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Analysis of Bird Habitat Suitability in Chongming Island Based on GIS and Fragstats

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***Abstract*— *With the development of society, the degree of human exploitation of nature is becoming more profound, which makes the fragmentation of the global environment more serious, leading to the reduction of species' Lebensraum and having a huge negative impact on the survival and development of various species. In this paper, we select the Chongming Island area in Shanghai as the study area and use the landscape pattern analysis and suitability analysis methods to comprehensively analyze the characteristics of the habitat pattern in this area as well as the suitability impact on the local birds. The research results show that the fragmentation of local habitats has decreased, but the connectivity between patches is low, and the changes in bird populations are relatively stable, showing a stable and positive trend.*
Keywords*— *Suitability analysis; Migratory bird habitats; Landscape pattern; Biodiversity indicators; Analytic Hierarchy Process (AHP).

I. INTRODUCTION

Birds are an important part of the ecosystem. They are at different trophic levels in the food chain of the ecosystem. They have ecological functions such as spreading plant seeds, clearing animal debris, controlling prey populations, promoting material circulation, and maintaining the balance and stability of the biosphere (Xu, 2021). The bird colony is an important functional group in the local ecosystem, and bird diversity not only reflects the condition of the bird colony itself but also reflects the interrelationship between birds and the ecosystem in the region. At the same time, birds are sensitive to environmental changes caused by humans and nature and are easy to observe, so they are often used as indicators for biodiversity monitoring. Moreover, bird watching, as an "environmentally friendly leisure" activity, is gradually being recognized by people and has significant economic value. Therefore, studying bird diversity is of great significance for local ecological assessment and management protection (Chen, 2019; Xu, 2022).

At present, there are a total of nine migration routes for migratory birds worldwide. According to the second wetland resource survey in China, there are 1332 species of birds in China, accounting for approximately 13.7% of the world's total bird population. Among them, there are over 600 species of migratory birds, accounting for 20% of the world's migratory birds. Among the global migratory bird migration routes, East Asia, Australia, Central Asia, West Asia, and East Africa are all closely related to

China. China plays a very important role in Bird conservation (Yin, 2015; Jiao, 2015).

Based on ArcGIS and Fragstats, this study uses bird observation data (Xu et al., 2022; Tang et al., 2020), land use cover change (LUCC), road and residential distribution, and other data in Chongming Island to generate a biological diversity index, landscape characteristic value, land use status, comprehensively evaluate the quality of bird habitat in Chongming Island, and provide a scientific basis for local bird conservation.

II. STUDY AREA AND DATA SOURCES

2.1 Study Area

Chongming Island, located at the midpoint of the Coastline of China along the western Pacific coast, is 121 ° 09 ′ 30 ″ to 121 ° 54 ′ 00 ″ east longitude and 31 ° 27 ′ 00 ″ to 31 ° 51 ′ 15 ″ north latitude, and is located at the estuary of the Yangtze River, China's largest river (Figure 1). By 2022, with an area of 1269.1 square kilometers, 80 kilometers long from east to west, and 13 to 18 kilometers wide from north to south, it will be the world's largest estuary alluvial island and the third-largest island in China after Taiwan Island and Hainan Island. Together with Changxing Island and Hengsha Island, it forms the Chongming District of Shanghai.

Located in the northern subtropical zone, the climate is mild and humid, with four distinct seasons. It is hot and humid in the summer, with a southeast wind prevailing, and dry and cold in the winter, with a northerly wind prevailing. It is a typical subtropical monsoon climate. The Chongming Dongtan National Nature Reserve for Birds is located within it. It is a migration route for cranes and ducks in Northeast Asia, as well as for waders in East Asia and Australia. Nearly a million migratory and wintering birds pass through this area every year, making it an important migration and wintering place for migratory birds.

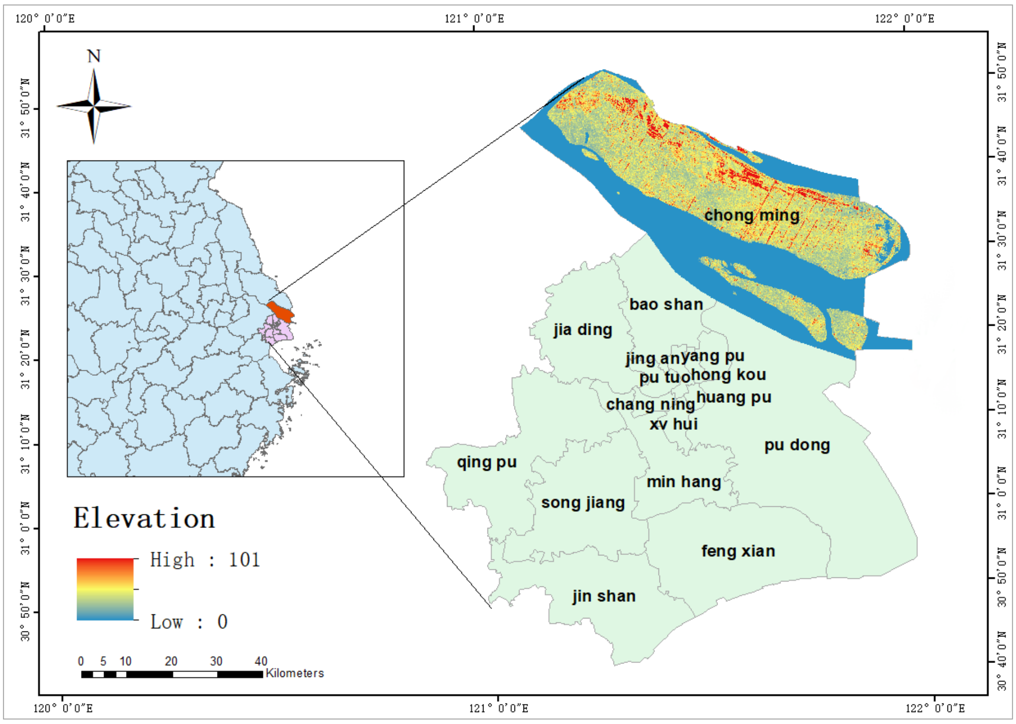

Fig.1: Location Map of the Study Area

2.2 Data Sources

The main data of this article includes image data of bird surveys and land use, as well as vector data of roads and residential areas (Table 1).

Table 1 Data and Source

Data type	Data sources	Application
Bird dataset	China-Bird Report (http://www.birdreport.cn/)	Calculate Shannon-Weiner diversity index (H), Pielou evenness index (J) and community dominance index (S)
Global Land Use/Land Cover Map （LUCC）	Sentinel-2 image with 10 meter resolution from ESA （https://arcgis.com）	Generate landscape pattern index and calculate suitability distribution weight
Residential area vector data	(https://www.webmap.cn/)	Calculation of suitability distribution weight
Road vector data	(https://www.webmap.cn/)	Calculation of suitability distribution weight

Bird data sourced from the China Bird Watching Record Center (http://www.birdreport.cn/). Statistics show that from 2017 to 2021, the number and quantity of bird species on Chongming Island will generally increase (Table 2 and Figure 2), and the number of rare species will also increase. In this paper, the main protected species in Chongming Dongtan Bird National Nature Reserve, namely Anseriformes, gulls, and shorebirds, are selected as the main analysis groups, and the more high-risk and indicative species, namely the Scaly-sided merganser, Saunders's gull, and Far Eastern curlew, are selected as the analysis objects.

Table 2 Bird Population Dataset for the Study Area from 2017 to 2021 (Units: kinds)

Year	Quantity	Type	Non-hazardous Species	Vulnerable Species	Near Threatened Species	Endangered	Critically Endangered
2017	517	144	125	3	12	3	1
2018	808	188	166	5	12	4	1
2019	526	138	123	4	9	2	0
2020	1339	229	202	6	15	5	1
2021	5325	257	223	7	18	6	3

Land use data, sourced from the 10-meter resolution Sentinel-2 image of the European Space Agency (ESA), mainly from the 2022 Global Land Use/Land Cover Map (LUCC) data (https://arcgis.com). The landscape pattern index of Chongming Island was generated through Fragstats 4.2, and its bird habitat was reclassified using ArcGIS.

The data for roads and residential areas comes from the National Geographic Information Resource Catalog Service System, with a 1:250000 public versions of basic geographic data (https://www.webmap.cn/). Reclassification use ArcGIS for suitability analysis of bird habitats.

III. METHODOLOGY

Based on a variety of analysis tools, this paper explores the laws of data by means of statistics and spatial analysis and conducts research in the following aspects (Figure 3):

(1) Using ArcGIS to reclassify data on land use, roads, and residential areas and weight them to

obtain bird habitat suitability scores. Then, combined with the weighted sum, calculate the distribution of bird habitat suitability.

(2) By calculating the dataset of observed species and numbers of local birds, indices such as biodiversity, evenness, and community dominance can be obtained.

(3) Using Fragstats software to calculate the actual values of landscape features for land use data, and finally, use SPSS software to analyze the correlation between the two dataset to obtain a correlation matrix of the impact of landscape change on birds (Liu, 2016).

(4) Analyzing the correlation matrix between bird habitat suitability and the impact of landscape changes on birds and obtaining a comprehensive evaluation of local bird habitat quality.

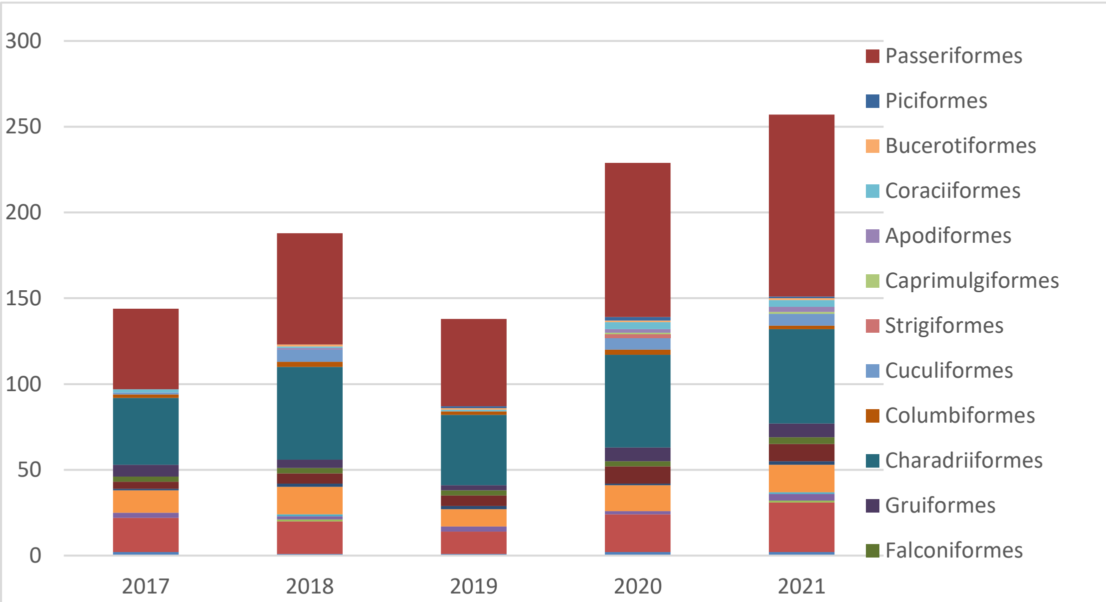

Fig.2 The Composition of Bird Species in the Study Area from 2017 to 2021

3.1 Analysis of Migratory Bird Colony

This article analyzes the diversity, uniformity, and dominance of migratory bird datasets to determine the fluctuations of migratory bird colony and the competition among different groups of migratory birds. Shannon-Weiner diversity index (H), Pielou evenness index (J), and community dominance index (S) are used for calculation, respectively. The calculation formulas are as follows:

$$H=-\sum^{S}_{i=1} pi*\ln pi \quad (1)$$

$$J=H/\ln S \quad (2)$$

$$Ti=Ni/N \quad (3)$$

In Formulas (1) to (2), pi is the ratio of the number of birds of the ith species in the community to the total number of individuals in the community; H is the diversity index; J is the evenness index of the community; and S is the number of species in the community. Ti is the dominance index of the community, and in Formula (3), Ni is the number of species of the ith species in the community, and N is the total number of species in the community. The higher the Shannon index (H), the higher the diversity of bird populations in the region, and the closer the index is to 0, the fewer species in the community. The Pielou evenness index (J) ranges from 0 to 1, and the closer it is to 1, the higher the species evenness within the community. The community dominance index (S) represents the proportion of species in the community (Ma, 2022).

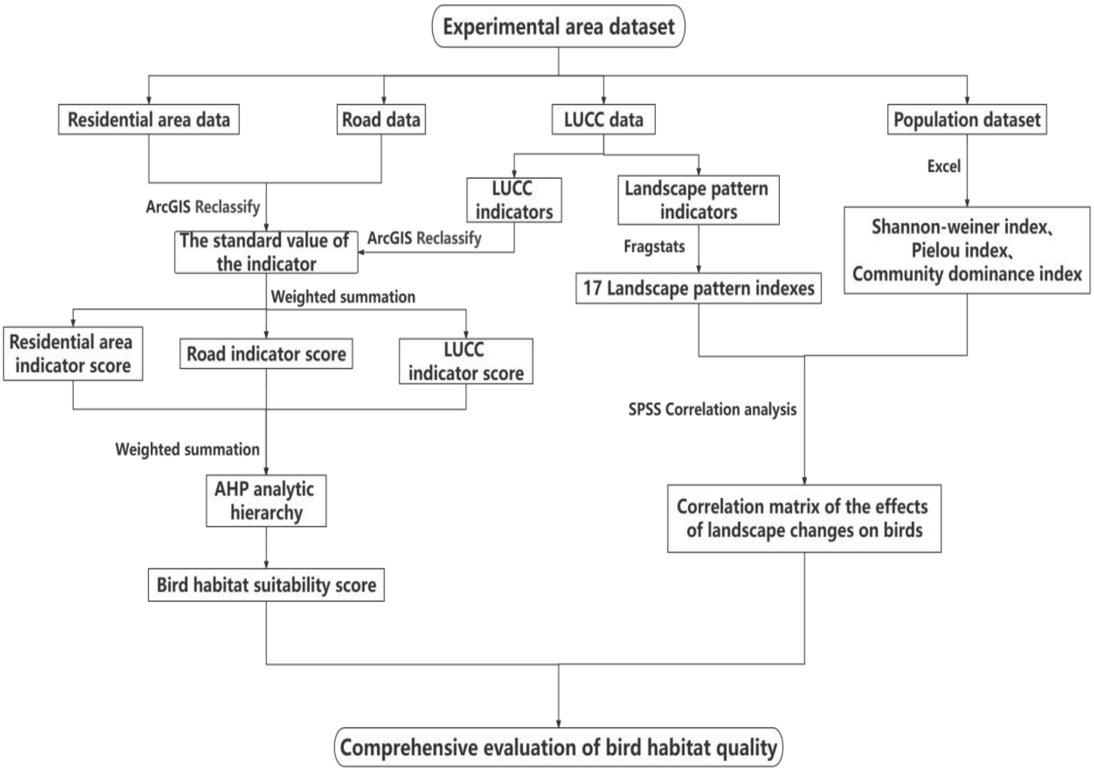

Fig.3 The schema flowchart of the study

3.2 Landscape Pattern Analysis

Landscape pattern is a specific manifestation of the spatial variability of an ecosystem's or system's attributes, including spatial heterogeneity, spatial correlation, spatial regularity, and hierarchy. It is a comprehensive reflection of soil, hydrogeology, vegetation, and other levels. Studying and analyzing the local landscape pattern and its changes can help us understand human utilization and transformation of the natural environment, as well as the impact of natural environmental changes on the habitat and survival of birds (Fang and Fang, 2022).

This study divides remote sensing images into nine types of habitats based on land use data, namely water bodies, forestland, wetlands, Farmland, building land, bare land, snow/ice, clouds, and grasslands.

Landscape pattern analysis is calculated using Fragstats software. It is a professional tool for the calculation of landscape pattern index with built-in multiple functional modules such as cell-based indicators, surface indicators, sampling strategies, and functional indicators, helping users more conveniently analyze and control environmental variables through the process. Fragstats can calculate many metrics to describe a single patch, the structure of the same type of patch category or collection, and the entire landscape mosaic of the collage mosaic.

This article uses the following landscape pattern indices when analyzing landscape patterns. In this study, the research and analysis of a single patch cannot reflect the regular characteristics of the landscape pattern, so four types of indicators of patch type and six types of indicators of landscape level index are selected for analysis to make a more scientific analysis of the spatial pattern evolution of the landscape pattern in Chongming District.

The area index represents the area, dominance, and lateral impact of human activities on the landscape and patches. The shape index describes the complexity of landscapes and patches, evaluates their anti-interference ability, and indirectly determines the degree of human activity's impact. The diversity index, analyze the heterogeneity of landscape and understand the annual change of landscape fragmentation through the annual change of diversity index. The aggregation and dispersion index can reflect the integrity of the landscape and patches and indirectly reflect the fragmentation of the landscape and patches. The connectivity index can reflect the degree of connection between patches of the same type, and the deeper the connection, the closer the material and energy exchange between patches. The fragmentation index intuitively reflects the degree of fragmentation of the landscape.

Finally, correlation testing is used to determine which indicators have a high impact on bird numbers and species. The level indicators of patch types are mainly divided into four categories: area indicators, connectivity indicators, aggregation indicators, and fragmentation indicators. Landscape-level indicators can be divided into six categories: area indicators, shape indicators, aggregation and dispersion indicators, connectivity indicators, fragmentation indicators, and diversity indicators. The specific indicators and meanings are shown in Table 3.

Selection of patch type and level indicators: Area indicators: Total landscape area (TA), Perimeter-area fractal dimension (PAFRAC), Percent of landscape (PLAND). Aggregation indicators: Interspersion & juxtaposition index (IJI) and Aggregation index (AI). Connectivity indicators: Patch cohesion index (COHESION) and Connectance (CONNECT). Fragmentation indicators: Number of patches (NP), Patch density (PD), and Mean patch size (AREA_MN).

Selection of landscape-level indicators: Area indicators: Total landscape area (TA), Largest patch index (LPI). Shape indicators: Edge density (ED), Perimeter-area fractal dimension (PAFRAC), and Landscape shape index (LSI); Aggregation index (AI); Splitting index (SPLIT). Connectivity indicators: Patch cohesion index (COHESION) and Connectance (CONNECT). Fragmentation indicators: Number of patches (NP), Patch density (PD), and Landscape division index (DIVISION). Diversity indicators: Shannon's diversity index (SHDI) and Shannon's evenness index (SHEI) (Tang et al., 2020).

Table 3: Analysis of the Meaning of Landscape Index

Serial Number	Index Name	Unit	Analysis Type	Application scale	Meaning
1	LPI	%	Area indicators	Type /Landscape	Used to determine dominance in the landscape
2	PLAND	%		Patch/type	The proportion of various types of land types to the total area, with the largest area being the main landscape
3	TA	ha		Type /Landscape	Denotes the landscape area
4	LSI	%	Shape indicators	Type /Landscape	Describe the regularity and complexity of landscape patch boundaries
5	PAFRAC	None		Type /Landscape	Reflecting the complexity of landscape shape and reflecting the degree of human activity
6	ED	m/ha		Type /Landscape	Reflect the degree to which the landscape or type is divided by boundaries
7	SHDI	None	Diversity indicators	Landscape	Describe the diversity of patches
8	SHEI	None		Landscape	Describe the uniformity of patches

9	IJI	%	Aggregation indicators	Type /Landscape	Describe the probability of a certain type of patch being adjacent to other different types of patches
10	AI	%		Type /Landscape	The better the overall description of the plaque
11	SPLIT	%		Type /Landscape	Reflect the Statistical dispersion of the spatial distribution of different patches in a landscape
12	CONNECT	%	Connectivity indicators	Type /Landscape	Reflects the functional connectivity between landscape components
13	COHESION	%		Type /Landscape	Describe the stability between patches
14	DIVISION	None		Type /Landscape	Indicates the degree of separation between various types of patches in the landscape
15	NP	#	Fragmentation indicators	Type /Landscape	This index reflects the degree of fragmentation
16	AREA_MN	ha		Type /Landscape	Represents the average area of the landscape
17	PD	#/100 ha		Type /Landscape	Reflecting the heterogeneity of the overall landscape

3.3 Analysis of Habitat Suitability for Migratory Birds

3.3.1 Selection of Evaluation Index Factors

This article selects independent factors that have a significant impact on the activities of waders, Anseriformes, and gulls as evaluation indicators and references studies by Zhang (2021), Wang et al. (2022), Lv (2021), etc. The indicator factors and their subdivision conditions are shown in Table 4. The subdivision conditions of each evaluation index factor are obtained and assigned values, respectively, and they are divided into four categories: very suitable (10-8), basic suitable (7.9999-6), low suitable (5.9999- 4), and unsuitable (3.9999-0).

Table 4: Selected Evaluation Index Factors for Different Bird Groups

Evaluation Factor	Condition	Saunders's Gull	Chinese Merganser	Far Eastern Curlew
		Value		
Land Cover	Water body	8	8	7
	forest land	5	7	4
	Wetland	10	10	10
	Farmland	6	5	5
	Building Land	2	2	2
	Bare land	0	0	0
	Grass	5	3	3
Water body（m）	0-10	0	5	0
	10-30	6	10	10
	30-50	10	6	6

	50-100	2	2	2
	>100	0	0	0
Residential Areas Distance	0-100	0	0	0
	0-500	2	2	2
	500-1000	6	6	6
	>1000	10	10	10
Road Distance	0-100	0	0	0
	100-500	2	2	2
	500-1000	6	6	6
	>1000	10	10	10

3.3.2 Determination and Validation of Evaluation Index Weights

This article uses the Analytic Hierarchy Process (AHP) to determine the weights of each evaluation indicator. The basic principle is to compare the importance of m evaluation indicators with respect to a certain evaluation objective, obtain the judgment matrix A, and then calculate the maximum eigenvalue of λ max (A) = m, whose eigenvector corresponds to ω = (1, ω 2, ω m) T, and normalize it to obtain the weight value of the evaluation index. Construct judgment matrices for different categories of migratory birds based on their habits (Tables 5, 6, and 7). Through calculation, the CR values were all less than 0.1, which passed the consistency test. By normalizing the feature vectors, the weight values of the evaluation indicators for two types of migratory birds are further determined (Tables 8, 9, and 10).

Table 5 Judgment Matrix of Saunders's Gull Evaluation Index

	Land Cover	Water Body	Residential areas Distance	Road Distance
Land Cover	1	3	5	7
Water Body	0.3333	1	5	6
Residential areas Distance	0.2	0.2	1	2
Road Distance	0.1429	0.1667	0.5	1

Table 6 Judgment Matrix of Merganser Evaluation Index

	Land Cover	Water Body	Residential areas Distance	Road Distance
Land Cover	1	3	5	6
Water Body	0.3333	1	5	6
Residential areas Distance	0.2	0.2	1	3
Road Distance	0.1667	0.1667	0.3333	1

Table 7 Judgment Matrix of Curlew Evaluation Index

	Land Cover	Water Body	Residential areas Distance	Road Distance
Land Cover	1	3	5	6
Water Body	0.3333	1	4	5

Residential areas Distance	0.2	0.25	1	3
Road Distance	0.1667	0.2	0.3333	1

Table 8 Weight of Saunders Gull Evaluation Index

	Feature Vector	Weights	Largest Characteristic Root	CI Value
Land Cover	2.1559	0.5519	4.1584	0.0593
Water Body	1.2376	0.304		
Residential Areas Distance	0.3771	0.0891		
Road Distance	0.2294	0.0551		

Table 9 Weight of Merganser Evaluation Index

	Feature Vector	Weights	Largest Characteristic Root	CI Value
Land Cover	2.0914	0.5371	4.2615	0.0979
Water Body	1.2412	0.3083		
Residential Areas Distance	0.4392	0.1011		
Road Distance	0.2281	0.0535		

Table 10 Weight of the Evaluation Index of the Great Curlew

	Feature Vector	Weights	Largest Characteristic Root	CI Value
Land Cover	2.1463	0.5471	4.2041	0.0765
Water Body	1.1412	0.2848		
Residential Areas Distance	0.4706	0.1104		
Road Distance	0.2419	0.0577		

IV. ANALYSIS AND RESULT

4.1 Bird Colony Changes

From 2017 to 2021, the diversity index of the bird colony showed a fluctuating trend of first increasing and then decreasing, then rising and then falling (Table 11 and Figure 4), with an overall increase of 0.21 (4.51%). The trend of the evenness index of the bird colony is consistent with the diversity index of the bird colony, with an overall decrease of 0.06 (6.4%). The diversity index of wild Anseriformes increased by 0.002 (0.3%), the evenness index decreased by 0.02 (14.39%), and dominance remained basically unchanged. The gull diversity index increased by 0.029 (20.28%), the evenness index increased by 0.001 (3.33%), and the dominance index increased by 0.002 (7.41%). The diversity index of waders decreased by 0.396 (39.13%), the evenness index decreased by 0.103 (48.13%), and the dominance index decreased by 0.097 (46.41%).

According to the bird dataset, the diversity of wild Anseriformes has increased while the uniformity has decreased, indicating a concentration of their habitats. This indirectly indicates a concentration of suitable environments for wild

Anseriformes to inhabit, and the environmental suitability is high with numerous species that can be accommodated, which has a high attraction to the wild Anseriformes populations. The increase in diversity, evenness, and dominance of gulls indicates an increase in the range of habitats suitable for gulls, making them more suitable for survival. However, the average annual dominance of gull colony is less than 0.1, indicating that the gull colony in the region is relatively small. The diversity, evenness, and dominance of shorebirds have all decreased, indicating that the community structure of shorebirds has shrunk and their habitats have been affected.

Table 11 Analysis Results of Diversity and Dominance Index

Type	Year	Diversity Index (H)	Year Change Rate	Evenness Index(J)	Year Change Rate	Dominance Index (S)	Year Change Rate
Bird Colony	2017	4.657	—	0.937	—	—	—
	2018	4.857	4.29%	0.928	-0.96%	—	—
	2019	4.626	-4.76%	0.939	1.19%	—	—
	2020	5.039	8.93%	0.927	-1.28%	—	—
	2021	4.867	-3.41%	0.877	-5.39%	—	—
Anseriformes	2017	0.66	—	0.139	—	0.137	—
	2018	0.332	-49.70%	0.063	-54.68%	0.061	-55.47%
	2019	0.602	81.33%	0.004	-93.65%	0.137	124.59%
	2020	0.489	-18.77%	0.09	2150.00%	0.095	-30.66%
	2021	0.662	35.38%	0.119	32.22%	0.137	44.21%
Gulls	2017	0.143	—	0.03	—	0.027	—
	2018	0.293	104.90 %	0.056	86.67%	0.058	114.81%
	2019	0.203	-30.72%	0.041	-26.79%	0.038	-34.48%
	2020	0.238	17.24%	0.044	7.32%	0.043	13.16%
	2021	0.172	-27.73%	0.031	-29.55%	0.029	-32.56%
Shorebirds	2017	1.012	—	0.214	—	0.209	—
	2018	1.237	22.23%	0.236	10.28%	0.252	20.57%
	2019	0.801	-35.25%	0.162	-31.36%	0.154	-38.89%
	2020	0.935	16.73%	0.172	6.17%	0.178	15.58%
	2021	0.616	-34.12%	0.111	-35.47%	0.112	-37.08%

4.2 Landscape Pattern Change

4.2.1 Habitat Type Changes

From 2017 to 2021, a total of 241.7106 km^2 of land formed the transfer of habitat types (Table 12). The area increment of construction land is the largest, with an increase of 42.5812 km^2. Secondly, the largest increase is in forest land, with an increase of 15.2807 km^2. Afterward, there are grasslands and wetlands, with an increase of 8.0082 km^2 and 3.6226 km^2. The area of farmland decreased the most from 2017 to 2021, with a decrease of 59.7451 km^2. Next is the water body, with a decrease of 6.7118 km^2, followed by a decrease of 3.0358 km^2 in bare land.

The study shows that from 2017 to 2021, the construction land on Chongming Island increased while the farmland area and water body decreased. Among them, the area of farmland converted to building land was the largest, while the area of water bodies converted to farmland was the largest. This indicates that the local government expanded and farmland by reducing farmland and filling lakes with farmland. Wetlands and grasslands showed an increasing trend from 2017 to 2021, with farmland contributing the most to grassland growth and water bodies contributing the most to wetland growth. The above shows that the land use planning of Chongming Island is based on development while taking environmental protection into account.

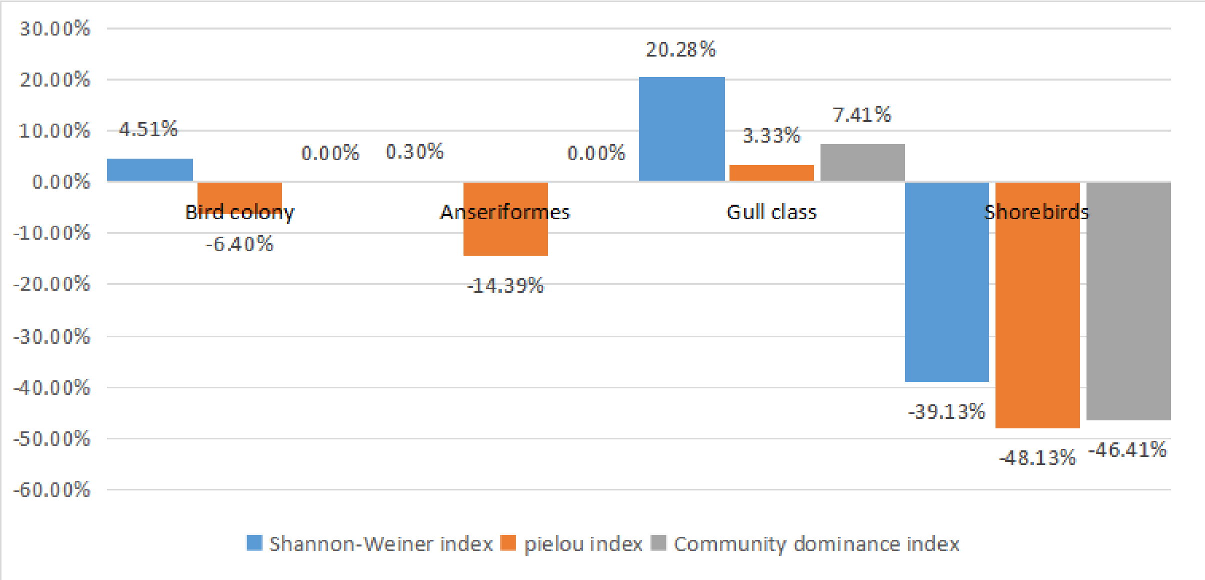

Fig.4 2017-2021 Total Change Rate of Diversity and Dominance Index

Table 12 Stochastic Matrix of Habitat Types from 2017 to 2021

Type /km²		2021							
		Grass	Farmland	Building Land	Forest Land	Bare Land	Wetland	Water Body	Total
2017	Grass	102.89	11.29	1.49	15.17	0.29	4.48	4.87	140.47
	Farmland	24.03	729.96	63.82	8.58	0.25	2.91	16.71	846.26
	Building Land	1.51	24.45	421.49	0.56	0.09	0.09	2.23	450.42
	Forest Land	1.20	5.96	2.06	13.97	0.00	0.08	0.47	23.73
	Bare Land	1.56	0.45	0.79	0.02	0.23	0.09	0.84	3.99
	Wetland	7.24	0.49	0.06	0.11	0.00	10.12	2.81	20.83
	Water Body	10.05	13.92	3.30	0.60	0.10	6.68	925.12	959.78
	Total	148.48	786.51	493.00	39.01	0.95	24.45	953.07	2445.48

4.2.2 Landscape Pattern Index

Analyze the statistical results of landscape-level indicators on Chongming Island (Table 13). Firstly, with the total area unchanged, the LPI index decreased from 2017 to 2021, indicating that the largest patch in the local area has been reduced due to human factors. Secondly, the shape index, PAFRAC is close to 1, indicating a relatively simple shape. A lower ED indicates a lower degree of landscape fragmentation, and a lower LSI indicates that the shape of the area is relatively simple and susceptible to external interference.

Subsequently, the connectivity indicators CONNECT and COHESION all decreased, indicating a decrease in connectivity among patches within the landscape and a decrease in communication between patches. The fragmentation index shows an increase in DIVISION and a decrease in PD and NP, indicating a decrease in landscape fragmentation. Then, the diversity of indicators SHDI and SHEI improved, indicating that the landscape distribution in the region is relatively uniform and there are no particularly prominent types of patches.

Finally, the aggregation indicators for AI and SPLIT are improved, indicating that the patch integrity is higher, but the statistical dispersion between patches is increased.

Table 13 Statistical Results of Landscape Level Index

Indicators	Index	2017 value	2018 value	2019 value	2020 value	2021 value	2017-2021 Index change rate（%）
Area indicator	TA	244548.11	244548.11	244548.11	244548.11	244548.11	0
	LPI	37.3656	35.6036	35.5994	37.1172	35.6392	-4.62%
Shape indicator	PAFRAC	1.2301	1.2295	1.228	1.2278	1.227	-0.25%
	ED	39.0178	38.5028	39.4431	38.6569	38.8241	-0.50%
	LSI	49.9919	49.3553	50.5177	49.5458	49.7526	-0.48%
Connectivity indicators	CONNECT	0.3352	0.3279	0.3044	0.3026	0.2891	-13.75%
	COHESION	99.8805	99.8886	99.8763	99.8808	99.8696	-0.01%
Fragmentation	DIVISION	0.844	0.8458	0.8542	0.8454	0.8571	1.55%
	NP	10658	10131	10748	9807	9915	-6.97%
	PD	4.3582	4.1427	4.395	4.0103	4.0544	-6.97%
Diversity	SHDI	1.3061	1.3163	1.3375	1.3328	1.3402	2.61%
	SHEI	0.6712	0.6765	0.6873	0.6849	0.6887	2.61%
Aggregation	SPLIT	6.4087	6.4859	6.8603	6.4675	6.9981	9.20%
	AI	98.0552	98.0812	98.0345	98.0736	98.0653	0.01%

Correlation analysis was conducted between bird species and area index, maximum patch index, percentage of patch type, edge density, landscape shape index, and connectivity index. The results are shown in Tables 14 and 15. There is a strong negative correlation between the number of local bird species and the number of patches (NP) and patch density (PD), indicating a significant correlation between bird habitat and habitat fragmentation. The more patches there are, the greater the patch density, and the higher the fragmentation, the less suitable it is for bird survival.

Table 14 Correlation between Bird Species and Various Indicators

Type	M（SD）	1	2	3	4	5	6	7
1 Bird species/kinds	191.2（52.026）	1						
2 TA	244548.11（0）	.a	1					
3 LPI	36.265（0.8957768）	-0.125	.a	1				
4 PAFRAC	1.22848（0.0012795）	-0.666	.a	0.387	1			
5 ED	38.88894（0.364297）	-0.625	.a	-0.099	-0.106	1		
6 LSI	49.83266（0.4503354）	-0.625	.a	-0.099	-0.106	1.000**	1	
7 CONNECT	0.31184（0.0191145）	-0.655	.a	0.385	.999**	-0.133	-0.133	1

Note: * indicates p<0.05: * * indicates p<0.01: “a” cannot be calculated because at least one variable is a constant

Table 15 Correlation between Bird Species and Various Index

Type	M（SD）	1	2	3	4	5	6	7	8	9
1 Bird species/kinds	191.2（52.026）	1								
2 COHESION	99.87916（0.0069493）	-0.352	1							
3 DIVISION	0.8493（0.0059245）	0.297	-0.82	1						
4 SPLIT	6.6441（0.2663111）	0.302	-0.824	1.00**	1					
5 NP	10251.8（429.269）	-.942*	0.04	-0.019	-0.022	1				
6 PD	4.19212（0.1755068）	-.942*	0.04	-0.019	-0.022	1.00**	1			
7 SHDI	1.32658（0.0147356）	0.505	-0.673	0.802	0.798	-0.356	-0.356	1		
8 SHEI	0.68172（0.007548）	0.507	-0.671	0.802	0.798	-0.358	-0.358	1.00**	1	
9 AI	98.06196（0.0181423）	0.63	0.472	-0.431	-0.428	-0.802	-0.803	-0.226	-0.223	1

Note: * indicates p<0.05: * * indicates p<0.01: “a” cannot be calculated because at least one variable is a constant

The landscape-type of level indicators is shown in the statistical results, firstly the area indicators (Figure 5 and Figure 6). From 2017 to 2021, except for the significant decrease in farmland and the significant increase in building land, the area of other patch types has changed relatively little. The shapes of each patch type are relatively simple, and the shapes of bare land and wetlands have undergone significant changes, indicating that they may be affected by human factors.

The landscape-type of level indicators is shown in the statistical results, firstly the area indicators (Figure 5 and Figure 6). From 2017 to 2021, except for the significant decrease in farmland and the significant increase in building land, the area of other patch types has changed relatively little. The shapes of each patch type are relatively simple, and the shapes of bare land and wetlands have undergone significant changes, indicating that they may be affected by human factors. Secondly, the fragmentation index (Figures 7, 8, and 9) shows a negative correlation between the average area and the growth trend of the number and density of patches. Between 2017 and 2021, the average area of building land steadily increased while the number and density of patches decreased, similar to the trend of water bodies, forests, and wetlands. This indicates that the fragmentation of these types decreased while the overall trend increased. The average area of farmland decreases, and the number and density of patches increase, indicating that farmland is affected by other types, resulting in a decrease in area and an increase in segmentation. The average area, number of patches, and patch density of bare land have all decreased, indicating a high degree of reduction in bare land, with some patches completely disappearing. Grassland changes are relatively fluctuating.

Next is the connectivity index (Figures 10 and 11). The cohesion index of water bodies, grasslands, farmland, and building land is relatively high, while the cohesion index of bare land and wetlands shows an upward trend. The low connectivity between patches indicates that the local patches are relatively stable, but the low connectivity is not conducive to the flow of substances in the same type of patch.

Finally, there is the clustering index (Figures 12 and 13). The clustering degree and arrangement of patches in this area are relatively high. Except for building land, the dispersion and juxtaposition index of other patches exceed 50%, and the arrangement between different patch types in the local area is relatively uniform.

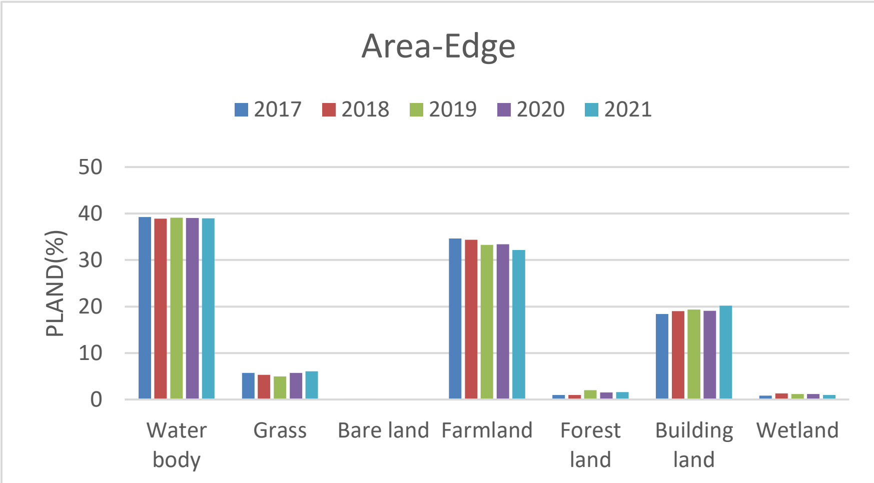

Fig.5 Chart of Percentage of Patch Types from 2017 to 2021

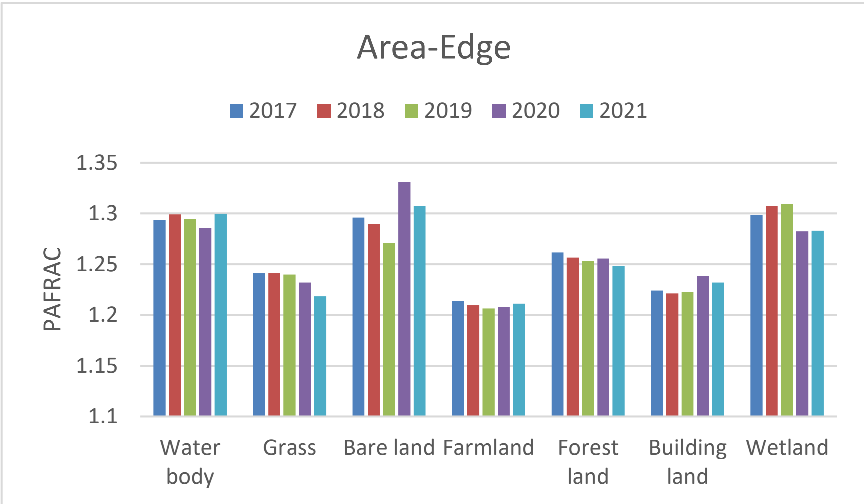

Fig.6 Chart of Fractal Dimension of Perimeter Area from 2017 to 2021

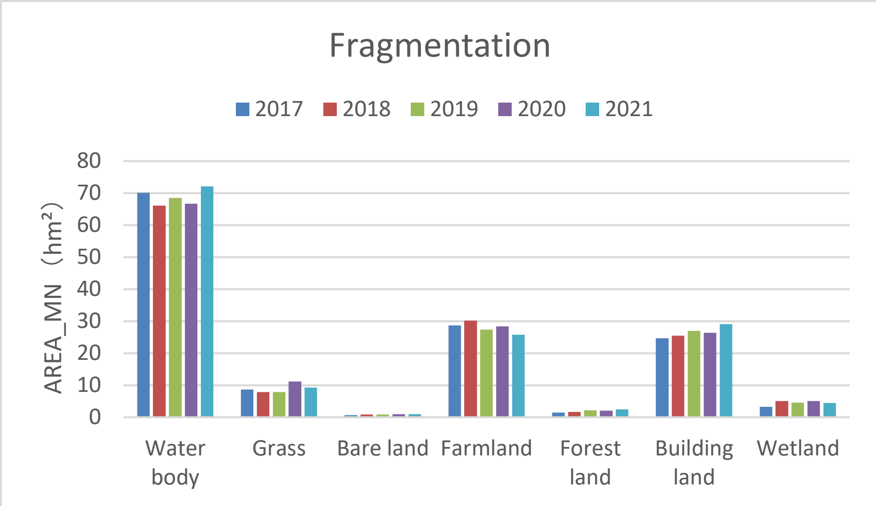

Fig.7 Chart of Average Patch Area from 2017 to 2021

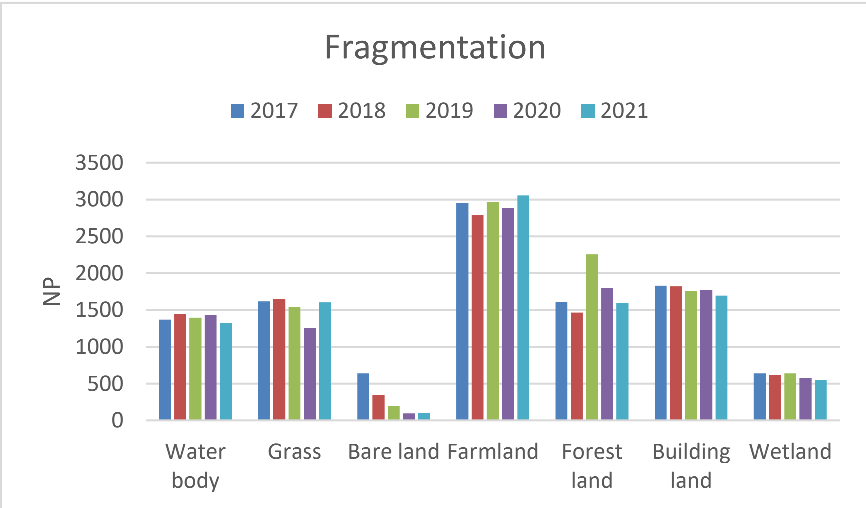

Fig.8 Chart of Numbers of Patches from 2017 to 2021

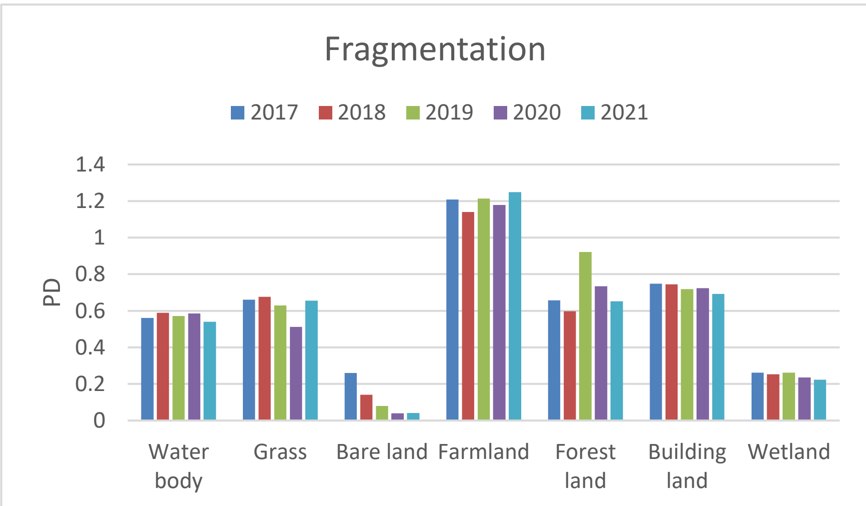

Fig.9 Chart of Patch Density from 2017 to 2021

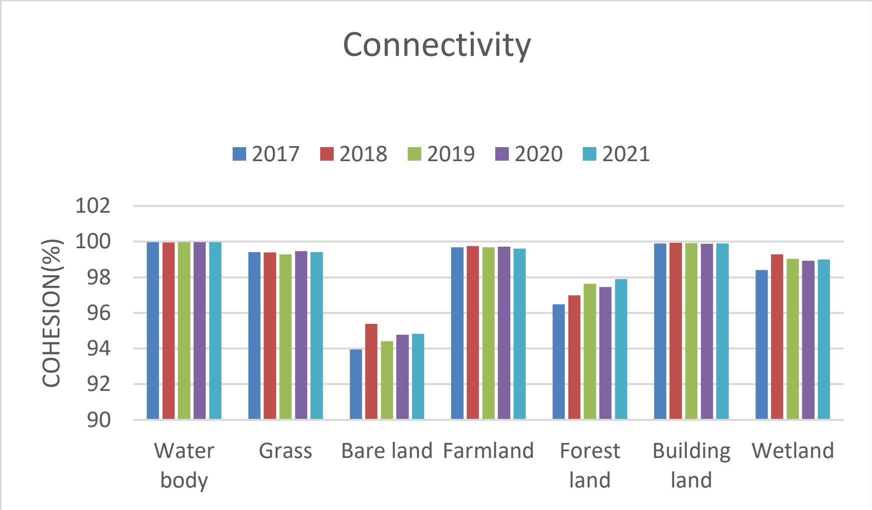

Fig.10 Chart of Patch Cohesion from 2017 to 2021

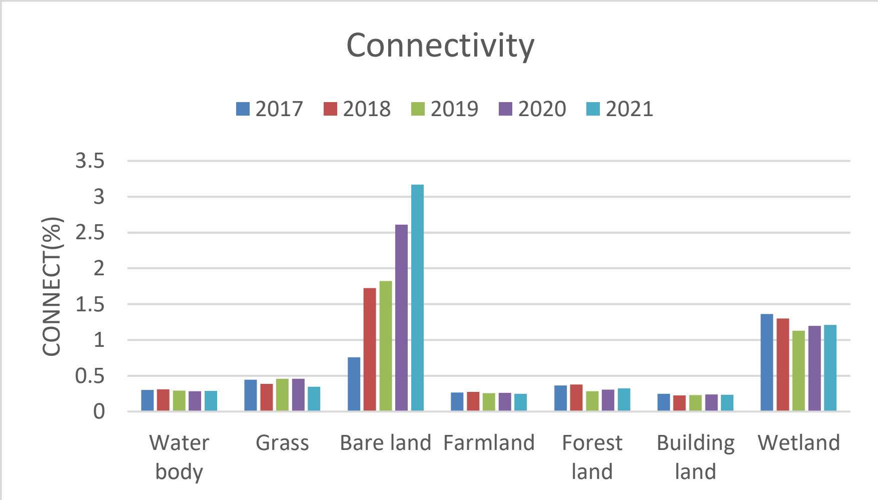

Fig.11 Chart of Patch Connectivity from 2017 to 2021

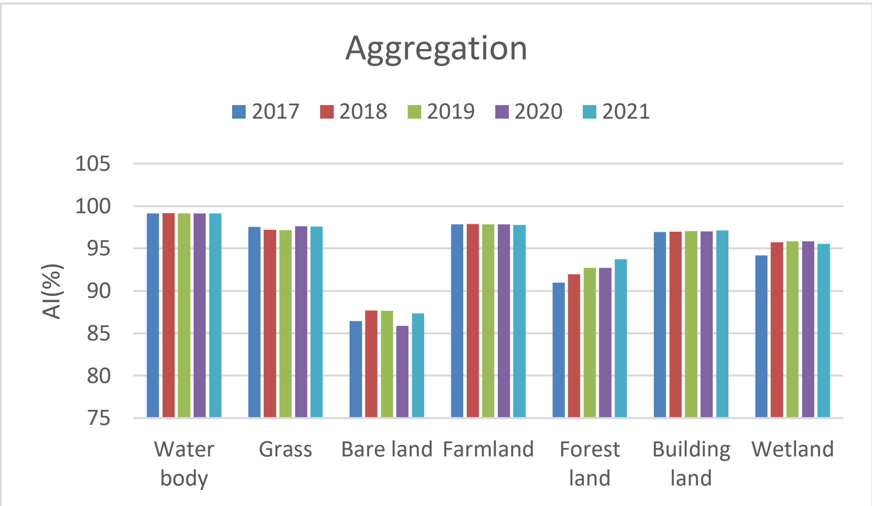

Fig.12 Chart of Patch Aggregation from 2017 to 2021

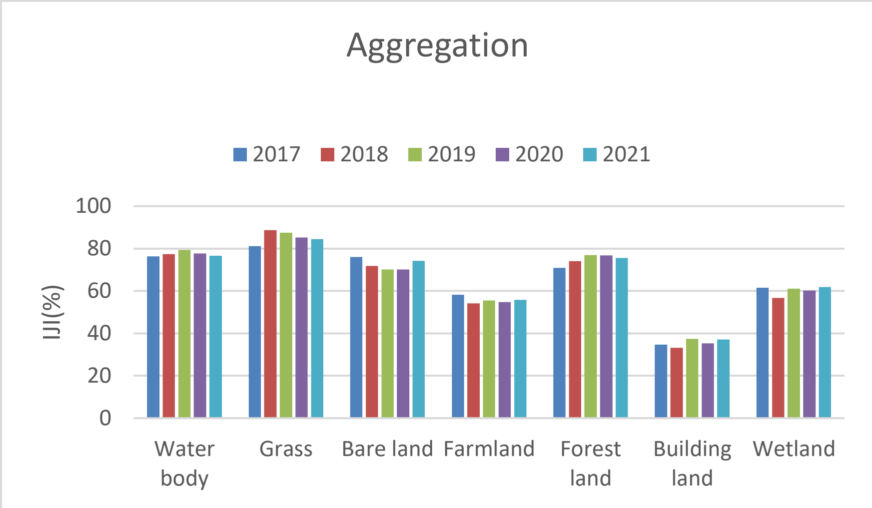

Fig.13 Chart of Walking and Parallelism Index from 2017 to 2021

At the level of landscape type, the correlation analysis between PD and NP of different landscape types and the number of bird species is shown in Tables 16 and 17. At the level of landscape type, there is a strong negative correlation between wetland type and bird species, indicating that an increase in wetland fragmentation will lead to a decrease in bird diversity.

Table 16 Correlation between Bird Species and PD of Various Landscape Types

Type	M（SD）	1	2	3	4	5	6	7	8
1 Bird species /kinds	191.2（52.026）	1							
2 Water body/PD	0.56922 （0.0199845）	-0.244	1						
3 Grassland/PD	0.62678 （0.0664774）	-0.322	-0.382	1					
4 Bare land/PD	0.11262 （0.0927232）	-0.664	0.009	0.521	1				
5 Farmland/PD	1.1979 （0.0408394）	0.179	-.925*	0.105	-0.193	1			
6 Forest land/PD	0.7128 （0.1263961）	-0.429	0.062	-0.327	-0.335	0.283	1		
7Building land/PD	0.7255 （0.0225871）	-0.63	0.62	0.152	0.788	-0.726	-0.267	1	
8 Wetland/PD	0.24732 （0.0165925）	-.984**	0.371	0.322	0.706	-0.34	0.316	0.746	1

Note: * indicates p<0.05: * * indicates p<0.01

Table 17 Correlation between Bird Species and NP of Various Landscape Types

Type	M（SD）	1	2	3	4	5	6	7	8
1 Bird species /kinds	191.2（52.026）	1							
2 Water body/NP	1392（48.842）	-0.245	1						
3 Grassland/NP	1532.8（162.638）	-0.322	-0.381	1					

4 Bare land/NP	275.4（226.754）	-0.664	0.009	0.522	1				
5 Farmland/NP	2929.4（99.916）	0.179	-.925*	0.104	-0.193	1			
6 Forest land NP	1743.2（309.055）	-0.43	0.063	-0.327	-0.335	0.283	1		
7 Building land/NP	1774.2（55.278）	-0.629	0.62	0.153	0.788	-0.727	-0.268	1	
8 Wetland/NP	604.8（40.616）	-.984**	0.372	0.323	0.707	-0.341	0.316	0.745	1

Note: * indicates p<0.05: * * indicates p<0.01

4.3 Bird Habitat Suitability Changes

In this paper, Anseriformes, gulls, and waders were taken as the analysis groups, and the more high-risk and indicative species, namely, the Scaly-sided merganser, Saunders's gull, and Far Eastern curlew, were taken as the analysis objects for suitability correlation analysis. Using the field calculator in ArcGIS, calculate the area of different habitat suitability for birds between 2017 and 2021 and obtain Tables 18, 19, and 20.

Table 18 Habitat Suitability Area in 2017

Type/Suitability/km²	Unsuitable	Low suitability	Basically suitable	Very suitable
Chinese Merganser	1122.54	1252.91	65.84	4.74
Saunders's gull	727.28	1642.55	72.43	3.77
Far Eastern curlew	1131.90	1247.14	63.22	3.76

Table 19 Habitat Suitability Area in 2021

Type/Suitability/km²	Unsuitable	Low suitability	Basically suitable	Very suitable
Chinese Merganser	1127.02	1246.11	66.96	5.94
Saunders's gull	753.67	1614.90	72.69	4.77
Far Eastern curlew	1149.97	1227.35	63.94	4.77

Table 20 Changes in Habitat Suitability from 2017 to 2021

Type/Change Type/km²	Optimize	Deterioration	Unchanged
Chinese Merganser	224.96	2221.06	0.01
Saunders's gull	125.75	2320.27	0.00
Far Eastern curlew	147.96	2298.06	0.01

4.3.3 Chinese Merganser

In 2017, the unsuitable area of Scaly-sided Merganser was 1122.54 km², concentrated in areas with active human activities in urban areas. With a low-suitable area of 1252.91 km², the distribution area is mainly composed of water bodies and farmland. With a basic suitable area of 65.84km², it is distributed in coastal wetlands, mudflats, and river islands far away from human activities. With a very suitable area of 4.74km², it roughly surrounds the basic suitable area. In 2021, the unsuitable area of the Scaly-sided Merganser will be 1127.02 km², the low suitability area will be 1246.11 km², the basic suitable land area will be 66.96 km², and the very suitable area will be 5.94 km². The distribution location is roughly similar to 2017 (Figures 14 and 15).

Based on the changes in bird habitat suitability from 2017 to 2021, the area of environmentally optimized areas is 224.96km². The northern region is more obvious, with a degraded area of 2221.06km². The area with unchanged suitability is 0.01km².

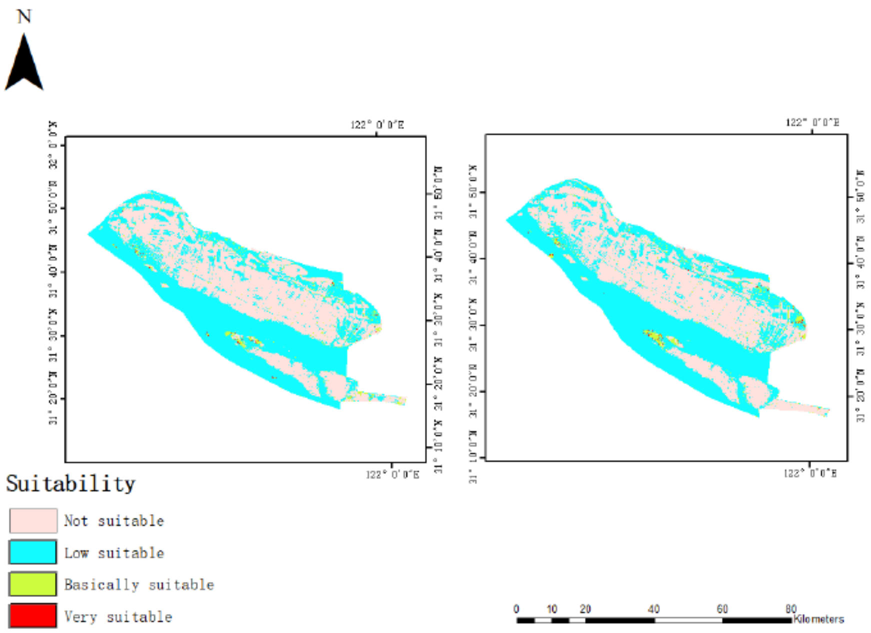

Fig.14 Degree Distribution of Habitat Fitness of Scaly-sided Merganser from 2017 (left) to 2021 (right)

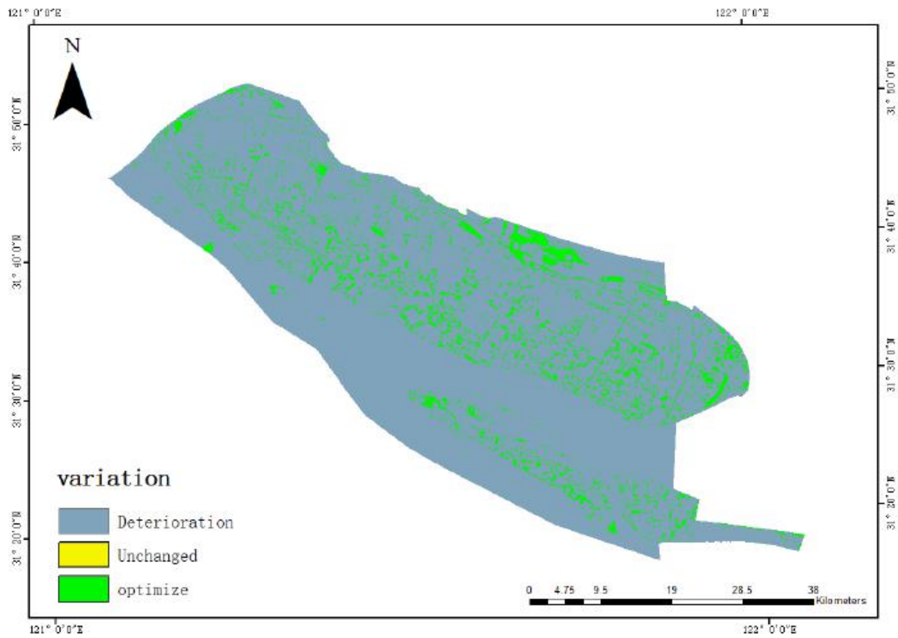

Fig.15 Changes in Habitat Suitability of Scaly-sided Merganser from 2017 to 2021

4.3.2 Saunders's Gull

In 2017, the unsuitable area of Saunders's gull was 727.28km², concentrated in areas such as towns where human activities are more active. The low suitability area is 1642.55km², the distribution area is mainly composed of water bodies and farmland. The basic suitable area is 72.43km², it is distributed in coastal wetlands, mudflats, and islands in the river far away from human activities. The very suitable area is 3.77km², is roughly surrounding the basic suitable area. In 2021, the unsuitable area for Saunders's gull will be 753.67km². The low suitability area is 1614.55km²; the basic suitable area is 72.69km²; the very suitable area is 4.77km², the distribution location is roughly similar to 2017 (Figures 16 and 17).

Based on the changes in bird habitat suitability from 2017 to 2021, the area of environmentally optimized areas is 125.75km²; and the area of degraded areas is 2320.27km².

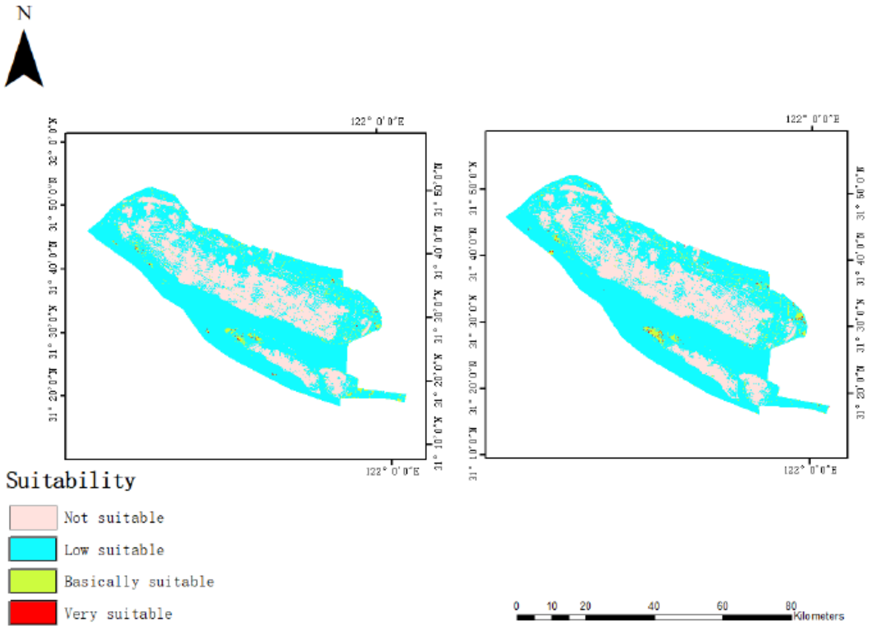

Fig.16 Degree Distribution of Saunders's Gull Habitation Fitness from 2017 (left) to 2021 (right)

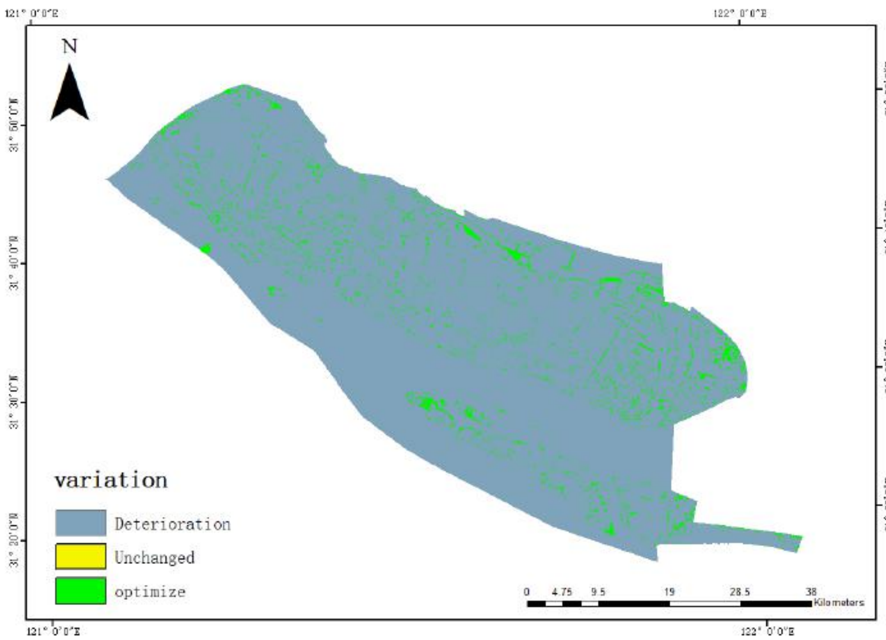

Fig.17 Changes in Habitat Suitability of Saunders's Gull from 2017 to 2021

4.3.3 Far Eastern Curlew

In 2017, the unsuitable area of the Far Eastern curlew was 1131.90km² almost all over the land area. The low suitability area is 1247.14km². The distribution area is mainly composed of water bodies and farmland. The basic suitable area is 63.22km². It is distributed in coastal wetlands, mudflats, and the river island, far away from human activities, with a very suitable area of 3.76km², roughly surrounding the basic, suitable area. In 2021, the unsuitable area of the Far Eastern curlew will be 1149.97km², the low suitability area will be 1227.35km², the basic suitable area will be 63.94km², and the very suitable area will be 4.77km². The distribution location is roughly similar to 2017 (Figures 18 and 19).

Based on the changes in bird habitat suitability from 2017 to 2021, the area of environmentally optimized areas is 147.96km². The area of degraded areas is 2298.06km². The area with unchanged suitability is 0.01km².

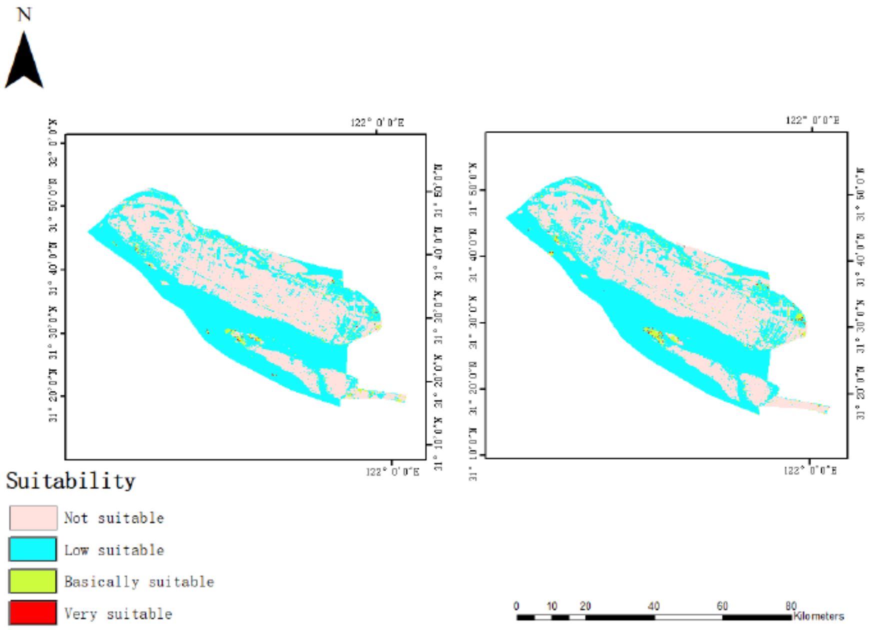

Fig.18 Degree Distribution of Habitation Fitness of Far Eastern Curlew from 2017 (left) to 2021 (right)

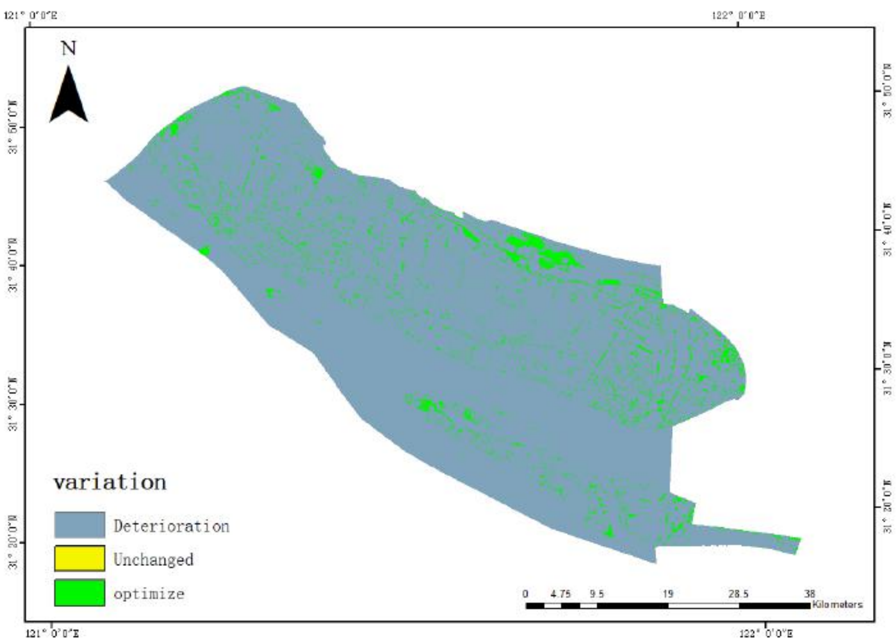

Fig.19 Changes in Habitat Suitability of Far Eastern Curlew from 2017 to 2021

In general, from the perspective of spatial distribution, the degree of distribution of habitat suitability of the three birds is highly similar, and they are concentrated in the Dongtan, Dongfeng Xisha, Qingcaosha Reservoir and other areas of Chongming Island. From the observation of spatial distribution changes, from 2017 to 2021, the suitability of Dongtan, Dongfeng Xisha, and Qingcaosha reservoirs in Chongming Island will be significantly improved, and the scope of basically suitable and very suitable areas will be expanded, while the suitability of Hengsha Island will decline, and the areas with high suitability will tend to be centralized.

Between 2017 and 2021, there was an increase in the area of unsuitable, basically suitable, and very suitable types, while the area of low-suitable types decreased. This may be due to the local development of towns while also protecting areas that are crucial for bird habitat.

In terms of changes in suitability, the suitability of most areas has decreased, indicating that the local ecological environment is generally deteriorating. However, based on the 2017 and 2021 habitat suitability maps, the areas with deteriorated suitability are low and unsuitable, while the areas with optimized suitability are distributed around the basic and very suitable areas. In addition, in terms of the area of change, the degree of fitness improvement from large to small is Scaly-sided merganser, Far Eastern curlew, Saunders's gull.

It can be seen that the bird habitat suitability of Chongming Island shows a deterioration trend in general, and the overall environment also shows a deterioration trend. However, in the areas with a great impact on bird habitat, the habitat suitability tends to be optimized, and the space suitable for bird survival has expanded, indicating that the birds on Chongming Island have a better living situation.

V. CONCLUSION

This study uses ArcGIS, Fragstats, SPSS, and other software, and the AHP analytic hierarchy process combined with a series of basic data to obtain the landscape pattern index and its correlation analysis, the biodiversity index, the evenness index, the community dominance index, and the habitat suitability score, and comprehensively analyze the quality of bird habitat in this area. The relevant research results are summarized as follows:

1. The observation of the number of birds from 2017 to 2021 shows that the number, species, and high rarity of bird populations have increased. It shows that this area is more suitable for birds to inhabit and survive, and the attraction to birds is increased. However, the diversity index, evenness index, and community dominance of shorebirds have dropped significantly, which needs to be paid attention to, and the reasons should be continuously explored and improved.

2. The habitat pattern of Chongming Island, affected by urbanization and human activities, undergoes dynamic changes, which in turn cause changes in the structure of bird communities in the region. Farmland and bare land are highly disturbed and may occupy other land uses as the degree of development deepens, such as wetland resources and areas with high land development intensity, and the risk of habitat loss and migratory bird colony reduction is higher.

3. Through correlation analysis in this study, it was found that there is a strong negative correlation between the number of patches (NP) and the patch density (PD), especially the changes in wetlands, which have a greater impact on the changes in the number of bird species, indicating that there is a greater relationship between the habitat of birds and the fragmentation of habitats, especially the fragmentation of wetlands. The greater the number of patches, the greater the density of patches, and the higher the degree of fragmentation, the less suitable it is for birds to survive, and the degree of fragmentation of the local landscape shows a downward trend, indicating that the local habitat is developing towards rationalization while ecological protection in the study area has been valued and protected..

The overall habitat pattern in the study area tends to be concentrated, and the transformation of regional habitat types is mainly through the occupation of farmland and bare land. Under the environmental policy of protecting the red line of farmland and the further improvement of urban planning, the distribution of various habitats will tend to be stable in the future, and the degree of regional fragmentation will be alleviated. In addition, the area of wetlands, woodlands, and grasslands in the region will increase between 2017 and 2021, which can provide alternative habitat space for bird colony and benefit further bird protection. However, the connectivity of the landscape in this region is poor. The following ideas for ecological restoration are proposed: (1) Classified and graded planning and protection; (2) Restoring and cultivating diverse habitats; (3) Activation and reconstruction of multiple corridors; and (4) improving the urban planning scheme.

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