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

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Summary

Jeju Island, designated by UNESCO as a world heritage site, continues to face the anthropogenic pressures of reckless development for regional tourism and economic revitalization purposes. Because land use/land cover (LULC) affects ecosystem services and human well-being, it is crucial to comprehensively identify the causes of changes in LULC based on long-term analyses. This study examined LULC changes on Jeju Island over 47 years from 1973 to 2019 and quantified changes in four ecosystem services: habitat quality, carbon stock, water yield and cumulative viewshed. From 1973 to 1998, forest land increased from 22% to 56%, but these restoration efforts were conducted in grassland, reducing that land type from 42% to 17%. This process increased the areas of highest habitat quality from 68% to 73%, and carbon stock increased from 20 to 30 million tonnes. Between 1998 and 2009, the area of cropland more than doubled from 21% to 44%. As a result, the areas of highest habitat quality decreased from 73% to 49%, and carbon stock decreased from 3.0 million tonnes to 2.3 million tonnes. Our analysis could help stakeholders and policymakers to develop their management planning and improve ecosystem services through restoration and conservation policies on Jeju Island.

Introduction

Human demand for ecosystem services has recently increased, imposing continuous threats upon natural environments (Millennium Ecosystem Assessment 2005, Xu et al. 2019, Yohannes et al. 2021). The number of tourists using ecosystem services is consistently increasing worldwide, particularly in areas that are 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 becoming increasingly rampant. Changes in land use/land cover (LULC), 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 management policies for the sustainability of 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 identify changes in land use from the past to the present and the resulting changes in ecosystem services (Nelson et al. 2009).

Changes in LULC can significantly 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). Management plans for sustainability 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, harbouring an outstanding natural landscape, and it is also a United Nations Educational, Scientific and Cultural Organization (UNESCO) world heritage site. It has achieved three UNESCO designations: as a Biosphere Reserve in 2002, a World Natural Heritage site in 2007 and a Global Geopark in 2010 (Kim et al. 2019). In addition, the island is home to two intangible UNESCO cultural heritages – the Chilmeoridanggut Intangible Cultural Heritage (ICH) and the Jeju Haenyeo ICH – as well as

Jeju Batdam, a world agricultural heritage site designated as an ICH by 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, forestland increased for *c.* 20 years after 1973, but LULC has changed rapidly due to increases in cropland 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 in the area, 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 thus continuous development pressure in the region due to this influx of visitors (Barr & Choi 2016).

Despite these recent trends (Polasky et al. 2011, Kim et al. 2019, Sun et al. 2019a, Xu et al. 2019) and Jeju Island's high ecological and cultural status, understanding of LULC changes over time, ecosystem service management and long-term planning have been inadequate. The consequences of LULC changes and management for ecosystem services need to be quantitatively assessed (Han et al. 2019, Sun et al. 2019a, Sharp et al. 2020). However, it is important not only to 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. Artificial Intelligence for Ecosystem Services (ARIES) and the Toolkit for Ecosystem Service Site-based Assessment (TESA) are useful tools to evaluate ecosystem services, 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. 2019b, 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 an opportunity to examine the causes of alterations in ecosystem services. On Jeju Island, ways to reduce the severe development pressures and increase biodiversity and ecosystem services are subject to ongoing discussion (Kim et al. 2019, Hong et al. 2021, Jun et al. 2021). Hence, this study is crucial for providing decision-makers and policymakers with a long-term perspective and fundamental data to improve land-use and ecosystem services management.

Materials and methods

Study area

Jeju Island (33°11′27′′–33°33′50′′N, 126°08′43′′–126°58′20′′E) 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. 1). The administrative district is centred on Mount Hallasan in the middle of the island, with the administrative areas of 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 cropland, the mid-mountain area is primarily grassland and the mountain area harbours most of the forestland, including Mount Hallasan at the centre of the island. Jeju Island also contains 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).

Data acquisition

We analysed 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 information 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).

Ecosystem services assessment

Changes in the four types of ecosystem services (Millennium Ecosystem Assessment 2005, Başkent 2021) related to LULC changes were assessed using the InVEST model consisting of HQ, CS and 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. 2019b, Sharp et al. 2020). The value of the habitat was assessed by distance from the threat and sensitivity was affected by the threat factor (Sharp et al. 2020). Based on a previous study, a threats and sensitivities 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 HQ.

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 CS (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 in Korea compared to in other regions (Mimura et al. 2007, Kwon et al. 2022).

The CV analysis refers to the frequency with which one point can be viewed from other points (Wheatley 1995), and it also functions to draw a line of sight between the observation point and the target point using numerical geographical information to determine whether the visibility of the area is blocked (Jeung et al. 2018). At the study site, random extractions of 1000 points for each of urban land, forestland and grassland were practised, and urban parks by time period were set as points. Regarding terrain height, a digital surface model was constructed based on the building data at the time, along with a digital elevation model. The points were extracted based on the LULC of the administrative district for ease of analysis because the centre of Jeju Island cannot be seen across due to Mount Hallasan (Fig. 1). Because Mount Hallasan reaches high altitudes in the centre of Jeju Island, the administrative areas of Jeju-si and Seogwipo-si were analysed separately.

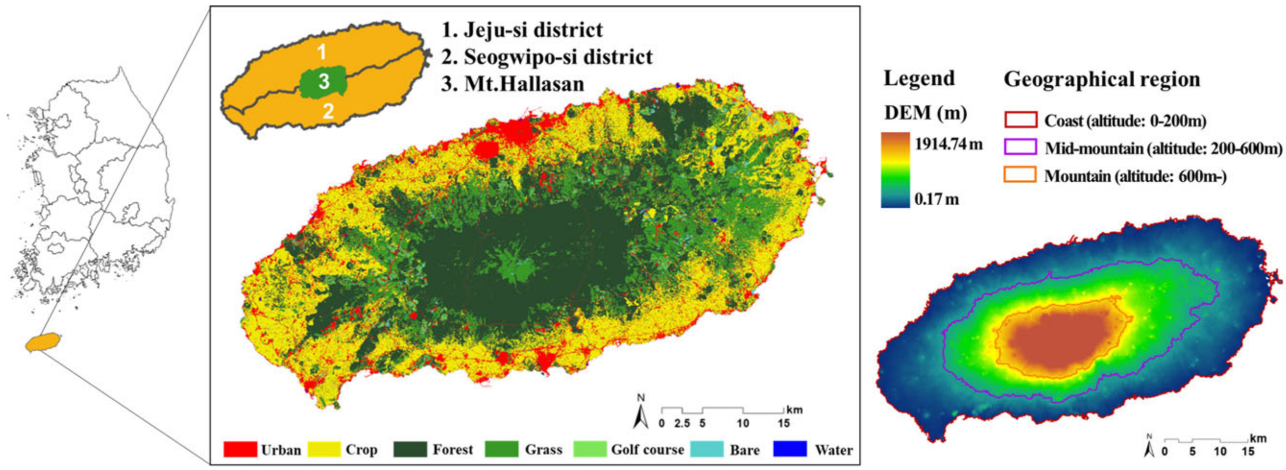

Fig. 1. Diagrammatic map of Jeju Island, Republic of Korea, in 2019. DEM = digital elevation model.

Results

LULC change over 47 years on Jeju Island

Three types of LULC, namely cropland, forestland and grassland (Figs 2 & Supplementary Fig. S1, available online), changed rapidly between 1973 and 1989 and between 1998 and 2009 (Fig. 2a). Between 1973 and 1989, cropland fell by 8.18%, while forestland increased by 27.76% and grassland decreased by 19.93% (Table S1). The forestland increase and grassland decrease occurred mainly in the coast and mid-mountain areas, respectively (Fig. 2b & c). Between 1998 and 2009, cropland increased by 23.4% (431.53 km^2), while forestland decreased by 21.29% (392.86 km^2; Fig. 2a & Table S1). These changes occurred primarily in the coast area, and 399.94 km^2 of forestland was converted to cropland (Fig. 2b & Table 1).

Changes in grassland between 1973 and 1989 were closely related to changes in forestland. In terms of LULC changes over time, large areas of grassland transitioned into forestland (Table 1). Grassland accounted for the largest area in 1973, consisting of 42.12% of the total area; however, in 1989, cropland comprised 222.99 km^2, and 322.51 km^2 of grassland had shifted to forestland, increasing the proportion of the latter to 50.14% (Tables 1 & S1).

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

Changes in ecosystem services over 47 years

Many gains and losses of ecosystem services occurred depending on time and region (Fig. 3 & Tables 2 & S3). The trends 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 rate of increase in ecosystem services. In 1989 compared to 1973, the HQ index values in the range of 0.25–0.50 decreased by 11.21% in the coast area, while values ranging from 0.75–1.00 increased by 9.57%. Between 1973 and 1989, forestland in the coast area increased by 29.98%, cropland decreased by 17.75% and grassland decreased by 12.41%. Subsequently, no meaningful changes in HQ occurred until 1998. However, in 2009, cropland in the coastal area increased by 37.36% (377.2 km^2), while forestland decreased by 34.48% (348.55 km^2). During the same period, HQ index values in the range of 0.75–1.00 decreased by 20.37% in the coast area. In the mid-mountain area from 1973 to 2009, the 0.25–0.50 range of HQ continued to increase and then decreased in 2019. The 0.75–1.00 range of HQ was highest in 1973 at 30.51% but decreased to 25.86% in 2019. However, with changes in LULC, forestland increased by 31.99% between 1973 and 1989, and grassland decreased by 37.14% in the mid-mountain area (Table S2). Forestland 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 cropland, 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 cropland and decreased forestland.

Unlike HQ and CS, WY peaked in 2019 and was at its lowest level in 1973 (Table 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 to 1739.82 mm.

Jeju-si obtained a higher value than Seogwipo-si for the 0–5% range of CV, and no meaningful changes occurred over time. For the 5–50% range of CV, Seogwipo-si obtained a higher value, but Jeju-si obtained a higher value for the 50–100% range (Fig. S2 & Table S3).

Discussion

Spatiotemporal variations of LULC and ecosystem services

LULC changes occurred over 47 years on Jeju Island, and these strongly influenced ecosystem services (Fig. S1 & Table 2). Similarly to previous studies of such effects (Nelson et al. 2009,

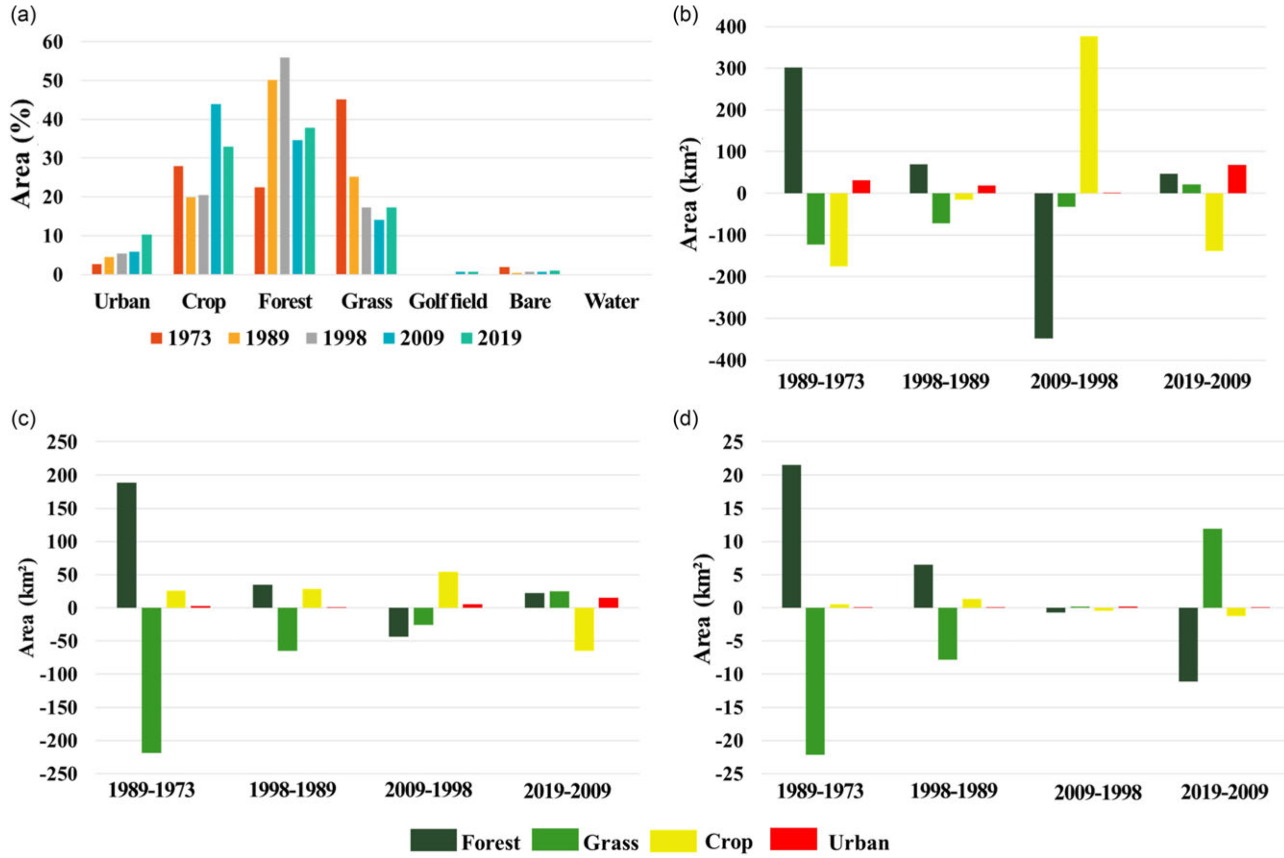

Fig. 2. (a) Proportional changes in total area by land type from 1973 to 2019; (b) land-use/land-cover (LULC) changes in the coast area; (c) LULC changes in the mid-mountain area; and (d) LULC changes in the mountain area.

Polasky et al. 2011, Crossman et al. 2012, Haase et al. 2012, 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, the threat factors affecting ecosystem services were considered to be urban land, cropland and industry (Table S5). Between 1973 and 1998, concomitant increases in forestland and grassland as well as decreases in cropland led to sharp increases in ecosystem services (Fig. S1 & Tables 2 & S1). These findings suggest that declines in ecosystem services can be accelerated if cropland and urban land increase rapidly as forestland and grassland decrease.

The changes in LULC on Jeju Island can be divided into two categories: increased forestland and increased cropland. Between the 1970s and 1980s, grassland sharply declined while forestland increased, and between 1998 and 2009, cropland greatly increased. Consequently, both HQ and CS increased until 1998 and then decreased in 2009, and these outcomes were prominently centred in the coast area (Fig. 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 cropland. During this period, forestland was converted to cropland in the coast area because the steep slopes at altitudes above 400 m were unsuitable for cropland, leading to changes in ecosystem services. In addition, Jeju Island's agriculture was predominantly conducted simply to achieve self-sufficiency before the economic growth of the 1990s, but after that period, the area of cropland increased as the island's overall farming behaviour shifted to high-income commercial agriculture of products such as tangerines, vegetables and flowers (Lim 2013, Kim & Kang 2015). In locations where the slope is less steep, ecological degradation can occur due to high levels of human intervention such as urban development and agricultural land reclamation (Peng et al. 2018). Jeju Island could easily be converted into cropland because the coastal area has a relatively gentle slope. Similarly, Upadhaya and Dwivedi (2019) found that HQ decreased due to increases in cropland and blueberry arable land in a mountainous area. On Jeju Island, Mount Hallasan occupies most of the mountain area, and this 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 forestland and grassland into cropland or urban land, which can substantially impact ecosystem services in the region.

However, LULC changes did not have much effect on cultural services. These would not affect CV as LULC has changed mainly to cropland in the mid-mountain area, although the development of urban areas occurred predominantly in the coast area. This study is limited in that it is a macro-analysis for all of Jeju Island; however, this makes it possible to propose more efficient management measures for areas experiencing changes in LULC and ecosystem services that have been rapidly degraded.

Restoration intervention on Jeju Island

Forest restoration is an extremely important factor in supplying ecosystem services (Chazdon 2008, Rodríguez et al. 2016,

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Table 1. Land-use/land-cover transitions from 1973 to 2019 (km^2).

		1989						
		Urban land	Cropland	Forestland	Grassland	Golf course	Bare land	Water
1973	Urban land	30.35	8.54	7.33	0.72	0	0.23	0.05
	Cropland	35.19	200.77	222.99	50.65	0.01	1.80	0.24
	Forestland	3.92	29.21	349.54	26.30	0.02	0.40	0.04
	Grassland	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	0.30	0.03
	Water	0.07	0.10	0.07	0.01	0	0.04	0.33
		1998						
		Urban land	Cropland	Forestland	Grassland	Golf course	Bare land	Water
1989	Urban land	47.58	21.57	9.83	1.05	0	1.20	0.01
	Cropland	29.95	182.51	102.68	43.58	0.20	4.74	0.02
	Forestland	15.27	74.11	789.47	39.57	0.40	1.84	0.04
	Grassland	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	1.30	2.29	0.42	0.74	0.01	1.43	0.03
	Water	0.06	0.13	0.10	0.01	0	0.14	0.38
		2009						
		Urban land	Cropland	Forestland	Grassland	Golf course	Bare land	Water
1998	Urban land	85.77	12.90	0.24	0.22	0.04	0.27	0.05
	Cropland	10.94	344.81	8.88	10.16	1.11	1.85	0.26
	Forestland	6.27	399.94	606.09	13.33	4.06	1.60	0.57
	Grassland	2.19	49.87	23.80	235.46	4.69	1.01	0.39
	Golf course	0	0	0	0	2.39	0	0
	Bare land	1.53	2.50	0.10	0.12	0.04	8.35	0.08
	Water	0.08	0.02	0.02	0	0	0.03	0.53
		2019						
		Urban land	Cropland	Forestland	Grassland	Golf course	Bare land	Water
2009	Urban land	101.89	2.03	1.14	1.10	0	0.46	0.07
	Cropland	65.09	594.54	67.51	74.35	0	6.42	0.42
	Forestland	8.44	4.96	563.67	59.64	0.31	1.59	0.17
	Grassland	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

Chazdon et al. 2017, Huang et al. 2018, Paudyal et al. 2019), and the forest restoration of the 1970s and 1980s on Jeju Island significantly affected the current level of ecosystem services. We observed a dramatic increase in forestland from 1973 to 1989, concomitant with a rapid decrease in grassland (Fig. S1 & Table S1). These changes were driven by increased forestland through a National Greening Programme 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 grassland and bare land (Jeju Province 2006, Bae et al. 2012, Park & Lee 2014); Fig. S3 shows seedlings being grown in 1973 through transplant work. Over 16 years (1973–1989), forestland expansion more than doubled from 409.83 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 forestland, while other areas, such as grassland, are developed in response to socioeconomic demands such as tourism (Schirpke et al. 2017, Bengtsson et al. 2019). On Jeju Island, grassland was mainly converted to forestland (Table 1), but because grassland accounts for close to 30% of the mid-mountain region, this area may be exposed to development risk (Table S2). The forest restoration policy of the Republic of Korea succeeded in vastly increasing forestland (Bae et al. 2012, Le et al. 2012, Park & Lee 2014). Although ecosystem services were quantitatively enhanced through afforestation, Jeju Island harbours the highest proportion of grassland ecosystems in all of the Republic of Korea at 48.15%, and this type of land is otherwise scarce in the country (Dolezal et al. 2012, MAFRA 2021). Grassland can also provide various functions such as CS, 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 grassland restoration should be considered. As cropland was originally converted from grassland, there is a risk of adverse ecosystem changes such as biodiversity degradation and soil carbon loss (Bengtsson et al. 2019, Tang et al. 2019, Bardgett et al. 2021). Knowledge of the biodiversity level of the restoration area should inform measures to improve ecosystem services in the decision-making sector (Rizvi et al. 2015, Sabogal et al. 2015, Bengtsson et al. 2019).

Conclusion

Forty-seven years of changes in LULC and ecosystem services on Jeju Island highlight the importance of ecosystem services

Table 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
	0.25–0.50	28.32	17.11	16.51	36.89	29.56
	0.50–0.75	0.04	0.03	0.07	0.10	0.13
	0.75–1.00	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
	0.25–0.50	1.51	3.17	4.72	8.09	4.78
	0.50–0.75	0	0.01	0.01	0.04	0.02
	0.75–1.00	30.51	28.64	27.02	23.30	25.86
Mountain	0–0.25	0.03	0.03	0.03	0.04	0.05
	0.25–0.50	0	0.04	0.11	0.13	0.08
	0.50–0.75	0	0.01	0.01	0.01	0.01
	0.75–1.00	13.39	13.33	13.22	13.19	13.25
Total	0–0.25	2.59	4.47	5.38	5.81	10.14
	0.25–0.50	29.83	20.32	21.34	45.11	34.42
	0.50–0.75	0.04	0.05	0.09	0.15	0.16
	0.75–1.00	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)		1.917	1.958	2.497	2.167	3.165

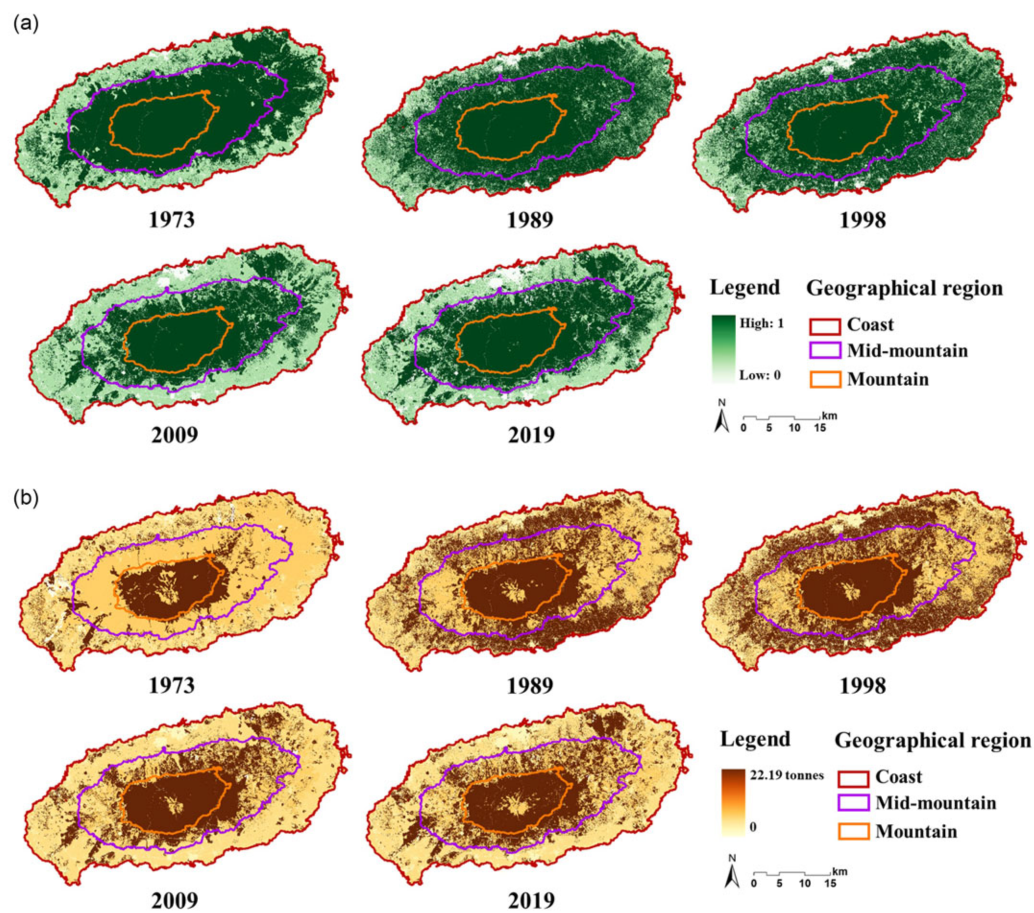

Fig. 3. Spatial distribution of changes in ecosystem services from 1973 to 2019: (a) habitat quality (index: 0–1); (b) carbon stock (tonnes).

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management that balances human supply and demand in terms of conserving nature. Supporting and regulating ecosystem services increased sharply in the 1980s and 1990s due to increases in forestland, while ecosystem services fell sharply in the 2000s due to increases in cropland. In particular, ecosystem services decreased rapidly in coastal areas. Hence, measures to improve ecosystem services should be incorporated into ecological planning by utilizing projected future scenarios. One novel aspect of the present study is that the long-term dynamics of LULC and changes in ecosystem services were studied together. Jeju Island has 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 demonstrated that there had been various changes in ecosystem services across the various periods that were studied and the various geographical regions of Jeju Island. We expect that this study could provide valuable guidance to help with making policy decisions and also provide scientific information to stakeholders and decision-makers by highlighting the restoration and conservation ecologies in specific areas such as Jeju Island's coastal area.

Supplementary material. To view supplementary material for this article, please visit https://doi.org/10.1017/S0376892922000285.

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Competing interests. The authors declare none.

Ethical standards. None.

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