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Biodiversity Indicator Assessment in Jeju and Gochang Biosphere Reserves, Korea*

한국 제주도 및 고창 생물권보전지역 생물다양성 지표 평가

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요약: 생물다양성 지표는 생물권보전지역을 관리하고 보전하는 데 있어 매우 중요한 도구이다. 따라서 본 연구에서는 다양한 생물다양성 지표를 평가하여 생물권보전지역의 생물다양성 현황을 파악하고 효율적인 위협 관리 전략을 논의하고자 한다. 전체 생물종 다양성 평가는 국내 조사 및 학술 논문을 바탕으로 제주도와 고창 생물권보전지역에서 각각 5,911종, 2,323종의 생물종이 확인되었다. 적색목록 지수는 제주도와 고창 생물권보전지역이 각각 0.960점, 0.965점으로 제주도보다 고창의 멸종위기종이 더 양호한 상태인 것으로 나타났습니다. 제주도와 고창 생물권보전지역에는 각각 237종과 129종의 외래종이 서식하고 있었다. 제주도 생물권보전지역은 생태계 면적비율은 악화되고 식생등급은 개선되었으며, 자연공간의 평균 패치 크기는 유의미한 경향을 보이지 않았고, 고창 생물권보전지역은 자연공간의 평균 패치 크기와 식생등급은 개선되었으며, 생태계 면적비율은 유의미한 경향을 보이지 않았다. 보호지역 비율은 제주와 고창 생물권보전지역 모두에서 개선된 것으로 나타났다. 생물권보전지역은 핵심지역, 완충지역, 전이지역으로 구분하여 목적과 용도를 달리하고 있다. 완충지역을 보호지역으로 지정하는 것은 생물다양성의 지속적인 보전과 생태계의 안정을 위해 매우 중요한 단계이다. 따라서 실질적인 생물다양성 평가를 위해 핵심 및 완충지역의 모니터링과 보고는 차별화 되어야 한다. 그러나 두 지역 평가를 위한 데이터 축적에 대한 문제를 피하기 위해 더 많은 모니터링과 보고가 필요한 실정이다. 이 연구에서는 데이터 가용성 문제로 인해 이러한

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구역을 구분하지 않았다. 향후 생물권보전지역의 생물다양성 평가를 위한 모니터링, 보고, 평가 시스템에서는 이러한 구역을 고려해야 할 것이다.
핵심주제어: 생물다양성, 지표 평가, 생물권보전지역, 관리, 보전

Abstract: Biodiversity indicators are crucial tools in managing and conserving biosphere reserves. Therefore, in this study, we determine the biodiversity status of biosphere reserves by evaluating various biodiversity indicators and discussing efficient threat management strategies. For the assessment of overall species diversity, based on national surveys and academic papers, 5,911 and 2,323 species in Jeju and Gochang biosphere reserves, respectively, were identified. Regarding the Red List Index, Jeju and Gochang biosphere reserves scored 0.960 and 0.965, respectively, indicating a more favorable status of endangered species in Gochang than in Jeju. Jeju and Gochang biosphere reserves had 237 and 129 alien species, respectively. In the Jeju Biosphere Reserve, the ecosystem area ratio deteriorated, vegetation grade improved, and average patch size in natural space showed no significant trend, while in the Gochang Biosphere Reserve, the average patch size in natural space and vegetation grade improved and the ecosystem area ratio showed no significant trend. The protected area ratio was enhanced in both Jeju and Gochang biosphere reserves. Biosphere reserves have different purposes and uses for their core, buffer, and transition areas. Designating the buffer zone as a protected area is a crucial step for the ongoing conservation of biodiversity and the stability of ecosystems. Therefore, monitoring and reporting should be differentiated accordingly for practical biodiversity assessment. However, more monitoring and reporting on these zoning areas are needed to avoid data accumulation issues. In this study, these zoning areas were not considered due to data availability problems. Future monitoring, reporting, and assessment systems for biodiversity assessment in biosphere reserves must consider these zoning areas.
Key Words: Biodiversity, Indicator Assessment, Biosphere Reserve, Management, Conservation

I. Introduction

Biosphere reserves, designated by UNESCO, are areas that consist of outstanding terrestrial, coastal, and marine ecosystems globally, aimed at harmonizing biodiversity conservation with sustainable use (Korean National Commission for UNESCO, 2020). The biosphere reserve status began in 1976 when 57 sites around the world were first designated at the International Coordinating Council of the Man and the Biosphere Programme, and by 2022, including transboundary areas, 727 sites in 131 countries were registered in the World Network of Biosphere Reserves.

Starting with Mt. Seorak Biosphere Reserve in 1982, nine sites in South Korea, including Jeju Island, Shinan Dadohae, Gwangneung Forest, Gochang, Suncheon, Gangwon Eco-Peace, Yeoncheon Imjin River, and Wando, have been designated as biosphere reserves (MAB National Committee for the Republic of Korea, 2023). Because biosphere reserves fundamentally aim for the coexistence of nature and humans, it is necessary to establish a platform for communication among stakeholders, and the need to promote the economic development of local communities along with the conservation of biodiversity is emerging (Park and Yeom, 2023). Therefore, strategies for sustainable conservation and management of biosphere reserves are urgently needed.

Biodiversity indicators are crucial tools for managing and conserving different ecosystem types (McQuatters-Gollop et al. 2019, Martinez-Jauregui, Touza, White, and Solino, 2021). They serve multiple roles, including monitoring the current state of species, habitats, and ecosystems and identifying potential threats. These indicators are instrumental in evaluating the effectiveness of conservation efforts and aid informed management decisions. Providing comprehensive data enables reserve managers to allocate resources more efficiently, prioritize protective actions, and engage effectively with local communities. Biodiversity indicators form the foundation of educational and public awareness campaigns. Accurate and comprehensible data are vital for communicating the significance of biosphere reserves to local communities and policymakers. These indicators also play a crucial role in assessing the vulnerability and resilience of biosphere reserves to external challenges, such as climate change, ecological shifts, and human impacts.

To effectively implement the functions of biosphere reserves, three

zones have been established: the core, buffer, and transition areas (Palliwoda, Büermann, Fischer, Kraemer, and Schröter, 2021). The core area is strictly protected and consists of one or more regions dedicated to conserving biodiversity and minimizing interference. Activities such as ecosystem monitoring, nondestructive research, and low-impact use (e.g., education) are permitted. The buffer area is adjacent to the core area and is used for cooperative activities suitable for sound ecological practices, including environmental education, recreation, ecotourism, and primary and applied research. The transitional area is used for various agricultural activities, residences, and other purposes. In this zone, the local community, management authorities, scholars, NGOs, cultural groups, economic interest groups, and other stakeholders collaborate to sustainably manage resources and develop the area (Kang et al. 2021). The buffer area of biosphere reserves, a potentially protected area, requires an analysis through biodiversity indicator assessments to determine its need for protection.

Therefore, in this study, we determine the biodiversity status of biosphere reserves by evaluating various biodiversity indicators and discussing efficient threat management strategies.

II. Data and Methodology

1. General Information of Jeju and Gochang biosphere reserves

As biodiversity is an important criterion for the designation of biosphere reserves, diagnosing the biodiversity of a biosphere reserve is a very important diagnostic indicator for the management and conservation of biosphere reserves〈Table 1〉.

〈Table 1〉 Implications of Biosphere Reserve and Biodiversity

	Biosphere Reserve	Biodiversity
Academic Implications	Ecosystem areas recognised globally as being worthy of conservation and capable of providing scientific knowledge, technology and human values to support sustainable development.	The concept of biodiversity as the diversity of life phenomena at all levels, including molecular, genetic, species and ecosystem levels.
Policy Implications	Areas designated to conserve biodiversity, promote community development and maintain cultural values.	An important basis for the conservation of nature and sustainable resource utilisation
Institutional Implications	Subdivided into core areas, buffer zones, and transition zones in accordance with national legislation, and systematically managed to prevent overexploitation.	Refers to the diversity of living organisms from all sources, including terrestrial and aquatic ecosystems and their complexes

In this research, Jeju and Gochang were selected to compare inland and island areas among the 9 biosphere reserves in Korea. The Jeju was designated on 16 December 2002 and covers an area of 3,871.94km^2. It consists of a core area of 399.51km^2(10%), a buffer area of 722.86km^2(19%), and a transition area of 2,749.57km^2(71%). The Gochang was designated on 28 May 2013 and covers an area of 671.52km^2. It consists of a core area of 91.28km^2(14%), a buffer area of 265.54km^2(39%), and a transition area of 314.70km^2(47%).

2. Criteria for selecting biodiversity indicators in biosphere reserves

When selecting biodiversity indicators, it is crucial to define the selection criteria and select the indicators accordingly. The criteria for selecting biodiversity indicators for biosphere reserves in Korea are listed in 〈Table 2〉. Biodiversity indicators were selected by reviewing the indicator selection criteria with the authors and biodiversity experts.

〈Table 2〉 Selection criteria of biodiversity indicators in biosphere reserves

Indicator Selection Criteria	Description
Indicator Representativeness and Relevance	Select indicators that represent the sub-categories of biodiversity being assessed and are closely related to the biodiversity assessment
Verified Indicators	Choose indicators that have been applied in previous biodiversity assessments and have been validated. In cases where an indicator is absent, develop a new one and verify its usefulness.
Indicator Universality and Scalability	Select indicators that are likely to have accumulated data in the countries of the Asia-Pacific region and, therefore, can be applied to the biodiversity assessment of biosphere reserves in this region. Provide alternative indicators that can be used for assessment even without data.
Data Availability and Sustainability	Choose indicators for which the necessary data is continuously measured and accumulated domestically, ensuring that they can be used for assessment and that future data accumulation is feasible.

3. Selection of biodiversity indicators in biosphere reserves

1) Species Richness

Species richness is a universal indicator in biodiversity assessment studies to evaluate the overall species diversity. It is calculated based on the number of all species identified through research (Pearman and Weber 2007, Jaunatre et al. 2013, Santini et al. 2017, Hansen et al. 2021)

where, "" refers to the total number of species. Based on the National List of Species (National Institute of Biological Resources, 2020), all species were categorized into their respective phylum, class, order, family, and genus.

2) Red List Species

The IUCN assesses the status of each species globally to understand the

status of endangered species. The Red List Index (RLI) is an indicator for gauging the status of endangered species according to the IUCN Red List classification, with different weights assigned to each classification. The classification of species extinction risk levels was based on the Korean Endangered Species data published by the National Institute of Biological Resources, which were produced based on the Korean Red List assessment statuses (2020). The calculation formula is as follows (Butchart et al. 2010; Hoffmann et al. 2010; Hoffmann et al. 2011; IUCN 2012; Szabo et al. 2012):

$$RLI = 1 - \frac{0LC_i + 1NT_i + 2VU_i + 3EN_i + 4CR_i + 5RE_i + 5EW_i + 5EX_i}{5LS_i}$$

Here, LC is the number of least concerned species, NT is the number of near-threatened species, VU is the number of vulnerable species, EN is the number of endangered species, CR is the number of critically endangered species, RE is the number of regionally extinct species, EW is the number of species extinct in the wild, EX is the number of extinct species, and Total is the number of all listed species with sufficient data.

3) Invasive Alien Species Number

By estimating the number of invasive alien species identified through research, the status of the invasive alien species can be determined. This indicator is widely used in national and regional biodiversity assessments in Singapore, Vietnam, and Europe (Butchart et al. 2010; EEA, 2010; Singapore government, 2016; Vietnam Ministry of Natural Resources and Environment, 2014). In the present study, we used the Korean list of invasive alien species.

4) Ecosystem Area Ratio

The health of ecosystems, which play a crucial role as habitats for various species, such as forests, coastal wetlands, inland wetlands, rivers, and lakes, can be assessed by estimating ecosystem areas and changes over time (Butchart, Walpole, Van Strien, and Scharlemann, 2010; Ershov, Isaev, Lukina, Gavrilyuk, and Koroleva, 2016). The total area of the key ecosystems included the combined areas of forests, coastal wetlands, inland wetlands, and water bodies. Urban green spaces were excluded from the total ecosystem area.

Here, , , , and , are the areas (km^2) of the forest, coastal wetland, inland wetland, and water body, respectively, and is the total area of the biosphere reserve (km^2).

5) Average Patch Size in Natural Space

The average size of natural space patches refers to the patches in natural spaces such as forests, grasslands, and wetlands. It is an effective indicator of habitat connectivity and fragmentation levels (EEA 2007; EEA, 2010; Ershov et al. 2016; Hansen et al. 2021; Walz, 2015).

$$QM_{ps} = \sqrt{\frac{PS^2 + PS^2_{+\cdots+PS^2_{m}}}{1}}$$

Here, represents the size of patch (km^2) and indicates the number of patches.

6) Ecological and Natural Maps (Vegetation grades)

For biodiversity assessments, vegetation levels are evaluated using

vegetation indices such as the Normalized Difference Vegetation Index (Tucker, 1979). However, in South Korea, because of the limitations of vegetation indices in capturing certain plant species and tree breast-height diameters, the results of the Ecological and Natural Maps vegetation conservation grade study, which takes these factors into account, are used for analysis. The Ecological and Natural Map grades the natural environment into 1st to 3rd grades and separately managed areas by considering ecological, natural, and landscape values. The vegetation conservation grade in the Ecological and Natural Maps is differentiated into 1st to 5th grades based on the distribution rarity of vegetation, potential for vegetation restoration, integrity of constituent plant species, structural integrity of the vegetation, habitat of key species, and tree breast-height diameter during reforestation. The vegetation grades were calculated by assigning weights—5 for grade 1, 4 for grade 2, 3 for grade 3, 2 for grade 4, and 1 for grade 5—and multiplying them by the area of each grade and then dividing by the total area. The calculation formula is as follows:

$$VC = \frac{5\,C1_a + 4\,C2_a + 3\,C3_a + 2\,C4_a + 1\,C5_a}{BR_a}$$

Here, represents the vegetation grade and , , , , and are the areas (km^2) of vegetation conservation grade 1, 2, 3, 4, and 5, respectively.

7) Protected Area Ratio

The ratio of protected areas is an indicator widely used in biodiversity assessments. It is calculated by summing the areas of natural environment conservation areas, national parks, and water quality

protection regulated areas within biosphere reserves and then dividing this by the total area of the biosphere reserve. The calculation formula is as follows (Botswana government, 2012; Butchart et al. 2010; IPBES 2018, 2019; Republic of Indonesia government, 2014):

$$RPA = \frac{\sum_{i} PA_i}{TA}$$

Here, RPA represents the ratio of the protected area, is the area of protected area type , and is the total area of the specific biosphere reserve. This calculation also includes other effective area-based conservation measures.

4. Data Collection of biodiversity indicators in Korean biosphere reserves

For each indicator, we extracted data for Jeju and Gochang at the national or local scale, and analysed comparable data for the time series between 1976 and 2020. Since 1986, the Korean Ministry of Environment has conducted the National Natural Environment Survey from the first to the fourth round to understand the distribution and status of biodiversity components. The fifth round of the survey is in progress as of 2021. Based on this, Ecological and natural Maps have been produced and made publicly available. The country is divided into three major regions, and detailed areas, such as vegetation, flora, mammals, birds, fish, amphibians and reptiles, terrestrial insects, benthic macroinvertebrates, and terrain, are defined for surveying terrestrial ecosystem biodiversity.

Furthermore, studies on distinctive ecosystems have been conducted through various surveys such as the National Uninhabited Islands Natural

Environment Survey (since 1998), the National Natural Caves Survey (2002–2006), the National Coastal Dune Detailed Survey (since 2003), the Estuary Ecosystem Detailed Survey (2004–2015), the National Inland Wetlands Survey (since 2000), the DMZ Ecosystem Survey (since 2012), the Baekdu Daegan Ecosystem Survey (2007–2010 and 2015) and its Detailed Survey (2012–2014), and the Specific Islands Detailed Survey (since 2006). Surveys on ecologically and scenically outstanding areas (2018) and the Ecological Landscape Conservation Area Detailed Survey (since 2012) have also been conducted to investigate biologically significant regions. Additionally, research on migratory species has been conducted through the Winter Bird Simultaneous Census (since 1999), Migratory Bird Migration Route and Arrival Status Survey (since 1999), Detailed Survey of Alien Species (since 2006), and Monitoring of Ecosystem Disturbing Species (since 2010). Long-term studies on species changes have also been conducted through the National Long-Term Ecological Research (since 2004).

The National Institute of Biological Resources, through its native species survey and excavation project, holds 23,181 natural specimens of each species as of 2020, and continues to survey and discover undiscovered species. Additionally, as of 2020, 54,428 species have been listed on the National Species List, with 35,429 specimens secured. From 2008 to 2020, DNA barcode information for Korean species was compiled, holding 9,530 species DNA barcode information. The required data and sources for each evaluation indicator are shown in Appendix 1.

Data collection for species diversity analysis was also performed using biological species papers. Fifty-six domestic papers were obtained by searching RISS with "Biodiversity" + "Pilot Area Name (in Korean)," "Species" + "Pilot Area Name (in Korean)," and "Taxonomic Group Name

(in Korean)" + "Pilot Area Name (in Korean)." The Taxonomic Group Names (in Korean) included "plant," "mammal, " "bird," "reptile," "amphibian," "herpetology," "fish," "invertebrate," and "insect." Four international papers were obtained by searching Web of Science with "Biodiversity" + "Pilot Area Name (in English)," "Species" + "Pilot Area Name (in English)," and "Taxonomic Group Name (in English)" + "Pilot Area Name (in English)." The Taxonomic Group Names (in English) included "plant," "mammal," "bird," "reptile," "amphibian," "herpetology," "fish," "invertebrate," and "insect."

Ⅲ. Result

1. Species Richness

The assessment of the species richness of the Jeju Biosphere Reserve based on national surveys and academic papers showed that the reserve is home to 19 phyla, 47 classes, 242 orders, 909 families, 3,052 genera, and 5,911 species. There were 42 mammal, 240 bird, 21 reptile, 12 amphibian, 401 fish, seven pseudocoelomate, 460 invertebrate (excluding insects), 2,516 insect, 2,218 terrestrial plant, and one fungal species. There were no records of algae, protozoa, bacteria, or Archaea 〈Table 3〉.

Based on national surveys and academic papers, when assessing the species richness of the Gochang Biosphere Reserve, it was found that the reserve contained 11 phyla, 23 classes, 145 orders, 439 families, 1,276 genera, and 2,323 species. There were 17 mammal, 205 bird, 13 reptile, 12 amphibian, 81 fish, 87 invertebrate (excluding insects), 863 insect, 1,045 terrestrial plant, and one fungal species. No records existed for pseudocoelomates, algae, protozoa, bacteria, or Archaea.

〈Table 3〉 Species richness in Jeju and Gochang biosphere reserves

Taxa	Phylum		Class		Order		Family		Genus		Species	
	JJ*	GC**	JJ	GC	JJ	GC	JJ	GC	JJ	GC	JJ	GC
Mammal	1	1	1	1	7	5	16	10	26	13	42	17
Bird	1	1	1	1	17	16	50	48	119	106	240	205
Reptile	1	1	1	1	2	2	8	7	13	10	21	13
Amphibian	1	1	1	1	2	2	5	6	8	9	12	12
Fish	1	1	3	2	31	14	141	28	291	57	401	81
Urochordata	1	0	1	0	3	0	5	0	7	0	7	0
Invertebrate***	12	6	26	9	72	25	205	50	347	68	460	87
Insect	1	1	1	1	19	18	250	154	1,407	587	2,516	863
Terrestrial plant	5	4	13	7	92	63	234	136	845	427	2,218	1,045
Algae	0	0	0	0	0	0	0	0	0	0	0	0
Fungi	1	1	1	1	1	1	1	1	1	1	1	1
Protozoa	0	0	0	0	0	0	0	0	0	0	0	0
Bacteria	0	0	0	0	0	0	0	0	0	0	0	0
Archaea	0	0	0	0	0	0	0	0	0	0	0	0
Total	19	11	47	23	242	145	909	439	3,052	1,276	5,911	2,323

* JJ – Jeju, ** GC – Gochang, *** excluding insect

2. Red List Species

The Red List assessment status of the Jeju Biosphere Reserve included two RE, eight CR, 35 EN, 68 VU, 56 NT, 450 LC, 83 data-deficient (DD), 974 not evaluated (NE), and 11 not applicable (NA) species. The Red List assessment status of the Gochang Biosphere Reserve included one CR, 10 EN, 27 VU, 15 NT, 202 LC, 6 DD, 319 NE, and 4 NA species 〈Table 4〉.

Based on the Red List assessment status, the Red List Index for the Jeju Biosphere Reserve was 0.960 and that for the Gochang Biosphere Reserve was 0.965 〈Table 5〉.

〈Table 4〉 Red List status by taxonomic group in Jeju and Gochang biosphere reserves

Red List Category	Mammal		Bird		Amphibian & Reptile		Fish		Insect		Invertebrate (excluding insect)		Terrestrial plant		Total	
	JJ	GC	JJ	GC	JJ	GC	JJ	GC	JJ	GC	JJ	GC	JJ	GC	JJ	GC
CR	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
EN	0	0	8	7	0	1	0	1	3	0	0	0	24	1	35	10
VU	1	0	17	17	1	3	0	1	14	3	2	3	33	0	68	27
NT	1	1	5	1	2	1	1	2	10	3	10	6	27	1	56	15
LC	5	0	20	14	14	16	1	8	215	134	147	21	48	9	450	202
DD	0	0	0	0	1	0	1	1	34	5	45	0	2	0	83	6
NE	0	0	0	0	0	0	1	1	941	310	7	0	25	8	974	319
NA	0	0	1	0	0	0	0	0	9	2	1	2	0	0	11	4
Total	8	1	52	39	18	21	4	15	1,227	457	212	32	166	19	1,687	584

〈Table 5〉 Red List Index by taxonomic group in Jeju and Gochang biosphere reserves

Taxa	Red List Index	
	Jeju	Gochang
Mammal	0.800	0.800
Bird	0.738	0.713
Amphibian & Reptile	0.956	0.905
Fish	0.950	0.853
Insect	0.992	0.996
Invertebrate (excluding insect)	0.987	0.925
Terrestrial Plant	0.767	0.958
Total	0.960	0.965

3. Invasive Alien Species Number (Invasive Species Status)

In the Jeju Biosphere Reserve, 237 alien species were identified. The number of invasive alien species by taxonomic group was as follows: three mammal, five bird, two reptile, one amphibian, nine fish, 24 invertebrate, and 193 terrestrial plant species. In the Gochang Biosphere

Reserve, 129 alien species were identified. The number of invasive alien species by taxonomic group was as follows: two mammal, five bird, one reptile, one amphibian, ten fish, 13 invertebrate, and 97 terrestrial plant species.

4. Ecosystem Area Ratio

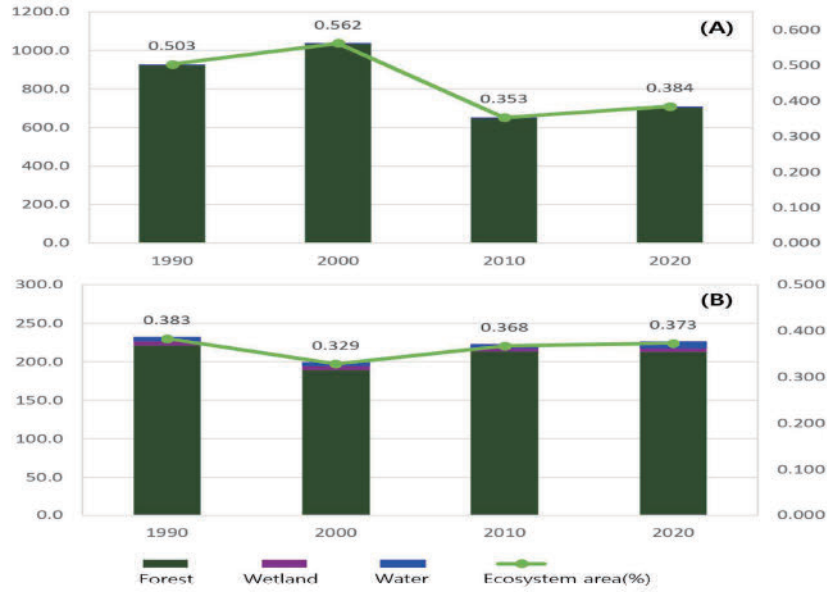
Most of the ecosystem area within the Jeju and Gochang Biosphere Reserve is occupied by forests, and the ecosystem area and area ratio have changed significantly owing to changes in the forest area. In 2020, the ecosystem area within the Jeju and Gochang Biosphere Reserve saw a significant decrease in forests and wetlands compared to 1990, whereas aquatic areas slightly increased. The total ecosystem area in Jeju Biosphere Reserve decreased from 927.4 km^2 in 1990 to 1036.3 km^2 in 2000, 651.9 km^2 in 2010, and 708.8 km^2 in 2020. The total ecosystem area in Gochang decreased from 232.7 km^2 in 1990 to 199.5 km^2 in 2000, 223.2 km^2 in 2010, and 226.5 km^2 in 2020 〈Table 6〉.

Accordingly, the ecosystem area ratio in the Jeju Biosphere Reserve has decreased from 0.503 in 1990 to 0.562 in 2000, 0.353 in 2010, and 0.384 in 2020. In the Gochang Biosphere Reserve, the ecosystem area ratio also changed, decreasing from 0.383 in 1990 to 0.329 in 2000, increasing to 0.368 in 2010, and finally to 0.373 in 2020 〈Figure 1〉.

〈Table 6〉 Biosphere reserve area change by ecosystem type (1990–2020; km^2)

Ecosystem types	1990		2000		2010		2020	
	JJ	GC	JJ	GC	JJ	GC	JJ	GC
Forest	923.8	221.0	1034.7	189.4	648.7	213.7	704.8	213.2
Wetland	0.6	5.9	0.1	5.3	0.1	4.0	0.1	4.4
Water	3.0	5.8	1.5	4.8	3.1	5.5	3.9	8.9
Ecosystem	927.4	232.7	1036.3	199.5	651.9	223.2	708.8	226.5
Total Biosphere Reserve Area	1854.8	465.4	2072.6	399.0	1303.8	446.4	1417.6	453.0

〈Figure 1〉 Jeju (A) and Gochang (B) biosphere reserve area (km^2) and area ratio change by ecosystem type (1990–2020)



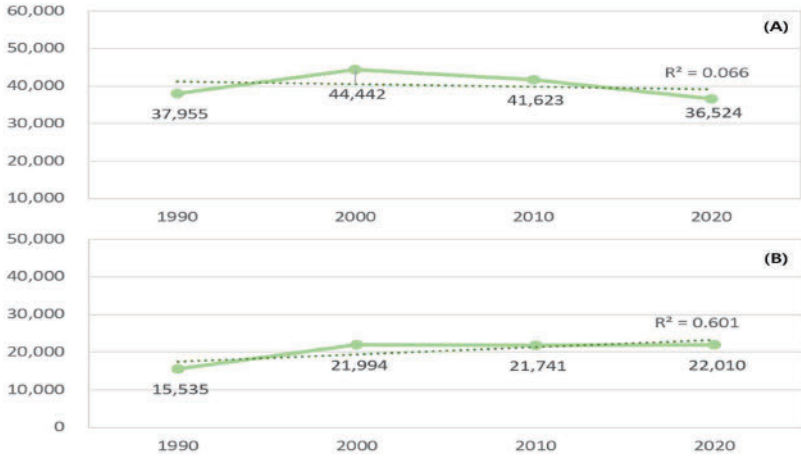
5. Average Patch Size in Natural Space (Habitat Connectivity)

Among the three ecosystem types in the Jeju Biosphere Reserve, wetlands decreased the most 〈Table 7〉; however, the average patch size of the natural spaces did not show a consistent trend (R^2=0.066). Specifically, the sizes were 37,955 m^2 in 1990, 44,442 m^2 in 2000, 41,623 m^2 in 2010, and 36,524 m^2 in 2020. The average patch size of natural spaces within the Gochang Biosphere Reserve increased (R^2=0.601). Specifically, it increased from 15,535 m^2 in 1990 to 21,994 m^2 in 2000, 21,741 m^2 in 2010, and 22,010 m^2 in 2020 〈Figure 2〉.

〈Table 7〉 Average change in patch size of different ecosystem types in natural space of Jeju and Gochang biosphere reserves (1990–2020, m^2)

Ecosystem Types	1990		2000		2010		2020	
	JJ	GC	JJ	GC	JJ	GC	JJ	GC
Forest	62,937	57,269	77,381	93,015	74,543	6,901	57,906	77,387
Grassland	21,372	3,684	18,823	4,210	20,288	2,829	20,540	2,910
Wetland	4,342	14,567	2,441	12,967	2,489	9,272	1,924	9,719

〈Figure 2〉 Estimated changes in the average patch size of natural space in Jeju (A) and Gochang (B) biosphere reserves (1990–2020, m^2)



6. Ecological and Natural Maps (Vegetation Grade)

The analysis was conducted using data on changes in the Ecological and Natural Maps areas constructed at the provincial level 〈Table 8〉. The Ecological and Natural Maps grades in the Jeju Biosphere Reserve increased steadily (R^2=0.431). Specifically, they were 1.45 in 2007, 1.46 in 2013, 1.46 in 2015, 1.46 in 2016, 1.54 in 2017, and 1.54 in 2018.

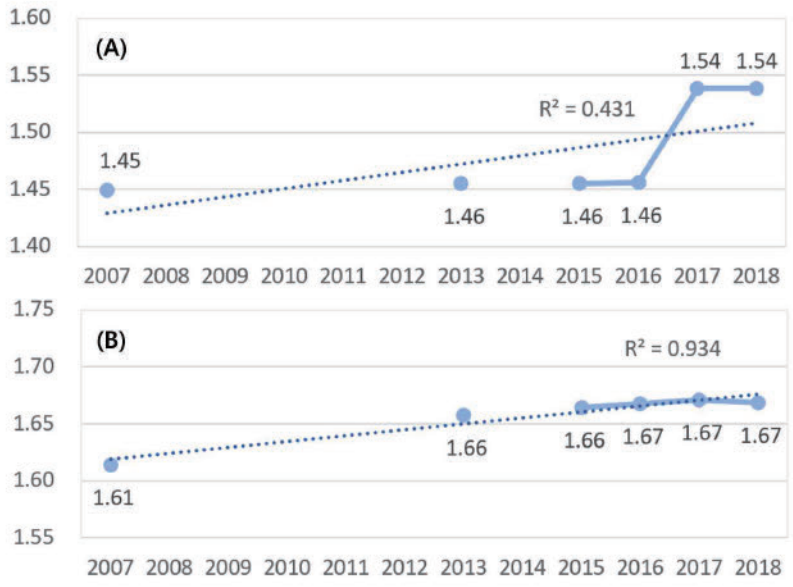
Because the analysis was conducted using data on changes in the area of the Ecological and Natural Maps constructed at the provincial level, vegetation grades were analyzed using the area of each grade of the

Ecological and Natural Maps of Jeollabuk-do, which includes the Gochang Biosphere Reserve. The Ecological and Natural Map grades of the Gochang Biosphere Reserve increased steadily (R^2=0.934). Specifically, they were 1.61 in 2007, 1.66 in 2013, 1.66 in 2015, 1.67 in 2016, 1.67 in 2017, and 1.67 in 2018 〈Figure 3〉.

〈Table 8〉 Ecological and Natural Maps grades of Jeju and Gochang biosphere reserves (2007-2018, km^2)

Year	First grade zones		Second grade zone		Third grade zone		Separately managed zone		Total	
	JJ	GC	JJ	GC	JJ	GC	JJ	GC	JJ	GC
2007	107.3	107.3	292.4	292.4	1,294.5	1,294.5	164.2	164.2	1,858.4	1,858.4
2013	104.4	104.4	290.6	290.6	1,290.1	1,290.1	173.3	173.3	1,858.4	1,858.4
2015	104.4	104.4	290.6	290.6	1,290.1	1,290.1	173.3	173.3	1,858.4	1,858.4
2016	104.4	104.4	290.6	290.6	1,289.2	1,289.2	174.3	174.3	1,858.5	1,858.5
2017	128.7	128.7	403.5	403.5	1,156.3	1,156.3	169.9	169.9	1,858.4	1,858.4
2018	128.6	128.6	403.5	403.5	1,156.4	1,156.4	169.9	169.9	1,858.4	1,858.4

〈Figure 3〉 Ecological and Natural Maps grade change in Jeju (A) and Gochang (B) biosphere reserves (2007-2018)



7. Protected Area Ratio

The legally protected areas within the Jeju Biosphere Reserve as of 2020 include provincial parks, wetland protection areas, urban natural park zones, natural monuments, scenic spots, forest genetic resource protection areas, and disaster-prevention protection areas. Provincial parks were first designated in 2011. Wetland protection areas have been increasing since their first designation in 2009. Urban natural park zones have been maintained since their first designation in 2005. Natural monuments have been steadily growing in designated areas since 1976. Scenic spots first established in 2008 have been increasing in area. Forest genetic resource protection areas were first set in 2011. And areas designated as disaster prevention protection areas before 1976 have been maintained. As a result, the area of protected areas within the Jeju Biosphere Reserve steadily increased from 4.30 km^2 in 1980 to 4.66 km^2 in 1990, 5.84 km^2 in 2000, 107.47 km^2 in 2010, and 117.41 km2 in 2020, with a rapid increase between 2000 and 2010. Accordingly, the ratio of each type of protected area within the Jeju Biosphere Reserve has also increased steadily from 0.001 in 1980 to 0.001 in 1990, 0.002 in 2000, 0.028 in 2010, and 0.030 in 2020. This rapid increase is closely related to the growth of natural monuments.

The legally protected areas within the Gochang Biosphere Reserve as of 2020 include wildlife, wetland, and tidal flat wetland protection areas; natural monuments; scenic spots, type 1 water source conservation areas, and disaster prevention protection areas. Wildlife protection areas were first designated in 2006, and their areas have steadily increased. Wetland protection areas have grown since their first designation in 2009 and tidal flat wetland protection areas have been maintained since their first designation in 2007. The area designated as a natural monument has been

steadily increasing since 1976 and scenic spots, first established in 2009, have also been increasing. Areas designated as type 1 water source conservation and disaster prevention protection areas have been maintained since their designation before 1976. The total area of protected areas within the Gochang Biosphere Reserve steadily increased from 26.72 km^2 in 1980 to 26.72 km^2 in 1990, 26.72 km^2 in 2000, 102.64 km^2 in 2010, and 103.36 km^2 in 2020, with a rapid increase between 2000 and 2010. Accordingly, the ratio of each type of protected area within the Gochang Biosphere Reserve has also increased steadily, from 0.040 in 1980 to 0.040 in 1990, 0.040 in 2000, 0.153 in 2010, and 0.154 in 2020 〈Table 9〉. This rapid increase is closely related to the designation of tidal flat wetland protection areas.

〈Table 9〉 Area changes by protected area type in Jeju (A) and Gochang (B) biosphere reserves (1980–2020, km^2)

Protected Area Type	1980		1990		2000		2010		2020	
	JJ	GC	JJ	GC	JJ	GC	JJ	GC	JJ	GC
Provincial Park	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.59	0.00
Wildlife Protection Area	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.32	0.00	8.32
Wetland Protected Area	0.00	0.00	0.00	0.00	0.00	0.00	1.33	1.90	2.50	2.62
Urban Natural Park Area	0.00	0.00	0.00	0.00	0.00	0.00	5.74	0.00	5.74	0.00
Wetland Protected Area (Tidal Flat)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	64.63	0.00	64.63
Natural Monument	3.56	0.05	3.92	0.05	5.10	0.05	99.35	0.17	99.42	0.17
Scenic Site	0.00	0.00	0.00	0.00	0.00	0.00	0.31	0.95	1.47	0.95
Forest Genetic Resources Reserve	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.94	0.00
Catchment Reserve Protection Area	0.00	26.52	0.00	26.52	0.00	26.52	0.00	26.52	0.00	26.52
Disaster Prevention Area	0.74	0.15	0.74	0.15	0.74	0.15	0.74	0.15	0.74	0.15
Total	4.30	26.72	4.66	26.72	5.84	26.72	107.47	102.64	117.41	103.36

Ⅳ. Conclusions

1. Research Result Summary and Implications

For the assessment of overall species diversity, based on national surveys and academic papers, 5,911 and 2,323 species in Jeju and Gochang biosphere reserves, respectively, were identified. It was confirmed that Jeju has more species than the Gochang Biosphere Reserve, probably due to the larger area and more diverse ecosystems of the Jeju Biosphere Reserve compared to those of Gochang. Regarding the Red List Index, Jeju and Gochang biosphere reserves scored 0.960 and 0.965, respectively, indicating a more favorable status of endangered species in Gochang than in Jeju. Moreover, Jeju and Gochang biosphere reserves had 237 and 129 invasive alien species, respectively.

The Jeju Biosphere Reserve showed a deteriorating ecosystem area ratio, improved vegetation grade, and no significant trend in average patch size in natural space. The Gochang Biosphere Reserve showed improvement in average patch size in natural space and vegetation grade and no significant trend in ecosystem area ratio. In the Jeju Biosphere Reserve, the ecosystem area ratio indicator deteriorated, whereas the vegetation grade and ratio of the area affected by forest fires improved. The average patch size of natural spaces and the ratio of the area may have been affected by wind. Forest fires may have affected the ecosystem area ratio in the Gochang Biosphere Reserve. The ratio of protected areas improved in both Jeju and Gochang biosphere reserves. The Jeju and Gochang Biosphere Reserves have analyzed an increase in both vegetation grade and protected area percentage, which is a result of the efforts of both regions to enhance biodiversity. However, while Gochang maintained its ecosystem area ratio for 30 years (1990-2020), Jeju Island

showed a decreasing trend. This suggests that the area of ecosystems has decreased due to development projects on Jeju Island. Therefore, both regions should continue to maintain the trend of increasing the vegetation grade and protected area ratio to promote biodiversity, and it is urgent for Jeju to promote the project to restore the ecosystem area ratio to the 1990 level.

For the sustainable conservation of the Jeju and Gochang Biosphere Reserves, the diversity of animal and plant species found in various ecosystems in the region should be surveyed and evaluated to establish management measures for endangered and endemic species. In addition, habitat environmental factors in each area should be analysed to assess the suitability of habitats for animal and plant species, and measures for sustainable habitat conservation and restoration of damaged areas should be explored. In addition, for efficient management of the Jeju and Gochang Biosphere Reserves, it will be necessary to prepare response and prevention strategies that take into account the possibility of natural disasters occurring in each region. To implement these strategies effectively, it will be necessary to (1) establish a system for real-time monitoring of local ecosystems and (2) encourage active participation of local residents and communities.

The national or local scale biodiversity survey data used in this research did not distinguish among core, buffer, and transition areas. In addition, there is no data on the distinction between core, buffer, and collaborative areas in the Jeju and Gochang Biosphere Reserves because the designation application was prepared based on qualitative data on biodiversity when registering the Biosphere Reserves. Therefore, it is essential to investigate the biodiversity of core, buffer, and transition areas when designating or reviewing Korean Biosphere Reserves in the

future. Of the three zones of Biosphere Reserves, protected areas are surveyed for biodiversity assessment, but buffer zones, although potential areas for inclusion as protected areas, are relatively un-surveyed for biodiversity assessment. There is an urgent need for biodiversity surveys and assessments of buffer zones as a way to expand protected areas in the country.

Setting the buffer zone as a protected area is a crucial step for the ongoing conservation of biodiversity and the stability of ecosystems. The continuous assessment of biodiversity indicators in the buffer zone is essential for monitoring and adjusting conservation policies. This ongoing assessment allows for a quantitative understanding of the effectiveness of conservation efforts and measures how biodiversity within the protected area changes over time. Such assessments identify the health status of ecosystems, enabling early intervention and formulating strategies for sustainable conservation. Thus, designating the buffer zone as a protected area is a critical decision for the health and sustainability of the global ecosystem. Through this approach, we can preserve biodiversity and maintain a foundation for the coexistence of diverse ecosystems on Earth while fostering local communities' development and equilibrium.

2. Research Limitations and Future Research Projects

National surveys such as inland wetland monitoring and detailed investigations, estuarine ecosystem thorough investigations, and winter bird censuses have been systematically conducted using monitoring systems for species diversity data. However, the methods for reporting and disclosing these data are primarily PDF reports. Consequently, to statistically or spatially analyze these data, they must be first converted

into a database. Continuous biodiversity monitoring is essential; however, considering that the "Periodic Review for Biosphere Reserve" occurs every ten years after the designation of biosphere reserve areas, it is appropriate to conduct biodiversity assessments every ten years.

Currently, biodiversity is described qualitatively in the submission of relevant data for the designation of Biosphere Reserves. Therefore, the use of biodiversity indicators will provide a reference data to diagnose changes in the past and present in a quantitative manner. To date, the biodiversity assessment of the nine Biosphere Reserves in Korea is qualitative, and the biodiversity indicators presented in this study can be used as a basis for comparative analysis in future indicator researches. Biosphere conservation areas have different purposes and uses for their core, buffer, and transitional areas; therefore, monitoring and reporting should be differentiated accordingly for practical biodiversity assessment. More monitoring and reporting on these zoning areas are needed to avoid data accumulation issues. This study conducted analysis without distinguishing between these zoning areas due to data availability problems. Future monitoring and reporting systems for biodiversity assessment in biosphere conservation areas should consider these zoning areas.

▌References ▌

Botswana government, 2012, Selected Botswana Biodiversity Indicators 2011, Department of Environmental Affairs, Ministry of Environment Wildlife and Tourism, Gaborone: Botswana.

Butchart, S.H., M. Walpole, B. Collen, Van Strien, A., Scharlemann, J. P. W., Almond, R. E. A., ··· Watson, R. (2010). "Global Biodiversity: Indicators of Recent Declines". *Science*, 328(5982), 1164 LP - 1168. https://doi.org/

10.1126/science.1187512

EEA, 2007, Europe's environment – The fourth assessment. Copenhagen. Denmark.

EEA, 2010, Assessing biodiversity in Europe – the 2010 report. Copenhagen, Denmark.

Ershov, D. V, Isaev, A.C., Lukina, N. V, Gavrilyuk, E.A., Koroleva, N. V., 2016, "Assessment of biodiversity in Central Federal District using satellite-based maps of terrestrial ecosystems". *Contemp. Probl. Ecol.* 9, pp.791-804. https://doi.org/10.1134/S1995425516070040

Hansen, A.J., Noble, B.P., Veneros, J., East, A., Goetz, S.J., Supples, C., … Virnig, A.L.S., 2021, "Toward monitoring forest ecosystem integrity within the post-2020 Global Biodiversity Framework". *Conserv. Lett.* 14, e12822. https://doi.org/https://doi.org/10.1111/conl.12822

Hoffmann, M., Hilton-Taylor, C., Angulo, A., Böhm, M., Brooks, T.M., Butchart, … Stuart, S.N., 2010, "The impact of conservation on the status of the world's vertebrates". *Science*, 80(330), pp.1503-1509. https://doi.org/10.1126/science.1194442

Hoffmann, M., Belant, J.L., Chanson, J.S., Cox, N.A., Lamoreux, J., Rodrigues, A.S.L., Schipper, J., Stuart, S.N., 2011, "The changing fates of the world's mammals". *Philos. Trans. R. Soc. B Biol. Sci.* 366, pp. 2598-2610. https://doi. org/10.1098/rstb.2011.0116

IPBES, 2018, The IPBES regional assessment report on biodiversity and ecosystem services for Asia and the Pacific. Karki, M., Senaratna Sellamuttu, S., Okayasu, S., and Suzuki, W.(eds). *Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*, Bonn, Germany.

IPBES, 2019, *Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*. E. S. Brondizio, J. Settele, S. Díaz, and H. T. Ngo(editors). IPBES secretariat, Bonn, Germany. https://doi.org/10.5281/zenodo.3831673

IUCN, 2012, IUCN Red List Categories and Criteria: Version 3.1. Second edition. Gland, Switzerland and Cambridge, UK.

Jaunatre, R., Buisson, E., Muller, I., Morlon, H., Mesléard, F., Dutoit, T., 2013, "New synthetic indicators to assess community resilience and restoration success". *Ecol. Indic.* 29, pp. 468-477. https://doi.org/https://doi.org/10.1016/j.ecolind.2013.01.023

Kang, S., Jang, I., Yoon, S., Lee, S., Kim, J., Hong, M., and Park, E., 2021,

International cooperation for ecological issue and policy. National Institute of Ecology.

Korean National commission for UNESCO, 2020, https://www.unesco.or.kr

MAB National Committee for the Republic of Korea, 2023, http://www.unescomab.or.kr

Martínez-Jauregui, M., Touza, J., White, P. C., and Solino, M., 2021, "Choice of biodiversity indicators may affect societal support for conservation programs". *Ecological Indicators*, 121, 107203. https://doi.org/10.1016/j.ecolind.2020.107203

McQuatters-Gollop, A., Mitchell, I., Vina-Herbon, C., Bedford, J., Addison, P. F., Lynam, C. P., ... and Otto, S. A., 2019, "From science to evidence–how biodiversity indicators can be used for effective marine conservation policy and management". *Frontiers in Marine Science*, 6, 109. https://doi.org/10.3389/fmars.2019.00109

Palliwoda, J., Büermann, A., Fischer, J., Kraemer, R., and Schröter, M., 2021, "Zoning of UNESCO Biosphere Reserves: A Comprehensive Set of Geodata for Europe". *Frontiers in Ecology and Evolution*, 9, 736358. https://doi.org/ 10.3389/fevo.2021.736358

Park, C. and Yeom, S., 2023, "Basic Research for the Efficient Management and Operation of Biosphere Reserves (A Case Study of the Gwangneung Forest Biosphere Reserve)". *J. Env. Sci. Int.* 32(6), pp. 453-464. https://doi.org/10.5322/JESI.2023.32.6.453

Pearman, P.B. and Weber, D., 2007, "Common species determine richness patterns in biodiversity indicator taxa". *Biol. Conserv.* 138, pp.109-119. https://doi.org/https://doi.org/10.1016/j.biocon.2007.04.005

Republic of Indonesia government (2014). The Fifth National Report of Indonesia to the Convention on Biological Diversity.

Santini, L., Belmaker, J., Costello, M.J., Pereira, H.M., Rossberg, A.G., Schipper, A.M., ··· Rondinini, C., 2017, "Assessing the suitability of diversity metrics to detect biodiversity change". *Biol. Conserv.* 213, pp.341-350. https://doi. org/https://doi.org/10.1016/j.biocon.2016.08.024

Singapore government, 2016, Singapore Fifth National Report to the Convention on Biological Diversity(2010-2014).

Szabo, J.K., Butchart, S.H.M., Possingham, H.P., and Garnett, S.T., 2012, "Adapting global biodiversity indicators to the national scale: A Red List Index for Australian birds". *Biol. Conserv.* 148, pp.61-68. https://doi.org/https://doi.

org/10.1016/j.biocon.2012.01.062

Tucker, C.J., 1979, "Red and photographic infrared linear combinations for monitoring vegetation". *Remote Sens. Environ.* 8, pp. 127-150. https://doi.org/https://doi.org/10.1016/0034-4257(79)90013-0

Vietnam Ministry of Natural Resources and Environment, 2014, Vietnam's Fifth National Report to the United Nations Convention on Biological Diversity.

Walz, U., 2015, Indicators to monitor the structural diversity of landscapes. *Ecol. Modell.* 295, pp. 88-106. https://doi.org/https://doi.org/10.1016/j.ecolmodel.2014.07.011

〈Appendix 1〉 Biodiversity Indicator Assessment Data Resources

Indicator	Data	Data Sources
Species Diversity		
Total Species Diversity		
Species Richness	Number of Species in Biosphere Reserves	1. 2nd National Natural Environment Survey (1997–2005) 2. 3rd National Natural Environment Survey (2006–2013) 3. 4th National Natural Environment Survey (2014–2018) 4. National Uninhabited Islands Natural Environment Survey (1998–2020) 5. National Coastal Dune Detailed Survey (2003–2018) 6. Ecological Landscape Conservation Area Detailed Survey (2012–2020) 7. Specific Islands Detailed Survey (2006–2020) 8. Estuary Ecosystem Detailed Survey (2004–2020) 9. Winter Waterbird census of Korea (1999–2020) 10. Monitoring for National Inland Wetlands (2016–2020) 11. Intensive Survey on National Inland Wetlands (2016–2020) 12. Monitoring of Invasive Alien Species (2006–2020) 13. National Natural Caves Survey (2002–2006) 14. Investigating Ecological Risk of Alien Species (2006–2020) 15. Nationwide Survey of Non-native Species in Korea (2015–2020) 16. Project of Long-Term Ecological Research (2004–2020)
Species Richness	Number of Indicator Species	1. Same as above
Endangered Species		
Red List Index	Red List of Species Number	1. Red Data Book of Republic of Korea (2011, 2019) 2. Same as above
Alien Species		
Number of Alien Species	1. Alien Species List 2. Number of Alien Species in Biosphere Reserves	Alien Species List in Korea (2020) 2. Same as above
Ecological Health		
Ecosystem Area		
Ecosystem Area Rate	Land Cover Area	Environmental Geographic Information Services (EGIS), Level-1 Land Cover Map (1990–2020)
Conte Habitat Connectivity		

Average of patch size in Natural Space	High-Resolution Aerial Photographs	1. EGIS, Level-1 Landcover Map (1990-2020) 2. Geospatial Web Platform, Orthophoto (2010-2019)
Vegetation Grade		
Vegetation Grade	Ecology and Nature Grade	EGIS, Ecology and Nature Map (2021) Eco-bank, Ecology and Nature Grade (2007-2019)

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