Evolution of landscape dynamics in the Yangtze River Delta from 2000 to 2020

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ABSTRACT

Based on the 2000–2020 land cover data, the landscape dynamics and landscape pattern index are used to study the landscape pattern changes of the Yangtze River Delta. The results show that with the growth of built-in land area, the dominance of natural landscape in the Yangtze River Delta is gradually weakened. From the perspective of the overall landscape pattern, the degree of landscape fragmentation in this area is increasing, and the degree of landscape connectivity and aggregation are decreasing in varying degrees. The regional landscape is developing toward homogeneous distribution and increasing complexity. At the same time, from the perspective of classified landscape, the spatial distribution of various landscapes shows a strong correlation between climate and landform. Through comparative analysis, this study puts forward that the development of the Yangtze River Delta needs to pay attention to maintaining the integrity of the regional dominant landscape and paying attention to the diversity and connectivity of the natural landscape with high ecological service value.

Key words: landscape index, landscape pattern, spatial-temporal evolution, Yangtze River Delta

HIGHLIGHTS

- From the perspective of overall landscape pattern, this paper studies landscape fragmentation, connectivity, and aggregation.
- The study found that the spatial distribution of various landscapes showed a strong correlation between climate and landform.
- The study found that the change degree of landscape structure such as forest land and wetland with high ecological service value.

1. INTRODUCTION

China’s rapid urbanization process in the past 40 years has increased the urbanization rate from 17.9% in 1978 to 60.6% in 2019 (Liu & Ye 2020). Rapid urbanization, while meeting the growing needs of the people for a better life, has inevitably caused a series of ecological and environmental problems due to the rough and disorderly urbanization and the rapid expansion of land for construction (Bai et al. 2014). The encroachment and destruction of the natural bedrock of the region caused by human activities further affect the ecological function of the region due to the changes of the regional landscape pattern, which resulted in the ecological landscape differentiation on the territorial spatial scale of the country. Human activities are also the main cause of global warming, while land-use changes are an intuitive manifestation of the environmental impact of human activities (IPCC 2014; Mundaca & Markandya 2016), and changes in the types of surface cover in the region can affect the structure, function, and ecological processes of ecosystems (Zhao et al. 2004, 2013; Priess et al. 2007; Ricketts et al. 2008). Different types of surface cover have corresponding ecological effects, such as vegetation as a link to natural factors that can respond to climate change and further slow it down (Mahmood et al. 2014; Wang et al. 2015), wetlands that can regulate climate, conserve water sources and maintain biodiversity (Ramachandra et al. 2005), and waters that are highly correlated with hydrological processes, often coupled with climatic conditions, can have an impact on the intensity and frequency of extreme weather events (Chang et al. 2018; Ekwueme & Agunwamba 2020; Hamid et al. 2021). The disorderly expansion of built-in land will further lead to environmental risks, extreme weather, geological disasters, urban flooding, and other problems (Liu et al. 2010; Qiu et al. 2016; Jaiswal et al. 2017; Shan et al. 2019; Kavianpour et al. 2020; Yan et al. 2021). Therefore, studying the interaction law of regional construction and development with regional ecological functions and ecological processes...
from the perspective of territorial spatial planning is of great significance for guiding the urban development and even urban agglomerations.

Landscape patterns are the distribution patterns and composite structures of landscape units in the space in different numbers, types, densities, and configurations (Turner 1990; Hu 2003), which are influenced by both natural and anthropogenic factors, which in turn restrict various ecological processes, thus further influencing the social and economic aspects of the region (Hao et al. 2017; Hashem et al. 2019). Quantitative studies of landscape patterns often use the landscape pattern index directly related to land use (Alberti 2005), or evaluate the resources and environmental status of the research area (Guiamé & Lee 2020) and forecast the future development (Gao et al. 2021; Zango et al. 2021) by various kinds of assessment and prediction model. The scope of study includes watersheds (Nuanchan et al. 2015; Li et al. 2019), deserts (Duan et al. 2012), wetlands (Gong et al. 2011), etc., delimited by ecological scope, as well as provinces and municipalities delimited by administrative or territorial scope, and countries (Zhao et al. 2007; Cirelli & Vineri 2014; Burgalassi & Luzzati 2015; Li & Qi 2019). The research content extends to urban structure (Yang et al. 2017), urban flooding (Velasco et al. 2014; Philip et al. 2021), low-carbon cities (Piao et al. 2009; Li & Zhou 2021), and urban climate (Suder & Szymański 2014). Urban expansion, a process of human-driven disturbance, has an increasingly significant impact on regional landscape patterns and ecological functions and processes (Zeng & Jiang 2000). The corresponding landscape patterns changes are also greatly influenced by climate change, geographical conditions, socio-economic conditions, regional population, and other factors (Zhang et al. 2021). Yang used runoff data from eight hydrologic stations in the upper reaches of the Yangtze River to study the spatial-temporal characteristics in runoff change between 1951 and 2013, and the results showed that runoff decreased at a rate of 7.6 km3 per decade during the study period, of which climate change was the main cause of this phenomenon. Yang et al. (2021) studied the effects of climate change on runoff in the upper reaches of the Yangtze River over the next 50 years by coupling the Statistical Downscaling Model (SDSM) and the Soil and Water Assessment Tool (SWAT). The results showed that with the increase of emissions, the maximum temperature and minimum temperature in the study area increased and the annual runoff showed an upward trend. Wu et al. (2020) used the land use data of Shenzhen for nearly 20 years to study the spatiotemporal changes in the landscape pattern of the region using the landscape pattern index and the landscape transfer index, and analyzed the main drivers of land expansion in the region, proposed that the urbanization process should maintain as much as possible the landscape diversity of ecological areas and urban green spaces. Li & Qi (2019) quantitatively depict the evolution of the landscape pattern over the whole of China over the past 40 years based on the land use data, while analyzing the spatiotemporal dimensional influence of the urbanization process on the evolution of the landscape pattern. The results show that the intensity and frequency of human activities' interference with the landscape have been increasing for 40 years.

From the above-mentioned research progress, we can learn that the research content of landscape pattern covers climate change, environmental pollution, extreme weather, ecological process, etc. The research area also covers many scales such as land, ecological area, and individual city and study areas related to landscape patterns cover a variety of scales such as territory, ecological zones, and individual cities. However, the regional ecological characteristics and the impact of disturbances on regional ecology reflected in different research scales may vary, due to the scale effects and research methods. National-scale landscape pattern research often cannot reflect the internal connections of urban ecosystems in an all-round way due to the large scale of the research grid, while single-city-scale research lacks the expression of regional ecosystem heterogeneity. Besides, it is difficult for the ecological zone-scale research to reflect the driving or restricting effect of regional socio-economic factors on the evolution of landscape patterns. Therefore, it is still necessary to study the overall and local landscape heterogeneity in the evolution of landscape patterns under multi-scale synthesis, in order to further combine regional socio-economic data under administrative divisions to carry out research.

With the help of ArcGIS and FRAGSTATS software, this paper quantitatively studies the temporal and spatial differentiation and evolution law of landscape pattern in the region of the Yangtze River Delta Urban Agglomeration in 2000–2020. This paper mainly discusses the connectivity and aggregation of the landscape in the Yangtze River Delta from the perspective of the overall landscape pattern, and discusses the characteristics of the regional landscape. At the same time, from the perspective of classified landscape, this paper discusses the correlation between the spatial distribution of various landscapes and climate and landform. This paper puts forward the important significance of maintaining the diversity and continuity of high ecological landscape in the Yangtze River Delta.
2. METHODOLOGY

2.1. Research area overview
The Yangtze River Delta region includes three provinces as Jiangsu, Zhejiang, and Anhui provinces and one city as Shanghai municipality (Figure 1), with a total scale of 350,000 km² and contains both subtropical monsoon climate and temperate monsoon climate types. The region is economically developed and densely populated and is the most economically powerful, densely populated, and densely populated area with the highest urban density in China (Li & Gu 2018). By the end of 2019, the resident population reached 235 million, accounting for 16.76% of the national population in the same period, the urbanization rate reached 67.78%, and the regional GDP reached 23.73 trillion RMB, accounting for 23.94% of the national GDP.

2.2. Data information and pre-processing
The spatial and temporal scope included in this study is the Yangtze River Delta region of China from 2000 to 2020, with a 10-year time section for data extraction and research analysis. The data sources used are:

Three phases of the Yangtze River Delta surface cover raster data (2000, 2010, and 2020) with a spatial resolution of 30 m×30 m, from the Ministry of Natural Resources of China (http://www.globallandcover.com/defaults.html?src=/Scripts/map/defaults/browse.html&head=browse&type=data). Since the proportion of landscape types such as bare land and tundra within the study area is very small, the surface cover types in the study area are reclassified into six landscape types: cropland, forest land, grassland, wetland, water body, and built-in land.

The 2019 administrative division data of the provinces and cities included in the Yangtze River Delta region were obtained from the Resource and Environment Science Data Center of the Chinese Academy of Sciences (http://www.resdc.cn/).

2.3. Landscape degree of the dynamics model
The landscape degree of dynamics can reflect the trend of regional landscape change and its dramatic degree, and in order to fully reflect the spatial and temporal scale changes of various landscape types in the study area, the degree of dynamics model and the relative degree of dynamics model were introduced (Wang et al. 2017).

\[ K = \frac{U_b - U_a}{T U_a} \times 100\% \]  
\[ R = \frac{(K_b - K_a)}{(C_b - C_a)/C_a} \]  

where \( K \) is the degree of dynamics of a landscape type; \( U_a \) and \( U_b \) are the areas of a landscape type at the beginning and end of the study period, respectively; and \( T \) is the time span of the study.

Figure 1 | Details of the study area.
where $R$ is the relative degree of dynamics of a landscape type; $K_a$ and $K_b$ are the area of a landscape type in a region at the beginning and end of the study period; and $C_a$ and $C_b$ are the area of a landscape type in the whole study area at the beginning and end of the study period, respectively.

### 2.4. Selection and calculation of landscape index

In this study, the raster data reflecting the land use form is selected as the basis of the landscape index calculation. Considering the limitation of calculation volume and the accuracy and continuity of landscape type discrimination, the raster data of ground cover data were resampled to a grid with a resolution of 100 m x 100 m in ArcGIS, retaining the landscape plaques of villages, urban river corridors, waterfront green areas, and other land types within the study site as accurately as possible while reducing the calculation volume. The landscape pattern index was calculated using the landscape pattern analysis software FRAGSTATS 4.2 to analyze the landscape pattern characteristics of the study area in different areas and at different times.

According to the landscape type and scale, the landscape pattern index can be divided into three classes as plaque, Class, and Land, in order to effectively quantify the spatial and temporal variation of various landscape types in the study area, as well as the changing characteristics of the overall landscape system in the Yangtze River Delta region. With reference to related studies (Li et al. 2004; Wang et al. 2017), 11 landscape indices were selected in this paper, namely plaque type area, plaque number, plaque density, edge density, average plaque area, bonding index, spreading index, aggregation index, fragmentation index, SHDI diversity index, and SHDI evenness index in the two classes of class and landscape (Table 1).

### 3. RESULTS AND DISCUSSION

#### 3.1. Landscape dynamics in the study area

In this study, with the help of ArcGIS, the dynamic area and proportion of various types of landscapes in the study area were counted (Table 2 and Figures 2–4), and the dynamic changes of various types of landscapes in the Yangtze River Delta, the three provinces and one city, and the overall region were calculated using the landscape degree of dynamics model (Tables 3 and 4), and the results showed below.

From the overall area dynamics of the study area, cropland has always been the dominant landscape in the Yangtze River Delta as a whole, accounting for 56, 54, and 49% of the landscape, respectively, in the past two decades, all exceeding the second largest and stable proportion of 27% of the woodland landscape. Wetland landscape area is the smallest, with the proportion in 20 years at about 1%. The proportion of land used in woodland, grassland, wetland, and waters in the study area did not change by more than 1% during the study period. The main changes in surface cover are reflected in the transfer of cropland to built-in land, which is closely related to the rapid economic development of the Yangtze River Delta region. The spatial variation of the internal landscape of the study area is obvious, Shanghai, as the area with the highest economic strength of the Yangtze River Delta urban group, has the fastest decline in the proportion of cropland, accounting for 57, 46, and 38%, respectively, in the 3 years, while the proportion of built-in land area is 23, 34, and 39%, and the dominant landscape has been transformed from cropland to built-in land in 2020. The area change of woodland, grassland, and wetland was about 1%, and the proportion of waters landscape decreased by 3%. Jiangsu Province has the highest proportion of cropland landscape, but the proportion decreased from 73 to 63%, of which the rate of decline between 2010 and 2020 reached 8%, mainly for built-in land. Zhejiang Province’s dominant landscape has always accounted for more than 50% of the woodland, with only 1% change in 20 years, the main landscape transformation process takes place between cropland and built-in land. The proportion of landscape composition in Anhui Province is similar to that of the Yangtze River Delta as a whole, with no significant changes in the proportion of each type of landscape during the study period. The landscape dynamics of the provinces and cities in the study area are unified, showing the trend of the flow of cropland to built-in land. The proportion of landscape area in various regions also shows the characteristics of comprehensive influence of landform, climate, and economic development. For example, located south of the Qinling-Huaihe River line, the climate type is the subtropical monsoon climate of Zhejiang Province, southern Anhui Province, with a relatively high forest landscape. The terrain is mainly plain in Jiangsu Province and the northern plain area of Zhejiang Province, with a high proportion of cropland landscape. Shanghai, which has the most active economic activities and the highest degree of opening up to the outside world in the Yangtze River Delta region, has a high proportion of built-in land area, which has been transformed into dominant landscape in 2020.
From the viewpoint of landscape dynamics in the Yangtze River Delta, the landscape types showing an increasing trend are grassland, waters, and built-in land, while those showing a decreasing trend are cropland, woodland, and wetland. In the overall landscape of the study area, the landscape dynamics of built-in land is the largest, reaching 4.58% during 2010–2020, the main landscape transfer direction is the conversion of cropland to built-in land, with a conversion area of over 20,000 km², with the main driver of landscape transfer being human activity. The increase of waters landscape is also related to water resources development, flood, and other reasons, such as the transfer of large areas of cropland to the waters landscape in the water source area of the South-North Water Transfer Project, the construction of reservoirs directly leads to the increase of water area (Kong et al. 2018). Woodland landscape dynamics are the smallest, with only 0.04% between 2000 and 2020. The largest decline in landscape activity was in wetlands, which fell by 1.29% from 2000 to 2020. The area of woodland and wetland with high ecological service value in the study area is decreasing continuously, and the overall landscape dynamics in the Yangtze River Delta is strongly disturbed by human during 2000–2020.

From the perspective of the relative dynamics of the landscape within the study area, among the landscape types accounting for more than 10% of the total area in 2020, only the dynamic direction of Shanghai’s waters landscape is opposite to that of the Yangtze River Delta as a whole, and the relative dynamic attitude of the landscape is −1.11, which continues to decrease under the circumstances of the increase of the overall water area of the Yangtze River Delta region. The main reason is the increase of flood disasters in the Yangtze River basin under the background of climate change, and the

| Landscape Pattern Index | Index Name | Index Range and Meaning |
|------------------------|------------|------------------------|
| CA                     | area of plaques type, unit: hm² | CA > 0, reflecting the dominant plaques and inferior plaques type in the landscape |
| NP                     | number of plaques, unit: piece | NP > 0, reflecting the number of plaques of the type |
| PD                     | plaques density, unit: piece/100 hm² | PD > 0, reflecting the number of certain landscape plaques per unit area; if the PD value becomes larger, the landscape tends to be composed of mostly smaller plaques |
| ED                     | edge density, unit: m/hm² | ED > 20, an indicator of plaques shape, indicating the degree of landscape fragmentation; the larger the ED value, the greater the degree of landscape fragmentation and the more dispersed the layout |
| AREA_MN                | average plaques area, unit: hm² | AREAMN > 0, reflecting the fragmentation degree of the type landscape; the smaller the value, the larger the fragmentation degree of the plaques, and the landscape tends to be composed of mostly smaller plaques |
| COHESISON              | cohesion index | 0 < COHESION < 100, reflecting the degree of connectivity of the class landscape; the higher the value, the higher the degree of aggregation or interconnectivity of the class landscape, and vice versa, the smaller |
| CONTAG                 | spreading index | O < CONTAG ≤ 100, reflecting the connectivity of the dominant landscape; the larger the value, the higher the integrity of the landscape pattern |
| AI                     | aggregation index | O ≤ AI ≤ 100, reflecting the degree of aggregation of plaques; if the AI value becomes smaller, the landscape tends to be composed of smaller plaques with uniform distribution; if the AI value becomes larger, the landscape is composed of a smaller number of large plaques or highly connected between plaques |
| DIVISION               | division index | 0 ≤ DIVISION < 1, reflecting the fragmentation degree of the landscape; when the value is 0, the landscape is composed of single plaques; the larger the value, the higher the degree of fragmentation of the landscape by different plaques |
| SHDI                   | SHDI diversity index | SHDI ≥ 0, reflecting the heterogeneity of the landscape; the higher value indicates the increase of plaque types or the tendency of the plaques in the landscape to homogenize the distribution |
| SHEI                   | SHEI evenness index | O ≤ SHEI ≤ 1, indicating the maximum possible diversity of the landscape under a certain landscape abundance; the higher the value, the more stable the regional ecosystem tends to be; the lower the value; the lower the regional ecosystem stability accordingly |

Note: The formula for calculating a specific landscape index refers to the Fragstats 4.2 help file.
### Table 2 | The scale and proportion of various landscapes in the study area

| Year | Landscape type | Yangtze River Delta | Shanghai | Jiangsu | Zhejiang | Anhui |
|------|----------------|---------------------|----------|---------|----------|-------|
|      | Area (km²)     | Percentage          | Area (km²) | Percentage | Area (km²) | Percentage | Area (km²) | Percentage | Area (km²) | Percentage |
| 2000 | Cropland       | 197,428 0.56        | 4,474 0.57 | 75,096 0.73 | 34,644 0.34 | 83,223 0.59 |
|      | Woodland       | 96,572 0.27         | 2 /       | 2,202 0.02 | 57,414 0.56 | 36,952 0.26 |
|      | Grassland      | 7,464 0.02          | 18 /      | 433 /      | 4,074 0.04 | 2,946 0.02 |
|      | Wetland        | 2,048 0.01          | 126 0.02  | 814 0.01   | 251 /      | 859 0.01   |
|      | Waters         | 25,903 0.07         | 1,484 0.19| 13,396 0.13| 2,741 0.03 | 6,284 0.04 |
|      | Built-in land  | 25,532 0.08         | 1,807 0.23| 10,330 0.10| 3,650 0.03 | 9,748 0.07 |
| 2010 | Cropland       | 191,132 0.54        | 3,682 0.46| 72,370 0.71| 33,090 0.32| 81,991 0.59 |
|      | Woodland       | 95,907 0.27         | 10 /      | 2,108 0.02| 57,227 0.55| 36,566 0.26 |
|      | Grassland      | 7,767 0.02          | 21 /      | 728 0.01  | 5,947 0.04| 3,078 0.02 |
|      | Wetland        | 1,723 0.01          | 231 0.03  | 614 0.01  | 350 /      | 529 /      |
|      | Waters         | 24,413 0.07         | 1,374 0.17| 13,386 0.13| 2,847 0.03 | 6,812 0.05 |
|      | Built-in land  | 32,859 0.09         | 2,738 0.34| 13,171 0.13| 5,907 0.06 | 11,043 0.08 |
| 2020 | Cropland       | 175,001 0.49        | 3,107 0.38| 64,642 0.63| 27,732 0.27| 79,519 0.57 |
|      | Woodland       | 95,895 0.27         | 101 0.01  | 2,447 0.02| 57,238 0.55| 36,116 0.26 |
|      | Grassland      | 7,748 0.02          | 111 0.01  | 673 0.01  | 5,858 0.04| 3,106 0.02 |
|      | Wetland        | 1,519 0.01          | 250 0.03  | 584 0.01  | 148 /      | 540 /      |
|      | Waters         | 26,262 0.07         | 1,321 0.16| 14,075 0.14| 4,220 0.04 | 6,646 0.05 |
|      | Built-in land  | 47,902 0.14         | 3,189 0.39| 20,201 0.20| 10,432 0.10| 14,082 0.10 |

Note: Values less than 0.01 in the table are omitted by /.

### Figure 2 | Surface cover in the Yangtze River Delta region in 2000.
Figure 3 | Surface cover in the Yangtze River Delta region in 2010.

Figure 4 | Surface cover in the Yangtze River Delta region in 2020.
implementation of the policy of ‘returning farmland to lake’ after the great flood in 1998, which led to an increase in the overall water area of the region (Haas & Ban 2014). There is no complete river and lake basin system in Shanghai, and the waters landscape is more affected by human activities such as agricultural development and reclamation. The relative dynamic magnitude of all types of landscapes in Zhejiang and Anhui provinces is small, only the woodland landscape area in Anhui Province decreases by 450 km² from 2010 to 2020, and the relative dynamic attitude reaches 98.36, and the landscape shift basically presents the same as that of the Yangtze River Delta as a whole. Shanghai and Jiangsu show larger relative dynamic attitude of two types of landscapes, woodland and grassland, because the overall area share is about 1%, and these two types of landscapes in the Yangtze River Delta overall region base is high and dynamic attitude is not high, so the relative dynamic attitude value is higher, but also it may be related to the regional development of green space system, country park construction, and the increase of woodland and grassland landscape. The relative dynamic attitude of wetland landscape in Jiangsu, Zhejiang, and Anhui provinces is greater than 0, which shows that the wetland landscape in the three

### Table 3 | Landscape dynamics in the Yangtze River Delta

| Research Scope       | Landscape Type | 2000–2010 Area Change (km²) | 2010–2020 Area Change (km²) | 2000–2020 Area Change (km²) |
|----------------------|----------------|----------------------------|-----------------------------|-----------------------------|
|                      |                | 2000–2010 Degree of dynamics (%) | 2010–2020 Degree of dynamics (%) | 2000–2020 Degree of dynamics (%) |
| The Yangtze River Delta | Cropland       | -6,296                      | -16,131                     | -22,427                     |
|                      | Woodland       | -665                        | -12                         | -677                        |
|                      | Grassland      | 303                         | -19                         | 284                         |
|                      | Wetland        | -325                        | -204                        | -529                        |
|                      | Waters         | 510                         | 1,849                       | 2,359                       |
|                      | Built-in land  | 7,327                       | 15,043                      | 22,370                      |
| Shanghai             | Cropland       | -792                        | -575                        | -1,367                      |
|                      | Woodland       | 8                           | 91                          | 99                          |
|                      | Grassland      | 3                           | 90                          | 93                          |
|                      | Wetland        | 105                         | 19                          | 124                         |
|                      | Waters         | -110                        | -53                         | -165                        |
|                      | Built-in land  | 931                         | 451                         | 1,382                       |
| Jiangsu              | Cropland       | -2,726                      | -7,728                      | -10,454                     |
|                      | Woodland       | -94                         | 339                         | 245                         |
|                      | Grassland      | 295                         | -55                         | 30.88                       |
|                      | Wetland        | -200                        | -30                         | 124                         |
|                      | Waters         | -10                         | 689                         | 679                         |
|                      | Built-in land  | 2,841                       | 7,030                       | 9,871                       |
| Zhejiang             | Cropland       | -1,554                      | -5,358                      | -6,912                      |
|                      | Woodland       | -187                        | 11                          | -176                        |
|                      | Grassland      | -127                        | -89                         | -216                        |
|                      | Wetland        | 99                          | 4.87                        | -103                        |
|                      | Waters         | 106                         | 1,373                       | 1,479                       |
|                      | Built-in land  | 2,257                       | 4,525                       | 6,782                       |
| Anhui                | Cropland       | -1,232                      | -2,472                      | -3,704                      |
|                      | Woodland       | -386                        | -450                        | -836                        |
|                      | Grassland      | 132                         | 28                          | 160                         |
|                      | Wetland        | -330                        | 11                          | -319                        |
|                      | Waters         | 528                         | -166                        | 362                         |
|                      | Built-in land  | 1,295                       | 3,039                       | 4,334                       |

### Table 4 | Relative dynamics of the landscape in the three provinces and one city in the study area

| Research Scope | Landscape Type | 2000–2010 Area Change (km²) | 2010–2020 Area Change (km²) | 2000–2020 Area Change (km²) |
|----------------|----------------|----------------------------|-----------------------------|-----------------------------|
|                |                | 2000–2010 Relative degree of dynamics (%) | 2010–2020 Relative degree of dynamics (%) | 2000–2020 Relative degree of dynamics (%) |
| Shanghai       | Cropland       | -792                        | -575                        | -1,367                      |
|                | Woodland       | -94                         | 339                         | 245                         |
|                | Grassland      | -127                        | -89                         | -216                        |
|                | Wetland        | 99                          | 4.87                        | -103                        |
|                | Waters         | 106                         | 1,373                       | 1,479                       |
|                | Built-in land  | 2,257                       | 4,525                       | 6,782                       |
| Jiangsu        | Cropland       | -2,726                      | -7,728                      | -10,454                     |
|                | Woodland       | -94                         | 339                         | 245                         |
|                | Grassland      | 295                         | -55                         | 30.88                       |
|                | Wetland        | -200                        | -30                         | 124                         |
|                | Waters         | -10                         | 689                         | 679                         |
|                | Built-in land  | 2,841                       | 7,030                       | 9,871                       |
| Zhejiang       | Cropland       | -1,554                      | -5,358                      | -6,912                      |
|                | Woodland       | -187                        | 11                          | -176                        |
|                | Grassland      | -127                        | -89                         | -216                        |
|                | Wetland        | 99                          | 4.87                        | -103                        |
|                | Waters         | 106                         | 1,373                       | 1,479                       |
|                | Built-in land  | 2,257                       | 4,525                       | 6,782                       |
| Anhui          | Cropland       | -1,232                      | -2,472                      | -3,704                      |
|                | Woodland       | -386                        | -450                        | -836                        |
|                | Grassland      | 132                         | 28                          | 160                         |
|                | Wetland        | -330                        | 11                          | -319                        |
|                | Waters         | 528                         | -166                        | 362                         |
|                | Built-in land  | 1,295                       | 3,039                       | 4,334                       |
provinces has decreased to different degrees. Only the wetland area of Shanghai has been increasing continuously, there are more wetland patches in the mouth of the Yangtze River on the south side of Chongming Island, the landscape of natural wetlands, marshes is still shrinking, the main increase in area comes from artificial wetlands (Jia et al. 2020), so it is necessary to strengthen the protection and attention of natural wetlands in the basin.

3.2. Study area landscape pattern index

3.2.1. Changes in the landscape pattern index of the study area landscape levels

In this study, with the help of the landscape pattern index analysis method, the landscape rank landscape pattern index (Table 5) was calculated for the three periods (2000, 2010, and 2020) in the study area, and quantitative analysis was conducted on the landscape index to determine the overall change characteristics of the study area landscape, and the results showed below.

From the viewpoint of the spreading index of the landscape classes in the study area, the overall dominant landscape connectivity of the Yangtze River Delta experienced two processes: a slow decline from 2000 to 2010 and a rapid decline from 2010 to 2020. The integrity of the overall pattern continues to decline, and the restriction and diffusion of landscape systems on landscape flows such as non-point source pollution in the region decreases. Although the overall trend of the spreading index of the provinces and cities in the study area is the same as that of the Yangtze River Delta landscape, Shanghai experienced a dominant landscape turnover between 2010 and 2020. The expansion and filling development of urban areas in 2000–2010 increased the connectivity of the dominant landscape of cropland, while the expansion and development of satellite cities for built-in land in 2010–2020 decreased significantly in the corresponding spread index, the overall index showed an increase and then a decrease. Jiangsu had the highest spreading index, which was related to the high proportion of dominant landscape types in the region. Although the dominant landscape of woodland in Zhejiang Province had less degree of dynamics, the spreading index decreased between 2010 and 2020, partly indicating that human activities were cutting woodland landscape systems in the area and that biological habitats were in a tendency to fragment. Anhui Province has the highest overall landscape motility similar to the Yangtze River Delta. However, the spread index is the smallest in the study area, this phenomenon and Anhui Province across the Qinling-Huaihe River dividing line, climate and vegetation system north-south differentiation correlation, spread index first rise and fall, and the integrity of the dominant landscape fluctuates significantly.

From the aggregation and division indices, the overall aggregation index of the Yangtze River Delta accelerated the decline, and the division index accelerated rise. The connectivity of the overall landscape system in the study area experienced a slow decline from 2000 to 2010 and an accelerated decline from 2010 to 2020, with an overall increase in landscape plaques or a decrease in the size of large plaques. The landscape layout of built-in land and cropland in Shanghai is more compact, and the

Table 5 | Landscape level landscape index of the study area in 2000, 2010, and 2020

| Research Scope         | Year | CONTAG | AI   | DIVISION | SHDI | SHEI |
|------------------------|------|--------|------|----------|------|------|
| The Yangtze River Delta| 2000 | 63.7872 | 87.8904 | 0.8517 | 1.2071 | 0.5242 |
|                        | 2010 | 63.0079 | 87.7342 | 0.8594 | 1.2355 | 0.5366 |
|                        | 2020 | 60.9686 | 87.0675 | 0.8817 | 1.3002 | 0.5647 |
| Shanghai               | 2000 | 61.2934 | 89.7258 | 0.8060 | 1.1578 | 0.5847 |
|                        | 2010 | 62.8367 | 90.1718 | 0.8844 | 1.1734 | 0.5643 |
|                        | 2020 | 59.0226 | 88.4720 | 0.9206 | 1.2598 | 0.6038 |
| Jiangsu                | 2000 | 73.4194 | 91.3026 | 0.7043 | 0.8913 | 0.3871 |
|                        | 2010 | 70.7047 | 90.9461 | 0.7216 | 0.9384 | 0.4271 |
|                        | 2020 | 67.3726 | 89.7119 | 0.7820 | 1.0391 | 0.4729 |
| Zhejiang               | 2000 | 63.7174 | 85.1235 | 0.8958 | 1.1446 | 0.4971 |
|                        | 2010 | 63.0449 | 85.1215 | 0.8985 | 1.1754 | 0.5105 |
|                        | 2020 | 58.7177 | 83.9212 | 0.9028 | 1.2423 | 0.5654 |
| Anhui                  | 2000 | 59.7396 | 87.3413 | 0.7502 | 1.1005 | 0.5655 |
|                        | 2010 | 61.7309 | 87.1768 | 0.7609 | 1.1184 | 0.5378 |
|                        | 2020 | 58.1591 | 87.4109 | 0.7781 | 1.1549 | 0.5935 |
proportion of cropland in Jiangsu is the highest and the continuity is good in each research area, so the aggregation index of the two places is higher. However, the proportion of cropland and built-in land in Shanghai is homogeneous, so the division index continues to rise, while the dominant landscape area of Jiangsu Province is high, so the division index is low. Zhejiang Province has complex terrain, misplaced woodland distribution and cropland, the lowest aggregation index, high division index, and no obvious change. Anhui Province, because the proportion of various types of landscape is similar to the overall structure of the Yangtze River Delta, the evolution is similar to the Yangtze River Delta, although the overall landscape aggregation in 2020 rebounded, but the change is not obvious.

From the diversity index, the SHDI diversity index of the Yangtze River Delta as a whole and the three provinces and one city in the interior gradually increased between 2000 and 2020, which indicates various types of landscape plaques were tended to be evenly distributed in space. This phenomenon is related to the transformation of cropland to built-in land implied by urban expansion in various regions, which also reflects the decrease of the area of large natural patches such as the Taihu Lake, the Gaoyou lake, the Hongze Lake, and its’ surrounding wetland and forest area. The SHEI evenness index shows fluctuating growth in each region, and the dominant type of dominant landscape in each region decreases with the advancement of urban construction process, but the capacity of landscape diversity increases. In addition, the diversity index of Jiangsu province is significantly lower than other regions in each data set, which is closely related to the high proportion of dominant landscape of cropland in Jiangsu province, and likewise affects the spreading index, aggregation index, etc. Regional native large-scale natural plaques often play an important regulatory role in the local climate environment, playing the role of ecological source, so in the development of urbanization need to strengthen the protection of large-scale natural plaques (Jiang et al. 2006; Zhao et al. 2007).

3.2.2. Changes in the landscape pattern index of the category levels in the study area

On the basis of interpreting the overall landscape change characteristics of the study area, due to the great difference in ecological service values of each type of landscape, in order to analyze the spatial and temporal change characteristics of each type of landscape, the study then calculates the category level landscape pattern index of the study area for three periods (2000, 2010, and 2020) (Tables 6–10), the analysis results showed below.

From two types of landscapes with human-led changes, cropland, and built-in land, there is a high degree of similarity in the evolution patterns of each region. As extreme weather disasters deepen the contradiction between limited land resources and rapidly increasing population, arable land reclamation and urban expansion have caused great damage to the regional ecological environment, climate-policy-reclamation often forms an organic chain (Gao & Yi 2012; Shi & Shi 2015). The spatial distribution of cropland shows the characteristics of dense north and sparse south, with a continuous decrease in the area of

| Year | Landscape type | NP | PD | ED | AREA_MN | COHESION |
|------|----------------|----|----|----|---------|----------|
| 2000 | Cropland       | 72,529 | 0.2037 | 19.2067 | 272.2061 | 99.9602 |
|      | Woodland       | 62,813 | 0.1764 | 11.3599 | 153.7455 | 99.9135 |
|      | Grassland      | 198,374 | 0.5572 | 4.9214 | 3.7626 | 81.0884 |
|      | Wetland        | 3,212 | 0.09 | 0.3400 | 63.7718 | 96.0650 |
|      | Waters         | 103,825 | 0.2916 | 4.3237 | 23.0230 | 98.8361 |
|      | Built-in land  | 108,664 | 0.3052 | 7.7900 | 23.4963 | 93.1434 |
| 2010 | Cropland       | 81,403 | 0.2286 | 19.4719 | 234.7975 | 99.9573 |
|      | Woodland       | 78,831 | 0.2124 | 11.5891 | 121.6619 | 99.9107 |
|      | Grassland      | 209,759 | 0.5891 | 5.1256 | 3.7030 | 81.4584 |
|      | Wetland        | 2,669 | 0.075 | 0.2801 | 64.5399 | 95.2765 |
|      | Waters         | 79,126 | 0.2222 | 4.3273 | 23.0230 | 98.8361 |
|      | Built-in land  | 106,945 | 0.3040 | 7.7900 | 23.4963 | 93.1434 |
| 2020 | Cropland       | 97,456 | 0.2737 | 20.3110 | 179.5692 | 99.9494 |
|      | Woodland       | 69,683 | 0.1957 | 11.2715 | 137.6158 | 99.9096 |
|      | Grassland      | 200,261 | 0.5625 | 4.9073 | 3.8690 | 81.3086 |
|      | Wetland        | 2,907 | 0.0082 | 0.2708 | 52.2122 | 94.0639 |
|      | Waters         | 71,937 | 0.2020 | 4.5782 | 36.3075 | 99.2289 |
|      | Built-in land  | 104,327 | 0.2930 | 9.9303 | 43.9155 | 96.9836 |
land shifted to built-in land. The increase in the number of arable land plaques led to a decrease in the binding index of the average plaque area. As edge density increases, the shape of the plaques tends to become more complex, which also indicates that cropland is the most severely fragmented among all types of landscapes. Built-in land, on the other hand, shows the opposite characteristics of change, with an increase in land area, a decrease in the number of plaques, and an increase in the average plaque area. The general increase in the bonding index and the simultaneous increase in edge density indicate that the expansion pattern of built-in land is a combination of filling and spreading, which increases the resistance to the operation of some ecological flows in the region. Among them, the number of cropland plaques, the density of cropland plaques, the bonding index of built-in land in Shanghai shows a decreasing trend opposite to that of the region, indicating that the built-up area in the center of Shanghai experienced rapid urban development at the end of the last century continued to

Table 7 | Shanghai category levels landscape index for 2000, 2010, and 2020

| Year | Landscape type | NP   | PD     | ED    | AREA_MN | COHESION |
|------|----------------|------|--------|-------|---------|----------|
| 2000 | Cropland       | 1,153| 0.1426 | 19.0305| 388.0338| 99.8481  |
|      | Woodland       | 135  | 0.0167 | 0.0893 | 1.6074  | 34.3117  |
|      | Grassland      | 99   | 0.0122 | 0.1657 | 18.2929 | 92.3895  |
|      | Wetland        | 43   | 0.0053 | 0.6030 | 295.3953| 98.0967  |
|      | Waters         | 1,883| 0.2328 | 4.5492 | 78.8030 | 99.1289  |
|      | Built-in land  | 2,195| 0.2714 | 16.3821| 82.3390 | 99.0847  |
| 2010 | Cropland       | 1,504| 0.1859 | 17.7908| 244.8078| 99.7179  |
|      | Woodland       | 225  | 0.0278 | 0.2762 | 4.5067  | 73.2815  |
|      | Grassland      | 241  | 0.0298 | 0.4199 | 8.5477  | 82.4177  |
|      | Wetland        | 55   | 0.0068 | 0.7388 | 419.2182| 98.1125  |
|      | Waters         | 1,810| 0.2238 | 4.7472 | 75.9238 | 98.9399  |
|      | Built-in land  | 1,419| 0.1754 | 15.1174| 192.9803| 99.3599  |
| 2020 | Cropland       | 982  | 0.1214 | 18.7298| 316.3534| 99.6061  |
|      | Woodland       | 214  | 0.0265 | 0.9898 | 47.0841 | 91.8845  |
|      | Grassland      | 398  | 0.0492 | 1.4054 | 27.9673 | 86.4043  |
|      | Wetland        | 119  | 0.0147 | 1.0924 | 209.9748| 96.8928  |
|      | Waters         | 2,462| 0.3044 | 6.2346 | 53.6747 | 98.8226  |
|      | Built-in land  | 1,910| 0.2361 | 17.5117| 166.9639| 99.3335  |

Table 8 | Jiangsu category levels landscape index in 2000, 2010, and 2020

| Year | Landscape type | NP   | PD     | ED    | AREA_MN | COHESION |
|------|----------------|------|--------|-------|---------|----------|
| 2000 | Cropland       | 5,129| 0.0500 | 15.8634| 1464.1400| 99.9753  |
|      | Woodland       | 3,223| 0.0314 | 1.0458 | 68.3183 | 98.1173  |
|      | Grassland      | 4,304| 0.0419 | 0.6234 | 10.0606 | 89.1995  |
|      | Wetland        | 1,201| 0.0117 | 0.3840 | 67.7935 | 95.9674  |
|      | Waters         | 38,941| 0.3793 | 6.4807 | 34.4002 | 99.0930  |
|      | Built-in land  | 33,413| 0.3254 | 10.1453| 30.9148 | 92.6041  |
| 2010 | Cropland       | 5,075| 0.0494 | 16.2252| 1426.0160| 99.9739  |
|      | Woodland       | 7,001| 0.0682 | 1.3316 | 30.1077 | 97.7842  |
|      | Grassland      | 11,348| 0.1105 | 1.1620 | 6.4151 | 89.5967  |
|      | Wetland        | 703  | 0.0068 | 0.2962 | 87.3713 | 95.6936  |
|      | Waters         | 32,842| 0.3199 | 5.9273 | 40.7575 | 98.8122  |
|      | Built-in land  | 33,894| 0.3201 | 11.0259| 38.8599 | 94.5914  |
| 2020 | Cropland       | 10,543| 0.1027 | 18.3207| 613.1295| 99.9656  |
|      | Woodland       | 4,891| 0.0476 | 1.3330 | 50.0282 | 97.9754  |
|      | Grassland      | 8,635| 0.0841 | 0.9709 | 7.7975 | 87.1697  |
|      | Wetland        | 1,046| 0.0102 | 0.3101 | 55.8451 | 94.1277  |
|      | Waters         | 30,023| 0.2924 | 7.1270 | 46.8816 | 99.2770  |
|      | Built-in land  | 30,928| 0.3012 | 12.883 | 65.3163 | 97.2282  |
develop in the form of landscape enclaves to the peripheral range after the infill expansion. The number of arable land and built-in land plaques in Zhejiang Province has increased greatly, which indicates that the expansion and development of built-in land is also restricted to a certain extent by the mountainous landscape of Zhejiang Province, so urban development is more concentrated in the northern plains of Zhejiang.

From the viewpoint of the main component landscapes of woodland and grassland systems, the number of plaques of grassland landscapes is the highest among all types of landscapes, and the floating changes of connectivity index are large, while woodland landscapes have more stable landscape changes compared to woodland landscapes. In addition to other provinces and cities outside Zhejiang Province, the number of plaques and patch density of grassland landscape have been increased, but the total area of woodland, grassland landscape in Zhejiang Province is much higher than other provinces and cities.

### Table 9 | Zhejiang category levels landscape index in 2000, 2010, and 2020

| Year | Landscape type | NP   | PD   | ED   | AREA_MN | COHESION |
|------|----------------|------|------|------|---------|----------|
| 2000 | Cropland       | 38,593 | 0.3668 | 20.2711 | 89.7692 | 99.5205 |
|      | Woodland       | 24,735 | 0.2350 | 21.7073 | 232.1348 | 99.9272 |
|      | Grassland      | 121,720 | 1.1567 | 9.8457 | 3.3469 | 69.7051 |
|      | Wetland        | 525   | 0.0050 | 0.1310 | 47.7848 | 96.0539 |
|      | Waters         | 20,405 | 0.1939 | 2.8345 | 13.4336 | 96.9586 |
|      | Built-in land  | 12,871 | 0.1223 | 3.5523 | 28.3564 | 93.3087 |
| 2010 | Cropland       | 43,875 | 0.4170 | 20.5860 | 75.4179 | 99.3988 |
|      | Woodland       | 22,774 | 0.2164 | 21.6461 | 251.2802 | 99.9268 |
|      | Grassland      | 119,623 | 1.1568 | 9.5906 | 3.2992 | 68.7521 |
|      | Wetland        | 148   | 0.0014 | 0.0964 | 256.4662 | 97.5681 |
|      | Waters         | 14,808 | 0.1407 | 2.4538 | 19.2271 | 97.2955 |
|      | Built-in land  | 12,675 | 0.1205 | 3.8431 | 46.6043 | 96.086 |
| 2020 | Cropland       | 53,131 | 0.5049 | 21.8127 | 52.1951 | 98.8668 |
|      | Woodland       | 21,108 | 0.2006 | 21.1859 | 271.1688 | 99.9275 |
|      | Grassland      | 116,049 | 1.1029 | 9.3086 | 3.2428 | 68.6851 |
|      | Wetland        | 135   | 0.0013 | 0.0507 | 109.6593 | 95.5711 |
|      | Waters         | 15,150 | 0.1440 | 3.8774 | 27.8554 | 97.9202 |
|      | Built-in land  | 18,040 | 0.1714 | 6.7738 | 57.8268 | 97.4856 |

### Table 10 | Anhui category levels landscape index in 2000, 2010, and 2020

| Year | Landscape type | NP   | PD   | ED   | AREA_MN | COHESION |
|------|----------------|------|------|------|---------|----------|
| 2000 | Cropland       | 28,190 | 0.2013 | 20.8400 | 295.2214 | 99.9650 |
|      | Woodland       | 34,695 | 0.2477 | 11.7873 | 106.5044 | 99.8792 |
|      | Grassland      | 72,494 | 0.5176 | 4.6577 | 4.0638 | 87.2993 |
|      | Wetland        | 1,476 | 0.0105 | 0.4484 | 58.2276 | 95.5643 |
|      | Waters         | 43,270 | 0.1407 | 2.4538 | 19.2271 | 97.2955 |
|      | Built-in land  | 60,178 | 0.4297 | 8.8931 | 16.1989 | 83.1397 |
| 2010 | Cropland       | 31,690 | 0.2263 | 21.1003 | 258.7286 | 99.9622 |
|      | Woodland       | 48,746 | 0.3481 | 12.1866 | 232.1348 | 99.8760 |
|      | Grassland      | 79,053 | 0.5644 | 4.9553 | 3.8931 | 87.0423 |
|      | Wetland        | 1,761 | 0.0126 | 0.3762 | 30.0557 | 92.5594 |
|      | Waters         | 14,808 | 0.1407 | 2.4538 | 19.2271 | 97.2955 |
|      | Built-in land  | 53,131 | 0.5049 | 21.8127 | 52.1951 | 98.8668 |
| 2020 | Cropland       | 32,718 | 0.2336 | 20.6543 | 243.0433 | 99.9592 |
|      | Woodland       | 43,283 | 0.2477 | 11.7873 | 252.1348 | 99.9272 |
|      | Grassland      | 116,049 | 1.1029 | 9.3086 | 3.2428 | 68.6851 |
|      | Wetland        | 135   | 0.0013 | 0.0507 | 109.6593 | 95.5711 |
|      | Waters         | 15,150 | 0.1440 | 3.8774 | 27.8554 | 97.9202 |
|      | Built-in land  | 59,288 | 0.4297 | 8.8931 | 16.1989 | 83.1397 |
indicating that the total amount of natural plaques in these two types of landscape is still reduced under the interference of human activities, while the increase of the two types of landscapes are mostly derived from the urban green space system or the implementation of the policy of returning farmland to forest. However, the spatial distribution of these two types of landscapes is strongly influenced by climate, and a large number of them are distributed in the southern part of Anhui and Zhejiang Province within the subtropical monsoon climate zone, and the regional variation of the landscape is strong, and the plaque density and edge density of such landscapes in Zhejiang and Anhui are significantly higher than those in Shanghai and Jiangsu. The number of plaques and the average plaque area growth ratio of these two types of landscapes in Shanghai are higher. However, the native woodland and grassland landscape in Shanghai are scarce, the park urban planning and riverside green space transportation plan in Shanghai promote the increase of these two kinds of landscapes. Zhejiang Province grassland landscape integration index is the lowest, where this type of landscape often occurs simultaneously with woodland landscape and exists in a smaller plaque form in another landscape, and such mixed landscapes in southern Anhui also have the same pattern characteristics.

In terms of watershed and wetlands, the distribution of these two types of landscapes is mainly concentrated in the lower reaches of the Yangtze River and the related watersheds of the Taihu Lake, the Gaoyou Lake, and the Hongze Lake, while wetland landscapes are often distributed around large-scale watershed plaques or at river crossings and sea inlets. While the area of watershed landscapes increases and the number of plaques decreases year by year, wetland landscapes are the most decreasing landscape type in the study area. Jia et al. (2020)’s research shows that although the overall water ecosystem area has increased, the landscape types with high ecological service values are decreasing rapidly. Wetland landscape, as one of the most sensitive land types to basin hydrological systems, often has an impact on hydrological water resources and hydro-ecological interaction processes in basins in the context of global climate change (Dong & Zhang 2011; Li et al. 2013). The density of wetland landscape boundaries is the lowest among all types of landscapes and shows a decreasing trend, the shape of plaques tends to be simpler in the process of landscape reduction, and the overall landscape bonding also shows a decreasing trend, the surrounding ecosystem between the ecological flow is affected to varying degrees. In each province and city, except for Shanghai, where the number of plaques is increasing, the number of plaques in the waters of the other three provinces is decreasing while the total area is increasing, and the connectivity of plaques is increasing, and the landscape expansion process is linking multiple plaques of waters, which may be related to the frequent flooding disasters in the lower reaches of the Yangtze River under the influence of climate (Jiang et al. 2005). The number of wetland plaques in Jiangsu and Anhui provinces, where wetland landscapes are more distributed, decreased instead of increasing, and the average plaque area and bonding index decreased significantly. The natural wetland landscape is reduced in continuity under the disturbance of human activities, and the wetland landscape such as the National Wetland Park of The Caizi Lake in the north of Anqing City, Anhui Province, and the Shijiu Lake in southern Jiangsu Province deteriorate rapidly, and there is an obvious phenomenon of wetland plaque shrinking or disappearing during the study period.

4. CONCLUSION
Changing climatic conditions and increasingly drastic human activities have had a significant impact on the regional environment, and it is, therefore, necessary to develop targeted strategies for regional development. This paper studies the land use dynamics and landscape pattern changes in the Yangtze River Delta as a whole and its constituent provinces and cities for 20 years, and presents the main analytical conclusions in terms of the category landscape dynamics and the spatial and temporal evolution of the regional landscape, with a view to providing targeted suggestions and strategies for regional urbanization development.

During the study period, the landscape area of three categories, namely cropland, woodland and wetland, declined, and the landscape area of grassland, waters, and built-in land increased. Although cropland has always been the dominant landscape in the Yangtze River Delta, the dominance of non-natural landscapes in the region has gradually increased, mainly manifested by the accelerated transformation of the cropland landscape to the built-in land landscape, with the area share of the former decreasing by 7% and the area share of the latter increasing by 6%, and the transformation area exceeding 20,000 km², with built-in land having replaced cropland as the dominant landscape in Shanghai in 2020.

The dominant landscape connectivity of the Yangtze River Delta and its internal constituent provinces and cities in the overall landscape perspective shows a slow decline from 2000 to 2010 and a rapid decline from 2010 to 2020. Similarly, the decrease of aggregation index and the general increase of fragmentation index indicate that the overall landscape system tends to be scattered and uniformly distributed, the degree of habitat fragmentation increases, the degree of
aggregation of similar landscape plaques in all regions except Anhui Province decreases, the indeterminate information content increases, the complexity of the overall landscape increases, and regional environmental risks increase.

The spatial characteristics of the distribution of various landscape types in the study area are obvious, with woodland, grassland distributed in large numbers in Zhejiang Province and southern Anhui Province in the subtropical climate zone, and wetlands often appearing in the lower Yangtze River basin together with waters. Cropland is severely fragmented and fragmentation increases due to urban expansion, while built-in land expands mainly in the form of a combination of infilling and spreading. The landscape integrity of woodlands among the landscape types with high ecological service value is significantly higher in Zhejiang and Anhui than in Shanghai and Jiangsu. The area of wetland landscape and the number of plaques tend to decrease in all regions, and the wetland landscape in Anhui Province deteriorates at the fastest rate among all regions.

The landscape pattern index used in this study can evaluate the overall ecological characteristics of regional landscape for surface cover or land use information, thus further guiding the land use development plan of the research area and coordinating the issue of land use for construction and development and the protection of various ecological areas. Based on the above study, it is considered that the Yangtze River Delta regional development and urbanization process should pay attention to maintaining the integrity of regional dominant landscapes of cropland, while protecting the diversity and connectivity of natural landscapes with high ecological service value, and maintaining the ecological service value of various kinds of landscapes. While strictly implementing the red line of ecological protection and the red line of cropland protection, the regional landscape pattern should be optimized according to the spatial distribution characteristics and development level of different regions, so as to improve the land utilization rate and maximize the landscape value to coordinate the common development of human and nature.

There are some limitations in this study, mainly in terms of data continuity and land use data accuracy. This study used three phases of surface cover data over a 10-year span for computational study, the interpretation of continuous changes in regional ecosystems still has some limitations, in the future, a larger time range, and a shorter year frequency of time panel data can be developed to systematically assess the regional urban process for decades. Because the landscape system has a scale effect, the surface coverage data of 100 m × 100 m used in the study still lack the ecological characteristics of small- and medium-scale areas, and further research on municipal scale can be carried out in the future to further reveal the relationship between the overall and local landscape patterns of the region under various scales. In addition, this study only cares about the ecological characteristics of landscape pattern at the land use data level, the influence of urban development on regional ecosystems is still limited, and further research can be carried out in the future in the light of regional socio-economic data to guide the urbanization development and ecological protection of different developed regions.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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