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Dynamic Landscape Fragmentation and the Driving Forces on Haitan Island, China

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Abstract: Island ecosystems have distinct and unique vulnerabilities that place them at risk from threats to their ecology and socioeconomics. Spatially exhibiting the fragmentation process of island landscapes and identifying their driving factors are the fundamental prerequisites for the maintenance of island ecosystems and the rational utilization of islands. Haitan Island was chosen as a case study for understanding landscape fragmentation on urbanizing Islands. Based on remote sensing technology, three Landsat images from 2000 to 2020, landscape pattern index, transect gradient analysis, and moving window method were used in this study. The results showed that from 2000 to 2020, impervious land increased by 462.57%. In 2000, the predominant landscape was cropland (46.34%), which shifted to impervious land (35.20%) and forest (32.90%) in 2020. Combining the moving window method and Semivariogram, 1050 m was considered to be the best scale to reflect the landscape fragmentation of Haitan Island. Under this scale, it was found that the landscape fragmentation of Haitan Island generally increased with time and had obvious spatial heterogeneity. We set up sampling bands along the coastline and found that the degree of landscape fragmentation, advancing from the coast inland, was decreasing. Transects analysis showed the fragmentation intensity of the coastal zone: the north-western and southern wooded zones decreased, while the concentration of urban farmland in the north-central and southern areas increased. The implementation of a comprehensive experimental area plan on Haitan Island has disturbed the landscape considerably. In 2000, landscape fragmentation was mainly influenced by topography and agricultural production. The critical infrastructure construction, reclamation and development of landscape resources have greatly contributed to the urbanisation and tourism of Haitan Island, and landscape fragmentation in 2013 was at its highest. Due to China's "Grain for Green Project" and the Comprehensive Territorial Spatial Planning policy (especially the protection of ecological control lines), the fragmentation of Haitan Island was slowing. This study investigated the optimal spatial scale for analyzing spatiotemporal changes in landscape fragmentation on Haitan Island from 2000 to 2020, and the essential influencing factors in urban islands from the perspective of natural environment and social development, which could provide a basis for land use management and ecological planning on the island.

Keywords: island; landscape index; landscape fragmentation; spatio-temporal variation; moving window; driving factor

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1. Introduction

Haitan Island has obvious spatial isolation, geographic specificity, and land–sea dichotomy, and is situated in a unique land–sea dual interaction zone [1–3]. The demand for resources and economic interests have led to the extension of human activities from the mainland. In the last few decades, the urbanization, industrialization and tourism of the island has brought about rapid economic and social development [4–7]. However, these human interferences have caused dramatic changes in land use and land cover on island, and inevitably have raised a series of ecological problems, such as changes in landscape patterns, shoreline erosion, encroachment of natural habitats, species decline, and the consequent fragmentation of landscapes [4,8–10]. The intensification of landscape fragmentation largely strays from natural habitats [11], and directly affects ecological features and processes, such as energy flow and material cycling in the landscape [12], which may bring devastating and irreversible consequences to regional ecosystems [13,14]. Therefore, land use and land cover (LULC) changes on urbanizing islands and the effects of landscape fragmentation have received extensive attention from land use planning and policy decision makers [15–17].

Landscape fragmentation is manifested as a decrease in the contiguity and connectivity of large habitats (a single, homogeneous and concentrated contiguous landscape becomes a complex, heterogeneous and fragmented landscape of smaller patches) and specifically includes landscape changes in the area, distance and distribution [14,18,19]. Landscape fragmentation is mainly influenced by land cover and land use [20,21], therefore, the monitoring of LULC changes can help to understand the spatial and temporal characteristics of regional landscape fragmentation [22,23]. Thanks to the current development of remote sensing technology, large scale and multi-temporal land use information was provided for this research. For instance, Tian et al. [17] used orthophoto maps to assess green space fragmentation in compact cities. Chi et al. [1] evaluated the ecological elements of land and surrounding waters sub-ecosystems and established an evaluation model on island ecological vulnerability, based on the remote sensing image of WorldView-1 satellite and field investigations. Li et al. [2] used a time series of annual land use/cover data from the European Space Agency (ESA) and landscape pattern indicators found opposite spatial characteristics of coastal landscape fragmentation in urban fringe areas and remote areas. Islands have dual characteristics of land and sea, and any change in marine or terrestrial ecosystems will lead to changes in landscape structure.

Regional variation in vegetation cover, biological species, soil composition, topographic features, and the degree of human disturbance can cause spatial differences in landscape fragmentation [13,24–26]. To explore the spatial differences, researchers set up special sampling bands to study the degree of landscape fragmentation from both anthropogenic and natural elements. Felt et al. [27] established concentric rings and transects from human aggregation centers to explore the spatial differences in the radiative capacity of urban development and its impact on landscape patterns. Focusing on the urban fringe, Wadduwage et al. [28] used urban-to-rural gradients to identify agricultural land fragmentation. Shi et al. [29] discussed the relationship between ecosystems and human interference in terms of topographic gradients. However, Haitan Island is an independent space surrounded by water, and the coastal area is influenced by the sea ecosystem. Haitan Island is the area most influenced by climatic and anthropogenic-driven factors. Under the strengthening of urban expansion, reclamation projects, coastal tourism and other human activities, the spatial differences of the island landscape have shown a special gradient structure in coastal areas [30]. Haitan Island (the main island of Pingtan Comprehensive Experimental Area) is the fifth largest island in China, connecting both sides of the Taiwan Strait. With its unique geographical position, Pingtan has attracted great attention from the state and was officially established as “Fuzhou (Pingtan) Comprehensive Experimental Area” in 2009 and upgraded to a provincial administrative area in 2013. In order to highlight the advantages of the location and give full play to the role of the strategic position of the “Maritime Silk Road”, Pingtan is actively exploring and creating a business environment that is in line with international standards and building a window of cooperation between Fujian and Taiwan, and a window to the outside. In recent years, Pingtan has explored the new mode of international island tourism development. With the accelerating urbanization process, the urban landscape of Haitan Island has undergone a radical change. The urbanisation rate was 10.26% in 2000 and raised to 51.50 percent in 2020, and the economic growth in terms of total GDP raised from 3098 million yuan (mY) to 28,285 million yuan (2000–2020). It is important to explore the spatial and temporal landscape characteristics of such a key island.

In fact, researchers have paid attention to the relationship between urban construction and ecological environment since the implementation of Pingtan Comprehensive Experimental Area, and explored the ecological and environmental sustainability evaluation index system [31,32], including urban expansion [33], the implementation of a comprehensive experimental zone plan [34], gale and atmospheric particulates mitigation [35–37], ecological sensitivity [31,38], ecosystem services and conservation [39,40] and so on. The available studies of landscape change on Haitan Island have mostly explored the landscape structure of ecological habitats within the urban or coastal areas of the island from the perspective of the region as a whole, while relatively few studies have analyzed the internal structure and function of Haitan Island and the spatial variation of human activities disturbing the island on a smaller scale. Therefore, this study aimed to investigate the landscape fragmentation of Haitan Island based on sampling bands and transects methods, focusing on the spatial and temporal differences in landscape fragmentation, aiming to address: (1) whether there is a gradient in landscape fragmentation from the coast to the interior of island, and (2) determine the dominant drivers of landscape fragmentation on urbanizing islands.

2. Study Areas

Haitan Island is located in Fujian Province off the southeast coast of China. It is only 68 km away from Taiwan in the east and is the closest location of mainland China to Taiwan. The topography is dominated by hills, followed by plains and tablelands. The highest elevation is 435 m on Jun Mountain (Figure 1). Haitan Island belongs to a subtropical marine monsoon climate, with an annual average temperature of 19.6 °C and annual precipitation of 1200 mm.

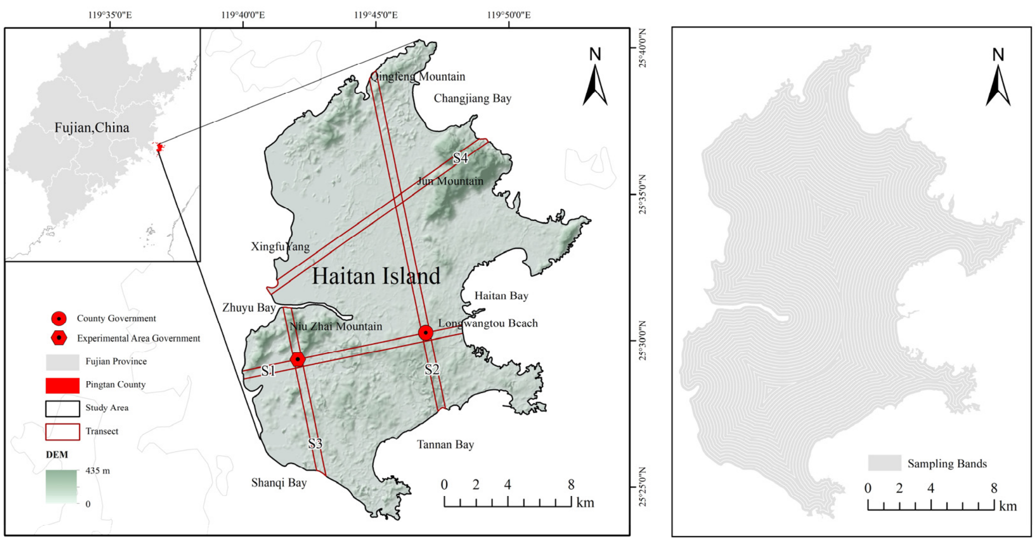

Figure 1. Location of the study area.

Due to the spatial gradient structure of the coastal zone [30], this study set up sampling bands at 200 m intervals. With the support of ArcGIS10.6 software, a total of 30 buffer zones were delineated within the whole island to analyze the change gradient characteristics of the landscape fragmentation from the coastline to the inner island.

The topographic features, the degree of urban expansion, socio-economic factors, and tourism island development in the study area have great influence on the spatio-temporal variation of land use and landscape pattern. These provide the basis for transects selection. According to the different topographic and socio-economic features of the study area, we focused on the regions with a faster expansion of impervious land and forest. What is more, Haitan Island has formed a dual-center development model with the county center and the experimental area center after the implementation of the Comprehensive Experimental Area, so the location and direction of the transects was mainly determined by the administrative centers and the topography. The different transects extend to the whole study area as far as possible and cover the classified land use types. Finally, this study set up four representative transects: S1 connected the county government and the experimental area government, and extended the Strait One Bridge and Longwangtou Beach. S2 was the vertical line between the county government and S1, connecting Qingfeng Mountain and Tannan Bay. S3 was the vertical line between the experimental government area and S1, connecting Niuzhai Mountain and Shanqi Bay. S4 connected Jun Mountain with the artificial sand blowing project of XingfuYang. The transect width was set to 500 m (Figure 1).

3. Methods

3.1. Data Preparation

The Landsat7 image of 2000, and the Landsat8 images of 2013 and 2020 were selected as the data source, and the cloudiness of all these images is less than 5% (http://www.gscloud.cn/ accessed on 8 July 2021). The pre-processing of images was conducted on ENVI 5.3, including atmospheric correction, radiometric correction, and geometric correction. Additionally, the images were fused with multispectral and panchromatic bands to obtain images with a spatial resolution of 15 × 15 m. The random forest classifier was used for classification. Combined with the actual situation and research needs, Haitan Island was divided into five landscape types: water, forest, impervious land, cropland and other land (including unused land, low cover land, etc. Figure 2). Datasets including Pingtan forest inventory data, 1:10,000 topographic map of Pingtan County, land use status map of Pingtan Comprehensive Experimental Area in 2012, and field survey data in 2020 were used as references for accuracy verification. The accuracy was verified by randomly selecting 200 sample points from Google Earth high-resolution images and comparing them with the classification type. Then, the result of class confusion matrix of three periods was obtained on ENVI 5.3, and the value of kappa coefficient was 0.87(2000), 0.92(2013), 0.95(2020), respectively, which met the accuracy requirements [41].

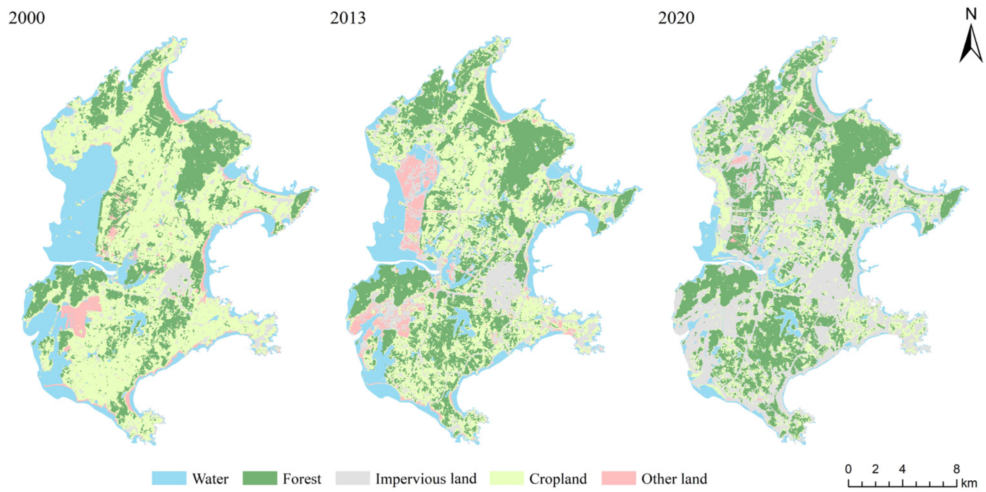

Figure 2. Landscape type distribution map on Haitan Island of 2000, 2013 and 2020.

3.2. Landscape Transfer Matrix

The landscape transfer matrix can clarify the loss and shift between landscape types in each period of the study area, and obtain information on the transformation between different landscape types in the early and late periods of the study period, which has rich statistical significance [26,42,43]. This study mainly depicted landscape transfer in 2000–2013 and 2013–2020 using Sankey energy balance diagrams.

3.3. Landscape Index Analysis

The landscape index can highly condense the information on landscape spatial patterns and reflects the characteristics of the structural composition and spatial configuration of the region [44,45]. FRAGSTATS 4.2 software was used to calculate landscape index. Patch density (PD), largest patch index (LPI), landscape shape index (LSI), and Shannon's diversity index (SHDI) were selected as essential indices for monitoring the changes in landscape fragmentation on Haitan Island. Among them, PD can indicate the composition of the landscape. SHDI expresses the heterogeneity of the landscape. LPI reflects the degree of influence of the largest patches on the whole landscape (or type). Additionally, LSI can describe the shape variation of the landscape [17,22,27].

3.4. Moving Window Method and Semivariogram

In order to comprehensively understand the evolution of the spatial pattern of landscape fragmentation in the study area, we calculated the selected landscape indices through the moving window function of FRAGSTATS 4.2 software. The determination of the moving window radius is very important, and if it is too large or too small it cannot accurately reflect the landscape characteristics of the region. Therefore, the radius of the window f must be determined first. The moving window radius was set as 150, 300, 450, 600, 750, 900, 1050, 1200, 1350, 1500 m, respectively, and the semivariogram model was used to determine the characteristic scale. The semivariogram function method of geostatistical methodologies was used to determine the characteristic scale for analyzing landscape fragmentation. The semivariogram function can reveal the spatial heterogeneity of variables based on data point variance values and data point distances [46–48]. The nugget/sill provides an estimate of the importance of the random factor in the total spatial variance, which reflects the degree of spatial variability of the variable. The value represents the degree of spatial variability [49]. The higher the ratio of the nugget/sill is, the more obvious the spatial autocorrelation is, and the lower the proportion of spatial heterogeneity caused by the random part [47,50]. ArcGIS10.6 was used to simulate the semivariogram function of landscape fragmentation under different moving window radii, and the spatial characteristics of the landscape index were analyzed by the variation pattern of the nugget/sill in response to the scale. When the nugget/sill reaches a relatively stable level, it indicates that the spatial variability of the landscape index tends to be stable, and this scale is considered to be a suitable window radius for expressing the landscape index of the study area. Under this window radius, the landscape index maps obtained by the moving window method were used to reflect the spatial variation of landscape fragmentation on Haitan Island.

4. Result and Analysis

4.1. The Scale Effects and Semivariogram Analysis

The spatial variability characteristics of the landscape indices were explored at multiple continuous scales (Figure 3), which determined the characteristic scales. The results showed that nugget/sill of the landscape fragmentation index decreased with the increase in the window radius, which indicated that the degree of spatial variability decreases with the increase in the scale, and the spatial autocorrelation became more obvious and stable. Nugget/sill decreased significantly and changed unstably at 450, 600, and 750 m, while it started to stabilize at about 1050 m. Therefore, 1050 m was considered to be the best scale to reflect the spatial variability characteristics of landscape fragmentation in the study area.

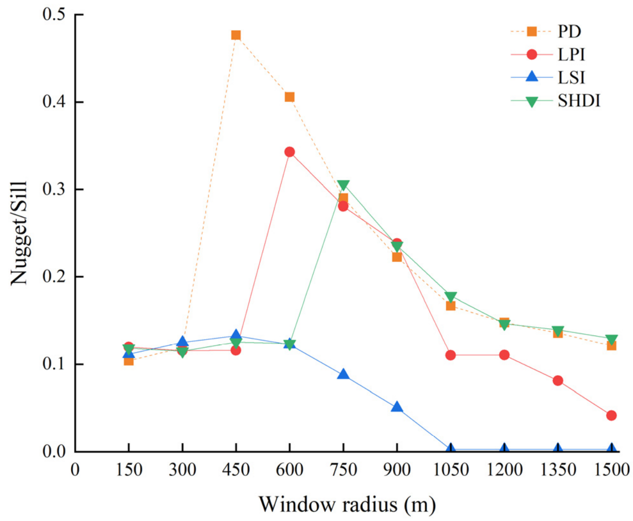

Figure 3. The trend of characteristic values of spatial fragmentation within different extents.

4.2. Spatio-Temporal Variation of Landscape Fragmentation on Haitan Island

4.2.1. Land Cover Change and Transformation

According to Table 1, cropland was the dominant land type, with an area of 150.53 km^2, accounting for 46.34% of the island in 2000. Water and forest accounted for 20.80% and 22.25%, respectively, and the sum of the three accounted for nearly 90% of the study area. In 2013, the area of forest and cropland were 97.20 km^2 and 105.20 km^2, respectively, and the impervious land was about the same as the water. In 2020, the impervious land continued to increase, and the area reached 114.34 km^2.

Table 1. Summary of land cover classes and change on Haitan Island, China.

	Area (km^2) (%)					
	2000	**2013**	**2020**	**2000–2013**	**2013–2020**	**2000–2020**
Water	67.57 (20.80)	53.31 (16.41)	24.80 (7.64)	−14.26 (−21.10)	−28.51 (−53.47)	−42.77 (−63.29)
Forest	72.28 (22.25)	97.19 (29.92)	106.88 (32.90)	24.91 (34.47)	9.69 (9.97)	34.60 (47.87)
Impervious land	20.33 (6.26)	52.75 (16.24)	114.34 (35.20)	32.42 (159.53)	61.59 (116.77)	94.02 (462.57)
Cropland	150.54 (46.34)	105.20 (32.38)	76.72 (23.62)	−45.34 (−30.12)	−28.48 (−27.07)	−73.81 (−49.03)
Other land	14.16 (4.36)	16.42 (5.05)	2.12 (0.65)	2.26 (15.98)	−14.30 (−87.08)	−12.04 (−85.01)

From 2000 to 2020, the area of forest and impervious land continued to increase. The area of water and cropland gradually decreased, and other land experienced an increase followed by a decrease. The transfer of other landscape types to impervious land reached 94.02 km^2, with an increase of 42.57%. From 2000 to 2013 and 2013 to 2020, the area of forest land increased by 24.91 km^2 and 9.69 km^2, respectively. During 2000–2010, the area of forest land increased by 24.91 km^2 and during 2013–2020 by 9.69 km^2. Water decreased from 67.57 km^2 in 2000 to 24.80 km^2 in 2020. The area of cropland has been decreasing, covering a maximum 46.34%, of the island in 2000, to just 23.62% in 2020, a decrease of 73.81 km^2. Other land increased by 2.26 km^2 from 2000 to 2013 and decreased by 14.30 km^2 from 2013 to 2020.

Based on the analysis of the overall landscape distribution on Haitan Island, a transfer matrix was used to quantify the interconversion of landscape types. The Sankey diagram of landscape transfer matrix (Figure 4) focused on the description of the "flow" of the landscape, which can better reflect the "source and sink" of the landscape. Cropland was the major "source" of change, and its dominant position was gradually replaced by impervious land, and gradually transformed into impervious land and forest. The impervious land changed the most and continued to increase, mainly from the conversion of cropland and water.

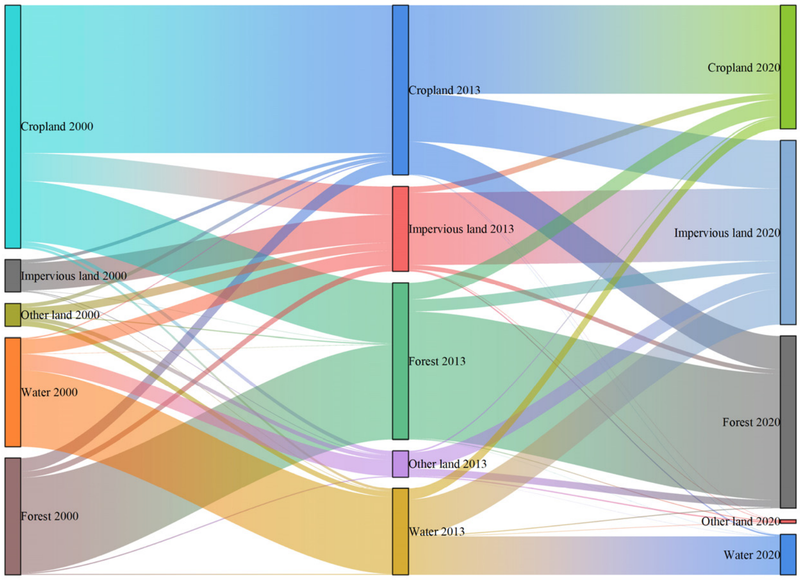

Figure 4. Sankey diagram of landscape transfer matrix.

4.2.2. Spatial Analysis of Landscape Fragmentation

The spatio-temporal variation of landscape fragmentation with the window size of 1050 m was shown in Figure 5: From 2000 to 2013, the high values of positive LPI change rate were mainly concentrated in the central area of the county, the northern mountainous coastal area, and forest of the central and western mountainous region. The high values of negative LPI variability were mainly concentrated in the west of artificial reclamation area and in the south agricultural land. From 2013 to 2020, the high value of positive LPI change rate was mainly concentrated in the southwestern port and the emerging center of the experimental area, and the overall performance was sporadic, respectively. The high value of negative LPI change rate was mainly seen in the southern coastal zone and some areas in the north farmland. The trend of LSI was similar to PD. The spatial distribution of PD and SHDI rates of change were roughly opposite to that of LPI. The high positive in LPI was often the high negative area of PD and SHDI. In contrast, the high negative rate of LPI was often the high positive rate in PD and SHDI. Human interference was more intense, and fragmentation began to increase in the central-northern and southern urban farmland areas, while in the northern forested zone, ecological restoration was good and fragmentation continued to decrease.

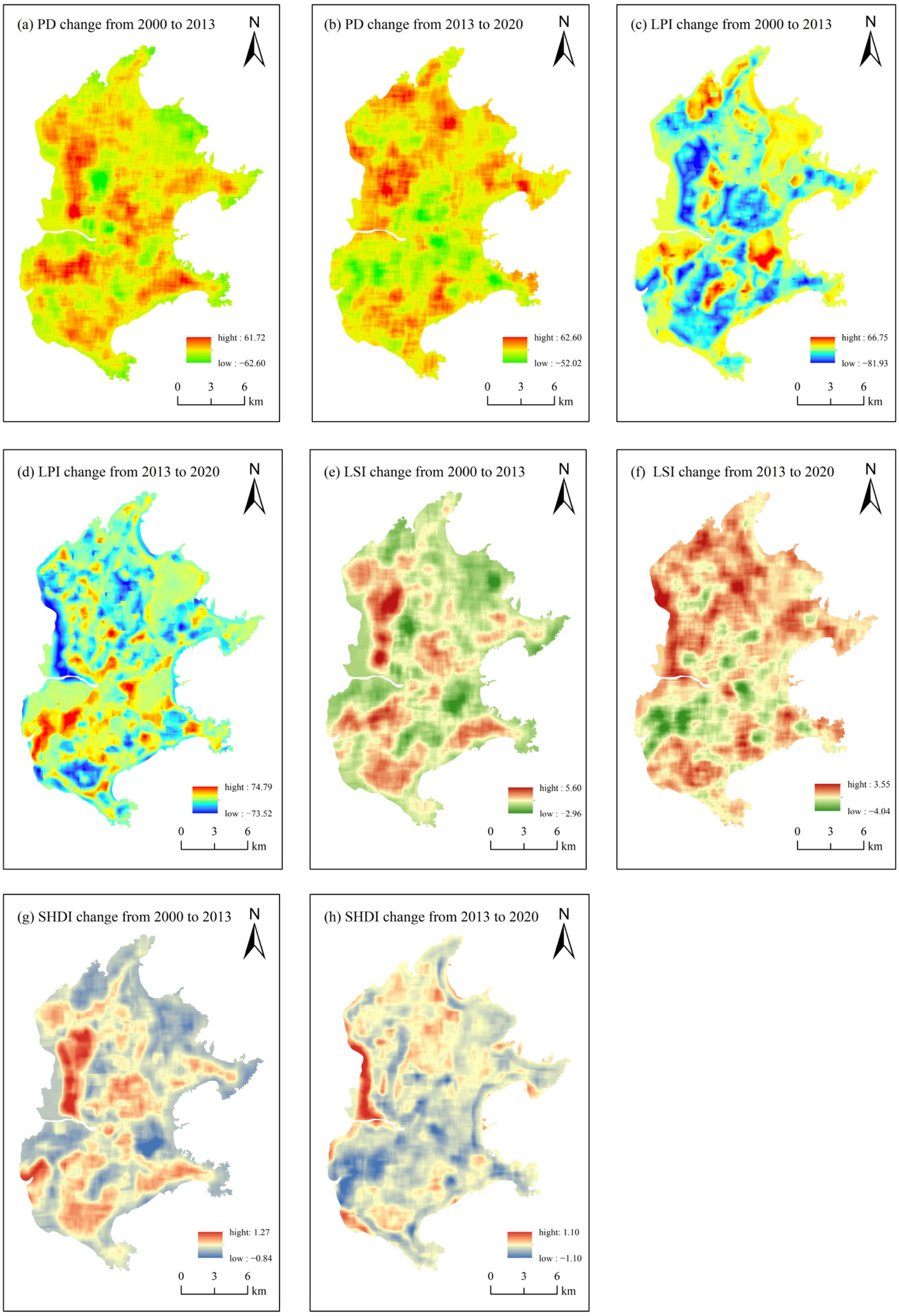

Figure 5. Spatial distribution of landscape index change.

4.3. Analysis of Landscape Fragmentation on Sampling Bands

Landscape fragmentation on the 30 sampling bands showed similar gradient change characteristics over the last 20 years (Figure 6). PD showed some regularity, but the spatial variation of PD value in the three periods were not obvious. PD in 2020 topped three years. LPI roughly showed a gradual increase from coastal to inland. Additionally, most of the sampling bands have the smallest value in 2000. SHDI showed a similar downward trend from coastline and inland in 2000 and 2013. SHDI in 2013 was higher than in 2000 and

2020 on sampling bands 2–20. Starting from sampling bands 21, SHDI began to increase in 2020, and diversity increased. LPI and SHDI changed relatively smoothly over the first 20 sampling bands, and others changed dramatically. As the coast advanced inland, LSI declined steadily and were at their lowest values in 2000.

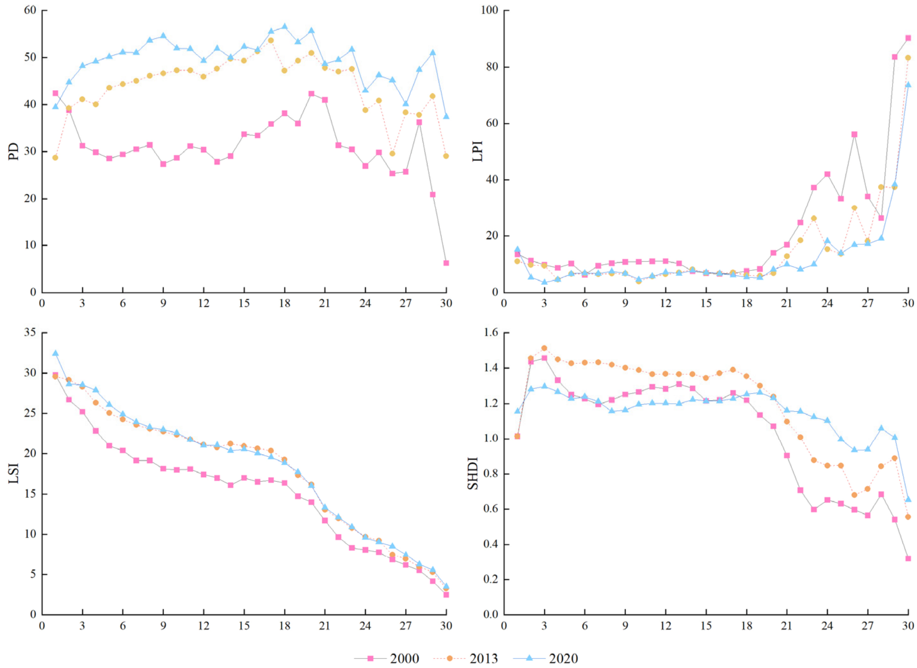

Figure 6. Changes in landscape fragmentation along the sampling bands.

The degree of landscape fragmentation, advancing from the coast inland, showed a decrease. Additionally, in the temporal dimension, there was also an increasing trend.

4.4. Analysis of Transects

4.4.1. Land Cover Change in Transects

From Figures 7 and 8, the land cover on the transects changed significantly from 2000 to 2020. Land cover of S1 changed greatly. The western part of S1, basically below 15 m, was dominated by the sea and saltworks in 2000. With the development and construction of the Fujian Pingtan Comprehensive Experimental Area in 2012, the sand blowing and land creation project was started on the original site of Pingtan Saltworks, and the embryonic form of emerging new urban centers began to appear. During 2013–2020, the 'Grain for Green Project' contributed the arable landscape replaced by forest landscape, and the cropland was mainly distributed at an elevation of 5–50 m. The eastern S1 was mainly a town landscape. With the construction of the international tourism island, part of the original sandy shoreline of Longwangtou Scenic Area on the eastern coast evolved into an artificial landscape shoreline. Due to government support, the urbanization process of Haitan Island entered a period of high-speed development from 2013 to 2020. The old city center of Haitan Island in the east gradually developed towards S1 center, occupying part of the cropland. Constructing of the emerging center also continued to develop towards S1 center, which formed a dual-center development model.

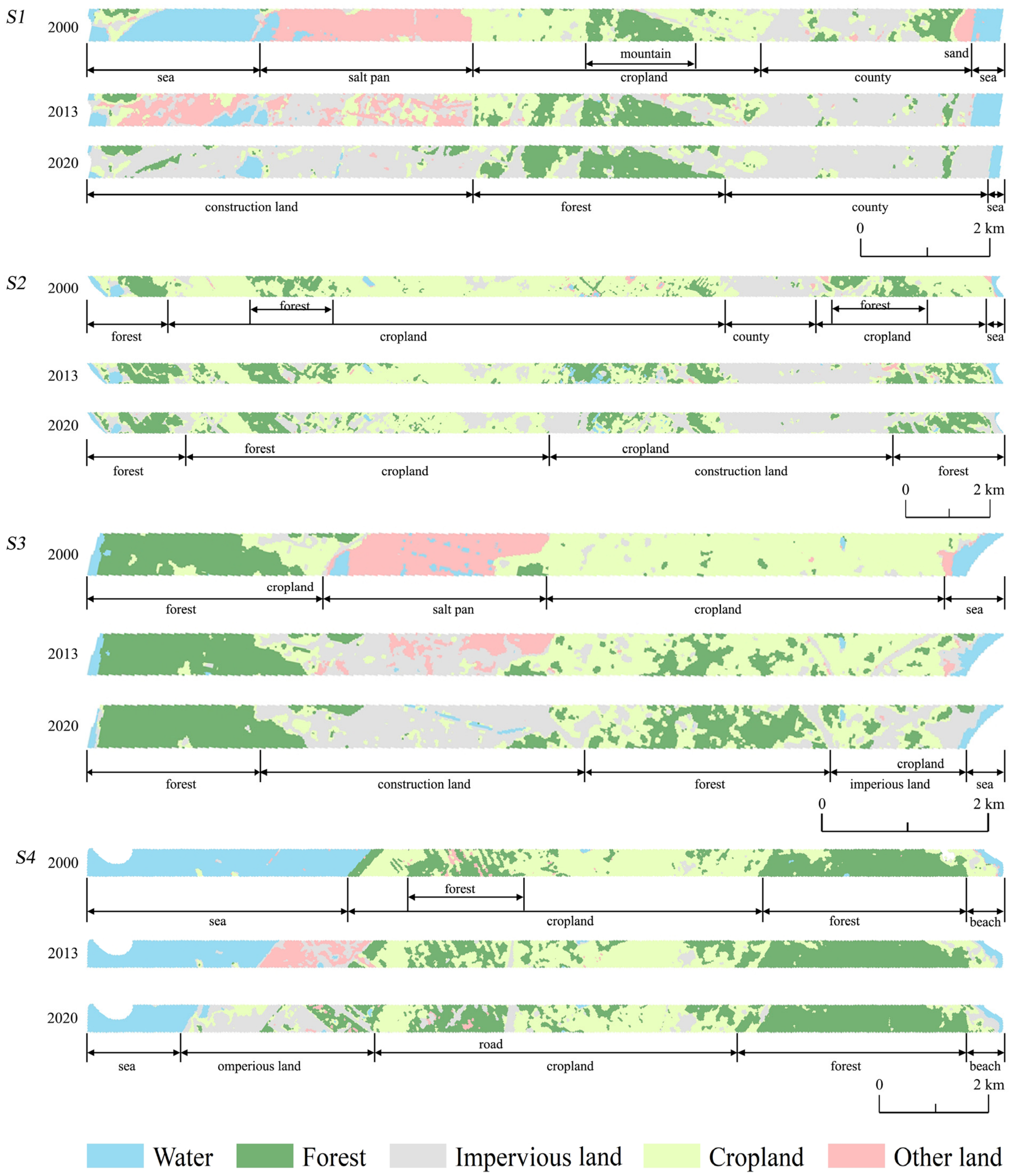

Figure 7. Landscape maps of land cover on transects.

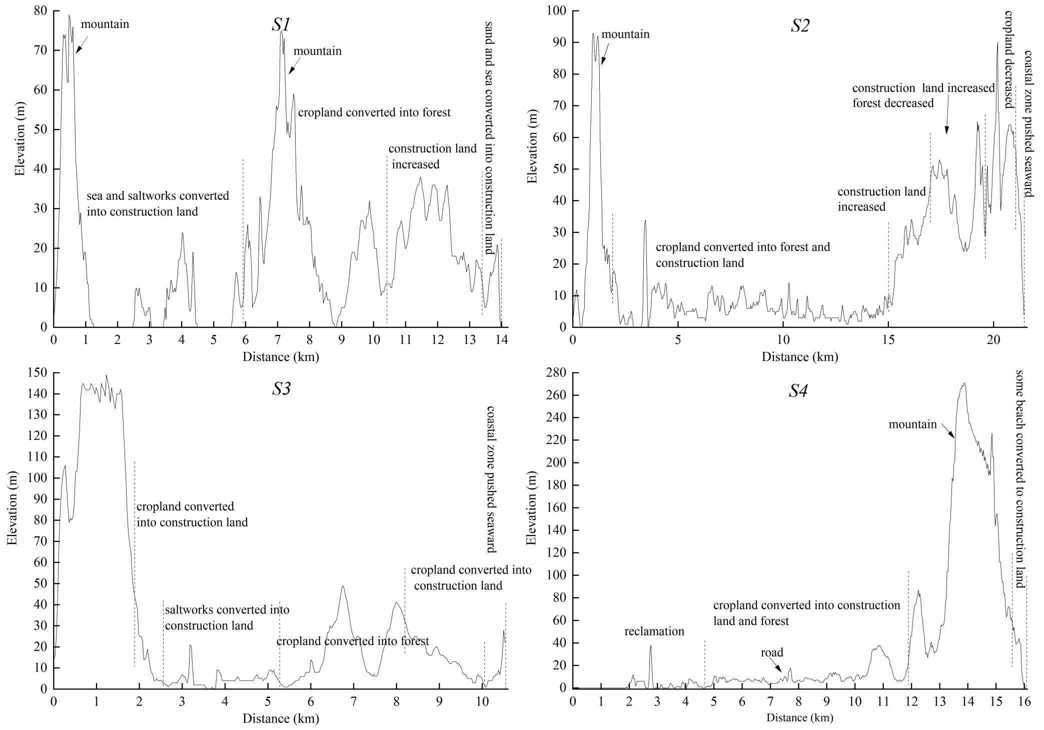

Figure 8. Topographic profiles of transects.

S2 and S3 were perpendicular to S1 through two urban centers. S2 in 2000 was dominated by cropland. With the acceleration of urbanization, the area of cropland on the lower elevations decreased rapidly from 2013 to 2020, converting into forest and construction land. The city continued to expand. The construction of the Tannan Bay scenic area in the south of S2 promoted the reforestation of the area. S3 in 2000 was also dominated by cropland, followed by saltworks and forest. From 2000 to 2020, the saltworks were gradually replaced by construction land. The cropland at the bottom of Mountain in the north was also gradually replaced by emerging new urban areas. The forest in the south of S3 was gradually shifted to a higher terrain. Construction of the southern part of the traffic circle, which started in February 2010, led to increased fragmentation of the cropland and showed a discrete distribution characteristic. The southern sandy shoreline was also replaced by an artificially landscaped shoreline.

The west coast of S4 was the site of the artificial sand blowing and land creation project. Between 2000 and 2020, the coastline was advanced to the sea for nearly 3 km or so, and the original mangrove shoreline was gradually replaced by construction land. The central area of S4 was mainly cropland and scattered forest. The eastern S4, Jun Mountain Scenic Area, exhibited little overall change. The same beach was artificially hardened, and the shoreline was advanced slightly to the sea.

4.4.2. Analysis of f Landscape Fragmentation in Different Transects

Setting a sample unit every 100 m for the four transect, we extracted the average value of PD, LPI, LSI, and SHDI (Figures 9 and 10). The transect S1 extended 7 km inland from the first bridge of the strait gradually transformed from sea area, saltworks and cropland to construction land, with greater PD, complex landscape shape and diverse landscape types. The PD values in 2013 were more increased than those in 2000, because Haitan Island belonged to the golden stage of extensive development around 2013 and the highest degree of landscape fragmentation. The LPI and LSI values varied sharply from year to year, with maximum values of 4–6 km and 11–13 km. The landscape diversity of S1 showed a wave-like pattern, with peak values occurring within 1 km inland from the coastal zone at both ends of the transect. Areas where there were affluent in land use, with the distribution of sea areas, roads, settlements, mountains and cultivated land, showed a high diversity index.

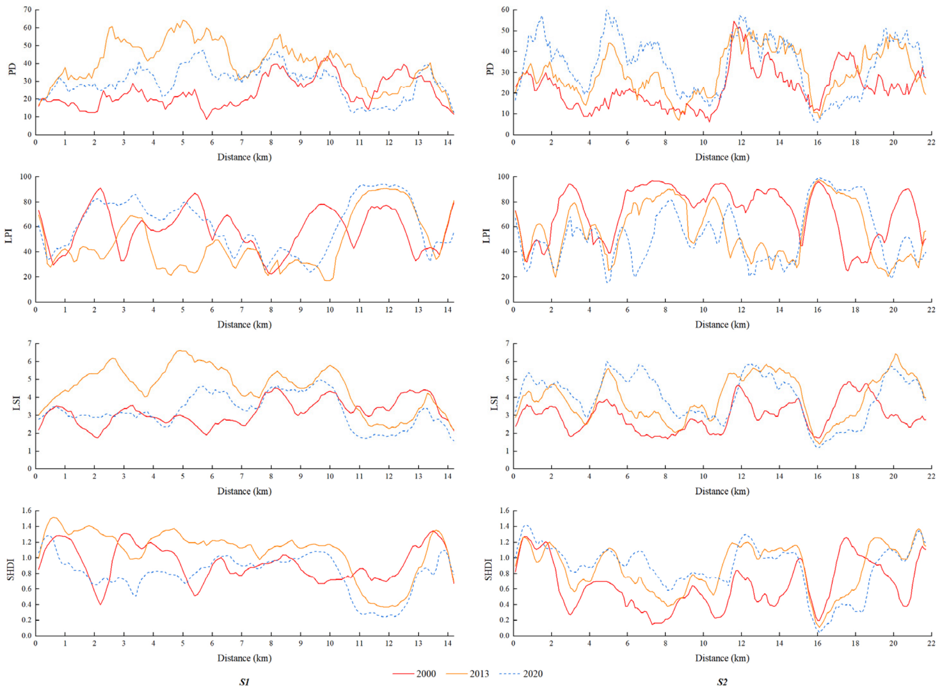

Figure 9. Landscape index changes of transect S1 and S2.

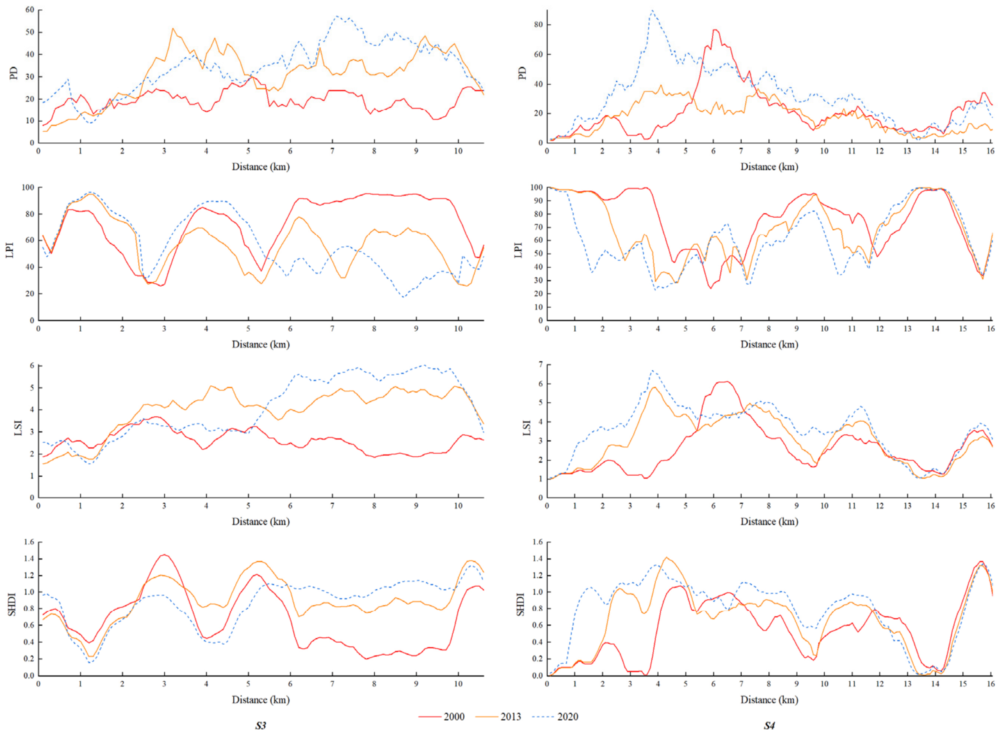

Figure 10. Landscape index changes of transect S3 and S4.

S2 was the longest, with varied topography and diverse landscape types. The overall trend of PD values from 2000 to 2020 did not change much, and the peaks were mainly at 11.3–14.5 km from the starting point (in north), where they had low elevation, a relatively gentle terrain, scattered settlements and rich land cover. The PD values in 2013 and 2020 increased with elevation at 16.1–21 km from the starting point. The SHDI, LSI and PD values of S2 were stable within 15 km from the starting point, where it had diverse landscape types and fragmented patches. At a distance of 15–18 km, the urban landscape was dominant, and the forest and cropland transformed into construction land. This was near the center of the county, with a single landscape type. Additionally, LPI values reached their maximum, and PD, SHDI and LSI values were at their lowest. From 2000 to 2020, patch density of landscape types and landscape heterogeneity increased, the landscape shape increased, and landscape fragmentation showed an overall upward trend.

In S3, the curve of PD in 2000 was flatter, and the main high value was at the location of Pingtan Saltworks at that time (Figure 10). In 2013, the high PD was mainly concentrated 2.6–5 km from the starting point, which had a gentler terrain and was an emerging new urban area. The curve fluctuation in 2020 was more significant, and the high value was mostly at 6.8–9 km, which, in recent years, has emerged as a scenic area. The three curves of LSI changed more gently and had the same trend. The main landscape at 5.4–9.8 km from the starting point (in north) was cultivated landscape. However, forest and impervious land were gradually scattered. LSI fluctuated more with the topography as a whole. The SHDI and LPI in S3 showed significant curve changes, obvious fluctuations and similar trends, especially from near the coast to emerging new urban centers. SHDI and LPI changed significantly with elevation, and the landscape dominance was obvious with high elevation, in Niu Zhai Mountain, 0.3–2.4 km from the starting point. The highest SHDI and LPI were found at 2.5–3.1 km and 4.6–6.4 km. This was due to the high human interference and landscape diversity at the junction of the natural landscape and construction land.

The overall elevation span of S4 was large. Jun Mountain Scenic Area located 11.8–15.5 km from the starting point (in west) was dominated by forest and scattered cropland, and all four landscape indices showed extreme values in this area: the PD value was small, and the landscape dominance was obvious, while the landscape diversity decreased and changed with the topographic slope. The PD curves of S4 showed ups and downs in the three periods. At 5.7–7.4 km and 12.7–16.2 km, the values in 2000 were larger than those in the other two years. The area extending 5 km inwards from the coast underwent a change from sea to mudflat to building land, as well as a continuous recession of the coastline, where there were large fluctuations in PD, SHDI and LSI. The gradual decrease in the dominance of the marine landscape and the increasing degree of fragmentation and landscape diversity further reflected the direction and extent of reclamation.

As a whole, the four typical transects from 2000 to the present presented a trend of landscape fragmentation that increased year by year.

5. Discussion

The special geographical location and isolated space of Haitan Island have created a special ecosystem, including the mainland ecosystem and the surrounding water ecosystem. The Chinese government has contributed many policies and financial support for the development of city and tourism on the Island to enhance its special political and economic strategic position. These efforts have made the landscape fragmentation of Haitan Island more obvious due to natural and human interference [51,52]. In landscape ecology and landscape planning, using landscape indices to analyze changes in landscape patterns have proliferated, especially, urban sprawl issues [22,25]. There are regional differences in the intensity of natural disturbance and human activities. Therefore, quantifying its differences can provide more refined information for tracking and managing the impact of human activities on the landscape.

5.1. Landscape Fragmentation from Land Use Conversion

The rapid transition of land use caused by population urbanization, tourism and agriculture has a huge impact on ecological environment [53–55]. The most obvious change in land use on Haitan Island was the replacement of a large amount of farmland by impervious land. This is consistent with the conclusion inferred by Shifaw [56]. The coastal landscape has a distinctive spatial gradient [30]; the fragmentation decreases and the landscape structure stabilizes at 4 km from the coastline of Haitan Island. However, the overall fragmentation in the coastal area was high due to intensive development and construction activities, and a large amount of forested and cultivated land fragmented by roads and construction land.

Therefore, based on urbanization characteristics and changes in landscape indices, the study area can be distinguished into the following patterns: (1) urban center area. As the urbanization process of Haitan Island continued to accelerate, the impervious land of the old city, the emerging new area, and the railway station area increased, and the road network was improved. Furthermore, the continued replacement of green space by built-up land has led increased fragmentation of the landscape, more complex landscape forms and a greater diversity of landscape types. (2) Radiation area in urban centers, represented by central S3 and south-central S4. Towns and village landscapes have expanded, disaggregating on both sides of the road and water. The landscape in the region was highly disturbed, and the landscape diversity increased. The landscape pattern changed from original cultivated landscapes to multiple landscapes. Spatially, the forest landscape at 100–250 m has proliferated. Cropland in coastal areas and high altitude were retired to form forest landscapes and tourism landscapes. (3) Cropland protection area. The cultivated land was mainly concentrated in the low altitude area of the central plain of Haitan Island. As in the central part of S2 and the northern part of S4, the cultivated land landscape gradually developed into settlement and forest. (4) Landscape Resource Protection area. This area has experienced significant development of tourism on Haitan Island to ecological protection. The main landscape was mainly forest and sea landscape, such as Jun Mountain Scenic Area (eastern S2), and the Tananwan Scenic Area (southern S4). This kind of areas have gone through the stage of landscape diversity, landscape shape from single to complex and then back to single.

5.2. Driving Analysis

Regional land use and landscape fragmentation normally change with natural environment, social, and economic development stages. Based on previous research experience [31,34,57] and research interviews with the government and planning agencies of Haitan Island, the change in landscape fragmentation on Haitan Island was the result of a combination of multiple factors, including the island ecosystem and the external environment (Figure 11).

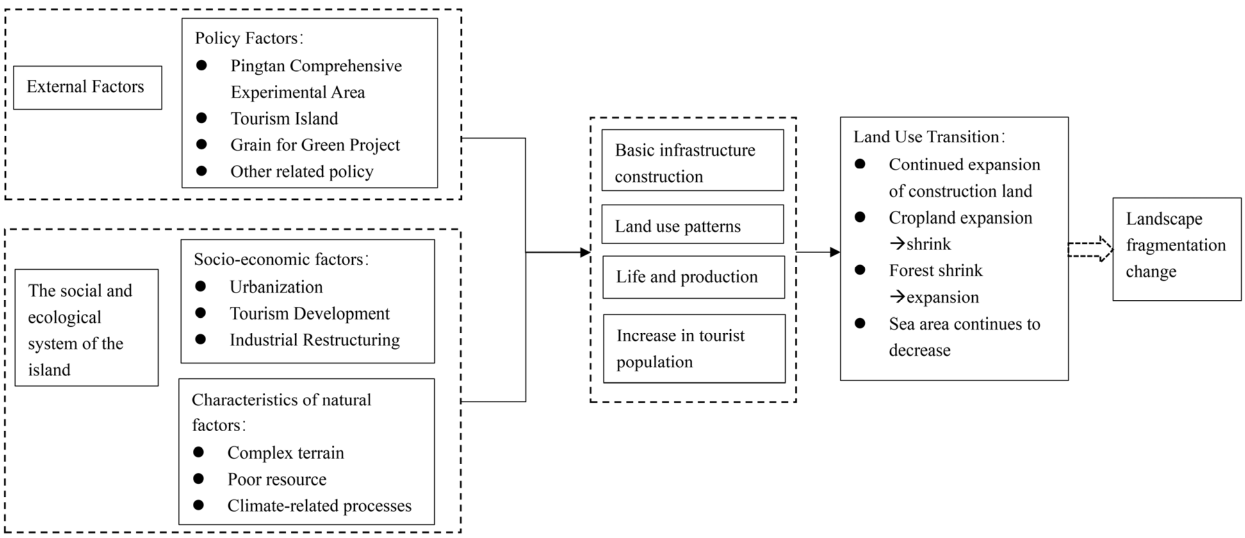

Figure 11. The driving mechanism of landscape fragmentation on Haitan Island.

Firstly, it is important to consider policy factors and socio-economic development (Table 2). Since 2000, the total population of Pingtan has shown a continuous upward trend. It increased from 3.9×10^5 in 2000 to 4.2×10^5 in 2013, and then to 4.517×10^5 in 2020, which intensified the demand for construction land. The dramatic changes in urban development and regional traffic demand are the result of the leapfrog development of Pingtan Comprehensive Experimental Area, which began in 2009. The construction of the cross-sea bridge, traffic road network and infrastructural brought about a radical change to Haitan Island [32,34,58], but high-intensity human interference also started from this period.

Table 2. Implementation of policy.

Year	Policy	Measures
2011	Urban and Rural Planning of Pingtan Comprehensive Experimental Area (2011–2013)	Land development intensity: 15.2%, total construction land: 59.7 km^2, buildable area: 121.65 km^2, restricted area 92.15 km^2, no-build area 70.67 km^2
2015	General Scheme of China (Fujian) Pilot Free Trade Zone	The area of Pilot Free Trade Zone of Fujian Province is 118.04 km^2, covering three zones, including 43 km^2 in Pingtan
2016	Regulations of Pingtan Comprehensive Experimental Area	Pingtan strictly protects the ecological environment in its jurisdiction, including the surrounding waters, and implements the target responsibility system for ecological environmental protection. The Government of Fujian Province incorporated indicators of resource consumption, environmental damage and ecological efficiency into the comprehensive evaluation system of economic and social development and the comprehensive assessment and evaluation system of leading cadres in the Pingtan Comprehensive Experimental Area. Additionally, a coordination mechanism for environmental protection between the island and the surrounding areas should be established.
2016	Construction Programme of Pingtan International Tourism Island	It should reasonably develop island ecological tourism resources, build an island ecological experimental zone, strengthen wetland restoration and maintain the balance of the marine ecosystem. Meanwhile, Haitan Island should support the protection of ecological, scenic spots such as Jun Mountain and Nanzhai Mountain, strictly prohibiting development activities that do not conform to functional positioning, and strengthen the comprehensive prevention and control of soil erosion.
2019	Comprehensive Territorial Spatial Planning for Pingtan Comprehensive Experimental Area (2018–2035)	Land development intensity: 21.8%, total construction land: 71.97 km^2, the scope of ecological control lines:33.69 km^2, the retention rate of the natural shoreline: 75.5%, the density of the road network in the built-up area: 7.5 km/km^2

Haitan Island experienced slow urban expansion before becoming an experimental zone in Fujian Province. The urbanisation rate was 10.26% in 2000 and only grew to a rate of 11.90% in 2013.However, between 2013 and 2020, the urbanisation rate increased by 3.33 times, raising to 51.50 percent in 2020, and the built-up area increased from 59.7 km^2 to 71.97 km^2.The density of the road network in built-up area was 4.64 km/km^2 in 2013, increasing to 7.5 km/km^2 by 2020. With the accelerated urbanization of Haitan Island, a large amount of construction land crowds the surrounding croplands, forest land and sea area. Related studies have shown that more than 40% of significant fragmented landscape in coastal cities of mainland China is mainly caused by the growth of built-up land [2], which further demonstrates that the extensive construction and development of Haitan Island has greatly deepened the fragmentation of the island's landscape. Furthermore, due to the limited scale, Haitan Island continues to request land from the sea for reclamation projects. As with most island cities, the large-scale land reclamation on Haitan Island has led to the shrinkage of shoreline resources, the reduction of shallow mudflats, and the obvious decline in the ecological function of local waters [59,60]. For example, the southwest of Haitan Island completed 3.8 km^2 of land reclamation, 0.24 km^3 of backfilling works in the whole site, and 905.5 m of permanent seawall was built. With the construction of the Pilot Free Trade Zone, the island's infrastructure of harbors, piers, causeways and roads is gradually being improved. However, the natural shoreline was reduced from 181.9 to 165.3 km (2000–2020), which increased landscape fragmentation in intensity and frequency. In general, with the accelerated urbanization of Haitan Island, human interference (such as the development of international tourist islands, mariculture, wind power plants, real estate development) have already enormously changed the coastal zone and caused its fragmentation to intensify. In order to coordinate territorial Spatial resources, Haitan Island has integrated the main functional area planning, land use planning, urban and rural planning and other spatial planning into a unified territorial spatial planning, strictly controlling the intensity of development. The land development and urban planning norms of Haitan Island have returned to rationality since 2018, which, to a certain extent, has alleviated the fragmentation of the island's landscape (Figure 5).

The tourist population to Haitan island has increased year by year since 2007, from 0.23 million to 5.83 million in 2019. In 2020, affected by COVID-19, the tourist population decreased by 1.24 million compared to 2019 (Figure 12). Most resort infrastructure and tourist accommodation were within 200 m of the coastline. Although a large number of tourists brought lucrative economic income to the local area, it brought great pressure on the ecology of the island. Forests, water sources, vegetation and species suffered damage and landscape fragmentation gradually intensified. Similar to most tourism-oriented islands, Haitan Island has begun to strengthen ecological construction and environmental protection of coastal area and wetland, while protecting tourism resources [61,62]. Since 2015, the experimental area has been strengthening the ecological construction and environmental protection of the near-shore sea area (Table 2). At the same time, driven by island tourism, Haitan Island has begun integrating and utilizing rural resources, gradually breaking away from the traditional fishery production method, transforming and developing the tourism service industry, and drawing on the management model of advanced leisure agriculture to create a tourism and sightseeing industry. This has not only brought economic benefits to farmers and enterprises, but it has also helped to reduce the sanding of farmland caused by abandonment. Furthermore, the optimization and upgrading of the industrial structure has achieved obvious results, with the structure of the thrice Industrial adjusted from 33:17:50 in 2008 to 12:28:60 in 2020 (Figure 13).

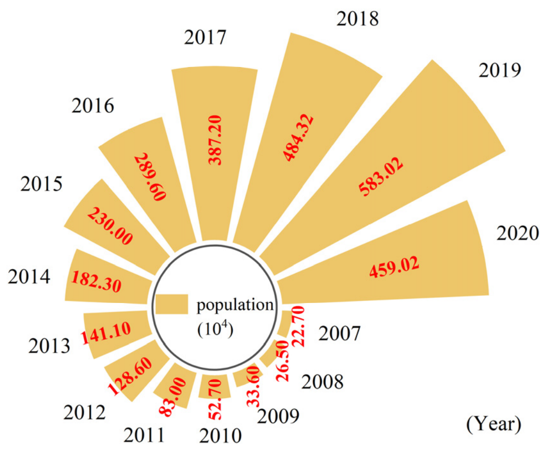

Figure 12. Trends in the tourism population of Hatan Island.

Moreover, the wind and sand on Haitan Island are extremely strong, making reforestation exceptionally difficult [33,35]. The coastal protection forests have become the main greening barriers of Haitan Island, but afforestation site conditions are poor, and most are barren IV land on Haitan Island. The area of bare and sea-facing hills accounts for more than 60% of the forested area. The sandy area was nearly 8000 km^2 and total width of windbreak was 21.3 km. Since 2000, urban construction, quarrying and sand dredging and other unreasonable acts have destroyed the coastal dry forest belt. Moreover, the distribution of coastal forest has been further reduced, and some parts of the coastal forest belt have broken into gaps. The fragmentation of the coastal zone landscape has been further aggravated. China has implemented "Grain for Green Project" programs with the goal of mitigating land degradation [63]. Conserving and expanding forests in recent years has greatly alleviated the desertification on Haitan Island.

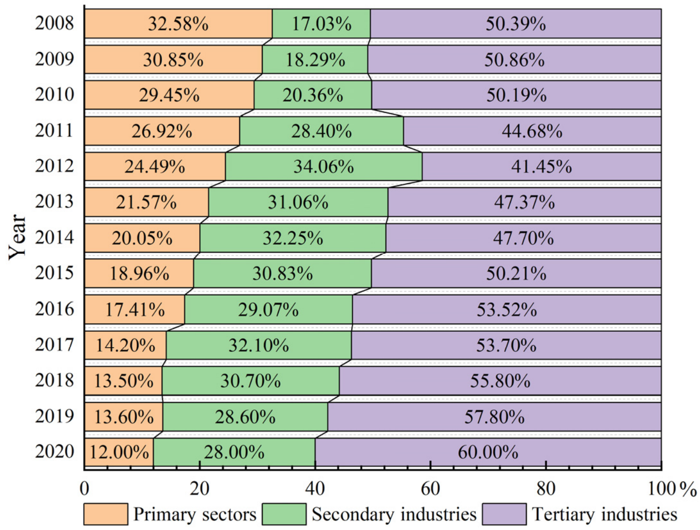

Figure 13. The structure of the thrice Industrial.

Haitan Island also affected by geological, hydrological and natural factors. Coastal erosion was serious, causing the shoreline to recede and the land area to shrink, particularly in the north-east [35]. Coastal erosion caused soil erosion and land degradation, which disrupted the ecological environment. Although related studies suggest that topography has little influence on the evolution of the landscape pattern of Haitan Island [33], we found that the landscape diversity and shape complexity decreased gradually with elevation and slope. The dominant landscape types and spatial heterogeneity varied by altitude.

5.3. Measures to Mitigate Landscape Fragmentation

Due to the continuous urbanization of islands throughout the world, it is urgent to take measures for reversing the negative effects of the associated fragmentation. (1) Urban center area. As the balance between jobs and housing provision is easily lost over time [64], this requires rational control of property development, such as increasing the urbanization rate and centralizing housing to alleviate the crowding of the cropland and sea [65,66]. (2) Radiation area of urban center (such as the south-central part of Haitan island) and the construction of green areas and waters should be increased. Although that will cause a certain degree of landscape fragmentation, it can play a positive role in landscape ecology [17]. (3) Cropland protection area. Optimizing the layout of water conservancy facilities and improving the planting structure should be carried out. These measures will increase the continuity of the landscape in cropland. (4) For areas of high touristic value, the government should take measures to curb the trend of landscape fragmentation when adjusting and optimizing tourism patterns [62]. All these will promote the sustainable development of the ecological environment of the island. The specific ecological restoration measures and spatial optimization are shown in Table 3 and Figure 14.

Table 3. Types and measures of ecological restoration.

Types of Ecological Restoration	Measures
Ecological restoration of coastline and coastal zone	Aim to enhance the anti-erosion restoration of the shoreline, including the removal of artificial structures, the removal of dangerous coastal rocks and debris, the restoration of shoreline vegetation. Installing the submerged sand piles for anchor the seabed at the outer 2 km of the shoreline and constructing of submerged sand barriers to carry out shoreline restoration work
Restoration of the water-bearing function	Plant water-retaining, soil-fixing and deep-rooting plants, mainly in water reserves and nature reserves
Salinity restoration	Plant species that tolerate saline-alkali soils, and improve soil properties
Restoration of coastal shelter forests	Plant wind resistant plants with large crowns and low branches to improve the hills' wind resistance, mainly in the outermost windward-facing hills of the island, such as Long Wang Tou, Jun Mountains, and Niu Zhai Mountains.
Ecological restoration of sand sources	Adopt a beach replenishment program, combined with fence maintenance, gradually replenish high quality sandy and sand-fixing vegetation. Moderate development
Restoration of agricultural Protection Forest	Lay out at a spacing and width appropriate to the needs of agricultural cultivation, mainly in areas of concentrated basic farmland and major agricultural development areas.
Restoration of landscape resource	Mainly located in the degraded vegetation areas of the hills around the construction sites of the town, the landscape restoration is mainly artificial and semi-artificial landscape restoration. plant native plants with rich flowers and fruits, beautiful trees and evergreen in all seasons, considering landscape, leisure and recreation functions,

Figure 14. Relative location of ecological restoration.

6. Conclusions

Based on ArcGIS10.6 software and Fragstats4.2, this study quantified the spatial and temporal differences in the landscape fragmentation of Haitan Island. We explored the evolution pattern of landscape fragmentation in different gradient spaces and revealed the overall pattern of landscape change in the process of island urbanization. Finally, combining the effects of natural and anthropogenic factors over the last 20 years, we determined the main drivers of change. The main findings were as follows:

The spatial–temporal landscape pattern on Haitan Island has changed significantly over the past 20 years. In terms of time, the expansion of impervious land and forest were significant, and the area of water and cropland showed a decrease. The change in impervious land area was the largest in all landscapes. Spatially, construction land has been continuously expanded along with the axis of urban development. Meanwhile, the reduction of water and croplands were mostly occupied by impervious land.

According to the gradient analysis, the degree of landscape fragmentation increased over time and gradually decreased from coastal to inland. The change in landscape indices on the whole island and in the typical transect showed different fluctuations, reflecting the spatial differentiation of the landscape pattern. Landscape fragmentation decreased in the near-coastal area and the northern forested area (e.g., northern areas of S2, S3, and S4), while it increased in the urban concentration area and the south-eastern near-inland zone (e.g., southern area of S2).

From the analysis of land use change and landscape pattern and driving factors, landscape fragmentation of Haitan Island was mainly subjected to natural factors and human interference. Additionally, policy factors (e.g., Comprehensive Experimental Area, International Tourism Island, Ecological Restoration and "Grain for Green Project") played a dominant role. Of course, this study needs to further quantify the impact of each driving factor on landscape fragmentation in order to make more specific and precise recommendations from an integrated perspective.

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