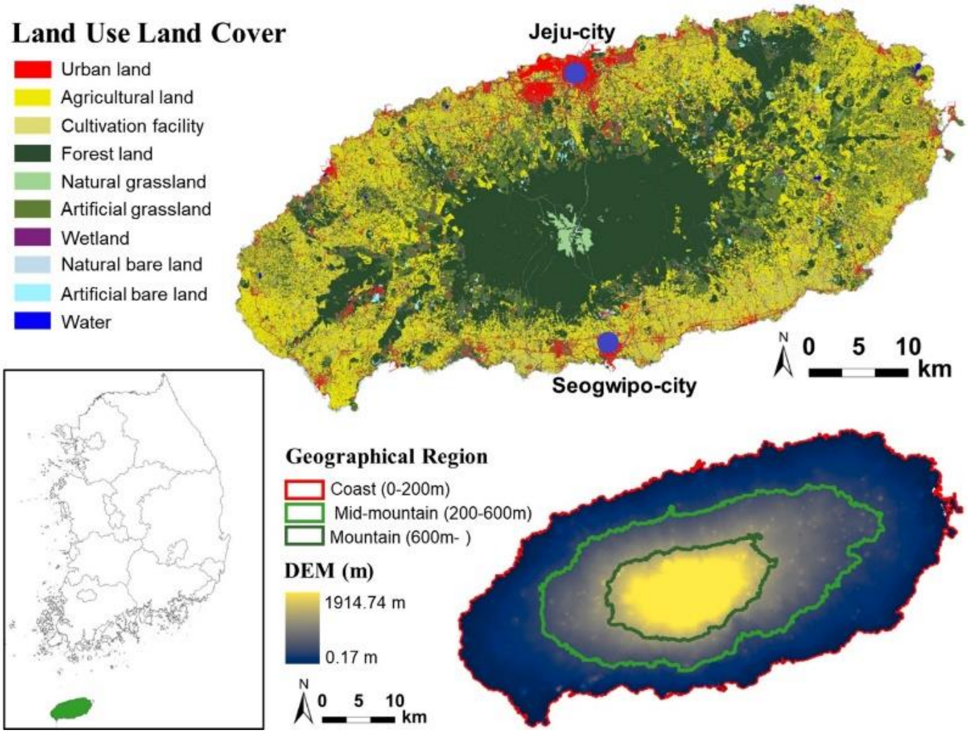

Fig. 3. 1. Map of Jeju Island, South Korea (33°10'–33°34'N, 126°10'–127°E) in 2020.

2.2. Identifying spatial conservation priorities

To identify priority conservation areas using ES and EC, we first determined the ecological source weight and resistance surface by quantitatively evaluating ES. Next, we assessed EC using the circuit theory-based omnidirectional Circuitscape (Omniscape) algorithm (McRae et al., 2016). Based on the EC evaluation results, we performed SCP analysis and landscape pattern index analysis.

2.2.1. Ecological source weight and resistance surface

ES evaluation was conducted to identify the ecological functions that contribute significantly to EC. Ecological sources are areas with the potential to provide ES or ecological functions to other parts of the landscape (Hilty et al., 2020; Peng et al., 2018b); their relative importance in contributing to EC on Jeju Island was determined. We selected three ecosystem services that represent supporting (Habitat Quality; HQ), regulating (Carbon Stock; CS), and provision (Seasonal Water Yield; SWY) services. HQ, which is associated with biodiversity, is particularly critical in Jeju Island, a UNESCO Natural World Heritage site with unique biodiversity (IUCN, 2020). CS is a key factor in climate regulation services, which is crucial in our era of climate change (Strassburg et al., 2020). Lastly, SWY was selected due to the importance of water availability on Jeju Island (Kwon et al., 2022). These evaluations were carried out using the InVEST model, which calculates the relative contribution of each landscape feature to ecological functions and ES (Sahle et al., 2019; Sánchez-Canales et al., 2012). The ecological source weight, which represents the importance of each ecological source area, was determined by combining the ES evaluation results with data on designated protected areas obtained from the Jeju Island administration. The ecological source weight in our study was based on the values used to evaluate the ecosystem services, which were derived from the Korea Environment Institute (KEI), an institution operating under the Korea Ministry of Environment (Lee et al., 2015). This weight reflects the level of connectivity among pixels, including the amount of ecological flow to and from each pixel (McRae et al., 2016). Following the evaluation of each service, the results were classified between 1 and 5 using the natural breaks method and subsequently normalized to a range of 0 to 1, as required by the EC model (Luo et al., 2021; McRae et al., 2016). Protected areas were initially assigned the maximum weight (5) due to their role in preserving and managing biodiversity.

HQ is a biodiversity indicator that is evaluated in terms of the degree of habitat change over a spatial extent (Sharp et al., 2020). It is determined according to habitat sensitivity and the influence of threat factors. We evaluated HQ based on data derived from a 2020 land cover map of Jeju Island; the threat factors included urban land, roads, industrial areas, cropland, and agricultural facilities (Tables S1 and S2).

CS is used to measure the carbon stored in each of four types of carbon pools (soil organic matter, aboveground biomass, belowground biomass, and dead organic matter) for each land use cover type. CS is used as an index to evaluate ecosystem functions, as it plays a pivotal role in terrestrial ecosystems (Sharp et al., 2020). We obtained carbon pool coefficients for Jeju Island from previous studies (Chun et al., 2019; Chung et al., 2015).

SWY is an indicator of seasonal water content, and is used to evaluate the impact of landscape management on water yield. It is calculated based on land use, monthly evapotranspiration, precipitation, rainfall occurrence, crop or vegetation coefficients, digital elevation model, watershed area, and an empirical curve number (Sharp et al., 2020). Rather than quantitatively evaluating baseflow, SWY determines the relative rapidity of flow for each cell in the target evaluation area. Detailed model equations and assumptions are described in the model documentation (Sharp et al., 2020). The resistance surface was created based on HQ. Areas with higher HQ values, indicating greater biodiversity, were assigned lower resistance values (Luo et al., 2021; Peng et al., 2018b). Conversely, regions with lower HQ values were assigned higher resistance values (≥ 1). The HQ values were determined by considering urban areas, roads, industrial areas, cropland, and facility cropland as threat factors (Lee et al., 2015). Thus, the process of creating the resistance surface integrated ecological and social factors to capture more comprehensively the real-world complexities of habitat quality and resistance.

2.2.2. EC analysis and model validation

EC refers to the degree of ecological flow within a landscape (Taylor et al., 1999). To adopt circuit theory for EC analysis, ecological flow can be compared to electric currents, because they share random walk characteristics (Peng et al., 2018b). We employed the Omniscape algorithm, which is a modified version of the Circuitscape algorithm developed using the Julia programming language (Landau et al., 2021; McRae et al., 2016). The ecological potential of a natural or semi-natural landscape generates, transmits, and receives more current than does a heavily modified area (Cameron et al., 2022; McRae et al., 2016). The ecological source value determines the amount of current flow (McRae et al., 2016), such that areas with high ecological source value will have higher current intensity and better EC. Unlike the conventional core-based approach, which is sensitive to the core location, the Omniscape algorithm adopts a coreless approach to calculate EC using a moving window method (Landau et al., 2021). The Omniscape algorithm has three outputs: current flow, potential flow, and normalized current flow. The normalized current flow output (F) is a value obtained by dividing the current flow by the potential flow, and is categorized as channeled ($F > 2.0$), high-intensity ($1.5 < F \leq 2.0$), low-intensity ($1 < F \leq 1.5$), diffused ($0.5 < F \leq 1$), or impeded ($0 < F \leq 0.5$). Channeled flow has the most concentrated current and typically produces more flow than expected. High- and low-intensity flows have few restrictions, and produce high current flow. Diffused flow produces the expected current flow. Impeded flow has highly restricted flow (Cameron et al., 2022; McRae et al., 2016).

For model validation, we performed the Wilcoxon rank sum test to evaluate significant differences between EC analysis results and species distribution data provided by the Ministry of Environment of the Republic of Korea. Species with > 100 data points were included in these tests;

species with > 30 data points were considered species of interest or endangered species.

2.2.3. Zonation analysis for SCP identification

SCP is a comprehensive approach to spatial conservation management that considers multiple factors to balance conservation with economic development (Jalkanen et al., 2020a; Kukkala & Moilanen, 2017). In this study, we integrated ES and EC into our SCP approach to account for the interaction of landscape elements, including ecological functions. First, we identified areas requiring protection based on their ecological importance and potential to provide ES. Previous studies have achieved this goal using spatial prioritization tools such as the Zonation software (Lehtomäki & Moilanen, 2013), which can identify regions with high conservation value based on a range of criteria including ES and EC (Jalkanen et al., 2020b; Peng et al., 2018b; Ramel et al., 2020). The Zonation software assumes that all areas require protection, which makes it a useful tool for identifying areas that are critical for conservation (Jalkanen et al., 2020a). We used Zonation v4.0 to identify SCP areas by repeatedly removing grid cells that minimized aggregate marginal loss, ranking the least useful locations lowest and the most useful locations highest (Moilanen et al., 2005), and applied the removal rule of the addictive benefit function to assign higher weight to high-EC results to identify conservation priority areas. High EC is crucial for maintaining ecological function and providing ES (Kukkala & Moilanen, 2017). Based on the five EC classes that most reflect ES, we assigned the highest conservation value to channeled areas, followed by high-intensity, low-intensity, diffused, and impeded areas.

2.2.4. Landscape pattern index

The SCP areas identified by the Zonation software were delineated into a landscape matrix, and a landscape pattern index was calculated using the Fragstats v4.2.1 software. This index was calculated based on the number of patches, patch density, patch shape, degree of fragmentation, and the area of the largest patch in the landscape (An et al., 2020).

3. Results

3.1. Spatial distribution of ES and protected areas

The distributions of the three ES indices are shown in Fig. 3.2. HQ and CS showed similar trends, whereas SWY was higher in eastern Jeju Island than in the west. Low-HQ regions were distributed in the north and south, where urban areas are mainly concentrated. HQ was high in central Jeju Island, where Mt. Hallasan National Park is located. The total area of regions with HQ = 5 was 912.31 km^2, accounting for 32.92% of the total area. Similarly, lower CS values were distributed in the north, and the total area of regions with CS = 5 was 975.22 km^2 (34.56%). SWY distribution differed between east and west, likely due to higher precipitation levels and forest and grassland proportions in the east. The total area of regions with SWY = 5 was 367.19 km^2 (19.9%). The large protected region in central Jeju Island had an area of 417.37 km^2, accounting for 22.62% of the total area. This protected area consists mainly of circular patches east and west of Mt. Hallasan. A river network connects the central protected area with coastal areas to the north and south, forming an ecological corridor.

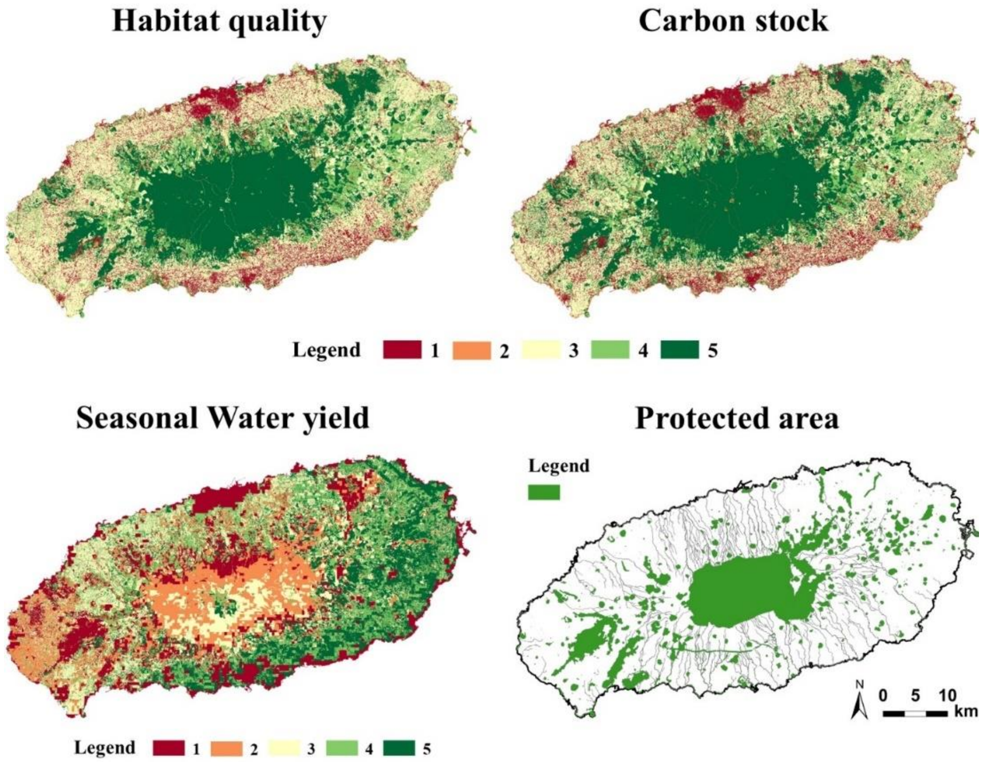

Fig. 3. 2. Spatial distributions of ecological services (ES) and protected areas on Jeju Island. ES evaluation results are not mean absolute values, but relative values for the target area. Habitat quality and carbon stock showed similar patterns, whereas seasonal water yield distribution differed. The bottom right panel shows a large protected area (green shading) concentrated in central Jeju Island, with a river network (blue lines) connecting the central and coastal areas.

3.2. Spatial patterns of ecological source weights and the resistance surface

The ecological source weights and resistance surface based on the ES evaluation results are shown in Fig. 3.3. The ecological source weight is a key factor that determines EC. The ES evaluation results and protected area results were combined and reclassified to a range from 0 to 1. The average ecological source weight for Jeju Island was 0.56. Above-average values were mainly located in central and eastern Jeju Island, with below-average values for urban areas in the north and south and the southwest coast. The resistance surface comprised HQ values ranging from 1 to 500. The highest resistance values were concentrated in dense urban areas such as Jeju in the north and Seogwipo in the south (Fig. 3.1). Urban areas in the north and south also had high resistance values, which hindered ecological processes and functions.

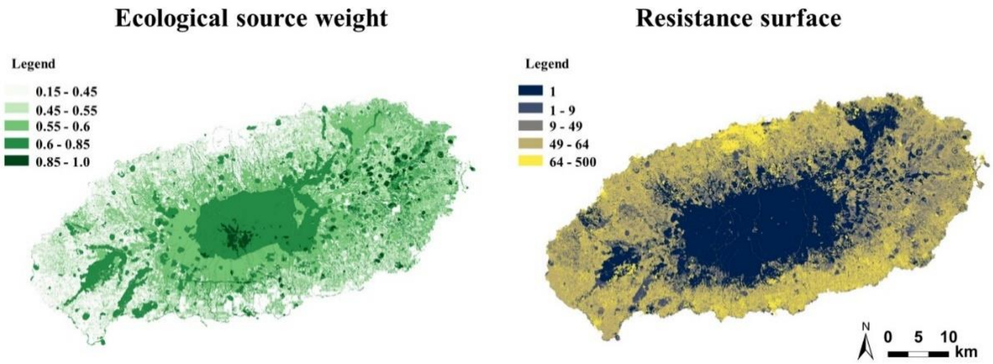

Fig. 3. 3. Spatial patterns of ecological source and resistance surface values.

3.3. Spatial patterns of EC and conservation priority zone analysis

Mid-mountain areas adjacent to coasts and small rivers contributed greatly to EC (Fig. 3.4). Our channel flow analysis identified a contiguous corridor from the central mountain range to the dense urban area at the north of the island that is characterized by interconnection between high resistance surface and high ecological source values (Fig. 3.4e). Channeled flow (red) regions acted as ecological corridors and contained pinch point areas. Coastal areas were mainly characterized by diffused flow (61.04% of the total coastal area), whereas mid-mountain areas mainly showed diffused and low-intensity flow (33.43% and 30.04%, respectively) (Table 1). Thus, current flow is widely diffused or unrestricted in coastal areas, and more concentrated in mid-mountain areas. Mid-mountain areas had the highest proportion of channeled flow areas or pinch points (8.87% of the total mid-mountain area), due to low ecological source values in coastal areas and high resistance values, which led to a concentration of channeled flow in mid-mountain areas. To evaluate model accuracy, we validated the current map using observed distribution data for 17 species; we detected no significant difference between model results and observation data for 14 of the 17 species (Table S6).

Table 3. 1. Geographical regions (% area) of Jeju Island classified by flow type, indexed according to flow variation. SD, standard deviation.

Normalized current flow	Geographical region		
	Coastal	Mid-mountain	Mountain
Impeded (< 0.5 SD)	3.04	14.01	2.59
Diffused (0.5–1.0 SD)	61.04	33.43	28.72
Low-intensity (1.0–1.5 SD)	20.84	30.04	67.1
High-intensity (1.5–2.0 SD)	10.18	13.67	1.28
Channeled (> 2.0 SD)	4.92	8.87	0.33

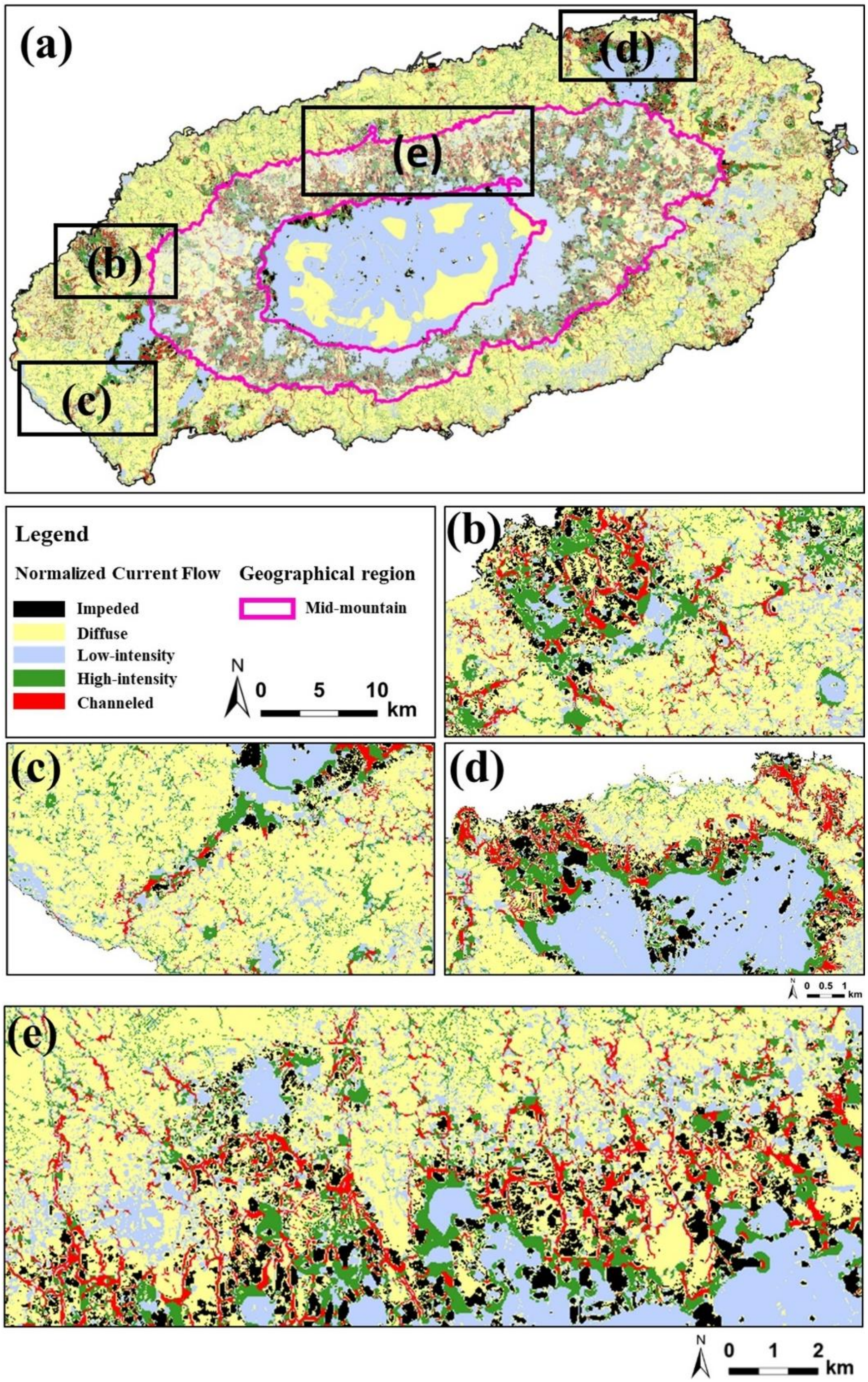

Fig. 3. 4. Spatial distribution of normalized current flow. (a) Results of overall EC analysis of the study site. Mid-mountain and mountain areas are densely heterogeneous. (b–d) Regions showing connections between coastal and mid-mountain areas. (e) Regions where high resistance surface and high ecological source values are interconnected.

Our model detected overlap between SCP areas and existing protected areas on Jeju Island (Fig. 3.5). SCP areas were identified based on the EC model results, with values ranging from 0 to 1 (Fig. 3.5a). Fig. 3.5b shows overlapping (light green) and non-overlapping (red) areas between the top 10% of SCP areas and existing protected areas. The area of overlapping and non-overlapping regions differed among agricultural land, forest, and artificial grassland (Fig. 3.6, Table S7). Agricultural land accounted for 14.99% and 2.44%, and forest accounted for 56.11% and 83.91%, of the non-overlapping and overlapping area between SCP areas and protected land, respectively (Fig. 3.6). Approximately 80% of both overlapping and non-overlapping area was classified as having mid-mountain geography, representing 46.26 and 97.52 km^2 of overlapping and non-overlapping land, respectively. Thus, mid-mountain areas require additional conservation or protection (Table 3.2).

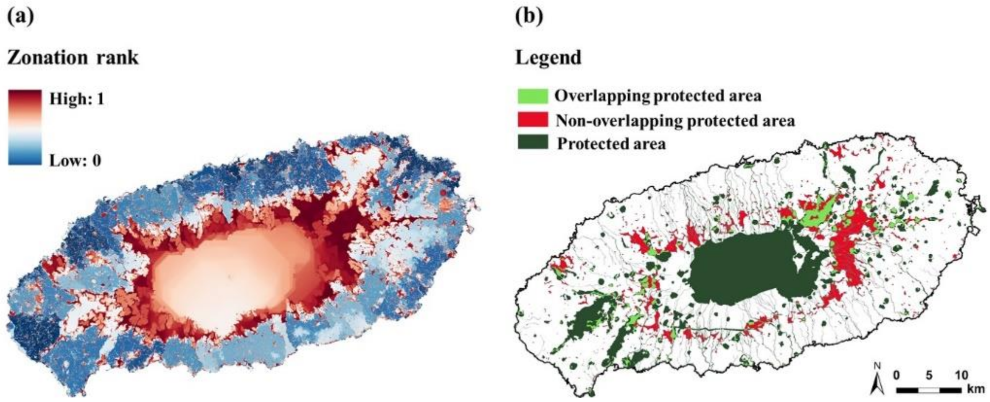

Fig. 3. 5. Spatial distribution of SCP ranks (left) and overlap between SCP areas and protected areas (right).

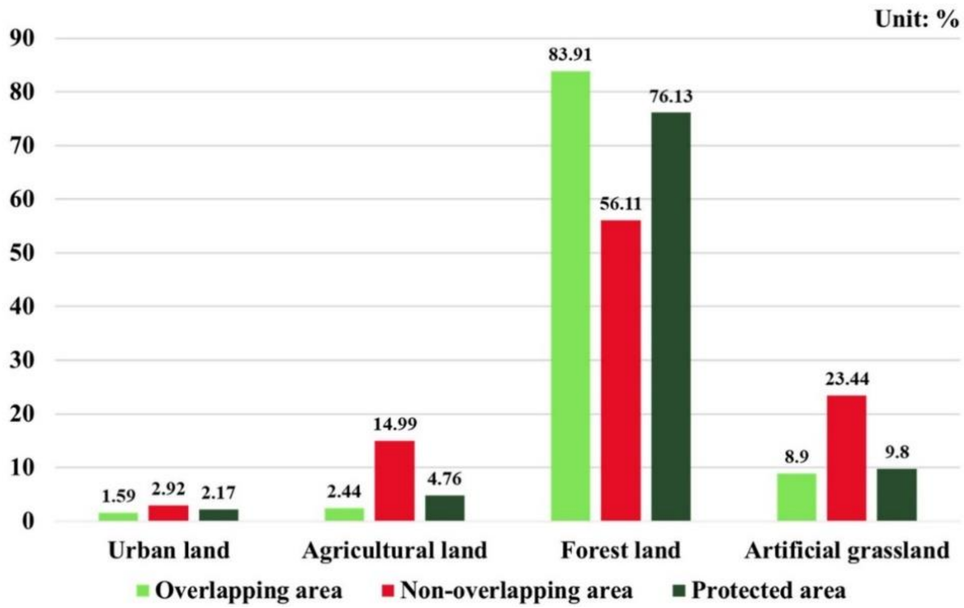

Fig. 3. 6. Summary of overlap (% area) between SCP areas and existing protected areas for four land use types.

Table 3. 2. Summary of overlap (% area) between SCP areas and existing protected areas.

Geographical region	Altitude (m)	Overlapping area (km^2)	Non-overlapping area (km^2)	Top 10% SCP areas (%)
Coastal	0–200	10.51 (18.15%)	22.06 (18%)	3.23
Mid-mountain	200–600	46.26 (79.86%)	97.52 (79.54%)	24.42
Mountain	> 600	1.15 (2.01%)	3.03 (2.48%)	1.71
Total		57.92	122.61	29.36

The distribution of patches in the top 10% SCP areas is shown in Table 3.3. There were 359, 218, and 9 patches in coastal, mid-mountain, and mountain areas, respectively. Coastal and mid-mountain areas had patch density index values of 11.03 and 1.52, respectively, showing a > 10-fold higher patch density in coastal areas than in mid-mountain areas. The landscape shape index was highest in coastal areas (25.02), followed by mid-mountain (19.18) and mountain (4.22) areas. The largest patch index was lowest in coastal areas (13.76), followed by mid-mountain (33.52) and mountain (45.43) areas. Thus, the quantity and density of patches were high in coastal areas, whereas the patches were larger in mid-mountain and mountain areas.

Table 3. 3. Landscape pattern indices for each geographic region and the entire study area

Geographical region	NP	PD	LPI	LSI
Coastal	359	11.03	13.76	25.02
Mid-mountain	218	1.52	33.52	19.18
Mountain	9	2.15	45.43	4.22
Total	502	2.77	28.31	27.65

NP, number of patches; PD, patch density; LPI, largest patch index; LSI, landscape shape index.

4. Discussion

4.1. Identification of SCP areas using the EC model

We identified SCP areas through ES and EC evaluation. Compared with the existing protected areas, newly identified SCP areas were mainly found in agricultural land and artificial grassland areas (Figs. 3.5 and 3.6). Among non-overlapping areas (122.61 km^2), 97.52 km^2 (79.54%) were in mid-mountain regions (Table 3.2). Thus, although some areas of Jeju Island are protected, it is necessary to consider implementing new management plans for agricultural land and artificial grassland in mid-mountain areas. Our method for identifying SCP areas based on ES and EC evaluation is appropriate for sites with high protection value, such as Jeju Island, which is a UNESCO Natural World Heritage site. Although previous studies have evaluated ES and EC, this study is the first to offer an intuitive method that considers ecosystem function to identify new regions that require protection. Prior EC analyses based on ES have described distributions of key ecological corridors; however, there has been insufficient discussion of SCP areas, which could facilitate communication in land use planning and policy decision-making (Peng et al., 2018a; Xiao et al., 2020). Our results showed that channeled flow, which creates ecological pinch points, occurs mainly in mid-mountain areas, accounting for 8.87% of the total mid-mountain area (Table 3.1, Fig. 3.4). Measures are needed to allow concentrated or blocked currents to flow more easily in these regions. Therefore, it is imperative to both manage areas with high EC values and spread ecosystem functions over wider areas through conservation and restoration efforts. The ES and EC analysis method presented in this study allows researchers to efficiently identify the regions most in need of protection. These SCP areas can be used to support ecological planning for conservation and restoration measures (Zhang et al., 2017), in a manner that enhances functional aspects rather than simply expanding green infrastructure through restoration efforts based on EC. Efficient management measures require restoration or protection plans that consider the quantity and density of patches (Wang et al., 2020). Restoration strategies can vary depending on patch scale and location. For example, small-scale patch restoration may be preferable for coastal areas, whereas large-scale patch restoration is more appropriate for mid-mountain areas (Table 3.3). Our findings suggest that restoration efforts should prioritize large patches that do not overlap with existing protected areas in eastern Jeju Island, whereas small patches in the northern and southern regions require a different restoration strategy (Fig. 3.5b). Functional patches, which are crucial for biodiversity conservation and the provision of ES, should be maintained among habitat patches identified as SCP areas (Zhang et al., 2017). However, Jeju Island has already experienced intense development along the coastline, which is currently expanding to mid-mountain areas (Kim et al., 2022), whereas Mt. Hallasan is under strong protection as a national park (IUCN, 2020).

4.2. Expanding EC between the coast and inland

Our findings indicated that high EC indices formed an altitude-based band-shaped pattern in the mid-mountain areas of Jeju Island, whereas coastal EC values were isolated from other areas. High resistance surface values occurred around the densely populated urban coastal areas (Fig. 3.3), and EC rapidly increased in adjacent areas between coastal and mid-mountain areas, which are shown to be connected in Figs. 4c and d. Intense flow occurs over the coastal and mid-mountain areas, which extends to the mountain areas; thus, forests and grasslands connecting the coastal and mid-mountain areas can act as stepping stones to enhance EC and extend it to inland areas. To improve EC, it is crucial to preserve these mid-mountain areas and secure an alternative route through the restoration and conservation of patches scattered weakly in the coastal area (Fig. 3.5b). It is necessary to alleviate the EC index, which is concentrated in the channeled and high-intensity flow regions of the mid-mountain and mountain areas.

It remains challenging to achieve the opposing goals of development and conservation on islands, and their isolation increases their vulnerability to environmental disturbances such as development (Balzan et al., 2018; Guzmán-Colón et al., 2020; Liu et al., 2021). Although islands occupy only 5% of the global area, many island species constitute whole populations, and they exhibit high levels of endemism, with unique biodiversity (Guzmán-Colón et al., 2020; Kier et al., 2009). Enhancing EC while maintaining high biodiversity within the limited space of an island is a crucial conservation goal. Although several previous studies have been conducted at national or regional scales, very few EC studies have been conducted on islands (Liang et al., 2018). On islands, it is often difficult to expand EC inland due to intensive urban and port construction along the coast (Ai et al., 2022; Guzmán-Colón et al., 2020). Because Jeju Island is focused on tourism, agriculture, and fishery-related industries, several ports and tourist areas have been established in coastal areas. Recently interest in landscape development has expanded development to the mid-mountain areas of Jeju Island, leading to the severance of EC in various regions. To enhance EC efficiently, it is necessary to transform the perspectives of ecological planners to consider ES and EC simultaneously, as well as measures focused on the conservation of existing protected areas.

4.3. Limitations and potential future directions

This study had some limitations. First, we did not take into account cultural ES, which might have contributed to a more comprehensive understanding of the study area. Our primary focus was on the biophysical aspects and ecological functions of Jeju Island, as we aimed to evaluate EC using an approach that considers ES. The incorporation of cultural services into our analysis would have required data that pertain to natural areas preferred by humans or those with aesthetic functions, which were not directly aligned with the objectives of our study. This limitation should be recognized, as cultural ES can significantly influence perceptions and behaviors related to the natural environment (Barbosa et al., 2007). Future studies should consider integrating cultural ES into their analyses to obtain a deeper understanding of the study area. Second, in our assessment of ecological sources and resistance surfaces, we used HQ as a component of both the ecological source weight and resistance surface in the EC model. Although we justified our use of HQ as a resistance surface based on the assumption that areas with higher HQ are more valuable and should be prioritized for conservation and restoration to enhance EC, this approach may have limitations. We treated the HQ data as basic data because they were processed differently for the ecological source and resistance surface analyses. Additionally, limited data availability constrained our ability to include additional indices that might have enhanced the representation of biodiversity in the ecological source values, but we note that HQ input values incorporated expert opinion and social indicators. Despite these limitations, we believe that our findings provide valuable insights into the potential benefits of applying an integrated approach to EC modeling.

5. Conclusion

Establishing a conservation management plan that considers EC is critical for promoting biodiversity and sustainable development. EC links ecosystem functions that can influence each other, as well as provide ES. Because ES is the basis of ecosystem functions, it is imperative to analyze EC in a manner that considers ES. In this study, we identified SCP areas by integrating ES and EC throughout Jeju Island, South Korea. Three ES were evaluated (provision, regulation, and support), and EC analysis was performed by combining the evaluation results with data on existing protected areas. Pinch points were heterogeneously distributed, with the highest concentration in mid-mountain areas, leading to disconnection between coastal and mid-mountain areas. Approximately 80% of newly identified SCP areas were found in mid-mountain areas, mainly on agricultural land and artificial grassland. Based on these findings, new SCP areas can be identified intuitively based on existing protected areas, providing policymakers with a strategy for managing mid-mountain areas of Jeju Island.

Chapter 4. Prioritizing Conservation Areas on Jeju Island, South Korea: An assessment of Ecosystem Services and Land Ownership

1. Introduction

Ongoing threats to biodiversity emphasize the importance of spatial prioritization of protected areas (PAs) (Cazalis et al., 2020). One of the targets set by the Kunming-Montreal Global Biodiversity Framework (GBF), which was approved at the 2022 UN Convention on Biological Diversity (CBD, COP-15), was to designate and manage 30% of the world's inland waters, and terrestrial and marine areas for conservation, and to improve ecosystem function by 2030 (CBD, 2022). Biodiversity is directly linked to human well-being through its influence on food security and air and water quality (Bawa et al., 2021; Thomas et al., 2013). Biodiversity also has the potential to mitigate some aspects of anthropogenic climate change (Choe et al., 2018). Increased attention has been paid to the integration of biodiversity and ecosystem functioning in spatial conservation planning. This concern has been driven by the recognition that ecosystem services are in decline, and by the growing appreciation of their significance for human well-being (IPBES, 2018; Peng et al., 2018a; Ramel et al., 2020; Storch et al., 2022). The establishment of PAs can involve an integrated strategy to offer long-lasting ecosystem services while minimizing biodiversity loss. However, the identification of conservation priority areas remains a challenging task (Hanson et al., 2022). Decisionmakers typically attempt to achieve conservation goals with maximum efficiency but limited resources, and often prioritize their expansion (Benez-Secanho et al., 2022). However, new approaches to supplement existing PAs, which have often been established without considering ecosystem functions, have been actively discussed in recent studies (Lanzas et al., 2019; Ramel et al., 2020; Schröter & Remme, 2016; Vaz et al., 2021).

Incorporating ecosystem services into spatial planning provides an appropriate opportunity to comprehensively assess the practical impact of PAs (Darvill & Lindo, 2016). Ecosystem services refer to specific ecological functions that benefit humans, and can include climate regulation, habitat preservation, and aesthetic values, and are considered vital for human survival and quality of life (Kremen, 2005; Nichols et al., 2008). Measurable targets related to human well-being and stakeholder profit derived from ecosystem services can help conservation planners understand potential trade-offs and address land-use conflicts (Hashimoto et al., 2019). Although different ecosystem services exhibit complex spatial distribution patterns, PAs should still consider the provision of multiple services (Schröter & Remme, 2016). Given the unpredictable and intricate interplay between humans and the environment, reaching consensus among stakeholders requires a framework that prioritize the provision of ecosystem services while maximizing biodiversity (Ramel et al., 2020; Schwartz et al., 2018). In addition, improving network among PAs is crucial for achieving efficient allocation of limited resources toward their management (Cameron et al., 2022).

Establishing PA networks can be a critical strategy for conserving biodiversity and enhancing ecological functions (Heller & Zavaleta, 2009; Hilty et al., 2020; Keeley et al., 2018). The destruction and fragmentation of habitats in urban areas threaten ecosystems by reducing habitat size and network, resulting in higher extinction rates (Wang et al., 2021). Recent studies have revealed that well-designed PA networks strengthen both biodiversity and ecosystem services in PAs (Hanson et al., 2022; Maxwell et al., 2020; Zhang et al., 2018). Furthermore, better connected PAs tend to require fewer resources for management, as demonstrated by analyses based on market economics (Le bouilli et al., 2022; Sreekar et al., 2020). However, conservationists face the challenge of deciding where and how to most effectively allocate limited resources to achieve conservation management goals in various contexts (Cameron et al., 2022).

The promotion of area-based policies that encourage efficient resource use can be a key pathway to achieve effective long-term biodiversity conservation (Dawson et al., 2021). The Kunming-Montreal GBF highlighted the importance of managing biodiversity, ecosystem functions, and the provision of ecosystem services through the other effective area-based conservation measures (OECMs) framework (CBD, 2022). Conservation management that incorporates OECMs can contribute to networks of regionally based and representative PAs and has the potential to ensure effective biodiversity conservation (Borrini, 2010; Diz et al., 2018; Juffe-Bignoli et al., 2016). Furthermore, OECMs can contribute to equity in conservation management, as they can encompass the interests of diverse stakeholders (Maxwell et al., 2020). By complementing PAs and protecting diverse ecosystems and landscapes, OECMs have a positive impact on biodiversity and ecosystem services. As a result, conservation actions using OECMs at the regional scale may be more efficient than designating PAs at the national level (Donaldson et al., 2021; Maxwell et al., 2020), leading to increased biodiversity and ecological representation within conservation areas (Alves-Pinto et al., 2021). However, given the recent emergence of discussions around OECMs, further research is required regarding their integration with existing PAs.

There is a growing recognition of the need to prioritize the placement of PAs by setting area-based targets for the efficient use of resources, considering both biodiversity and ecosystem services (Nolte, 2020; Sarma et al., 2021). When developing practical conservation plans and policies, the potential influence of realistic constraints, such as the socioeconomic costs of conservation, should be considered (Shiono et al., 2021). In this study, we address this need by proposing a comprehensive approach to conservation planning. To analyze the complex interactions of ecological features and social factors, we considered ecosystem services, biodiversity indicators, land price, and land-ownership status. Conservation biologists, who often operate under resource limitations, face the challenge of balancing economic efficiency with conservation priorities (Carroll et al., 2021). Resource constraints can include the monetary costs of alternative conservation actions, which further highlights the complexities of conservation planning (Brown et al., 2015; Game et al., 2013; Naidoo et al., 2006). Although costs and social considerations are increasingly included in conservation planning, few studies have investigated the outcome of including socioeconomic variables in the planning process (Bottrill & Pressey, 2012; Ghoddousi & Kuemmerle, 2022).

In this study, we employed a prioritization approach, using Jeju Island as a case study, to identify the conservation priority areas for maximizing both biodiversity and ecosystem services. Jeju Island, located in South Korea, harbors significant ecological values and has been awarded UNESCO's "Triple Crown" designation, meaning that it has been declared a biosphere reserve, a Natural World Heritage site, and a global geopark (Kim et al., 2019). In addition to PAs, there are also areas of high biodiversity due to the terrain created by volcanic activity. However, Jeju Island is undergoing rapid urbanization, attracts large numbers of tourists, and faces conflicts between urban development and ecological conservation (Kim et al., 2022). Our goal was to facilitate an expansion of ecological functions on the island through efficient use of resources in area-based strategies. Specifically, we aimed to pinpoint spatially comprehensive areas, prioritized for conservation, exploring the land price. Our objectives were to identify potential priority PAs on Jeju Island based on their levels of ecosystem services and biodiversity, and develop conservation-management strategies for these priority PAs based on their ownership. By following this methodology, we aimed to derive valuable insights into the identification and management of conservation priority areas.

2. Study site and method

2.1. Study site

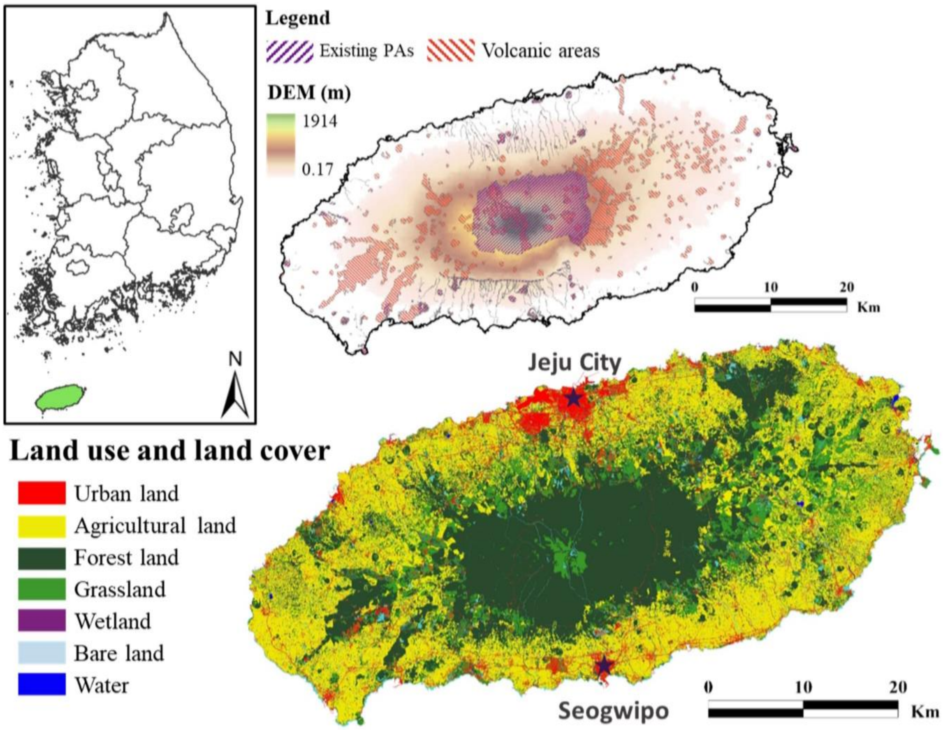

Fig. 4. 1. Land-use and land-cover map of Jeju Island, South Korea. The administrative cities of Jeju and Seogwipo are located to the north and south of the island, respectively. DEM, digital elevation model; PAs, protected areas.

The study area is an island located off the southern tip of South Korea (Fig. 4.1). Jeju Island (33°11′27″–33°33′50″N, 126°08′43″–126°58′20″E) is the country's largest island, covering approximately 1,850 km^2. As of 2023, it has a population of 677,031. The island, which has a mild oceanic climate, features a central volcanic mountain, Mount Halla, which reaches a height of 1,950 m above sea level. The land cover varies along a gradient of anthropogenic influence, which varies with elevation. Agricultural and urban lands are prevalent in the lowlands near the coast, whereas forests and grassland dominate the highlands. In addition to being an important site for biodiversity conservation, Jeju Island feature a diversity of volcanic features, including columnar joints, lava tubes, and parasitic cones (Kim et al., 2018). PAs cover 179.89 km^2 of the island, while the volcanic areas of Oreum and Gotjawal account for approximately 243 km^2. With its unique geographical and ecological features, Jeju Island is considered as a potential candidate for the establishment of OECMs that can contribute to global biodiversity conservation efforts. However, because it is a popular destination for ecotourism, Jeju Island receives tens of millions of visitors annually, which results in development pressure on its ecosystem (Kim et al., 2022).

2.2. Methods

2.2.1. Overview of analysis

To achieve the objectives of this study, we evaluated four representative ecosystem services and explored indicators of biodiversity using occurrence field data of plant species. To facilitate mathematical calculations, we standardized five biodiversity indicators within the range of 0–1. Given the complexity and difficulty of quantifying the relative importance of different indicators for ecological functions (Peng et al., 2018), we assigned equal weight to all indicators in this study. We then sought the identification of priority PAs by analyzing a variety of planning scenarios.

2.2.2. Evaluation of ecosystem services

Ecosystem services are primarily influenced by ecosystem functionality and biodiversity (Isbell et al., 2011; Maestre et al., 2012; Zhou et al., 2022). Key indicators of these aspects are essential for assessing ecosystem services (La Notte et al., 2017; Rieb et al., 2017). In this study, we assessed four ecosystem services: carbon stocks (CSs; regulation service), scenic quality (SQ; cultural service), seasonal water yield (SWY; provisioning service), and habitat quality (HQ; supporting service). The land-use and land-cover (LULC) data used for the assessment of ecosystem services was sourced from 2020 and had a 1-m resolution. We used the InVEST model in our assessment and analysis of ecosystem services. InVEST is a suite of geospatial models that assess and forecast the delivery of ecosystem services and habitat suitability. The model is based on land-use maps for a given geographic area, together with biophysical, economic, and institutional data associated with that area (Sharp et al., 2020). InVEST's equations and assumptions are detailed in the documentation of the model (Sharp et al., 2020).

A CS model was used to assess the ecosystem regulation of carbon, and included calculations of aboveground, belowground, soil, and dead matter carbon, based on land-cover data. CSs influence factors such as food production and climate regulation (Huang et al., 2020; Luo et al., 2021). Particularly on Jeju Island, there has been a significant reduction in CSs due to an increase in the area of agricultural land since the late 2000s (Kim et al., 2022). The carbon pool coefficient required for CSs was taken from Kim et al. (2022).

The SQ model assesses a landscape's visual quality based on existing or planned characteristics that affect its visual appeal (Sharp et al., 2020). Jeju Island is recognized for its exceptional natural landscape that attracts a significant number of tourists annually (Kim et al., 2022).

Considering the human population density, SQ was used to assess the demand for ecosystem function in the context of cultural services. To evaluate the percentage of the population enjoying scenic views of vegetation, a bespoke SQ model assumes that all vegetation enhances scenic quality and uses sampled observer points (Lourdes et al., 2022). The population density distribution required to calculate SQ was derived from Lourdes et al. (2022) and applied to the study area. The result is a service indicator that considers human demand for natural landscapes and their natural supply (Sharp et al., 2020). A more comprehensive explanation of the operational mechanism of the SQ model is provided in the supplemental information.

The SWY model, which was developed for estimating baseflow production in a watershed, evaluates the influence of changing LULC on water resources (Hamel et al., 2020; Kusi et al., 2020). In a geographical context such as an island, water yield can be considered an essential ecosystem function (Bremer et al., 2021). The model provides critical insights into the timing and quantity of water yield and enables informed decision-making in water-resource management (Sharp et al., 2020). The model requires soil hydrologic, digital elevation model, and threshold flow accumulation, biophysical, and rain-event data based on land-cover type. Input data for the SWY models are included in the Supplemental Information and Table S1.

The HQ model evaluates supporting services. HQ varies with habitat sensitivity and various threat factors related to human activity (Sharp et al., 2020). HQ can be measured by evaluating four factors: the relative impact of each threat, the relative sensitivity of the landscape to that threat, the distance between the habitat and the source of the threat, and the legal PA (Liu et al., 2017; Sharp et al., 2020). The habitat sensitivity and threats needed for the HQ model were derived from information given by Kim et al.

(2022). The results of the model are subject to a large degree of uncertainty because they are evaluated through a simplified process (Hamel et al., 2020); therefore, they should be interpreted as relative, rather than absolute, values.

2.2.3. Species distribution model

We employed the Maximum Entropy (MaxEnt) model to explore the distribution of biodiversity on Jeju Island. The MaxEnt model is particularly for the analysis of presence-only occurrence data, small samples, and non-probability-based data (Phillips et al., 2017). MaxEnt was implemented using the ‘dismo’ package in R version 4.2.0 (Hijmans et al., 2017).

Our study focused on selected plant taxa of Jeju Island, and specifically assessed species with 10 or more occurrence locations. The analysis drew from 12,400 occurrence records for 423 terrestrial plant species that were enumerated in the Third and Fourth National Ecosystem Survey of South Korea (available at http://ecobank.nie.re.kr). Climatic variables were derived from bioclimatic data for 1950–2000. Elevation data were drawn from 1 × 1-km resolution topographic data available at the WorldClim website (https://www.worldclim.org/). To minimize the influence of multicollinearity, we removed variables with a Pearson’s correlation coefficient $|r| > 0.7$. Out of 20 environmental variables that were available for analysis, the final MaxEnt model was calculated using five bioclimatic variables (bioclimate 03, 07, 14, 18, and elevation).

We randomly selected 25% of the data as test data and 75% species occurrence data as calibration data, and performed MaxEnt modeling using the default model settings. Model quality was primarily assessed using the area under the curve (AUC); models with AUC > 0.7 were considered to yield acceptable predictions and accurate performance (Swets, 1988). Of the

423 species analyzed, 247 had model results with AUC ≥ 0.7 (mean = 0.818, standard deviation = 0.076). We therefore concluded that the MaxEnt model provided an acceptable fit to the Jeju Island plant distribution data.

Biodiversity hotspots were identified based on overlapped binary maps at the site level (Ko et al., 2014). A cut-off is required to convert model-derived occurrence probabilities into binary presence or absence data. This step is essential for representing the potential ranges of species in a study area. To classify the model predictions into 'absent' and 'present,' we used the maximum of the sum of sensitivity and specificity (max SSS threshold) value as the range threshold for each species. These max SSS values were then used to generate hotspot maps by overlapping the binary maps for each species. We processed the MaxEnt model output layers for species diversity distribution using ArcGIS Pro 3.0.3.

2.2.4. Determination of conservation prioritization areas using PrioritizR

To analyze the complex interactions of ecological functions, we built and solved a spatial planning problem for decision-making using the R package PrioritizR 8.0.0, which incorporates a wide variety of customizable decision-analysis criteria (Hanson et al., 2023). Conservation-planning software can help policy-makers and practitioners to explore prioritization areas to conservation planning under constraints (Carroll et al., 2021; Schwartz et al., 2018). PrioritizR uses integer linear programming to achieve systematic conservation prioritization by optimizing objectives and making discrete decisions (Beyer et al., 2016). The software's exact algorithm solvers guarantee exhaustive optimal solutions, and significantly reduce computation time compared to other algorithms (Schuster et al., 2020). Our prioritization objectives were to simultaneously meet multiple conservation targets, maximize network, and minimize the area and cost of the solution. We incorporated seven layers into our PrioritizR analysis. These layers represented four ecosystem services (CSs, SQ, SWY, and HQ), species richness (derived from the MaxEnt model), land price, and current conservation status (locked in or out). These inputs were used to simulate 12 different scenarios.

Using the above-mentioned seven input criteria, we simulated 12 different scenarios. The scenarios accounted for both existing PAs (PA scenario) and areas that had high potential for OECM designation (OECM scenario) in service of the 17% and 30% conservation targets. Three boundary penalties, including a penalty of 0, 0.05, and 0.1, were applied in the conservation-planning scenarios to examine their functional role in influencing the boundary length of the PAs. As the penalty value increased, planning units became less spatially dispersed and more interconnected with adjacent PAs, which minimized edge effects and led to a preference for larger planning units (Choe et al., 2018). Official land prices from the Republic of Korea Ministry of Land, Infrastructure and Transport were used to determine prioritization conservation areas. Existing PAs (as designated by the national government) and OECMs were integrated into the solution via the locked-in function. OECMs pertain to areas that can effectively conserve biodiversity at a regional scale (Maxwell et al., 2020). The volcanic terrains of Jeju Island, notably Oreum and Gotjawal, have been identified as being pivotal to biodiversity and boast substantial conservation value (IUCN, 2020; Kim et al., 2018; Kim et al., 2022). Consequently, Oreum and Gotjawal were recognized as OECMs in this study. The locked-out function was implemented to exclude areas that were urbanized between 2019 and 2020 from the prioritization conservation areas.

3. Results

3.1. Spatial pattern of land price, ecosystem services, and species richness

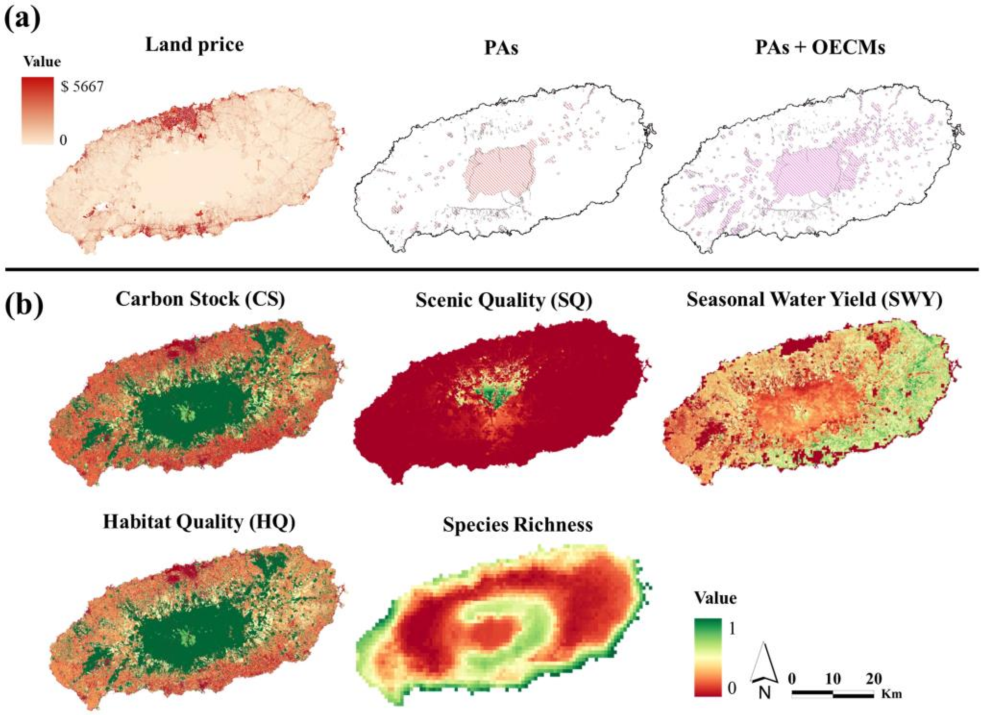

Fig. 4. 2. Spatial distributions of land price, ecosystem services, and species richness. (a) Public land price (m^2/USD). PAs consist of nationally designated PAs and PAs designated by the Jeju Island administration. The latter category principally includes Hallasan National Park and areas with high ecological protection value. PAs + OECMs signify areas that, beyond currently protected zones, exhibit potential for OECM designation. (b) The four ecosystem services and species richness results that were used to derive the conservation prioritization areas.

PAs tended to be located in areas with lower planning costs, while high land prices were concentrated in the northern and southern regions of the urban areas (Fig. 4.2a). The distribution of ecosystem services was heterogeneous (Fig. 4.2b), with similar trends being observed for CSs and HQ, while SQ, SWY, and species richness showed varying patterns. Areas with high land prices generally exhibited lower levels of ecosystem services and species richness, while SQ was higher in the center of the island, likely related to the concentration of populations in urban areas (Figs. 4.1 and s1).

3.2. Spatial distribution of priority conservation areas under different scenarios

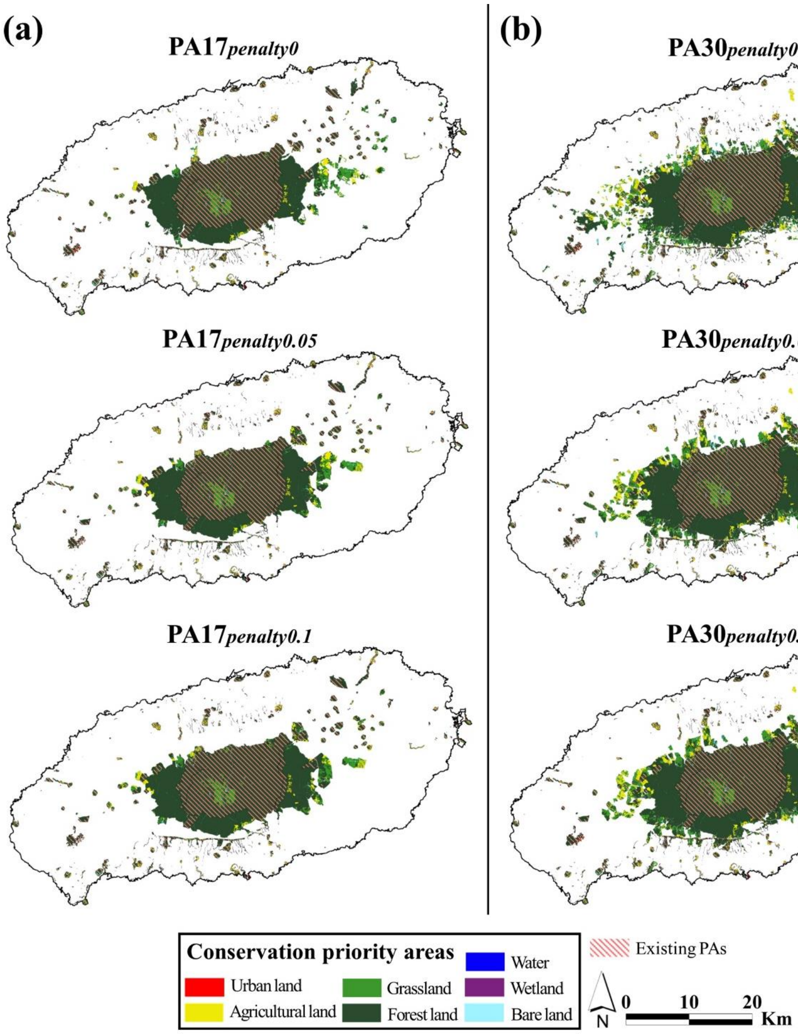

Fig. 4. 3. Spatial representation of protected area (PA) scenarios across the study area. (a) Scenario for a 17% target in existing PAs under the three penalties. (b) Scenario for a 30% target in existing PAs under the three penalties.

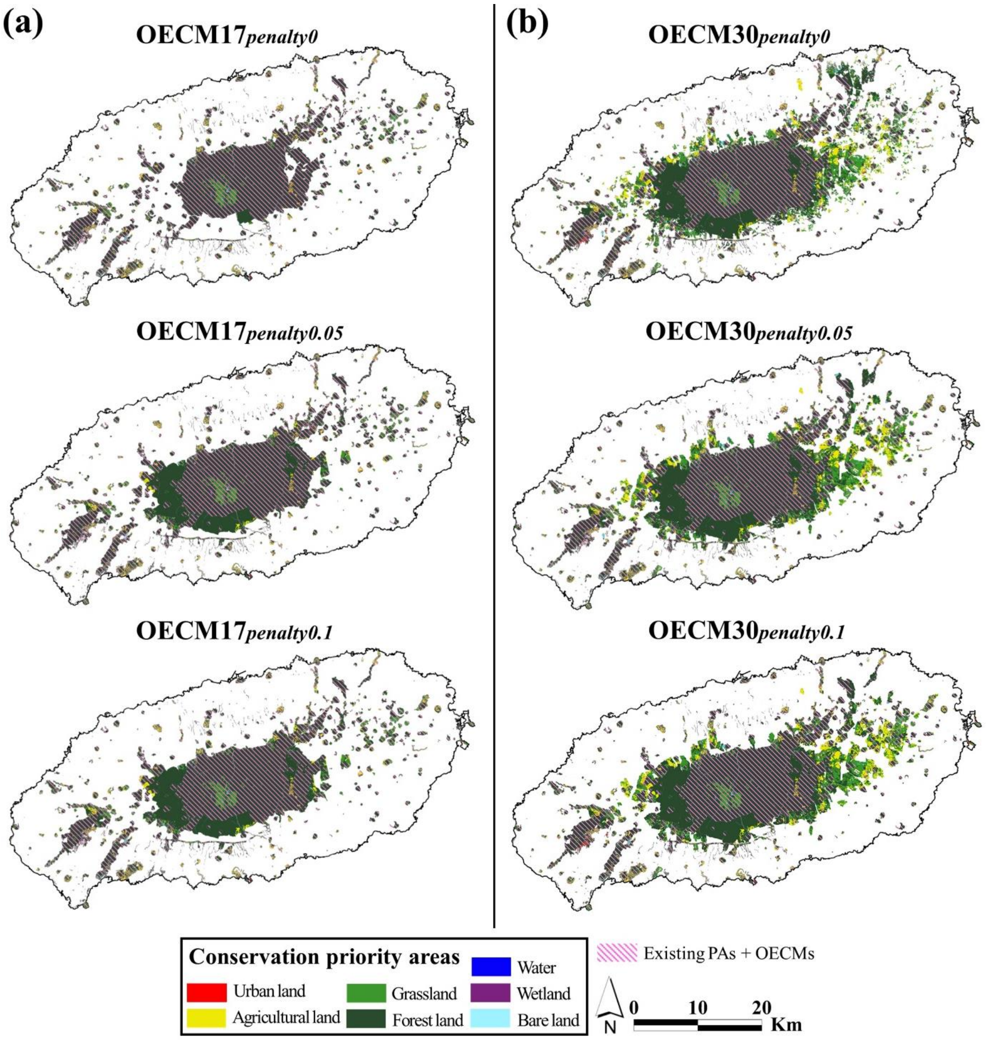

Fig. 4. 4. Spatial representation of other effective area-based conservation measures (OECMs) scenarios across the study area. (a) Scenario for a 17% target in existing protected areas (PAs) + OECMs under the three penalties. (b) Scenario for a 30% target in existing PAs + OECMs based on the penalty.

Most of the priority areas identified were adjacent to PAs under both the 17% and 30% targets (Figs. 4.3 and 4.4). When the target was increased, the conservation prioritization areas included areas farther to the east within the study area (Figs. 4.3b and 4.4b). Under the 17% target, conservation prioritization areas were predominantly forest land (Figs. 4.3a and 4.4a). However, under the 30% target, conservation prioritization areas included forest land, grassland, and agricultural land (Figs. 4.3b and 4.4b). Notably, the OECM17*penalty0* scenario yielded a conservation prioritization area of only 4.41 km^2, which was significantly lower than the areas in the other scenarios examined (Fig. 4.4a, Table 4.1). Furthermore, the conservation prioritization areas were dispersed when no penalty was applied, but became more concentrated as penalties were increased under both the 17% and 30% targets (Figs. 4.3 and 4.4, Table 4.1). This result probably arose because PAs in the OECM scenario only accounted for approximately 17% of the total area of the study region.

3.2. Ownership and cost of priority conservation areas

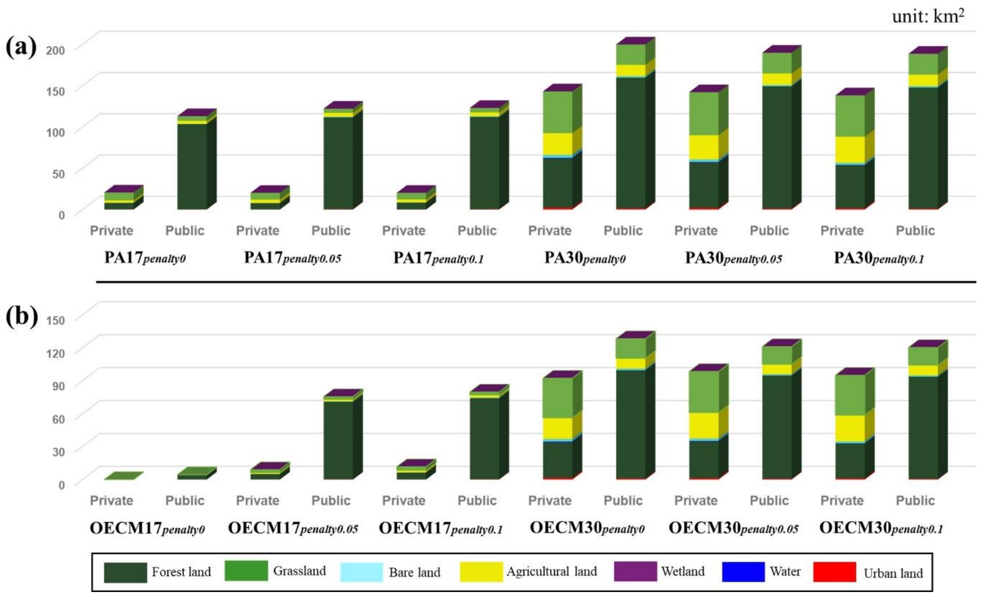

Fig. 4. 5. Comparison of land cover and ownership area (km^2) across scenarios based on the solution. (a) Land use and land cover (LULC) by ownership in the protected-area (PA) scenario, and (b) LULC by ownership in the OECM scenario.

We examined land ownership and LULC for each solution identified in our study (Fig. 4.5). Under the 17% target, public land dominated both the PA and OECM scenarios, but under the 30% target, private land increased dramatically in both scenarios. Under the PA scenario, the area of private land increased by about 120 km^2, while public land increased by approximately 60–80 km^2 (Table 4.1). In the OECM scenario, private land increased by approximately 90 km^2 and public land increased by around 40 km^2, except under the OECM30*penalty0* scenario (Table 4.1). Therefore, expansion of the target to 30% led to a greater proportion of private land relative to public land in both the PA and OECM scenarios.

The conservation prioritization areas were dominated by forest land under the 17% target, whereas under the 30% target, forest land, grassland, and agricultural land were identified (Fig. 4.5). In both the PA and OECM scenarios, the proportion of forest land in public areas was highest at the 17% target (Fig. 4.5, Tables S1 and S2). However, when the target was increased to 30%, forest land, grassland, and agricultural land in private areas increased substantially (Fig. 4.5, Tables S2 and S3). Under the 30% target, the area of grassland was higher than that of forest land. There was also a significant increase in agricultural land under the 30% target (Tables S2 and S3). These results imply that achieving the 30% target would cost approximately 5–7 times more than achieving the 17% target (excluding the OECM17*penalty0* scenario). When considering the cost and area of conserved land with penalties applied, the lengths of boundaries decreased in all scenarios as the penalty increased (Table 4.1). As the boundary length index decreased, conservation costs increased for the 17% target but decreased for the 30% target. Higher boundary penalties were associated with increasing conservation prioritization areas under the 17% target, but a contraction of those areas under the 30% target scenario.

Table 4. 1. Summary of planning cost, area, and boundary length with respect to ownership. Cost refers to the total price of land as officially announced in the study area, expressed per 1,000 US dollars. Boundary length represents the length of the boundaries for the proposed solutions under each protected area (PA) and other effective area-based conservation measures (OECM) scenario. Shorter boundary lengths indicate less fragmentation.

Scenario	**Cost (1,000 US $)**			**Area in km^2 (%)**			**Boundary length**
	Private	**Public**	**Total**	**Private**	**Public**	**Total**	
PA17*penalty0*	87,150	289,170	376,320	20.71 (15.5)	113.22 (84.5)	133.93	139,5567
PA17*penalty0.05*	100,281	365,682	465,964	20.30 (14.2)	122.28 (85.8)	142.58	122,1645
PA17*penalty0.1*	90,991	373,072	464,062	20.35 (14.2)	123.20 (85.8)	143.55	114,2669
PA30*penalty0*	1,803,555	954,161	2,757,716	143.21 (41.5)	201.93 (58.5)	345.14	3,470,810
PA30*penalty0.05*	1,727,406	876,508	2,603,914	142.26 (42.8)	190.13 (57.2)	332.38	1,858,952
PA30*penalty0.1*	1,497,529	866,008	2,363,538	138.44 (42.3)	188.83 (57.7)	327.27	1,758,806
OECM17*penalty0*	0	4,112	4,112	0 (0)	4.41 (100)	4.41	2,270,842
OECM17*penalty0.05*	44,956	203,312	248,268	9.01 (10.7)	75.64 (89.3)	84.65	2,064,023
OECM17*penalty0.1*	61,511	235,365	296,876	11.67 (12.8)	79.87 (87.2)	91.54	2,038,321
OECM30*penalty0*	1,171,378	610,924	1,782,302	92.42 (41.9)	128.45 (58.1)	220.87	3,340,101
OECM30*penalty0.05*	1,116,415	537,788	1,654,203	98.57 (44.8)	121.30 (55.2)	219.86	2,354,877
OECM30*penalty0.1*	1,043,634	537,348	1,580,982	95.11 (44.1)	120.49 (55.9)	215.60	2,071,586

4. Discussion

4.1 Spatial distribution of priority areas and landowners

This study demonstrated an approach to establishing conservation targets that enhances ecosystem services and biodiversity, and which identifies priority areas for the efficient management of key areas. A decision-support model was used to identify priority conservation areas, with the aim of enhancing the effectiveness of conservation efforts by providing clear guidance for policy implementation (Schwartz et al., 2018). Our findings emphasize the importance of prioritizing land cover and ownership at the local level, while highlighting the necessity of setting realistic targets at the regional scale (Monroe et al., 2021; Scott et al., 2001). In both the PA and OECM scenarios, priority areas were concentrated in the central and eastern regions of Jeju Island (Figs. 4.3 and 4.4). This pattern aligned with major concentrations of ecosystem services and biodiversity (Fig. 4.2). By contrast, few prioritized PAs were identified in the coastal lowlands of Jeju Island, potentially due to a lack of consideration for biodiversity and ecosystem services in urban areas (Ramel et al., 2020). Nevertheless, extending the conservation target to 30% expanded the land types identified from primarily forest land to agricultural and urban land, thereby facilitating the implementation of natural restoration measures in urban areas.

Areas with high ecological protection values for the island as a whole require protection measures that reflect local conditions (Cameron et al., 2022; Kim et al., 2022; Weeks & Adams, 2018). For areas that need prioritized protection, it is also crucial to develop a protection strategy that considers land ownership and conservation costs. While previous studies have identified areas requiring priority protection, they have generally given less consideration to land ownership, instead considering local conditions and the associated land costs (Luo et al., 2021; Mitchell et al., 2021; Peng et al., 2018b). The findings of this study can provide guidelines on prioritizing conservation measures in regions with conflicts between public and private lands, taking into account the types of land and their ownership status. Land-ownership patterns can significantly affect the sustainable management and effectiveness of priority PAs, and managing PAs on private land is essential for biodiversity conservation (da Silva et al., 2021). Studies have shown that private land incurs higher conservation costs compared to public land. Increasing the conservation target to 30% resulted in higher conservation costs due to the increase in private land area (Table 1). Forest land dominated the conservation allocations under the 17% target scenario, but under the 30% target scenario, the proportions of cropland and grassland increased along with the area of private land, which increased costs because agricultural land has a higher unit-area cost than forest land. Whereas public institutions are likely to manage public land, private land management can be challenging because it requires the participation and cooperation of local people. It is therefore necessary to adopt a comprehensive approach to the challenges of managing and conserving private lands for biodiversity protection. The cost of conservation is determined by considering the benefits of conservation and the willingness of landowners to cooperate in conservation efforts (Cameron et al., 2022). Although collaboration with landowners is essential if agricultural lands are to be secured as PAs, an alternative approach could prioritize the protection of grasslands or forests on public land, taking into consideration any conflicts of interest that might arise.

4.2. The role and impact of OECMs in network enhancement and biodiversity conservation

The conservation prioritization for identifying priority PAs on Jeju Island incorporated areas that could potentially be designated as OECMs. The construction of the OECM scenario demonstrated that ecological functions could be efficiently expanded on a regional basis instead of indiscriminately expanding PAs. OECMs can contribute to the enhancement of biodiversity, even though they are not strictly classified as PAs (Donaldson et al., 2021; Maxwell et al., 2020). OECMs have the potential to enhance broader conservation efforts by improving the ecological representation and network within conservation networks, promoting partnerships between conservation organizations and other stakeholders, and facilitating engagement with landowners to safeguard economically valuable natural resources (Diz et al., 2018; Jonas et al., 2017; Shwartz et al., 2017).

To manage PAs, external standards or interventions can be employed. However, these approaches often result in less effective conservation efforts and can have negative social consequences (Dawson et al., 2021). OECMs may play an important role in addressing the deficiencies that have been overlooked in the design of protected-area networks. Furthermore, incorporating conservation targets and response that serve the interests of multiple stakeholders can promote equity in area-based management (Maxwell et al., 2020). While the inclusion of PAs on a national scale remains essential, the designation and subsequent management of regions thought to contribute to biodiversity enhancement as OECMs represents a more area-based solution. Therefore, it may be more efficient to select PAs at the local level to reflect local conditions. For example, trekking routes on Jeju Island have been developed around areas with high elevations or scenic value to enhance their cultural services (Kim et al., 2021).

In this study, we implemented a penalty to assess the network improvement of the conservation prioritization. Boundary penalties can result in more expensive solutions if the total length of the boundaries in the priority areas can be reduced (Hanson et al., 2023). Expanding PAs can also improve ecosystem function by improving network in landscape conservation, provided that land price is formed as regional units that are adjacent to PAs (Choe et al., 2018; Duchardt et al., 2021). Although conservation costs may increase as the penalty increases, we observed two contrasting trends: increasing costs with increasing penalties under the 17% conservation target but decreasing costs with increasing penalties under the 30% conservation target (Table 4.1). While the PA30penalty0.1 and OECM30penalty 0.1 scenarios could potentially achieve the highest network among PAs at the lowest cost, enhancing ecosystem function through the utilization of small patches might pose a challenge. These findings imply that rather than pursuing unconditional area expansion, it could be more efficient to designate and manage areas that can enhance ecosystem function as PAs. Therefore, when expanding PAs, it is important to consider both quantitative and qualitative expansion that account for ecosystem functions and network (Coad et al., 2019).

Agencies and advocates could use the findings of this study to help design alternative management approaches and zonation strategies in situations where ecological functions are being degraded by anthropogenic developments such as resource extraction (Cameron et al., 2022). Such collaborative planning and partnerships within a region are critical for successful conservation (Keeley et al., 2018). Maximizing the network effect of PAs seems feasible, provided that public lands in newly identified priority PAs on eastern Jeju Island are included in conservation plans while preserving existing, more centrally located PAs (Figs. 4.3 and 4.4). Furthermore, when determining conservation priorities, the relative costs of conservation and the prioritization of PA networks can guide decision making. The policy direction can be determined based on whether conservation costs or PA network are emphasized during planning. When aiming for a 30% target, enhancing PA network can lead to a decrease in conservation costs. Consequently, a plan to protect small habitat fragments in urban areas could be costly and complex, making a scenario with a 0.1 penalty through network hardening a more suitable approach.

4.3. Limitations and future directions

We considered only 17% and 30% conservation targets in the absence of intermediate proportions between these extremes. In reality, setting such a steep increase in conservation targets at the national level can result in major repercussions. However, it can be argued that biodiversity faces such severe threats that ambitious goals are justified (CBD, 2022). A second limitation arose from the fact that the study did not account for the likelihood that many areas with high potential for OECMs are public lands or lands where transactions for profit are not feasible. These nuances of tenure could influence the practical application of conservation plans. Furthermore, cost estimates for areas identified as conservation prioritization were based on officially announced land prices. In real-world scenarios, the cost of implementing conservation measures in these areas could be substantially higher than the official land prices. To address these limitations, future research should consider the implementation of tiered conservation targets that gradually increase, rather than jumping directly from a 17% to 30% target. It would also be worthwhile to assess the feasibility of using certain lands, such as public lands, for conservation purposes. Researchers should also expand the types of costs evaluated to include the costs of conservation measures and potentially higher costs incurred from negotiations with landowners. Prioritizing the protection of forests and grasslands over agricultural lands could be a more cost-effective approach, given the current situation on Jeju Island.

Finally, future research should seek to enhance the participation of local communities in decision-making to ensure the successful management and preservation of biodiversity. The relationship between landowners and conservation managers could be enhanced by fostering dialogue and understanding about conservation and its benefits. All these improvements would contribute to refining the conservation planning process and its outcomes. Future research in this area will be critical for addressing the urgent challenge of preserving biodiversity and ecosystem services while balancing economic and societal needs.

5. Conclusion

This study provided insights into techniques for prioritizing the allocation of conservation areas. Our work accounted for ecosystem services, levels of biodiversity, land ownership, and costs. Setting realistic conservation targets that consider both regional and local conditions will be crucial for effective conservation management. Conservation planning scenarios that prioritized areas with high levels of ecosystem services and biodiversity frequently incurred higher costs, and the costs were typically associated with private land. This finding highlights the importance of creating strategies for public–private collaboration in conservation efforts. Future conservation policies must effectively balance the benefits of conserving biodiversity and ecosystem services with the costs of securing private lands. The inclusion of OECMs provides an innovative way to expand PAs by including other regions that enhance biodiversity. Our results emphasize the importance of considering both quantitative and qualitative aspects of PA expansion, especially levels of ecosystem services and network characteristics. In conclusion, this study signifies a critical step toward achieving better integration of sustainable conservation planning and policy-making. By combining ecosystem services, biodiversity, land ownership, and cost considerations, our approach offers a comprehensive framework for guiding conservation efforts and policies in Jeju Island and other regions. However, it is crucial to bear in mind that the success of such an integrative strategy will depend on the adoption of collaborative and context-specific approaches that account for local conditions and stakeholder interests.

Chapter 5. Conclusion

This study presents valuable insights for the conservation and management of Jeju Island's ecosystem services, ecological connectivity, biodiversity, and land ownership. It highlights the importance of balancing human demands and ecosystem service supply, particularly in terms of ecological planning and future scenarios. The analysis of 47 years of changes in land use and land cover and ecosystem services underscores the need for effective restoration and conservation measures, especially in coastal areas where ecosystem services have declined. The success of ecologically valuable forest restoration policies implemented in the 1970s and 1980s has contributed to the high conservation value of Jeju Island as a volcanic island.

Furthermore, the study emphasizes the critical role of considering ecological connectivity in conservation management plans to promote biodiversity and sustainable development. By integrating ecosystem services and ecological connectivity analysis, significant pinch points and disconnections between coastal and mid-mountain areas were identified. The identification of new conservation priority areas, primarily on agricultural land and grassland in mid-mountain areas, provides policymakers with a clear strategy for managing these regions.

The prioritization of conservation areas based on ecosystem services, biodiversity, land ownership, and costs is essential for effective conservation management. Private lands often incur higher costs, highlighting the importance of public-private collaboration in conservation efforts. Additionally, the inclusion of OECMs offers an innovative approach to expand protected areas and enhance biodiversity. The study emphasizes the significance of considering both quantitative and qualitative aspects of protected area expansion, considering ecosystem services and network characteristics.

In conclusion, this study represents a critical step towards the integration of sustainable conservation planning and policy-making. It provides a comprehensive framework for guiding conservation efforts and policies not only in Jeju Island but also in other regions. However, successful implementation relies on the adoption of collaborative and context-specific approaches that account for local conditions and stakeholder interests. By embracing such an integrative strategy, we can effectively balance the conservation of biodiversity and ecosystem services with the costs associated with securing private lands and promote the long-term sustainability of our natural resources.

Supplementary

Chapter 2. Supplementary

Data acquisition

Based on the 47-year land cover data, land use changes over time and corresponding ecosystem service changes were examined together. In this study, land type was divided into seven categories: urban land, crop land, forest land, grass land, golf course, bare land, and water. For 1989 and 1998, data were based on Landsat TM data, and in 2009 and 2019, Landsat 8 data were used to correct land conditions.

Method

Habitat Quality

The index is calculated using the following equation:

$$Q_{xj} = H_j \left[1 - \left(\frac{D_{xi}^z}{D_{xj}^z + k^z}\right)\right] \quad (1),$$

where Q_{xj} is the habitat quality value of grid cell x of LULC class j. H_j demonstrates the habitat suitability of the j LULC class. D_{xj} is the total threat level in grid cell x with LULC j. k is the half-saturation constant, which we set to 0.5. z is the normalized constant. The decrease in habitat quality due to threat factor distance will be reduced as a linear or exponential function, which is chosen by the user (Sharp et al., 2020). The threats and sensitivity tables were established by utilizing data proposed by experts who have experienced practical work in the environmental field (e.g., biodiversity, environmental ecology, environmental planning, and environmental geography information) for more than 10 years (KEI, 2015). The sensitivity and threat scores used to evaluate HQ are shown in Table S4 and S5.

Carbon Stock

In the CS model, the amount of carbon storage provided by the study site was estimated using LULC and carbon pool coefficients based on previously published values (Roh et al., 2016) (Table S6).

Water Yield

The model requires several variables, including LULC, average annual precipitation (mm), average annual reference evapotranspiration (mm), average root restricting layer depth (mm), plant available water content (mm), and study site watershed. Because the WY model calculates water yield as an annual average, it is difficult to consider extremes, alternative effective evapotranspiration, and thermal dimensions (Redhead et al., 2016). Model calculations used the following equation:

$$Y_x = \left(1 - \frac{AET_x}{P_x}\right) \cdot P_x \quad (2),$$

where Y_x is the total annual water yield in each grid cell *x*. AET_x represents annual actual evapotranspiration for cell *x*, and P_x is annual precipitation for cell *x*.

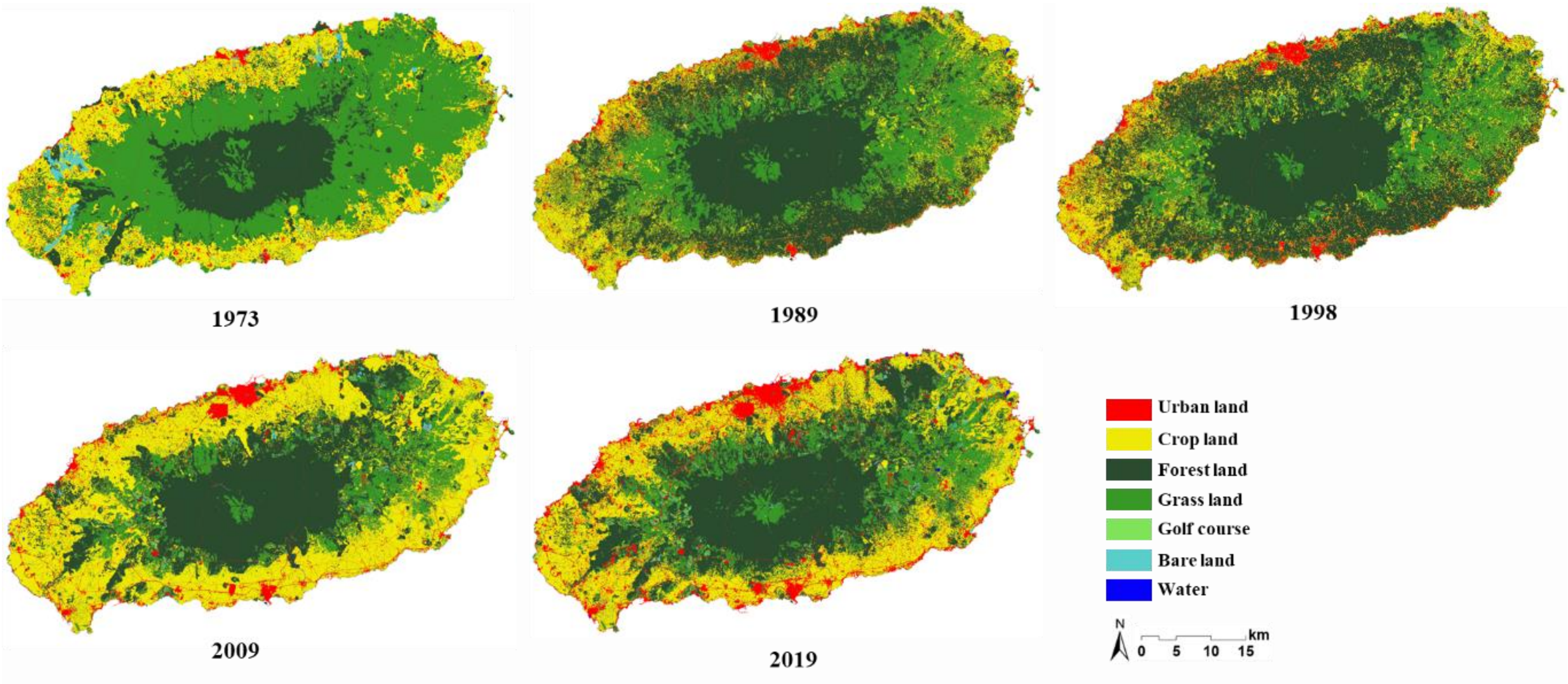

Fig S1. Land use and land cover from 1973 to 2019 on Jeju Island, Republic of Korea.

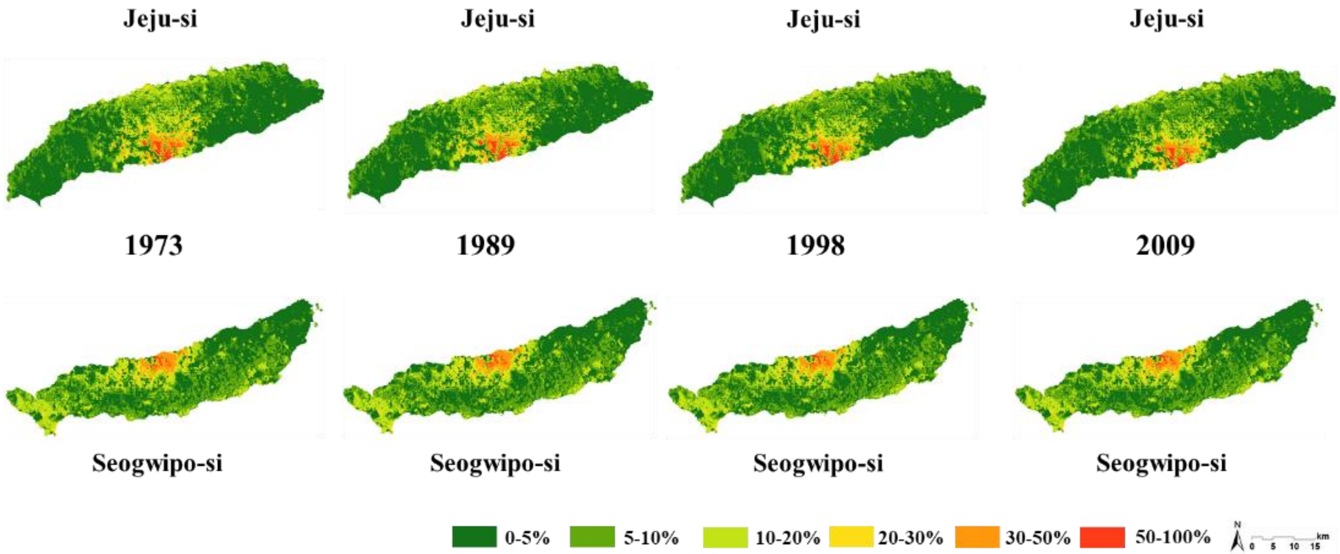

Fig. S2. Cumulative viewshed.

Table S1. Total land use and land cover (LULC) change.

	1973		1989		1998		2009		2019	
LULC	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%
Urban land	47.5	2.6	81.32	4.43	99.72	5.41	107.76	5.85	190.07	10.32
Crop land	512.43	27.98	363.71	19.8	378.59	20.53	810.12	43.93	605.75	32.89
Forest land	409.83	22.38	920.95	50.14	1032.01	55.95	639.15	34.66	696.5	37.81
Grass land	826.45	45.12	462.58	25.19	317.42	17.21	259.33	14.07	317.31	17.23
Golf course	0	0	1.05	0.06	2.39	0.13	12.33	0.67	12.87	0.7
Bare land	34.93	1.91	6.54	0.36	13.92	0.76	13.55	0.74	17.4	0.95
Water	0.64	0.04	0.81	0.05	0.77	0.05	1.9	0.11	2.34	0.13
Total	1831.78	100	1836.96	100	1844.82	100	1844.14	100	1842.24	100

Table S2. Land use and land cover (LULC) change by area.

Coast														
	1973		**1989**		**1998**		**2009**		**2019**		**1989–1973**	**1998–1989**	**2009–1998**	**2019–2009**
LULC	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)			
Urban land	44.08	4.42	75.31	7.51	93.65	9.27	95.72	9.48	163.18	16.19	31.23	18.34	2.07	67.46
Crop land	485.03	48.62	309.53	30.87	294.6	29.15	671.8	66.51	533.8	52.95	-175.5	-14.93	377.2	-138
Forest land	108.38	10.87	409.59	40.85	479.32	47.43	130.77	12.95	177.43	17.6	301.21	69.73	-348.55	46.66
Grass land	324.84	32.56	201.8	20.13	129.42	12.81	97.1	9.62	118.24	11.73	-123.04	-72.38	-32.32	21.14
Golf course	0	0	0	0	0.89	0.09	2.49	0.25	2.49	0.25	0	0.89	1.6	0
Bare land	34.74	3.49	5.88	0.59	12.13	1.21	11.02	1.1	11	1.1	-28.86	6.25	-1.11	-0.02
Water	0.64	0.07	0.78	0.08	0.73	0.08	1.18	0.12	2.05	0.21	0.14	-0.05	0.45	0.87

Mid-mountain														
	1973		**1989**		**1998**		**2009**		**2019**		**1989–1973**	**1998–1989**	**2009–1998**	**2019–2009**
LULC	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)			
Urban land	2.92	0.5	5.5	0.94	5.55	0.95	11.33	1.93	26.07	4.43	2.58	0.05	5.78	14.74
Crop land	27.4	4.66	53.68	9.12	82.11	13.95	136.87	23.25	71.71	12.18	26.28	28.43	54.76	-65.16
Forest land	98.18	16.68	286.55	48.67	321.42	54.59	277.83	47.19	299.67	50.89	188.37	34.87	-43.59	21.84
Grass land	460.19	78.15	241.48	41.01	176.55	29.99	150.58	25.58	175.5	29.81	-218.71	-64.93	-25.97	24.92
Golf course	0	0	1.04	0.18	1.49	0.26	9.26	1.58	9.81	1.67	1.04	0.45	7.77	0.55
Bare land	0.19	0.04	0.59	0.11	1.73	0.3	2.34	0.4	5.9	1.01	0.4	1.14	0.61	3.56
Water	0	0	0.03	0.01	0.02	0.01	0.66	0.12	0.26	0.05	0.03	-0.01	0.64	-0.4

Mountain														
	1973		1989		1998		2009		2019		1989–1973	1998–1989	2009–1998	2019–2009
LULC	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)			
Urban land	0.5	0.21	0.51	0.21	0.52	0.22	0.7	0.29	0.83	0.34	0.01	0.01	0.18	0.13
Crop land	0	0	0.5	0.21	1.88	0.77	1.45	0.6	0.25	0.11	0.5	1.38	-0.43	-1.2
Forest land	203.28	82.91	224.81	91.69	231.27	94.33	230.55	94.03	219.4	89.48	21.53	6.46	-0.72	-11.15
Grass land	41.42	16.9	19.3	7.88	11.44	4.67	11.65	4.76	23.58	9.62	-22.12	-7.86	0.21	11.93
Golf course	0	0	0.01	0.01	0.01	0.01	0.59	0.25	0.59	0.25	0.01	0	0.58	0
Bare land	0	0	0.06	0.03	0.06	0.03	0.2	0.09	0.51	0.21	0.06	0	0.14	0.31
Water	0	0	0.01	0.01	0.01	0.01	0.06	0.03	0.04	0.02	0.01	0	0.05	-0.02

Table S3. Changes in cumulative viewshed on Jeju Island during 1973–2019.

Percentage	Region	1973 (%)	1989 (%)	1998 (%)	2009 (%)	2019 (%)
0–5	Jeju-si	56.89	57.11	58.18	58.23	58.29
	Seogwipo-si	44.35	44.68	44.97	45.32	45.37
5–10	Jeju-si	23.43	24.72	24.84	25.53	25.53
	Seogwipo-si	32.22	32.18	32.09	31.93	31.93
10–20	Jeju-si	12.49	11.78	11.08	10.74	10.68
	Seogwipo-si	17	16.78	16.61	16.44	16.38
20–30	Jeju-si	3.84	3.28	2.98	2.71	2.7
	Seogwipo-si	3.26	3.22	3.21	3.19	3.19
30–50	Jeju-si	2.33	2.13	2	1.92	1.92
	Seogwipo-si	2.78	2.76	2.75	2.75	2.75
50–100	Jeju-si	1.04	1.01	0.95	0.9	0.9
	Seogwipo-si	0.41	0.41	0.4	0.4	0.4

Table S4. Habitat quality sensitivity score.

LULC	**HABITAT**	**L_urban**	**L_crop**	**L_industry**
Urban land	0	0	0	0
Crop land	0.3	0.69	0.03	0.75
Forest land	1	0.8	0.65	0.85
Grass land	1	0.65	0.57	0.7
Golf course	0.5	0.5	0.42	0.5
Bare land	0.3	0.05	0.15	0.03
Water	0.7	0.73	0.65	0.75

Table S5. Habitat quality threat score.

MAX_DIST	**WEIGHT**	**THREAT**	**DECAY**
6.8	1	Urban	Exponential
4	0.68	Crop	Linear
7.5	1	Industry	Exponential

Table S6. Estimation of **c**arbon stock in four carbon pools.

LULC	C_above	C_below	C_soil	C_dead
Urban land	0.2	0.59	33	0
Crop land	5.2	0.89	60	1.7
Forest land	102.6	47.2	65.55	31.25
Grass land	0.33	0.89	80.52	0.2
Golf course	0.1	0.5	70	0.1
Bare land	0	0.33	0.33	0
Water	0	0	0	0

Table S7. Water yield.

LULC	Kc	root_depth	usle_c	usle_p	load_p	eff_p	LULC_veg
Urban land	0.3	500	1	1	3200	5	0
Crop land	0.7	2000	250	350	1500	25	1
Forest land	1	7000	7000	200	11	75	1
Grass land	0.8	2000	2000	200	50	40	1
Bare land	0.6	1000	1000	100	50	40	1
Bare land	0.2	500	10	200	50	5	1
Water	1	1000	1	1	1	5	0

Table S8. Average annual precipitation (mm).

	Jeju (point 1)	Seongsan (point 2)	Seogwipo (point 3)	Gosan (point 4)	Total average
1973	1217.5	1595.3	1531.3	-	1448.03
1989	1358.6	1696.1	1681.9	1081.5	1454.53
1998	1581.1	2235.9	2091.9	1050.4	1739.82
2009	859.1	1364	1086.6	697.1	1001.7
2019	1979.9	2658.1	2210.3	1560.9	2102.3

Chapter 3. Supplementary

Table S1. Habitat quality sensitivity score on Jeju Island, South Korea.

LULC	Habitat	Urban area	Road	Industrial area	Crop land	Facility crop land	Reference
Urban land	0	0	0	0	0	0	Hong et al. 2021
Crop land	0.3	0.69	0.67	0.75	0	0.1	
Facility crop land	0.05	0.1	0.1	0.2	0	0	
Forest land	1	0.82	0.8	0.85	0.65	0.7	Kim et al., 2015
Natural grass land	1	0.68	0.65	0.7	0.57	0.6	
Artificial grass land	0.8	0.65	0.62	0.67	0.54	0.57	
Wetland	0.7	0.7	0.55	0.8	0.75	0.78	Hong et al. 2021
Natural bare land	0.5	0.15	0.2	0.24	0.17	0.2	
Artificial bare land	0.08	0.13	0.18	0.22	0.15	0.18	
Water	0.65	0.73	0.55	0.73	0.65	0.68	

Table S2. Habitat quality threat factors on Jeju Island, South Korea.

Max_Distance	Weight	Threat	Decay	Reference
5.9	0.88	Urban area	exponential	Hong et al., 2021
2.4	0.59	Road	linear	
5	0.5	Industrial area	exponential	
3.4	0.57	Crop land	linear	
3.8	0.62	Facility crop land	linear	

Table S3. Carbon pools score on Jeju Island, South Korea.

LULC	C_above	C_below	C_soil	C_dead	Reference
Urban land	0	0	0	0	Chun et al., 2019; Chun et al., 2015
Crop land	0	0	62.2	0	
Facility crop land	0	0	45.9	0	
Forest land	53.59	17.36	47.22	11.79	
Natural grassland	4.17	16.69	88.2	0	
Artificial grassland	2.8	8.3	88.2	0	
Wet land	0	0	88	11	

Natural bare land	1.28	5.13	42.4	0
Artificial bare land	0	0.33	0.33	0
Water	0	0	0	0

Table S4. Seasonal water yield data.

Name	Source	Resolution
LULC	Land use land cover map level 3 in 2020. The data is provided from Ministry of Environment South Korea(https://egis.me.go.kr/main.do)	1m
DEM	National Geographic Information Institute	90m
Precipitation	CHIRPS (Climate Hazards Group InfraRed Precipitation with Station data). Monthly precipitation data for 2020	1km
Evapotranspiration	The data set from MODIS Net Evapotranspiration. Monthly evapotranspiration data for 2020	500m
Watershed	The data is provided from Jeju Special Self-Governing Province Development Co.	-
Soil	The data comes from Rural Development Administration in South Korea (http://soil.rda.go.kr/soil/indexReg.jsp). Curve number values are assigned to each combination of soil group and land use/land cover class. The curve number (CN) is a straightforward method to represent the combined soil and land cover characteristics, where larger values of CN indicate increased runoff potential while smaller values are more conducive to infiltration.	-
Rain events	The data comes from The Korea Meteorological Administration (https://data.kma.go.kr/stcs/grnd/grndRnList.do)	-

Table S5. Seasonal water yield crop/vegetation coefficient (Kc) value.

	Kc ini	**Kc mid**	**Kc end**
Urban land	0.1	0.3	0.2
agricultural land	0.7	1.15	1
Cultivation facilities	0.5	0.8	0.7
Forest land	1.2	1.5	1.3
Natural grassland	0.3	1.15	1.1
Artificial grassland	0.4	0.9	0.8
Wet land	0.15	0.45	0.8
Natural barren land	0.8	1	0.95
Artificial barren land	0.15	0.2	0.05
Water	0.25	0.65	1.25

Table S6. Results of Wilcoxon-ranked sum test using of explicit species distribution.

Scientific name	**Number of observations**	**P-value**	**Distribution and habitat**
Apodemus agrarius	150	0.05467	Woodlands, grasslands, pastures, gardens, and urban areas
Capreolus pygargus	444	0.06823	Grasslands, Forests
Carduelis sinica	129	0.9521	Forests, near riverbeds, residential areas, and croplands
Copris tripartitus	44	0.1724	Grasslands, forests
Corvus macrorhynchos	244	0.8763	Woodlands, parks, croplands, and gardens
Cuculus canorus	76	0.1333	Forests, croplands
Eurema laeta	51	0.2995	Forests, stream banks and meadows
Horornis diphone	116	0.2877	Forests
Hynobius quelpaertensis	40	0.7913	Wet forests
Microscelis amaurotis	534	0.1383	Forests, urban areas
Mustela sibirica	112	< 0.001	Near waters, Forests
Papilio xuthus	100	0.05281	Urban areas, suburban, and woods

Parus major	125	0.3512	Urban areas, forests
Pica pica	314	0.6545	Urban areas, suburban, and forests
Rana dybowskii	44	0.6195	Wetlands
Streptopelia orientalis	146	0.01467	Vegetations, shrublands, forests
Zosterops japonicus	270	0.01538	Shrublands, forests

Chapter 4. Supplementary

Scenic Quality

We categorized the population density records required for the Scenic Quality model into quintiles using 2020 WorldPop data (WorldPop, 2020), with values ranging from 1 to 5, where 1 represents the lowest and 5 the highest population density. To obtain a sample of 500 observer points, we generated 100 random points for each class. Next, we executed the Scenic Quality model for each class and calculated a weighted overlay of the resulting five values, with each population group's weight being the ratio of the group's population density to the total population density (Lourdes et al., 2022). We designated locations with vegetation as '1' and locations without vegetation as '0' in the weighted outputs to determine the landscape's services for vegetation.

$$Weight_x = \frac{Population\ density_x}{Total\ population\ density\ in\ study\ area} \times 100\%$$

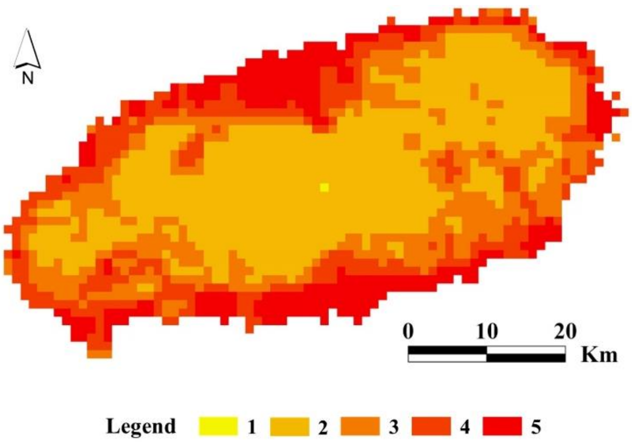

Fig. S5. Population density of Jeju Island.

Seasonal Water Yield

To drive the water yield model, we applied InVEST's seasonal water yield model. The data used in the model is as follows; Soil hydrology group (http://soil.rda.go.kr/soil/indexReg.jsp), DEM (National Geographic

Information Institute), rain events (https://data.kma.go.kr/stcs/grnd/grndRnList.do), precipitation (CHIRPS-Climate Hazards Group InfraRed Precipitation with Station data), evapotranspiration (MODIS Net Evapotranspiration)

Table S1. Seasonal water yield Kc (Evapotranspiration coefficient) table.

Description	Kc_1	Kc_2	Kc_3	Kc_4	Kc_5	Kc_6	Kc_7	Kc_8	Kc_9	Kc_10	Kc_11	Kc_12	CN_A	CN_B	CN_C	CN_D
Urban land	0.2	0.1	0.1	0.1	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	83	89	92	93
agricultural land	1	0.7	0.7	0.7	1.15	1.15	1.15	1.15	1.15	1	1	1	63	74	82	85
Cultivation facilities	0.7	0.5	0.5	0.5	0.8	0.8	0.8	0.8	0.8	0.7	0.7	0.7	76	85	89	91
Forest land	1.3	1.2	1.2	1.2	1.5	1.5	1.5	1.5	1.5	1.3	1.3	1.3	48	69	79	85
Natural grassland	1.1	0.3	0.3	0.3	1.15	1.15	1.15	1.15	1.15	1.1	1.1	1.1	30	58	71	78
Artificial grassland	0.8	0.4	0.4	0.4	0.9	0.9	0.9	0.9	0.9	0.8	0.8	0.8	49	69	79	84
Wet land	0.8	0.15	0.15	0.15	0.45	0.45	0.45	0.45	0.45	0.8	0.8	0.8	100	100	100	100
Natural barrenland	0.95	0.8	0.8	0.8	1	1	1	1	1	0.95	0.95	0.95	77	86	91	94
Artificial barrenland	0.05	0.15	0.15	0.15	0.2	0.2	0.2	0.2	0.2	0.05	0.05	0.05	68	79	86	89
Water	1.25	0.25	0.25	0.25	0.65	0.65	0.65	0.65	0.65	1.25	1.25	1.25	100	100	100	100

Table S2. Area by land cover and land ownership in the PA scenario (unit: km^2).

	Urban land	Forest land	Water	Bare land	Agricultural land	Grassland	Wetland	Total
PA17Penalty0	0.40	111.12	0.02	0.78	6.30	15.17	0.13	133.92
Private	0.15	7.86	0.02	0.30	2.81	9.54	0.02	20.70
Public	0.25	103.26	0.01	0.48	3.49	5.62	0.11	113.22
PA17penalty0.05	0.49	118.96	0.03	1.05	8.58	13.34	0.13	142.58
Private	0.12	7.62	0.01	0.25	4.01	8.28	0.01	20.30
Public	0.37	111.34	0.02	0.80	4.57	5.06	0.12	122.28
PA17penalty0.1	0.44	120.19	0.03	1.10	8.11	13.54	0.15	143.55
Private	0.07	8.37	0.01	0.26	3.44	8.17	0.03	20.35
Public	0.37	111.82	0.02	0.84	4.67	5.36	0.12	123.20
PA30penalty0	3.26	218.37	0.73	5.82	39.67	76.99	0.30	345.14

Private	2.05	59.91	0.66	3.78	26.16	50.52	0.12	143.21
Public	1.21	158.46	0.07	2.04	13.51	26.47	0.17	201.93
PA30penalty0.05	2.85	203.35	0.62	4.94	43.25	77.10	0.27	332.38
Private	1.84	55.12	0.56	3.23	29.40	52.01	0.10	142.26
Public	1.01	148.23	0.06	1.71	13.85	25.09	0.17	190.13
PA30penalty0.1	2.48	198.90	0.43	4.45	45.43	75.29	0.29	327.27
Private	1.52	52.11	0.37	2.66	31.60	50.07	0.11	138.44
Public	0.96	146.79	0.06	1.79	13.83	25.21	0.18	188.83
Total	9.92	970.89	1.86	18.14	151.34	271.42	1.28	1424.85

Table S3. Area by land cover and land ownership in the OECM scenario (unit: km^2).

	Urban land	Forest land	Water	Bare land	Agricultural land	Grassland	Wetland	Total
OECM17_p0	0.01	4.28	0	0	0.03	0.09	0	4.41
Private	0	0	0	0	0	0	0	0
Public	0.01	4.28	0	0	0.03	0.09	0	4.41
OECM17_p005	0.23	75.70	0.02	0.50	3.21	4.85	0.14	84.65
Private	0.05	4.99	0.01	0.07	1.40	2.49	0.01	9.01
Public	0.18	70.71	0.01	0.44	1.81	2.36	0.13	75.64
OECM17_p01	0.28	80.29	0.02	0.76	4.36	5.70	0.14	91.54
Private	0.06	6.34	0.01	0.10	2.04	3.11	0.01	11.67
Public	0.21	73.95	0.01	0.65	2.33	2.59	0.13	79.87
OECM30_p0	2.32	131.32	0.53	4.08	28.71	53.67	0.23	220.87
Private	1.43	32.70	0.47	2.46	19.30	35.97	0.08	92.42
Public	0.89	98.62	0.06	1.62	9.41	17.70	0.16	128.45
OECM30_p005	1.89	127.72	0.38	3.45	32.80	53.36	0.26	219.86
Private	1.22	33.62	0.35	2.24	23.69	37.36	0.09	98.57
Public	0.67	94.10	0.03	1.21	9.12	16.00	0.17	121.30
OECM30_p01	1.65	124.69	0.35	2.94	33.49	52.22	0.26	215.60
Private	1.07	31.57	0.32	1.71	24.09	36.26	0.09	95.11
Public	0.58	93.13	0.02	1.22	9.41	15.96	0.17	120.49
Total	6.37	544.00	1.29	11.73	102.61	169.90	1.04	836.94

Bibliography

Chapter I.

Bawa, K.S., Sengupta, A., Chavan, V., Chellam, R., Ganesan, R., Krishnaswamy, J., Mathur, V.B., Nawn, N., Olsson, S.B., Pandit, N. & Quader, S. (2021). Securing biodiversity, securing our future: A national mission on biodiversity and human well-being for India. *Biological Conservation*, 253, p.108867.

Cameron, D.R., Schloss, C.A., Theobald, D.M., Morrison, S.A., 2022. A framework to select strategies for conserving and restoring habitat connectivity in complex landscapes. *Conservation Science and Practice*, 4(6), e12698.

Carroll, K.A., Inman, R.M., Hansen, A.J., Lawrence, R.L. & Barnett, K., 2021. A framework for collaborative wolverine connectivity conservation. *Iscience*, 24(8), 102840.

Cimon-Morin, J. Ô., Darveau, M., & Poulin, M. (2013). Fostering synergies between ecosystem services and biodiversity in conservation planning: A review. *Biological Conservation*, *166*, 144–154.

Dawson, N.M., Coolsaet, B., Sterling, E.J., Loveridge, R., Gross-Camp, N.D., Wongbusarakum, S., Sangha, K.K., Scherl, L.M., Phuong Phan, H., Zafra-Calvo, N. and Lavey, W.G., 2021. The role of Indigenous peoples and local communities in effective and equitable conservation. Donaldson, L., Bennie, J.J., Wilson, R.J., Maclean, I.M., 2021. Designing effective protected area networks for multiple species. *Biological Conservation*, 258, 109125.

Hong, W., Guo, R., Su, M., Tang, H., Chen, L., & Hu, W. (2017). Sensitivity evaluation and land-use control of urban ecological corridors: A case study of Shenzhen, China. *Land Use Policy*, *62*, 316-325.

International Union for Conservation of Nature (IUCN). (2017). Con- nectivity conservation. IUCN, Gland, Switzerland. Available from https://www.iucn.org/theme/protected-areas/wcpa/what-we-do/ connectivity-conservation (accessed May 2023).

Kim, J., Choi, H., Shin, W., Yun, J. & Song, Y., 2022. Complex spatiotemporal changes in land-use and ecosystem services in the Jeju Island UNESCO heritage and biosphere site (Republic of Korea). *Environmental Conservation*, 49(4), 272-279.

Kukkala, A. S., & Moilanen, A. (2017). Ecosystem services and connectivity in spatial conservation prioritization. *Landscape Ecology*, *32*(1), 5–14.

Le Saout, S., Hoffmann, M., Shi, Y., Hughes, A., Bernard, C., Brooks, T. M., … Rodrigues, A. S. L. (2013). Protected areas and effective biodiversity conservation. *Science*, *342*(6160), 803–805.

Li, J., Li, C., Zhu, F., Song, C., & Wu, J. (2013). Spatiotemporal pattern of urbanization in Shanghai, China between 1989 and 2005. *Landscape Ecology*, *28*(8), 1545–1565.

Luo, Y., Wu, J., Wang, X., & Peng, J. (2021). Using stepping-stone theory to evaluate the maintenance of landscape connectivity under China's ecological control line policy. *Journal of Cleaner Production*, *296*, 126356.

Maxwell, S.L., Cazalis, V., Dudley, N., Hoffmann, M., Rodrigues, A.S., Stolton, S., Visconti, P., Woodley, S., Kingston, N., Lewis, E. & Maron, M., 2020. Area-based conservation in the twenty-first century. *Nature*, 586(7828), 217-227.

Qian, Y., Zhou, W., Li, W., & Han, L. (2015). Understanding the dynamic of greenspace in the urbanized area of Beijing based on high resolution satellite images. *Urban Forestry & Urban Greening*, *14*(1), 39–47.

Snäll, T., Lehtomäki, J., Arponen, A., Elith, J., & Moilanen, A. (2016). Green Infrastructure Design Based on Spatial Conservation Prioritization and Modeling of Biodiversity Features and Ecosystem Services. *Environmental Management*, *57*(2), 251–256.

Strassburg, B. B. N., Iribarrem, A., Beyer, H. L., Cordeiro, C. L., Crouzeilles, R., Jakovac, C. C., … Visconti, P. (2020). Global priority areas for ecosystem restoration. *Nature*, *586*(7831), 724–729.

Thomas, C.D., Anderson, B.J., Moilanen, A., Eigenbrod, F., Heinemeyer, A., Quaife, T., Roy, D.B., Gillings, S., Armsworth, P.R. & Gaston, K.J., (2013). Reconciling biodiversity and carbon conservation. *Ecology letters*, 16, 39-47.

Chapter 2.

Bae, J.S., Joo, R.W., & Kim, Y.S. (2012) Forest transition in South Korea: Reality, path and drivers. *Land Use Policy* 29(1): 198-207.

Bagstad, K.J., Johnson, G.W., Voigt, B., & Villa, F. (2013) Spatial dynamics of ecosystem service flows: A comprehensive approach to quantifying actual services. *Ecosystem Services* 4: 117-125.

Bagstad, K.J., Villa, F., Batker, D., Harrison-Cox, J., Voigt, B., & Johnson, G.W. (2014) From theoretical to actual ecosystem services: Mapping beneficiaries and spatial flows in ecosystem service assessments. *Ecology and Society* 19(2).

Barr, J.C., & Choi, B.K. (2016) How the West Sees Jeju: an analysis of westerners' perception of Jeju's personality as a destination. *International Journal of Tourism Sciences* 16(3):135-149.

Başkent, E.Z. (2021) Assessment and valuation of key ecosystem services provided by two forest ecosystems in Turkey. *Journal of Environmental Management* 285:112135.

Bengtsson, J., Bullock, J. M., Egoh, B., Everson, C., Everson, T., O'Connor, T., & others. (2019). Grasslands-more important for ecosystem services than you might think. *Ecosphere*, 10(2), e02582.

Aneseyee, A. B., Noszczyk, T., Soromessa, T., & Elias, E. (2020). The InVEST Habitat Quality Model Associated with Land Use/Cover Changes: A Qualitative Case Study of the Winike Watershed in the Omo-Gibe Basin, Southwest Ethiopia. *Remote Sensing*, 12(7), 1103.

Capitani, C., Van Soesbergen, A., Mukama, K., Malugu, I., Mbilinyi, B., Chamuya, N., Kempen, B., & others. (2019). Scenarios of land use and land cover change and their multiple impacts on natural capital in Tanzania. *Environmental conservation*, 46(1), 17-24.

Chazdon, R.L. (2008) Beyond Deforestation?: Restoring Degraded Lands. *Science* 320:1458-1460.

Chazdon, R.L., Brancalion, P.H.S., Lamb, D., Laestadius, L., Calmon, M., & Kumar, C. (2017) A Policy-Driven Knowledge Agenda for Global Forest and Landscape Restoration. *Conservation Letters* 10(1): 125-132.

Crossman, N.D., Burkhard, B., & Nedkov, S. (2012) Quantifying and mapping ecosystem services. International Journal of Biodiversity Science, *Ecosystem Services & Management* 8(1-2):1-4.

Daily, G. C., Polasky, S., Goldstein, J., Kareiva, P. M., Mooney, H. A., Pejchar, L., ... & Shallenberger, R. (2009). Ecosystem services in decision making: Time to deliver. *Frontiers in Ecology and the Environment*, 7(1), 21-28.

de Groot. R.S., Alkemade, R., Braat, L., Hein, L., & Willemen, L. (2010) Challenges in integrating the concept of ecosystem services and values in landscape planning. management and decision making. *Ecological Complexity* 7(3):260-272.

Deng, J., & Bauer, T. (2002) Evaluating natural attractions in tourism. *Annals of Tourism Research* 29(2): 422-438.

Dolezal, J., Altman, J., Kopecky, M., Cerny, T., Janecek, S., Bartos, M., & Song, J.S. (2012). Plant diversity changes during the postglacial in East Asia: insights from forest refugia on Halla Volcano. Jeju Island. *PLoS One* 7(3):e33065.

Egarter Vigl, L., Depellegrin, D., Pereira, P., de Groot, R., & Tappeiner, U. (2017). Mapping the ecosystem service delivery chain: Capacity, flow, and demand pertaining to aesthetic experiences in mountain landscapes. *Science of the Total Environment*, 574, 422-436.

Gao, J., Li, F., Gao, H., Zhou, C., & Zhang, X. (2017). The impact of land-use change on water-related ecosystem services: A study of the Guishui River Basin, Beijing, China. *Journal of Cleaner Production*, 163, S148-S155.

Rodríguez, L. G., Hogarth, N. J., Zhou, W., Xie, C., Zhang, K., & Putzel, L. (2016). China's conversion of cropland to forest program: A systematic review of the environmental and socioeconomic effects. *Environmental Evidence*, 5(1), 1-22.

Haase, D., Schwarz, N., Strohbach, M., Kroll, F., & Seppelt, R. (2012). Synergies, trade-offs, and losses of ecosystem services in urban regions: An integrated multiscale framework applied to the Leipzig-Halle region, Germany. *Ecology and Society*, 17(3).

Han, Y., Kang, W., Thorne, J., & Song, Y. (2019). Modeling the effects of landscape patterns of current forests on the habitat quality of historical remnants in a highly urbanized area. *Urban Forestry and Urban Greening*, 41, 354-363.

He, C., Zhang, D., Huang, Q., & Zhao, Y. (2016). Assessing the potential impacts of urban expansion on regional carbon storage by linking the LUSD-urban and InVEST models. *Environmental Modelling and Software*, 75, 44-58.

Huang, L., Shao, Q., Liu, J., & Lu, Q. (2018). Improving ecological conservation and restoration through payment for ecosystem services in Northeastern Tibetan Plateau, China. *Ecosystem Services*, 31, 181-193.

IPBES. (2019). Global Assessment Report on Biodiversity and Ecosystem Services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services.

Jeju Province. (2006). Jeju Forest 60 Years History. Jeju Province.

Jeju Tourism Association. (2020). Number of tourist visitors in Jeju in 2020. Retrieved April 18, 2021, from http://www.visitjeju.or.kr/web/bbs/bbsList.do?bbsId=TOURSTAT

Jeung, Y. H., Lee, S. M., Yoon, H. J., & Lee, D. K. (2018). A Study on the landscape change by Privately-invested Park of Long-term Non - executed Urban Parks by using accumulated viewshed analysis -. *Journal of the Korea Society of Environmental Restoration Technology*, 21(2), 65-75.

KEI. (2015). Development of Decision Supporting Framework to Enhance Natural Capital Sustainability: Focusing on Ecosystem Service Analysis (TRKO201800014564). Retrieved from https://www.kei.re.kr/elibList.es?mid=a10102070100&elibName=researchreport&class_id=&act=view&c_id=707847&m=483&nPage=49&keyField=&keyWord=

Ki, J. S., Jeon, Y., Ryu, C. K., & Kim, S. S. (2016). A signification and meaning of Geomunoreum as a representative geosite of Global Geoparks. *Journal of the Geological Society of Korea*, 52(5), 763-774.

Kim JS, Kim DS, Lee KC, Lee JS, King GM, Kang S (2018) Microbial community structure and functional potential of lava-formed Gotjawal soils in Jeju. Korea. *PLoS ONE* 13(10), e0204761.

Kim, K., Park, O. J., Barr, J., & Yun, H. J. (2019). Tourists' shifting perceptions of UNESCO heritage sites: lessons from Jeju Island-South Korea. *Tourism Review*, 74(1), 20-29.

Kim, T. Y., Song, C. H., Lee, W. K., Kim, M. I., Lim, C. H., Jeon, S. W., & Kim, J. S. (2015). Habitat Quality Valuation Using InVEST Model in Jeju Island. *Journal of the Korea Society of Environmental Restoration Technology*, 18(5), 1-11.

Le, H. D., Smith, C., Herbohn, J., & Harrison, S. (2012). More than just trees: Assessing reforestation success in tropical developing countries. *Journal of Rural Studies*, 28, 5-19.

Ministry of Agriculture, Food and Rural Affairs. (2021). Announcement of the results of the 2020 grassland management survey. Retrieved from https://www.mafra.go.kr/mafra/293/subview.do?enc=Zm5jdDF8QEB8JTJGYmJzJTJGbWFmcmElMkY2OCUyRjMyNjQzNSUyRmFydGNsVmlldy5kbyUzRmJic0NsU2VxJTNEJTI2cmdzRW5kZGVTdHIlM0QlMjZiYnNPcGVuV3JkU2VxJTNEJTI2cmdzQmduZGV.

Millennium Ecosystem Assessment. (2005). Ecosystems and Human Well-being: Synthesis. Island Press.

Nam, H. Y., Kim, E. M., Choi, C. Y., & Kang, C. W. (2019). Avifauna of Gungdae Oreum and its seasonal changes in the Jeju Eastern Oreum Group in Jeju Island. *Journal of Asia-Pacific Biodiversity*, 12(4), 515-521.

National Construction Research Institute. (1973). 土地利用現況圖 / 建設部 ; 國立地理院 [공편]. 1-10卷.

Nelson, E., Mendoza, G., Regetz, J., Polasky, S., Tallis, H., Cameron, D. R., ... & Shaw, M. R. (2009). Modeling multiple ecosystem services, biodiversity conservation, commodity production and tradeoffs at landscape scales. *Frontiers in Ecology and the Environment*, 7(1), 4-11.

O'Driscoll, J. (2017). Landscape prominence: Examining the topographical position of Irish hillforts using a cumulative viewshed approach. *Journal of Archaeological Science*, 16, 73-89.

Park, M. S., & Lee, H. (2014). Forest policy and law for sustainability within the Korean peninsula. *Sustainability*, 6(8), 5162-5186.

Paudyal, K., Baral, H., Bhandari, S. P., Bhandari, A., & Keenan, R. J. (2019). Spatial assessment of the impact of land use and land cover change on supply of ecosystem services in Phewa watershed, Nepal. *Ecosystem Services*, 36, 100895.

Polasky, S., Nelson, E., Pennington, D., & Johnson, K. A. (2011). The impact of land-use change on ecosystem services, biodiversity and returns to landowners: A case study in the state of Minnesota. *Environmental and Resource Economics*, 48(2), 219-242.

Posner, S., Verutes, G., Koh, I., Denu, D., & Ricketts, T. (2016). Global use of ecosystem service models. *Ecosystem Services*, 17, 131-141.

Redhead, J. W., Stratford, C., Sharps, K., Jones, L., Ziv, G., Clarke, D., & Bullock, J. M. (2016). Empirical validation of the InVEST water yield ecosystem service model at a national scale. *Science of the Total Environment*, 569, 1418–1426.

Ridding, L. E., Redhead, J. W., Oliver, T. H., Schmucki, R., McGinlay, J., Graves, A. R., & Bullock, J. M. (2018). The importance of landscape characteristics for the delivery of cultural ecosystem services. *Journal of Environmental Management*, 206, 1145-1154.

Rizvi, A. R., Baig, S., Barrow, E., & Kumar, C. (2015). Synergies between Climate Mitigation and Adaptation in Forest Landscape Restoration. Gland, Switzerland: IUCN.

Roh, Y. H., Kim, C. K., & Hong, H. H. (2016). Time-Series Changes to Ecosystem Regulating Services in Jeju : Focusing on Estimating Carbon Sequestration and Evaluating Economic Feasibility. *Journal of Environmental Policy and Administration*, 24(2), 29–44.

Ruhl, J. B., Kraft, S. E., & Lant, C. L. (2007). The Law and Policy of Ecosystem Services. Island Press, Washington, DC.

Sabogal, C., Besacier, C., & McGuire, D. (2015). Forest and landscape restoration: Concepts, approaches and challenges for implementation. *Unasylva*, 66(245), 3-10.

Schirpke, U., Kohler, M., Leitinger, G., Fontana, V., Tasser, E., & Tappeiner, U. (2017). Future impacts of changing land-use and climate on ecosystem services of mountain grassland and their resilience. *Ecosystem Services*, 26, 79-94.

Sharp, R., Douglass, J., Wolny, S., Arkema, K., Bernhardt, J., Bierbower, W., Chaumont, N., Denu, D., Fisher, D., Glowinski, K., Griffin, R., Guannel, G., Guerry, A., Johnson, J., Hamel, P., Kennedy, C., Kim, C. K., Lacayo, M., Lonsdorf, E., Mandle, L., Rogers, L., Silver, J., Toft, J., Verutes, G., Vogl, A. L., Wood, S., & Wyatt, K. (2020). InVEST 3.9.0.post74+ug.g0b3f465 User's Guide. The Natural Capital Project, Stanford University, University of Minnesota, The Nature Conservancy, and World Wildlife Fund.

Sun, X., Zhang, Y., Shen, Y., Randhir, T. O., & Cao, M. (2019). Exploring ecosystem services and scenario simulation in the headwaters of Qiantang River watershed of China. *Environmental Science and Pollution Research*, 26(34), 34905-34923.

Sun, X., Jiang, Z., Liu, F., & Zhang, D. (2019). Monitoring spatio-temporal dynamics of habitat quality in Nansihu Lake basin, eastern China from 1980 to 2015. *Ecological Indicators*, 102, 716-723.

Tao, Y., Wang, H., Ou, W., & Guo, J. (2018). A land-cover-based approach to assessing ecosystem services supply and demand dynamics in the rapidly urbanizing Yangtze River Delta region. *Land Use Policy*, 72, 250-258.

Upadhaya, S., & Dwivedi, P. (2019). Conversion of forestlands to blueberries: Assessing implications for habitat quality in Alabaha river watershed in Southeastern Georgia, United States. *Land Use Policy*, 89, 104229.

Verburg, P. H. (2006). Simulating feedbacks in land use and land cover change models. *Landscape Ecology*, 21(8), 1171-1183.

Verburg, P. H., van de Steeg, J., Veldkamp, A., & Willemen, L. (2009). From land cover change to land function dynamics: A major challenge to improve land characterization. *Journal of Environmental Management*, 90, 1327-1335.

Villa, F., Bagstad, K. J., Voigt, B., Johnson, G. W., Portela, R., Honzák, M., & Batker, D. (2014). A methodology for adaptable and robust ecosystem services assessment. *PLoS ONE*, 9(3), e91001.

Wheatley, D. (1995). Cumulative Viewshed Analysis: a GIS-based method for investigating intervisibility, and its archaeological application. In: Lock, G. R., & Stancic, Z. (eds). Archaeology and geographical information systems: a European perspective. Taylor & Francis, New York, 171-186.

Xu, Q., Zheng, X., & Zheng, M. (2019). Do urban planning policies meet sustainable urbanization goals? A scenario-based study in Beijing, China. *Science of the Total Environment*, 670, 498-507.
Yohannes, H., Soromessa, T., Argaw, M., & Dewan, A. (2021). Spatio-temporal changes in habitat quality and linkage with landscape characteristics in the Beressa watershed, Blue Nile basin of Ethiopian highlands. *Journal of Environmental Management*, 281, 111885.
You, W. H., Seo, S. J., & Choi, B. K. (2017). A comparative Study on Residents' and Visitors' Perceptions on Six Heritage in Jeju Designated by UNESCO and UNFAO. *Journal of the Korean Institute of Traditional Landscape Architecture*, 35(4), 134-143.
Zhai, T., Wang, J., Fang, Y., Qin, Y., Huang, L., & Chen, Y. (2020). Assessing ecological risks caused by human activities in rapid urbanization coastal areas: Towards an integrated approach to determining key areas of terrestrial-oceanic ecosystems preservation and restoration. *Science of the Total Environment*, 708, 135153.
Zhao, S., Peng, C., Jiang, H., Tian, D., Lei, X., & Zhou, X. (2006). Land use change in Asia and the ecological consequences. *Ecological Research*, 21(6), 890-896.

Chapter 3.

Ai, J., Yu, K., Zeng, Z., Yang, L., Liu, Y., & Liu, J. (2022). Assessing the dynamic landscape ecological risk and its driving forces in an island city based on optimal spatial scales: Haitan Island, China. *Ecological Indicators*, *137*, 108771.
An, Y., Liu, S., Sun, Y., Shi, F., & Zhao, S. (2020). Negative effects of farmland expansion on multi-species landscape connectivity in a tropical region in Southwest China. *Agricultural Systems*, *179*, 102766.
Babí Almenar, J., Bolowich, A., Elliot, T., Geneletti, D., Sonnemann, G., & Rugani, B. (2019). Assessing habitat loss, fragmentation and ecological connectivity in Luxembourg to support spatial planning. *Landscape and Urban Planning*, *189*(May), 335–351.
Balzan, M. V., Potschin-Young, M., & Haines-Young, R. (2018). Island ecosystem services: Insights from a literature review on case-study island ecosystem services and future prospects. *International Journal of Biodiversity Science, Ecosystem Services and Management*, Vol. 14, pp. 71–90.
Barbosa, O., Tratalos, J. A., Armsworth, P. R., Davies, R. G., Fuller, R. A., Johnson, P., & Gaston, K. J. (2007). Who benefits from access to green space? A case study from Sheffield, UK. Landscape and Urban planning, 83(2-3), 187-195.
Cameron, D. R., Schloss, C. A., Theobald, D. M., & Morrison, S. A. (2022). A framework to select strategies for conserving and restoring habitat connectivity in complex landscapes. *Conservation Science and Practice*, (December 2021), 1–16.
Chun, J., Kim, C. K., Kang, W., Park, H., Kim, G., & Lee, W. K. (2019). Sustainable management of carbon sequestration service in areas with high development pressure: Considering land use changes and carbon costs. *Sustainability (Switzerland)*, *11*(18), 1–20.
Chung, M. G., Kang, H., & Choi, S.-U. (2015). Assessment of Coastal Ecosystem Services for Conservation Strategies in South Korea. *PLOS ONE*, *10*(7), e0133856.

Cimon-Morin, J. Ô., Darveau, M., & Poulin, M. (2013). Fostering synergies between ecosystem services and biodiversity in conservation planning: A review. *Biological Conservation*, *166*, 144–154. Dong, J., Peng, J., Liu, Y., Qiu, S., & Han, Y. (2020). Integrating spatial continuous wavelet transform and kernel density estimation to identify ecological corridors in megacities. *Landscape and Urban Planning*, *199*, 103815.

Fahrig, L. (2003). Effects of Habitat Fragmentation on Biodiversity. *Annual Review of Ecology, Evolution, and Systematics*, *34*, 487–515.

Fu, Y., Shi, X., He, J., Yuan, Y., & Qu, L. (2020). Identification and optimization strategy of county ecological security pattern: A case study in the Loess Plateau, China. *Ecological Indicators*, *112*, 106030.

Guzmán-Colón, D. K., Pidgeon, A. M., Martinuzzi, S., & Radeloff, V. C. (2020). Conservation planning for island nations: Using a network analysis model to find novel opportunities for landscape connectivity in Puerto Rico. *Global Ecology and Conservation*, *23*, e01075.

Harris LD. (1984). The fragmented forest: island biogeography theory and the preservation of biotic diversity. University of Chicago Press, Chicago, Illinois.

Hilty, J., Worboys, G.L., Keeley, A., Woodley, S., Lausche, B.J., Locke, H., Carr, M., Pulsford, I., Pittock, J., White, J.W., Theobald, D.M., Levine, J., Reuling, M., Watson, J.E.M., Ament, R., Groves, C., Tabor, G.M. (2020). Guidelines for Conserving Connectivity through Ecological Networks and Corridors. IUCN, Gland, Switzerland.

Hodgson, J. A., Moilanen, A., Wintle, B. A., & Thomas, C. D. (2011). Habitat area, quality and connectivity: striking the balance for efficient conservation. *Journal of Applied Ecology*, *48*(1), 148–152.

Hong, H.-J., Kim, C.-K., Lee, H.-W., & Lee, W.-K. (2021). Conservation, Restoration, and Sustainable Use of Biodiversity Based on Habitat Quality Monitoring: A Case Study on Jeju Island, South Korea (1989–2019). *Land*, *10*(8), 774.

Hong, W., Guo, R., Su, M., Tang, H., Chen, L., & Hu, W. (2017). Sensitivity evaluation and land-use control of urban ecological corridors: A case study of Shenzhen, China. *Land Use Policy*, *62*, 316-325.

Huang, J., Hu, Y., & Zheng, F. (2020). Research on recognition and protection of ecological security patterns based on circuit theory: a case study of Jinan City. *Environmental Science and Pollution Research*, *27*(11), 12414–12427.

International Union for Conservation of Nature (IUCN). (2017). Con- nectivity conservation. IUCN, Gland, Switzerland. Available from https://www.iucn.org/theme/protected-areas/wcpa/what-we-do/ connectivity-conservation (accessed May 2023).

International Union for Conservation of Nature (IUCN). (2020). Jeju Volcanic Island and Lava Tubes Conservation Outlook Assessment. The IUCN World Heritage Outlook. Available from https://worldheritageoutlook.iucn.org/explore-sites/wdpaid/903130 (accessed May 2023).

Jalkanen, J., Toivonen, T., & Moilanen, A. (2020a). Identification of ecological networks for land-use planning with spatial conservation prioritization. *Landscape Ecology*, *35*(2), 353–371. Jalkanen, J., Fabritius, H., Vierikko, K., Moilanen, A., & Toivonen, T. (2020b). Analyzing fair access to urban green areas using multimodal accessibility measures and spatial prioritization. *Applied Geography*, *124*, 102320.

Jeju Tourism Organization (2020) Annual Report on Jeju Tourism Trends as of 2020. Available from https://ijto.or.kr/korean/Bd/view.php?btable=pds&bno=351&pds_skin=&p=1&lcate=1 (accessed May 2023)

Kier, G., Kreft, H., Tien, M. L., Jetz, W., Ibisch, P. L., Nowicki, C., … Barthlott, W. (2009). A global assessment of endemism and species richness across island and mainland regions. *Proceedings of the National Academy of Sciences of the United States of America*, *106*(23), 9322–9327.

Kim, J., Choi, H., Shin, W., Yun, J., & Song, Y. (2022). Complex spatiotemporal changes in land-use and ecosystem services in the Jeju Island UNESCO heritage and biosphere site (Republic of Korea). *Environmental Conservation*, *49*(4), 272-279.

Kim, S. Y., Cho, S. H., & An, S. L. (2020). Flora characteristics of vascular plants in the Geomun Oreum, UNESCO World Natural Heritage Site in Jeju Island, Korea. *Journal of Asia-Pacific Biodiversity*, *13*(4), 652–657.

Kim, T., Song, C., Lee, W.-K., Kim, M., Lim, C.-H., Jeon, S. W., & Kim, J. (2015). Habitat Quality Valuation Using InVEST Model in Jeju Island. *Journal of the Korea Society of Environmental Restoration Technology*, *18*(5), 1–11.

Kukkala, A. S., & Moilanen, A. (2017). Ecosystem services and connectivity in spatial conservation prioritization. *Landscape Ecology*, *32*(1), 5–14.

Landau, V. A., Shah, V. B., Anantharaman, R., & Hall, K. R. (2021). Omniscape.jl: Software to compute omnidirectional landscape connectivity. *Journal of Open Source Software*, *6*(57), 2829.

LaRue, M. A., & Nielsen, C. K. (2008). Modelling potential dispersal corridors for cougars in midwestern North America using least-cost path methods. *Ecological Modelling*, *212*(3–4), 372–381.

Lee, H., Kim, C., Hong, H., Rho, Y., Kang, S., Kim, J., Shin, S., Lee, S., Kang, J., Wood, S., Fisher, D. (2015). Development of Decision Supporting Framework to Enhance Natural Capital Sustainability: Focusing on Ecosystem Service Analysis. KEI (Korea Enviornment Institute).

Lehtomäki, J., & Moilanen, A. (2013). Methods and workflow for spatial conservation prioritization using Zonation. *Environmental Modelling & Software*, *47*, 128-137.

Le Saout, S., Hoffmann, M., Shi, Y., Hughes, A., Bernard, C., Brooks, T. M., … Rodrigues, A. S. L. (2013). Protected areas and effective biodiversity conservation. *Science*, *342*(6160), 803–805. https://doi.org/10.1126/SCIENCE.1239268/SUPPL_FILE/1239268.LESAOUET.SM.PDF

Li, J., Li, C., Zhu, F., Song, C., & Wu, J. (2013). Spatiotemporal pattern of urbanization in Shanghai, China between 1989 and 2005. *Landscape Ecology*, *28*(8), 1545–1565.

Li, S., Xiao, W., Zhao, Y., & Lv, X. (2020). Incorporating ecological risk index in the multi-process MCRE model to optimize the ecological security pattern in a semi-arid area with intensive coal mining: A case study in northern China. *Journal of Cleaner Production*, *247*, 119143.

Liang, J., He, X., Zeng, G., Zhong, M., Gao, X., Li, X., … Mo, D. (2018). Integrating priority areas and ecological corridors into national network for conservation planning in China. *Science of The Total Environment*, *626*, 22–29.

Liu, C., Yang, M., Hou, Y., Zhao, Y., & Xue, X. (2021). Spatiotemporal evolution of island ecological quality under different urban densities: A comparative analysis of Xiamen and Kinmen Islands, southeast China. *Ecological Indicators*, *124*, 107438.

Lundberg, J., & Moberg, F. (2003). Mobile link organisms and ecosystem functioning: Implications for ecosystem resilience and management. *Ecosystems*, *6*(1), 87–98.

Luo, Y., Wu, J., Wang, X., & Peng, J. (2021). Using stepping-stone theory to evaluate the maintenance of landscape connectivity under China's ecological control line policy. *Journal of Cleaner Production*, *296*, 126356.

McRae, B., Conservancy, T. N., Popper, K., Jones, A., Schindel, M., & Conservancy, T. N. (2016). Conserving Nature ' s Stage : Mapping Omnidirectional Connectivity for Resilient. In *The Nature Conservancy*.

McRae, B. H., & Beier, P. (2007). Circuit theory predicts gene flow in plant and animal populations. *Proceedings of the National Academy of Sciences*, *104(50)*, 19885-19890.

McRae, B. H., Hall, S. A., Beier, P., & Theobald, D. M. (2012). Where to Restore Ecological Connectivity? Detecting Barriers and Quantifying Restoration Benefits. *PLOS ONE*, *7*(12), e52604.

Mitchell, M. G. E., Bennett, E. M., & Gonzalez, A. (2013). Linking Landscape Connectivity and Ecosystem Service Provision: Current Knowledge and Research Gaps. *Ecosystems*, *16*, 894–908.

Moilanen, A., Franco, A. M. A., Early, R. I., Fox, R., Wintle, B., & Thomas, C. D. (2005). Prioritizing multiple-use landscapes for conservation: methods for large multi-species planning problems. *Proceedings of the Royal Society B: Biological Sciences*, *272*(1575), 1885–1891.

Ng, C. N., Xie, Y. J., & Yu, X. J. (2013). Integrating landscape connectivity into the evaluation of ecosystem services for biodiversity conservation and its implications for landscape planning. *Applied Geography*, *42*, 1–12.

Nistor, M.-M., & Porumb, G. C. G. (2015). How to compute the land cover evapotranspiration at regional scale? A spatial approach of Emilia-Romagna region. *GEOREVIEW: Scientific Annals of Stefan Cel Mare University of Suceava. Geography Series*, *25*(1), 38–53.

Nistor, M. (2017). Mapping evapotranspiration coefficients in the Paris metropolitan area. *Georeview*, (April), 1–15.

Peng, J., Pan, Y., Liu, Y., Zhao, H., & Wang, Y. (2018a). Linking ecological degradation risk to identify ecological security patterns in a rapidly urbanizing landscape. *Habitat International*, *71*, 110–124. https://doi.org/10.1016/j.habitatint.2017.11.010

Peng, J., Yang, Y., Liu, Y., Hu, Y., Du, Y., Meersmans, J., & Qiu, S. (2018b). Linking ecosystem services and circuit theory to identify ecological security patterns. *Science of the Total Environment*, *644*, 781–790.

Phillips, P., Clark, M. M., Baral, S., Koen, E. L., & Bowman, J. (2021). Comparison of methods for estimating omnidirectional landscape connectivity. *Landscape Ecology*, 1–15.

Qian, Y., Zhou, W., Li, W., & Han, L. (2015). Understanding the dynamic of greenspace in the urbanized area of Beijing based on high resolution satellite images. *Urban Forestry & Urban Greening*, *14*(1), 39–47.

Ramel, C., Rey, P. L., Fernandes, R., Vincent, C., Cardoso, A. R., Broennimann, O., Pellissier, L., Pradeervand, J., Ursenbacher, S., Schmidt, B., & Guisan, A. (2020). Integrating ecosystem services within spatial biodiversity conservation prioritization in the Alps. *Ecosystem Services*, *45*, 101186.

Sahle, M., Saito, O., Fürst, C., & Yeshitela, K. (2019). Quantifying and mapping of water-related ecosystem services for enhancing the security of the food-water-energy nexus in tropical data–sparse catchment. *Science of The Total Environment*, *646*, 573–586.

Sánchez-Canales, M., López Benito, A., Passuello, A., Terrado, M., Ziv, G., Acuña, V., …

Elorza, F. J. (2012). Sensitivity analysis of ecosystem service valuation in a Mediterranean watershed. *Science of The Total Environment*, *440*, 140–153.

Sharp, R., Douglass, J., Wolny, S., Arkema, K., Bernhardt, J., Bierbower, W., Chaumont, N., Denu, D., Fisher, D., Glowinski, K., Griffin, R., Guannel, G., Guerry, A., Johnson, J., Hamel, P., Kennedy, C., Kim, C.K., Lacayo, M., Lonsdorf, E., Mandle, L., Ro, K. (2020). *InVEST 3.10.2.post34+ug.ga66060d User's Guide*.

Snäll, T., Lehtomäki, J., Arponen, A., Elith, J., & Moilanen, A. (2016). Green Infrastructure Design Based on Spatial Conservation Prioritization and Modeling of Biodiversity Features and Ecosystem Services. *Environmental Management*, *57*(2), 251–256.

Strassburg, B. B. N., Iribarrem, A., Beyer, H. L., Cordeiro, C. L., Crouzeilles, R., Jakovac, C. C., … Visconti, P. (2020). Global priority areas for ecosystem restoration. *Nature*, *586*(7831), 724–729. https://doi.org/10.1038/s41586-020-2784-9

Taylor, P. D., Fahrig, L., Henein, K., & Merriam, G. (1999). Connectivity is a vital element of landscape structure. *NCASI Technical Bulletin*, *2*(781), 534.

Technica, G. (2016). *LAND COVER AND TEMPERATURE IMPLICATIONS FOR THE SEASONAL EVAPOTRANSPIRATION IN EUROPE*. *11*(2), 39–50.

United Nations Environment Programme (UNEP). (2015). UNEP launches global connectivity conservation project. UNEP, Nairobi. Available from http://www.unep-wcmc.org/news/unep- launches-global-connectivity-conservation-project (accessed May 2023).

Vitousek, P. M., Mooney, H. A., Lubchenco, J., & Melillo, J. M. (1997). Human domination of Earth's ecosystems. *Science*, *277*(5325), 494–499. https://doi.org/10.1126/science.277.5325.494

Wang, C., Yu, C., Chen, T., Feng, Z., Hu, Y., & Wu, K. (2020). Can the establishment of ecological security patterns improve ecological protection? An example of Nanchang, China. *Science of the Total Environment*, *740*, 140051.

Wang, F., Yuan, X., Zhou, L., & Zhang, M. (2022). Integrating ecosystem services and landscape connectivity to construct and optimize ecological security patterns: a case study in the central urban area Chongqing municipality, China. *Environmental Science and Pollution Research*, 1–17. https://doi.org/10.1007/S11356-021-16281-4

Xiao, S., Wu, W., Guo, J., Ou, M., Pueppke, S. G., Ou, W., & Tao, Y. (2020). An evaluation framework for designing ecological security patterns and prioritizing ecological corridors: application in Jiangsu Province, China. *Landscape Ecology*, *35*(11), 2517–2534.

Zhang, M. G., Slik, J. W. F., & Ma, K. P. (2017). Priority areas for the conservation of perennial plants in China. *Biological Conservation*, *210*, 56–63.

Chapter 4.

Alves-Pinto, H., Geldmann, J., Jonas, H., Maioli, V., Balmford, A., Latawiec, A. E., ... & Strassburg, B. (2021). Opportunities and challenges of other effective area-based conservation measures (OECMs) for biodiversity conservation. *Perspectives in Ecology and Conservation*, 19(2), 115-120.

Bawa, K. S., Sengupta, A., Chavan, V., Chellam, R., Ganesan, R., Krishnaswamy, J., ... & Quader, S. (2021). Securing biodiversity, securing our future: A national mission on biodiversity and human well-being for India. *Biological Conservation*, 253, 108867.

Benez-Secanho, F. J., Dwivedi, P., Ferreira, S., Hepinstall-Cymerman, J., & Wenger, S. (2022). Trade-offs Between the Value of Ecosystem Services and Connectivity Among Protected Areas in the Upper Chattahoochee Watershed. *Environmental Management*, 69(5), 937-951.

Beyer, H. L., Dujardin, Y., Watts, M. E., & Possingham, H. P. (2016). Solving conservation planning problems with integer linear programming. *Ecological Modelling*, 328, 14-22.

Borrini-Feyerabend, G., Kothari, A., Alcom, J., Amaya, C., Bo, L., Campese, J., & Carroll, M. (2010). Strengthening what works: recognising and supporting the conservation achievements of indigenous peoples and local communities. *IUCN Commission on Environmental, Economic and Social Policy. Gland.*

Bottrill, M. C., & Pressey, R. L. (2012). The effectiveness and evaluation of conservation planning. *Conservation Letters*, 5(6), 407-420.

Bremer, L. L., DeMaagd, N., Wada, C. A., & Burnett, K. M. (2021). Priority watershed management areas for groundwater recharge and drinking water protection: A case study from Hawai ‘i Island. *Journal of Environmental Management*, 286, 111622.

Brown, C. J., Bode, M., Venter, O., Barnes, M. D., McGowan, J., Runge, C. A., ... & Possingham, H. P. (2015). Effective conservation requires clear objectives and prioritizing actions, not places or species. *Proceedings of the National Academy of Sciences*, 112(32), E4342-E4342.

Cameron, D. R., Schloss, C. A., Theobald, D. M., & Morrison, S. A. (2022). A framework to select strategies for conserving and restoring habitat connectivity in complex landscapes. *Conservation Science and Practice*, 4(6), e12698.

Carroll, K. A., Inman, R. M., Hansen, A. J., Lawrence, R. L., & Barnett, K. (2021). A framework for collaborative wolverine connectivity conservation. *Iscience*, 24(8), 102840.

CBD. (2022). Decision 15/4: Kunming-Montreal Global Biodiversity Framework.

Choe, H., Thorne, J. H., Huber, P. R., Lee, D., & Quinn, J. F. (2018). Assessing shortfalls and complementary conservation areas for national plant biodiversity in South Korea. *PloS one*, 13(2), e0190754.

Coad, L., Watson, J. E., Geldmann, J., Burgess, N. D., Leverington, F., Hockings, M., ... & Di Marco, M. (2019). Widespread shortfalls in protected area resourcing undermine efforts to conserve biodiversity. *Frontiers in Ecology and the Environment*, 17(5), 259-264.

da Silva, J. M. C., Pinto, L. P., & Scarano, F. R. (2021). Toward integrating private conservation lands into national protected area systems: lessons from a megadiversity country. *Conservation Science and Practice*, 3(7), e433.

Darvill, R., & Lindo, Z. (2016). The inclusion of stakeholders and cultural ecosystem services in land management trade-off decisions using an ecosystem services approach. *Landscape Ecology*, 31, 533-545.

Dawson, N. M., Coolsaet, B., Sterling, E. J., Loveridge, R., Gross-Camp, N. D., Wongbusarakum, S., Sangha, K. K., Scherl, L. M., Phuong Phan, H., Zafra-Calvo, N., Lavey, W. G., Byakagaba, P., Idrobo, C. J., Chenet, A., Bennett, N. J., Mansourian, S., & Rosado-May, F. J. (2021). The role of Indigenous peoples and local communities in effective and equitable conservation. *Ecology and Society*, 26(3), 19.

Diz, D., Johnson, D., Riddell, M., Rees, S., Battle, J., Gjerde, K., Hennige, S., & Roberts, J. M. (2018). Mainstreaming marine biodiversity into the SDGs: the role of other effective area-based conservation measures (SDG 14.5). *Marine Policy*, 93, 251-261.

Donaldson, L., Bennie, J. J., Wilson, R. J., & Maclean, I. M. (2021). Designing effective protected area networks for multiple species. *Biological Conservation*, 258, 109125.

Duchardt, C. J., Monroe, A. P., Heinrichs, J. A., O'Donnell, M. S., Edmunds, D. R., & Aldridge, C. L. (2021). Prioritizing restoration areas to conserve multiple sagebrush-associated wildlife species. *Biological Conservation*, 260, 109212.

Game, E. T., Kareiva, P., & Possingham, H. P. (2013). Six common mistakes in conservation priority setting. *Conservation Biology*, 27(3), 480-485.

Ghoddousi, A., Loos, J., & Kuemmerle, T. (2022). An outcome-oriented, social–ecological framework for assessing protected area effectiveness. *Bioscience*, 72(2), 201-212.

Hamel, P., Valencia, J., Schmitt, R., Shrestha, M., Piman, T., Sharp, R. P., Francesconi, W., & Guswa, A. J. (2020). Modeling seasonal water yield for landscape management: Applications in Peru and Myanmar. *Journal of Environmental Management*, 270, 110792.

Hanson, J., Schuster, R., Morrell, N., Strimas-Mackey, M., Edwards, B. P. M., Watts, M. E., Arcese, P., Bennett, J., & Possingham, H. P. (2023). prioritizr: Systematic Conservation Prioritization in R.

Hanson, J. O., Vincent, J., Schuster, R., Fahrig, L., Brennan, A., Martin, A. E., Hughes, J. S., Pither, R., & Bennett, J. R. (2022). A comparison of approaches for including connectivity in systematic conservation planning. *Journal of Applied Ecology*, 59(10), 2507-2519.

Hashimoto, S., DasGupta, R., Kabaya, K., Matsui, T., Haga, C., Saito, O., & Takeuchi, K. (2019). Scenario analysis of land-use and ecosystem services of social-ecological landscapes: implications of alternative development pathways under declining population in the Noto Peninsula, Japan. *Sustainability Science*, 14, 53-75.

Heller, N. E., & Zavaleta, E. S. (2009). Biodiversity management in the face of climate change: a review of 22 years of recommendations. *Biological conservation*, 142(1), 14-32.

Hijmans, R. J., Phillips, S., Leathwick, J., Elith, J., & Hijmans, M. R. J. (2017). Package ‘dismo’. *Circles*, 9(1), 1-68.

Hilty, J., Worboys, G. L., Keeley, A., Woodley, S., Lausche, B., Locke, H., Carr, M., Pulsford, I., Pittock, J., White, J. W., & Theobald, D. M. (2020). Guidelines for conserving connectivity through ecological networks and corridors. *Best practice protected area Guidelines Series*, 30, p-122.

Huang, Z., Bai, Y., Alatalo, J. M., & Yang, Z. (2020). Mapping biodiversity conservation priorities for protected areas: A case study in Xishuangbanna Tropical Area, China. *Biological Conservation*, 249, 108741.

International Union for Conservation of Nature (IUCN). (2020). Jeju Volcanic Island and Lava Tubes Conservation Outlook Assessment. The IUCN World Heritage Outlook. Retrieved from https://worldheritageoutlook.iucn.org/explore-sites/wdpaid/903130

Isbell, F., Calcagno, V., Hector, A., Connolly, J., Harpole, W. S., Reich, P. B., Scherer-Lorenzen, M., Schmid, B., Tilman, D., Van Ruijven, J., & Weigelt, A. (2011). High plant diversity is needed to maintain ecosystem services. *Nature*, 477(7363), 199-202.

Jonas, H. D., Lee, E., Jonas, H. C., Matallana-Tobon, C., Sander Wright, K., Nelson, F., & Enns, E. (2017). Will 'other effective area-based conservation measures' increase

recognition and support for ICCAs? *Parks*, 23(2), 63-78.
Juffe-Bignoli, D., Harrison, I., Butchart, S. H., Flitcroft, R., Hermoso, V., Jonas, H., Lukasiewicz, A., Thieme, M., Turak, E., Bingham, H., & Dalton, J. (2016). Achieving Aichi Biodiversity Target 11 to improve the performance of protected areas and conserve freshwater biodiversity. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 26, 133-151.
Keeley, A. T., Ackerly, D. D., Cameron, D. R., Heller, N. E., Huber, P. R., Schloss, C. A., Thorne, J. H., & Merenlender, A. M. (2018). New concepts, models, and assessments of climate-wise connectivity. *Environmental Research Letters*, 13(7), 073002.
Kim, J., Choi, H., Shin, W., Yun, J., & Song, Y. (2022). Complex spatiotemporal changes in land-use and ecosystem services in the Jeju Island UNESCO heritage and biosphere site (Republic of Korea). *Environmental Conservation*, 49(4), 272-279.
Kim, J., Shin, H. H., Jeong, M., & Lee, W. S. (2021). Impact of tourists' psychological ownership of an eco-friendly trail on their behavior intention: an empirical investigation of Jeju Olle Trail in South Korea. *Asia Pacific Journal of Tourism Research*, 26(10), 1097-1110.
Kim, J. S., Kim, D. S., Lee, K. C., Lee, J. S., King, G. M., & Kang, S. (2018). Microbial community structure and functional potential of lava-formed Gotjawal soils in Jeju, Korea. *PLoS One*, 13(10), e0204761.
Kim, K., Park, O., Barr, J., & Yun, H. (2019). Tourists' shifting perceptions of UNESCO heritage sites: lessons from Jeju Island-South Korea. *Tourism Review*, 74(1), 20-29.
Ko, C. Y., Murphy, S. C., Root, T. L., & Lee, P. F. (2014). An assessment of the efficiency of protection status through determinations of biodiversity hotspots based on endemic bird species, Taiwan. *Journal for Nature Conservation*, 22(6), 570-576.
Kremen, C. (2005). Managing ecosystem services: what do we need to know about their ecology? *Ecology letters*, 8(5), 468-479.
Kusi, K. K., Khattabi, A., Mhammdi, N., & Lahssini, S. (2020). Prospective evaluation of the impact of land use change on ecosystem services in the Ourika watershed, Morocco. *Land Use Policy*, 97, 104796.
La Notte, A., D'Amato, D., Mäkinen, H., Paracchini, M. L., Liquete, C., Egoh, B., Geneletti, D., & Crossman, N. D. (2017). Ecosystem services classification: A systems ecology perspective of the cascade framework. *Ecological Indicators*, 74, 392-402.
Lanzas, M., Hermoso, V., de-Miguel, S., Bota, G., & Brotons, L. (2019). Designing a network of green infrastructure to enhance the conservation value of protected areas and maintain ecosystem services. *Science of the Total Environment*, 651, 541-550.
Le Bouille, D., Fargione, J., & Armsworth, P. R. (2022). Spatiotemporal variation in costs of managing protected areas. *Conservation Science and Practice*, 4(6), e12697.
Liu, J., Zhang, G., Zhuang, Z., Cheng, Q., Gao, Y., Chen, T., Huang, Q., Xu, L., & Chen, D. (2017). A new perspective for urban development boundary delineation based on SLEUTH-InVEST model. *Habitat International*, 70, 13-23.
Lourdes, K. T., Hamel, P., Gibbins, C. N., Sanusi, R., Azhar, B., & Lechner, A. M. (2022). Planning for green infrastructure using multiple urban ecosystem service models and multicriteria analysis. *Landscape and Urban Planning*, 226, 104500.
Luo, Y., Wu, J., Wang, X., & Peng, J. (2021). Using stepping-stone theory to evaluate the maintenance of landscape connectivity under China's ecological control line policy. *Journal of Cleaner Production*, 296, 126356.
Maestre, F. T., Quero, J. L., Gotelli, N. J., Escudero, A., Ochoa, V., Delgado-Baquerizo, M.,

García-Gómez, M., Bowker, M. A., Soliveres, S., Escolar, C., García-Palacios, P., ... & Escudero, C. G. (2012). Plant species richness and ecosystem multifunctionality in global drylands. *Science*, 335(6065), 214-218.
Maxwell, S. L., Cazalis, V., Dudley, N., Hoffmann, M., Rodrigues, A. S., Stolton, S., Visconti, P., Woodley, S., Kingston, N., Lewis, E., Maron, M., ... & Kingston, N. (2020). Area-based conservation in the twenty-first century. *Nature*, 586(7828), 217-227.
Mitchell, M. G., Schuster, R., Jacob, A. L., Hanna, D. E., Dallaire, C. O., Raudsepp-Hearne, C., Bennett, E. M., Lehner, B., & Chan, K. M. (2021). Identifying key ecosystem service providing areas to inform national-scale conservation planning. *Environmental Research Letters*, 16(1), 014038.
Monroe, A. P., Edmunds, D. R., Aldridge, C. L., Holloran, M. J., Assal, T. J., & Holloran, A. G. (2021). Prioritizing landscapes for grassland bird conservation with hierarchical community models. *Landscape Ecology*, 36, 1023-1038.
Naidoo, R., Balmford, A., Ferraro, P. J., Polasky, S., Ricketts, T. H., & Rouget, M. (2006). Integrating economic costs into conservation planning. *Trends in Ecology & Evolution*, 21(12), 681-687.
Nichols, E., Spector, S., Louzada, J., Larsen, T., Amezquita, S., Favila, M. E., & Network, T. S. R. (2008). Ecological functions and ecosystem services provided by Scarabaeinae dung beetles. *Biological Conservation*, 141(6), 1461-1474.
Nolte, C. (2020). High-resolution land value maps reveal underestimation of conservation costs in the United States. *Proceedings of the National Academy of Sciences*, 117(47), 29577-29583.
Peng, J., Pan, Y., Liu, Y., Zhao, H., & Wang, Y. (2018a). Linking ecological degradation risk to identify ecological security patterns in a rapidly urbanizing landscape. *Habitat International*, 71, 110-124.
Peng, J., Yang, Y., Liu, Y., Du, Y., Meersmans, J., & Qiu, S. (2018b). Linking ecosystem services and circuit theory to identify ecological security patterns. *Science of the Total Environment*, 644, 781-790.
Phillips, S. J., Anderson, R. P., Dudík, M., Schapire, R. E., & Blair, M. E. (2017). Opening the black box: An open-source release of Maxent. *Ecography*, 40(7), 887-893.
Ramel, C., Rey, P. L., Fernandes, R., Vincent, C., Cardoso, A. R., Broennimann, O., Pellissier, L., Pradervand, J. N., Ursenbacher, S., Schmidt, B. R., & Guisan, A. (2020). Integrating ecosystem services within spatial biodiversity conservation prioritization in the Alps. *Ecosystem Services*, 45, 101186.
Rieb, J. T., Chaplin-Kramer, R., Daily, G. C., Armsworth, P. R., Böhning-Gaese, K., Bonn, A., Cumming, G. S., Eigenbrod, F., Grimm, V., Jackson, B. M., Marques, A., ... & Marques, A. (2017). When, where, and how nature matters for ecosystem services: challenges for the next generation of ecosystem service models. *BioScienc*e, 67(9), 820-833.
Rounsevell, M., Fischer, M., Rando, A. T. M., Mader, A., Caplat, P., Ekroos, J., & Smith, H. G. (2018). The IPBES regional assessment report on biodiversity and ecosystem services for Europe and Central Asia. Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES).
Sarma, K., Saikia, M. K., Sarania, B., Basumatary, H., Baruah, S. S., Saikia, B. P., Kumar, A., & Saikia, P. K. (2021). Habitat monitoring and conservation prioritization of Western Hoolock Gibbon in upper Brahmaputra Valley, Assam, India. *Scientific*

Reports, 11(1), 1-11.
Schröter, M., & Remme, R. P. (2016). Spatial prioritisation for conserving ecosystem services: comparing hotspots with heuristic optimisation. *Landscape Ecology*, 31, 431-450.
Schuster, R., Hanson, J. O., Strimas-Mackey, M., & Bennett, J. R. (2020). Exact integer linear programming solvers outperform simulated annealing for solving conservation planning problems. *PeerJ*, 8, e9258.
Schwartz, M. W., Cook, C. N., Pressey, R. L., Pullin, A. S., Runge, M. C., Salafsky, N., Sutherland, W. J., & Williamson, M. A. (2018). Decision support frameworks and tools for conservation. *Conservation Letters*, 11(2), e12385.
Scott, T. A., Wehtje, W., & Wehtje, M. (2001). The need for strategic planning in passive restoration of wildlife populations. *Restoration Ecology*, 9(3), 262-271.
Sharp, R., Douglass, J., Wolny, S., Arkema, K., Bernhardt, J., Bierbower, W., Chaumont, N., Denu, D., Fisher, D., Glowinski, K., Griffin, R., Guannel, G., Guerry, A., Johnson, J., Hamel, P., Kennedy, C., Kim, C. K., Lacayo, M., Lonsdorf, E., Mandle, L., & Ro, K. (2020). InVEST 3.10.2.post34+ug.ga66060d User's Guide.
Shiono, T., Kubota, Y., & Kusumoto, B. (2021). Area-based conservation planning in Japan: The importance of OECMs in the post-2020 Global Biodiversity Framework. *Global Ecology and Conservation*, 30, e01783.
Shwartz, A., Davies, Z. G., Macgregor, N. A., Crick, H. Q., Clarke, D., Eigenbrod, F., Gonner, C., Hill, C. T., Knight, A. T., Metcalfe, K., & Osborne, P. E. (2017). Scaling up from protected areas in England: The value of establishing large conservation areas. *Biological Conservation*, 212, 279-287.
Sreekar, R., Zeng, Y., Zheng, Q., Lamba, A., Teo, H. C., Sarira, T. V., & Koh, L. P. (2022). Nature-based climate solutions for expanding the global protected area network. *Biological Conservation*, 269, 109529.
Storch, D., Šímová, I., Smyčka, J., Bohdalková, E., Toszogyova, A., & Okie, J. G. (2022). Biodiversity dynamics in the Anthropocene: how human activities change equilibria of species richness. *Ecography*, 45(4).
Thomas, C. D., Anderson, B. J., Moilanen, A., Eigenbrod, F., Heinemeyer, A., Quaife, T., Roy, D. B., Gillings, S., Armsworth, P. R., & Gaston, K. J. (2013). Reconciling biodiversity and carbon conservation. *Ecology Letters*, 16, 39-47.
Vaz, A. S., Amorim, F., Pereira, P., Antunes, S., Rebelo, H., & Oliveira, N. G. (2021). Integrating conservation targets and ecosystem services in landscape spatial planning from Portugal. *Landscape and Urban Planning*, 215, 104213.
Wang, S., Wu, M., Hu, M., Fan, C., Wang, T., & Xia, B. (2021). Promoting landscape connectivity of highly urbanized areas: An ecological network approach. *Ecological Indicators*, 125, 107487.
Weeks, R., & Adams, V. M. (2018). Research priorities for conservation and natural resource management in Oceania's small-island developing states. *Conservation Biology*, 32(1), 72-83.
Williams, S. H., Scriven, S. A., Burslem, D. F., Hill, J. K., Reynolds, G., Agama, A. L., Kugan, F., Maycock, C. R., Khoo, E., Hastie, A. Y., & Sugau, J. B. (2020). Incorporating connectivity into conservation planning for the optimal representation of multiple species and ecosystem services. *Conservation Biology*, 34(4), 934-942.
Zhang, J., Xu, W., Kong, L., Hull, V., Xiao, Y., Xiao, Y., & Ouyang, Z. (2018). Strengthening protected areas for giant panda habitat and ecosystem services.

Biological Conservation, 227, 1-8.
Zhou, P., Zhang, H., Huang, B., Ji, Y., Peng, S., & Zhou, T. (2022). Are productivity and biodiversity adequate predictors for rapid assessment of forest ecosystem services values?. *Ecosystem Services*, 57, 101466.

Abstract in Korean

제주도의 우선보호지역 선정을 위한 생태계서비스 및 연계성 통합 분석 연구

김지환
서울대학교 대학원 협동과정조경학 및
스마트시티 글로벌융합 전공
지도교수: 송영근

본 학위논문은 생태계서비스, 생물다양성 간의 상호 관계와 이들이 제주도의 생태 경관에 미치는 포괄적인 영향을 분석하였으며, 지속가능한 보전을 달성하기 위한 우선 보호지역을 식별하는 접근 방식을 제시하였다. 이 연구는 급변하는 환경 조건에서 47년 동안의 토지이용 변화를 심층적으로 탐구함으로써 보전 지역에 대한 이해를 높이는 것을 목표로 하였다. 분석 결과 제주도의 오랜 시기에 걸쳐 다양한 변화가 드러났다. 특히 연안지역은 생태적 가치의 급격한 감소로 인해 효과적인 보전 조치가 필요한 지역으로 확인되었다. 이러한 결과는 토지이용 변화가 생태계서비스에 영향을 미치는 방식에 대한 논의가 필요하며, 이를 통해 관련 보전 전략을 수립하는데 도움을 줄 수 있다. 또한, 1970년대와 1980년대에 시행 된 산림 녹화 정책의 영향력에 주목하면서, 이러한 이니셔티브가 제주도의 생태적 위상과 보전 가치를 크게 강화한 것으로 평가할 수 있다. 특히, 화산 활동으로 형성되고, 유네스코 자연유산으로 지정된 생태계의 맥락속에서 지속가능한 생태계 관리에 대한 담론에 대해서도 깊이를 더하였다. 또한, 보전 관리 계획에 생태적 연계성의 개념을 도입하여 생태 연결성 개선이 생태계 기능을 촉진한다고 볼 수 있다. 특히, 연안과 중산간 지역 사이의 주목할 만한 연결 지점과 단절 지점을 식별하여 향후 보존 우선순

위에 대한 중요한 논의를 제공할 수 있으며, 이는 보전 전략 수립에 있어서 생태적 연계성의 중요성을 강조하는 연구라고 할 수 있다. 이와 더불어 이 연구는 보전 계획의 복잡성을 고려하였을 때 토지 소유권 측면을 함께 살펴봄으로써 잠재적으로 더 높은 비용으로 인해 사유지에서의 보전 활동의 어려움으로 인해 효과적인 민관 협업을 강조하고 있다. 보호지역을 확인하기 위한 어려움을 해소하기 위한 노력의 일환으로 기타 효과적인 지역기반조치수단을 적용하여 우선보호지역을 확인하였다. 이 논문은 생태계서비스와 네트워크 특성에 중점을 두고 보호지역 확장의 양적, 질적 측면을 모두 고려한 균형잡힌 보전 조치의 필요성을 강조하였다. 결론적으로, 본 논문은 지속가능한 보전 계획을 위한 통합적인 프레임워크를 제시하며, 보전 의사결정을 위한 다양한 분석의 관련성을 연구하였다. 이 연구는 제주도의 초점을 맞추고 있지만 지역 여건과 이해관계자를 고려한 통합적이고 상황별 전략을 채택함으로써 보전과 비용의 효율적인 관리, 지속가능성 사이의 균형에 대한 논의를 제시하였다.

주요어: 보전 관리, 생태계획, 보호지역, 생태 연결성, 유네스코 자연유산, 제주도

학 번: 2019-30345