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Did improvements of ecosystem services supply-demand imbalance change environmental spatial injustices?

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ABSTRACT

Objective measurement of the supply-demand of ecosystem services and sustainable ecosystem management has received increasing attention from the scientific community and the general public. This study explored changes in the supply-demand of ecosystem services and their natural and social driving mechanisms using spatial analysis methodologies as well as the relationship between the supply-demand of ecosystem services and environmental justice in coastal regions in China. In this study, the ecosystem service supply-demand index (ESSDI) was proposed based on the ecosystem services provision index and the land development index. Results indicated that although the imbalance in the supply-demand pattern of ecosystem services was serious, the spatial imbalance in the supply-demand pattern of ecosystem services improved from 2000 to 2015. Notwithstanding that the correlation coefficient between natural factors and ESSDI was higher, the development of the economy and the improvement of the quality of the population also had a substantial effect on ESSDI and the improvement of environmental quality. The spatial imbalance in ESSDI also caused serious environmental injustice as a result of differences in natural background, national policies, development gaps, trade, and industrial shifts. However, the implementation of some ecological compensation projects changed the spatial imbalance in ESSDI and relieved the environmental injustice. This research supports auxiliary decision-making for the sustainable management of regional ecosystems.

1. Introduction

Since the industrial revolution, human activities have caused serious damage to the natural environment on which human beings depend for survival and development (Costanza et al., 1997; Sterling et al., 2013). More than 60% of ecosystem services in the world are degraded, and the loss of these ecosystem services is becoming more apparent (Beddoe et al., 2009; Zheng et al., 2013). One of the main causes is the absence of effective management of ecosystem services (Zheng et al., 2013). Objective measurement of ecosystem services and sustainable ecosystem management has received increasing attention from the scientific community and the public. Previous studies on ecosystem services focused on the definition, classification, measurement indicators, and assessment methods related to ecosystem services (Costanza et al., 1997; Daily, 1997; Millennium Ecosystem Assessment, 2005; Fisher et al., 2011; Bateman et al., 2013). A series of important research achievements have been made with respect to of ecosystem service classification (De Groot et al., 2002; Wallace, 2007), formation and impact mechanisms (Balvanera et al., 2006; Luck et al., 2009; Plantier-Santos et al., 2012), valuation of ecosystem services (Turner et al., 2000; Johnson et al., 2012), spatial mapping (Peters, 2012; Burkhard et al., 2012; Kroll et al., 2012), relationships with human social welfare (Anderson et al., 2006; Andam et al., 2010), and linkages between biodiversity attributes, such as species attributes, functional group attributes, and community/habitat attributes, and ecosystem services (Worm et al., 2006; Harrison et al., 2014).

The state of ecosystem services is not only affected by the function of the ecosystem but is also influenced by the social system. Research on ecosystem services has increasingly emphasized human-centered thinking. Without human beneficiaries, the structure and process of ecosystems cannot form ecosystem services. TEEB (The Economics of Ecosystems and Biodiversity) stated that the economic activities of stakeholders generate a huge demand for ecosystem services and cause changes in ecosystem services (Kumar, 2011). Ecosystem services have been in short supply due to the increasing demand for ecosystem services (Wei et al., 2017). Therefore, ecosystem service supply and demand should be considered in the evaluation of ecosystem services in order to develop scientific and rational management methods (Paetzold

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et al., 2010). Several scholars have studied the relationship between the supply and demand of ecosystem services, firstly focusing on provisioning services (Burkhard et al., 2012; Schröter et al., 2014; Schulp et al., 2014; Palacios-Agundez et al., 2015; Larondelle and Lauf, 2016), followed by regulating services (Nedkov & Burkhard, 2012; Stürck et al., 2014; Baró et al., 2015) and cultural services (Palomo et al., 2013; Peña et al., 2015), with less attention paid to supporting services. Most studies have focused on small and medium scales, such as city and watershed (García-Nieto et al., 2013; Peña et al., 2015; Palacios-Agundez et al., 2015; Li et al. 2016). The methods used in these studies included modeling, mapping, and participatory methods, among others (Wei et al., 2017). Many studies used data from remote sensing interpretation and questionnaires (Palomo et al., 2013; Peña et al., 2015; Li et al. 2016; Wu et al. 2019); only few studies used land survey data to conduct research on the urban scale (Burkhard et al., 2012). Spatial analysis of the supply-demand pattern of ecosystem services using land survey data at the regional scale was less utilized. Many scholars have also studied the spatial mismatch between the supply and demand of ecosystem services (Burkhard et al., 2012; Nedkov and Burkhard, 2012; García-Nieto et al., 2013; Schulp et al., 2014; Stürck et al., 2014; Baró et al., 2015; Larondelle and Lauf, 2016; Li et al. 2016; Wang et al., 2019a; Wu et al., 2019). These studies serve as reference points for the present study on ecosystem services supply and demand. However, the study of the ecosystem services supply and demand is still a difficult issue to be solved within the field of ecosystem management because of the influences of many non-linear factors.

The ecosystem not only provides food and other raw materials for the production and life, but also creates and maintains the life support system for mankind, and provides leisure, entertainment and aesthetic enjoyment for human life (Millennium Ecosystem Assessment, 2005). Ecosystem services and human well-being are becoming increasingly linked (Feng et al., 2018; Mexia et al., 2018). However, due to effects of climate, topography, land use type, biology, and other factors, the spatial distribution of ecosystem services supply varies significantly, resulting in significant spatial imbalance (Xie et al., 2015). The unbalanced spatial distribution of ecosystem services supply will lead to environmental injustice (Wolch et al., 2014). The concept of environmental justice originated from the environmental racism movement in the United States, which mainly emphasized the relationship between race and environmental waste distribution. Studies related to environmental justice have expanded in the fields of transportation, health, living conditions, land, resources, energy, and climate in recent years (Éloi, 2011; Germani et al., 2014; Warlenius et al., 2015; Rowangould et al., 2016; Roa-García, 2017; Jenkins, 2018; Mccauley and Heffron, 2018; Liu, 2018; Chaudhary et al., 2018; Łaszkiewicz et al., 2018). Currently, environmental justice in the human settlement environment is a research hotspot, especially in terms of urban ecological space. Most of these studies are based on socio-economic status (Kimpton, 2017), ethnic/national or religious characteristics (Comber et al., 2008), age (Shen et al., 2017), accessibility (Byrne et al., 2009), and population density (Xiao et al., 2017). Studies have shown that in the United States, non-white and low-income people usually occupy the urban core or low-income inner-ring suburbs, where green space is scarce or poorly maintained, and can only enjoy limited ecological services provided by that green space, including air purification, pollution removal, noise reduction, and cooling. Wealthier families usually live in the suburbs, where green space is abundant and well maintained, thus enabling them to enjoy more ecosystem services (Heynen et al., 2006). Landry and Chakraborty also found that neighborhoods comprised of African Americans and renters tended to have lower forest cover than affluent white neighborhoods (Landry and Chakraborty, 2009). In view of the complexity of ecosystem services, however, there are still very few studies on how to link ecosystem services with environmental justice, especially regarding environmental justice at a regional scale from the perspective of the supply-demand of ecosystem services (Ernstson, 2013).

Coastal areas are the interaction areas between oceans and the mainland, where the natural elements have undergone drastic changes, and human economic activities are most active (Lotze et al., 2006). Between 2000 and 2015, the area of construction land in China's coastal areas increased by about 2.5 million ha, and the area of marshy beaches decreased by about 600,000 ha (Wang et al., 2018). Wetland landscapes were severely damaged. Increasingly prominent ecological issues directly threaten the safety of marine and terrestrial ecosystems (He et al., 2014). Achieving coastal ecosystem management is of great significance for sustainable development. The purpose of this research was to study changes in the supply-demand of ecosystem services and their natural and social driving mechanisms using spatial analysis methodologies, as well as to explore the relationship between the supply-demand of ecosystem services and environmental justice in coastal regions in China. This study will provide scientific decision support for regional ecosystem management in the context of social and environmental justice.

2. Materials and methods

2.1. Study area

There are 10 provinces from the north to the south of the coastal region, namely Liaoning, Hebei, Tianjin, Shandong, Jiangsu, Shanghai, Zhejiang, Fujian, Guangdong, and Guangxi, as shown in Fig. 1. In 2015, the total economic output of the coastal areas accounted for 54.2% of the nationwide total, and the coastal population accounted for 42.64% of the nationwide total (National Bureau of Statistics of the People's Republic of China, 2016). The Yangtze River Delta, Pearl River Delta, and the Beijing-Tianjin-Hebei region are all located in this region.

2.2. Data sources

The land use data for this study was obtained from the series of national land surveys. The national land survey in China was the most comprehensive and legally effective survey, covering nearly 3000 counties, 43,000 towns, and 400,000 administrative units (Wang et al., 2018). Based on orthophoto maps, the land survey database covering four levels of the state, province, city, and county was established through field survey of land types, areas, ownership, and use rights (State Council of the People's Republic of China, 2008). The 2009 land use dataset was derived from the second land survey data in China, and

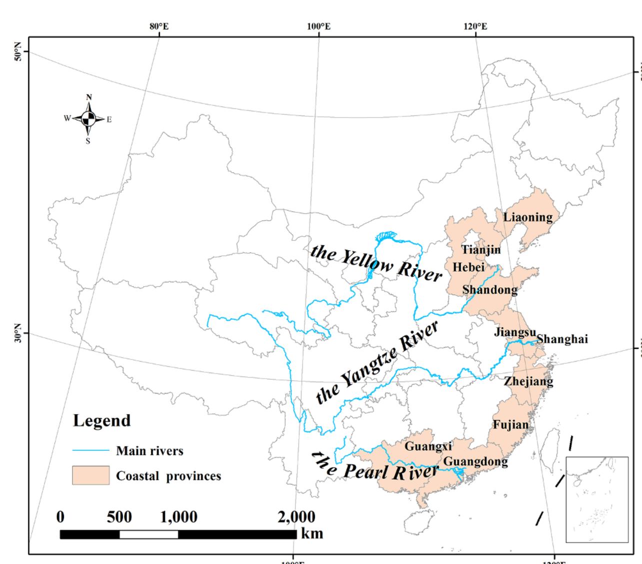

Fig. 1. The location map of the 10 provinces found in the coastal regions of China.

the 2000, 2005, and 2015 land use datasets were derived from the annual land use change survey conducted by the Ministry of Land and Resources. GDP, population, and other data were collected from statistical yearbooks of various provinces and cities. Software used included ArcGIS10.4, Geoda, and Data Processing System (DPS). The main methods used were exploratory spatial data analysis (Haining, 1990) and grey relational analysis (Tang and Zhang, 2013).

2.3. Calculation of the ecosystem services supply-demand index

In this study, the ecosystem service supply-demand index (ESSDI) was proposed based on the ecosystem services provision index (ESPI) and land development index (LDI). ESSDI referred to the ratio between ecosystem services supply and ecosystem services demand, reflecting the relationship between the two.

$$ESSDI = \frac{\mathrm{ESPI}}{LDI} \tag{1}$$

The ESPI was calculated by synthesizing a set of assessment factors including topography, climate, vegetation and soil, water resources, and socio-economics in three categories and 13 sub-categories of ecosystem services (Wang, 2015; Wang et al., 2018). Based on the 2009 distribution of ecosystems including wetland, desert, forest, grassland, water, and farmland and the distribution of ESPI, the ESPI per unit area of each ecosystem in each county was calculated and analyzed (Wang et al., 2019a). Values of ESPI in 2000, 2005, 2009, and 2015 were also calculated. Referring to the studies of Hitzhusen (2007) and Peng et al. (2017), the LDI was calculated using the proportion of developed land, population density, and economic density according to Equation (2), indicating the demand of ecosystem services in a given region. The significant difference between population density and economic density made the two indices fluctuate greatly. Logarithmic methods were used here to remove fluctuations.

$$LDI_i = D_i \times \lg(P_i) \times \lg(E_i) \tag{2}$$

where LDI_i is the index of the land development depicting the demand of ecosystem services in county *i*. D_i, P_i and E_i represent the proportion of developed land, population density, and economic density in county *i*, respectively. The index LDI_i indicating the demand of ecosystem services in 2000, 2005, 2009, and 2015 was also calculated. The ESPI and LDI were standardized using data range standardization.

In this study, counties with good eco-environmental quality, as noted by National Ecological Garden County (Ministry of Housing and Urban-Rural Construction of the People’s Republic of China, 2015), Demonstration County of Ecological Civilization Construction (Ministry of Environmental Protection of the People's Republic of China, 2017), and China Environmental State Bulletin in 2014 (Ministry of Environmental Protection of the People’s Republic of China, 2015) were regarded as sample areas with good supply-demand situation of ecosystem services. Alternatively, counties with poor eco-environmental quality were taken as samples of poor supply-demand situation of ecosystem services. Using statistical analysis, the mean ESSDI values of different samples were obtained. Combined with expert opinions, ESSDI was divided into five levels to establish ESSDI grading standards, as shown in Table 1. According to Eqs. (1) and (2) and Table 1, the distribution of ESSDI in the study area was obtained (Fig. 2).

2.4. Exploratory spatial data analysis

Exploratory spatial data analysis (ESDA) uses a combination of statistical principles and graphical expression to analyze and identify the nature of spatial information, so as to reveal the spatial dependence and spatial heterogeneity of data (Haining, 1990).

Spatial autocorrelation analysis is the core of ESDA. In this study, two spatial autocorrelation indicators were used to calculate the spatial distribution pattern of ESSDI. The first was the global spatial autocorrelation index Moran’s I, which was used to measure the spatial distribution of ESSDI in the whole research area (Anselin, 1998). Global Moran’s I was calculated using the following formula.

Table 1
Grading standards of the ecosystem service supply-demand index in the coastal region in China.

Type	Supply-demand situation	ESSDI
Ecological deficit area	Severe overload	ESSDI < 0.92
	Overload	0.92 ≤ ESSDI < 3.9
Ecological equilibrium area	Blance	3.9 ≤ ESSDI < 12.15
Ecological surplus area	Slight surplus	12.15 ≤ ESSDI < 50.6
	Surplus	ESSDI > 50.6

$$I = \frac{\sum_{i=1}^{n}\sum_{j\neq1}^{n} w_{ij}(x_i-\bar{x})(x_j-\bar{x})}{S^2\sum_{i=1}^{n}\sum_{j\neq1}^{n} w_{ij}} \tag{3}$$

where n is the total number of research areas, x_i is the value of ESSDI for the study area i, $s^2 = \frac{1}{n}\sum_{i=1}^{n}(x_i-\bar{x})^2, x = \frac{1}{n}\sum_{i=1}^{n} x_i$, and W_{ij} is a spatial weight matrix obtained through the rook adjacency matrix. The range of Moran’s I is $[-1, 1]$. A Moran’s I value less than 0 indicates that ESSDI appeared in a discrete pattern and that ESSDI in different regions had large spatial heterogeneity. A Moran's I value greater than 0 indicates that ESSDI revealed a spatial clustering pattern. The closer the value is to 1, the more significant the spatial correlation is. A Moran's I value of 0 indicates a variable without any spatial characteristics.

Local spatial autocorrelation was used to explore the correlation coefficient between the ESSDI in a certain area and neighborhood-specific ESSDI. Analysis of local spatial autocorrelation is carried out by combining the use of two tools: the Moran scatterplot and local indicator of spatial association (LISA). The LISA analysis can detect the presence of significant local patterns of spatial clustering by comparing the values in each specific location with values in neighboring locations (Anselin and Sridharan, 2007). It is calculated as follows:

$$I_i = \frac{x_i - x_n}{S}\sum_{j=1}^{n} W_{ij}(x_j-\bar{x}) \tag{4}$$

In the formula, $S = \sum_i \frac{(x_i-\bar{x})^2}{n}$. When I_i is a positive number, this indicates that similar values around the study area exhibit spatial aggregation, and when I_i is negative, this indicates that dissimilar values around the study area exhibit spatial aggregation. The Moran scatter plot is mainly used to explain the heterogeneity of the study area unit. There are four quadrants, representing different types of spatial clustering. Specifically, the first quadrant is High-High clustering (HH), showing areas with high ESSDI that are surrounded by areas whose ESSDI is also high; the second quadrant is Low–High clustering (LH), showing areas with low ESSDI that are surrounded by areas with high ESSDI; the third quadrant is Low-Low clustering (LL), showing the areas with low ESSDI that are surrounded by areas whose ESSDI is also low; the fourth quadrant is High-Low clustering (HL), showing the areas with high ESSDI that are surrounded by areas with low ESSDI. The HH and LL quadrants refer to positive spatial autocorrelation, indicating spatial clustering of similar values of a variable. LH and HL quadrants represent negative spatial autocorrelation, indicating spatial clustering of dissimilar values of a variable. Combining the Moran scatter plot and the LISA cluster map, the spatial relation between the units of the study area can be better explained.

2.5. Grey relational analysis

An ecosystem has characteristics such as openness, self-sustaining functions, and self-regulating functions. It is a complex system involving the interaction of natural and social factors. The supply-demand of

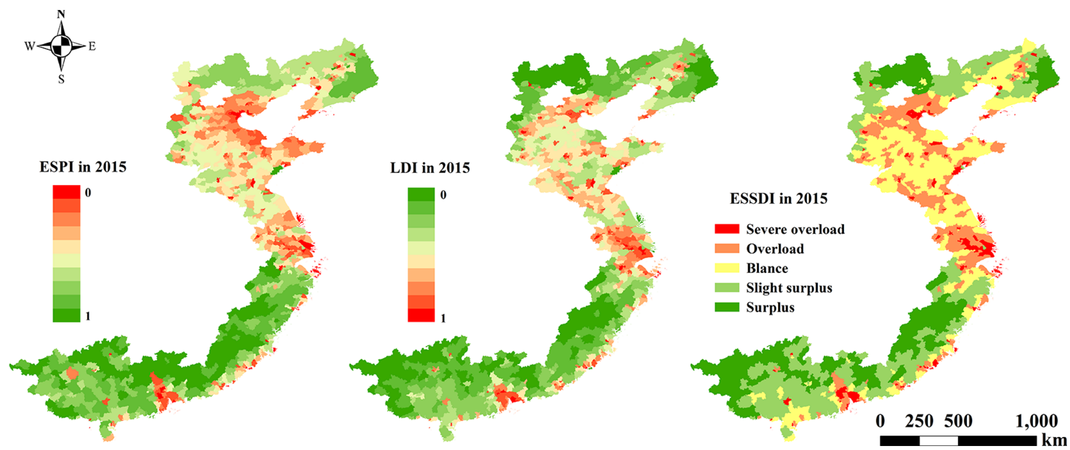

Fig. 2. Spatial distribution of ecosystem services provision index, land development index and ecosystem services supply-demand index in 2015 in Chinese coastal regions.

ecosystem services is also affected by both the natural environment and social factors. This study used the grey relational analysis method to study the relationship between ESSDI and natural and social factors.

The grey relational analysis method is a multi-factor statistical analysis method, and its essence is to judge the degree of influence on the whole system according to the differences among system factors. The greater the difference, the lower the degree of correlation, and the smaller the impact on the system. The smaller the difference, the higher the degree of correlation, and the greater the impact on the system. Conducting grey relational analysis is performed as follows:

$$r_{0i} = \frac{1}{N}\sum_{k=1}^{N} L_{0i}(k) = \frac{1}{N}\sum_{k=1}^{N} \frac{\Delta_{min} + \rho\Delta_{max}}{\Delta_{0i}(k) + \rho\Delta_{max}} \tag{5}$$

where r_{0i} is the correlation coefficient between the subsequence i and the parent sequence 0, N is the length of the time series (i.e., number of data), and $L_{0i}(k)$ is the correlation coefficient at time point k. $\Delta_{0i}(k)$ represents the absolute difference of two compared series at time point k (i.e., $\Delta_{0i}(k) = |x_0(k) - x_i(k)| (1 \le i \le m)$; Δ_{min} and Δ_{max} represent the maximum and minimum values, respectively, of the absolute difference from all time points between two compared series; and $\rho \in (0,1)$ is the resolution coefficient, normally taken from 0.1 to 0.5 (Tang and Feng, 1997; Tang and Zhang, 2013). DPS software was applied to carry out the analysis.

Here we selected four natural factors, including the proportion of ecological land, annual rainfall, normalized difference vegetation index (NDVI), and annual average temperature, as well as five social factors, including per capita GDP, population, the value-added of primary industry, social fixed-assets investment, and GDP to analyze the driving mechanism of changes in the supply-demand pattern of ecosystem services.

3. Results

3.1. Spatial imbalance in the supply-demand pattern of ecosystem services

The results in Fig. 2 indicated that the ESPI in the study area was high in the south and low in the north. High-value regions were mainly concentrated in parts of Guangxi, Fujian, Zhejiang, and Guangdong, and ESPI values in northern Hebei and eastern Liaoning were also relatively high. Regions with low ESPI-values were mainly located in the Yangtze River Delta, Pearl River Delta, and Beijing-Tianjin-Hebei region; in particular, the ESPI values in the North China Plain were relatively low. These results agree with those of Xie et al. (2015) and Zhang et al. (2016), indicating that valuable areas of ecosystem services are mainly distributed in southern China, especially in areas with dense vegetation, such as Fujian and Guangxi.

Regions with high LDI-values were mainly situated in the Yangtze River Delta, Pearl River Delta, Beijing-Tianjin-Hebei region, and North China Plain, while regions with low LDI-values were concentrated in the southern and northern parts of the study area.

In terms of spatial layout, surplus areas of ESSDI were concentrated in areas such as Guangdong, Guangxi, Fujian, and northern Hebei where vegetation covered more. Balanced areas were concentrated in the North China Plain, Liaohe Plain, and other grain-producing areas. Overloaded areas were mostly located in the Yangtze River Delta, Pearl River Delta, and developed coastal regions.

From the perspective of land area, the surplus, slight surplus, and balance pattern had the largest land area, and the severe overload pattern had the smallest land area. The overload and severe overload patterns represented the highest proportions of the GDP; surplus and slight surplus patterns represented the lowest proportions. In addition, the balance and overload patterns had the largest populations, followed by the slight surplus and severe overload patterns; the smallest population was associated with the surplus pattern. About 3.53% of the land in the severe overload regions made up 33.27% of the total GDP and 19.52% of the total population, as shown in Table 2. Overall, there was a clear spatial imbalance in the supply-demand pattern of ecosystem services.

3.2. Spatial-temporal variation in the supply-demand pattern of ecosystem services

3.2.1. Global spatial autocorrelation of the supply-demand pattern of ecosystem services

Table 3 showed the global spatial autocorrelation Moran's I of ESSDI during 2000–2015, and statistical significance was established at $p < 0.05$. ESSDI in the study area showed a positive correlation at different times, indicating a spatial aggregation phenomenon for ESSDI. Regions with higher ESSDI values were close to each other, and regions with lower ESSDI values were close to each other. Moreover, over time, the Moran's I of ESSDI showed an upward trend, rising from 0.4815 to 0.7014. The phenomenon of spatial aggregation increased. These

Table 2
Evaluation of ESSDI of coastal areas in 2015.

Supply-demand situation	GDP	Population	Land area
Surplus	2.70%	6.34%	24.89%
Slight surplus	8.68%	16.98%	30.04%
Blance	20.92%	28.16%	25.63%
Overload	34.43%	29.00%	15.90%
Severe overload	33.27%	19.52%	3.53%

Table 3
Global spatial autocorrelation Moran's I of ecosystem services supply-demand index in 2000, 2005, 2009 and 2015 in the coastal region in China.

Type	2000	2005	2009	2015
Moran's I	0.4815	0.6416	0.7033	0.7014
P value	0.001	0.001	0.001	0.001
Z value	24.1926	31.7701	34.7082	34.8816

results revealed that with the implementation of various environmental protection policies in China, the quality of the ecological environment improved, the spatial correlation of ESSDI continuously increased, and the agglomeration of the spatial distribution gradually increased.

3.2.2. Local spatial autocorrelation of the supply-demand pattern of ecosystem services

High-High clustering describes areas with high ESSDI that are surrounded by areas whose ESSDI values are also high. In 2000, there were 75 counties with High-High clustering, located in northern Hebei, northern Guangxi, and at the junction of Fujian and Zhejiang. In 2005, the number of counties experiencing High-High clustering increased substantially, and the growth was mainly located in southern regions, such as Guangxi, Guangdong, and Liaoning. The Natural Forest Protection Project implemented in the eastern Liaoning Province (Chinese Ministry of Agriculture, 2010) and water conservation forests, coastal shelter forest construction, and forest improvement projects implemented in Guangdong Province (China Forestry Network, 2015) have effectively increased forest coverage and improved ecosystems. After 2009, the number of counties with High-High clustering stabilized, primarily because large-scale projects of Grain for Green were suspended beginning in 2008. These results also confirmed that with the implementation of a large number of ecological protection projects, the spatial imbalance in the supply-demand pattern of ecosystem services improved.

Low-Low clustering describes areas with low ESSDI that are surrounded by areas whose ESSDI values are also low. These areas were located in the Yangtze River Delta, Pearl River Delta, Tianjin, Jiangsu, Shandong, Hebei, and some counties in Liaoning. These regions were mostly economically developed regions, with high population density, high levels of industrialization and large energy consumption. Economic development also brought a series of ecological and environmental problems. In response, the Chinese government issued corresponding policies. Three primary Chinese national programs, including eco-cities, districts and counties, low carbon eco-cities, and low carbon provinces and cities have been enacted and implemented (Jong et al., 2016). With the passage of time, counties and cities in Low-Low clustering decreased, indicating that the relevant policies implemented by China achieved initial results.

Counties and cities in High-Low clustering and Low-High clustering are transition areas between high and low ESSDI areas. As can be seen from the Figs. 3 and 4, as well as the Table 4, these two types of counties and cities were less common than High-High or Low-Low areas. ESSDI always had spatial autocorrelation and spatial heterogeneity and formed a relatively stable spatial pattern. High-High clustering was mainly distributed in ecologically better areas, and Low-Low clustering was mainly distributed in economically developed areas.

3.3. Driving mechanism of changes in the supply-demand pattern of ecosystem services

3.3.1. Impacts of natural factors on the supply-demand pattern of ecosystem services

As can be seen from the Table 5, the correlation coefficients were all above 0.8, indicating that all the selected factors were closely related to ESSDI. Compared with social factors, natural factors were more related.

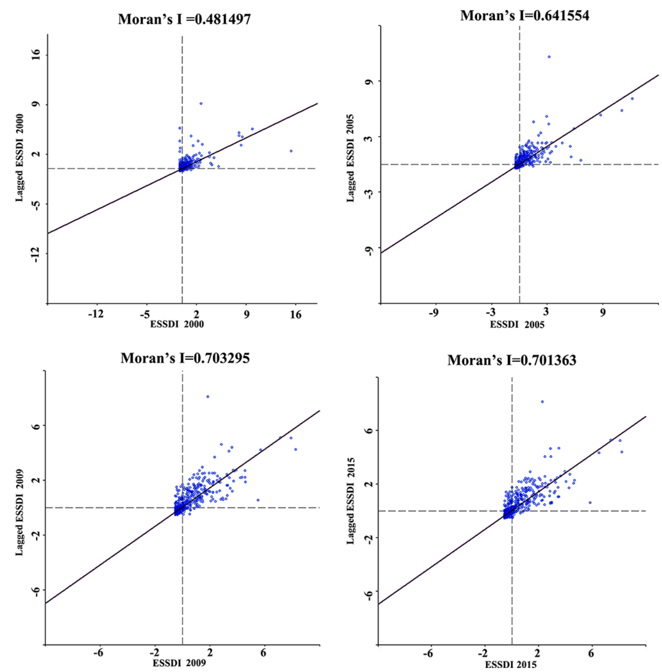

Fig. 3. Moran scatter of ecosystem services supply-demand index in 2000, 2005, 2009 and 2015 in the coastal region in China.

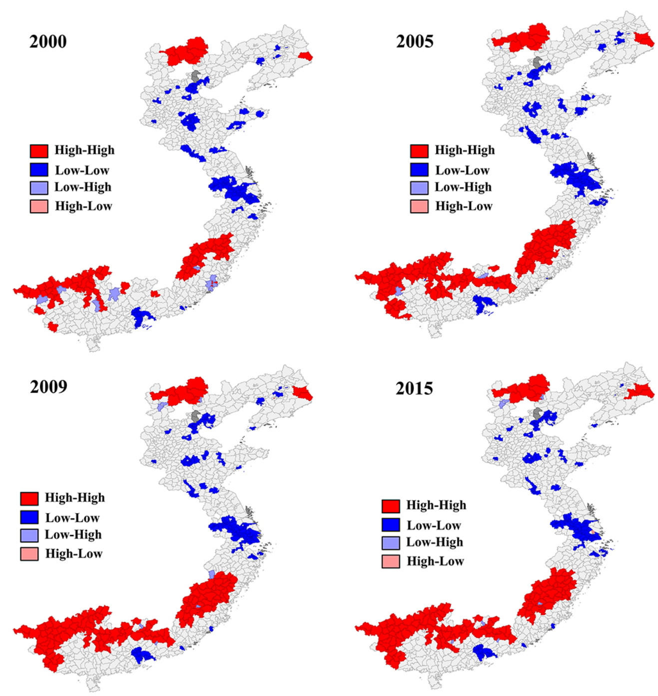

Fig. 4. Spatial distribution of LISA index for ecosystem services supply-demand index in 2000, 2005, 2009 and 2015 in Chinese coastal regions.

Table 4
The number of counties with different spatial clustering in 2000, 2005, 2009 and 2015 in the coastal region in China.

Type	2000	2005	2009	2015
High-High clustering	75	116	120	120
Low-Low clustering	174	177	161	156
High-Low clustering	0	0	1	1
Low-High clustering	9	4	6	6

Table 5
Correlation coefficients of different impacting factors on ecosystem services supply-demand index in 2000, 2005, 2009 and 2015 in the coastal region in China.

Impacting Factors	2000		2005		2009		2015	
	Correlation coefficient	Sequence	Correlation coefficient	Sequence	Correlation coefficient	Sequence	Correlation coefficient	Sequence
Proportion of ecological land	0.9659	1	0.9503	1	0.9003	1	0.8966	1
Annual rainfall	0.9605	2	0.9415	2	0.8704	2	0.8833	2
NDVI	0.9563	3	0.9333	3	0.8619	3	0.8610	3
Annual average temperature	0.9554	4	0.9331	4	0.8615	4	0.8595	4
Per capita GDP	0.9467	5	0.9166	7	0.8326	6	0.8307	6
Population	0.9455	6	0.919	5	0.8341	5	0.8297	7
The value-added of primary industry	0.9454	7	0.9181	6	0.8326	7	0.8327	5
Social fixed-assets investment	0.9438	8	0.9101	9	0.8228	8	0.8211	8
GDP	0.9415	9	0.9111	8	0.8224	9	0.8183	9

The four factors, including proportion of ecological land, annual rainfall, NDVI, and annual average temperature, were always ranked as the top four in different years. The order of the four factors was the proportion of ecological land > annual rainfall > NDVI > annual average temperature. Since the supply of ecosystem services depends on the scale and function of the natural ecosystem itself, changes in the proportion of ecological land has a decisive impact on ecosystem services. Further, precipitation changes a series of processes, such as photosynthesis and transpiration of plants and soil greenhouse gas emissions, and has an extremely important impact on ecosystem services. The proportion of ecological land and annual rainfall directly affect ESSDI. Vegetation has many ecological, social, and economic functions, and plays an important role in maintaining ecosystem balance, regulating climate, and protecting biodiversity. The quantity of vegetation, the structure of its composition, and its distribution characteristics directly affect the supply of ecosystem services. Meanwhile, temperature has a great impact on vegetation in coastal areas. The wet monsoon climate with abundant heat and rich precipitation in coastal areas could accelerate photosynthesis of plants, promote root growth, and increase the supply of ecosystem services. NDVI and annual average temperature also have great influence on ESSDI.

3.3.2. Impacts of social factors on the supply-demand pattern of ecosystem services

The sequence between per capita GDP and ESSDI showed an inverted U-shaped change between 2000 and 2015, as shown in Fig. 5. The main reason was that coastal areas had gradually entered mid- and post-industrialization stages with respect to economic development. In the process of industrialization, with a further increase of per capita GDP, the degree of environmental pollution showed a declining trend year by year, and the impact to the ecosystem also gradually decreased.

The sequence between population and ESSDI showed a U-shaped change between 2000 and 2015, as shown in Fig. 5. The reason was that with the development of science and technology and the improvement of population quality, coastal areas paid more attention to ecological protection and the impact of population on the ecosystem gradually become smaller. Wang et al. (2016) found similar results, showing that the increase in population brought about by urbanization did not lead to a decline in the overall ecosystem quality of the city, but rather improved the quality of ecosystems in urban and outlying suburbs. Zhou et al. (2013) also found that the eastern region was in a stage of continuous economic optimization driven by population quality.

The impact of the value-added of primary industry on ESSDI was relatively large, mainly due to the fact that in the agricultural production process, pollutants such as soil sediments, heavy metals, pesticides, and pathogens were inevitably generated, which had a substantial negative effect on the ecosystem. The order change between social fixed-assets investment and ESSDI was relatively small. The sequence between GDP and ESSDI was usually at the bottom. This may be the reason for synthesis of the development of the first, second, and third industries, which weakened the impact of ecosystem services supply and demand.

From 2000 to 2015, the difference value between the maximum and minimum value of the correlation coefficient showed an increasing trend. This indicated that with the development of cities and the social economy, the difference in the influence of each driving factor on the ESSDI of the research area was increasing. The driving mechanism was more reflected in the individual role of various factors.

4. Discussion

4.1. Spatial mismatch between supply and demand of ecosystem services

LDI and ESPI had obvious negative spatial correlation, as shown in Fig. 2. In regions with high LDI, ESPI tended to be lower; in regions with low LDI, ESPI tended to be higher. Reasons for the unbalanced spatial distribution of ESPI and LDI included the population, climate, and economic development of each region. Regions with high ESPI-values had small populations, relatively low economic development, and human activities had induced less damage to the ecological environment. Furthermore, the climate in these regions was mostly a monsoon climate with adequate rainfall. Regions with high ESPI-values had high vegetation coverage and could provide more ecosystem services. Areas with high LDI-values had large populations, a more developed economy, and various types of human activities, resulting in higher demands for ecosystem services. This study found that there was a significant spatial mismatch between supply and demand of ecosystem services.

In fact, the mismatch between supply and demand of ecosystem services is a common phenomenon at a specific scale or during a certain time period (Sun et al., 2019). The mismatch between supply and demand of ecosystem services also exists at many scales, from micro-scale, such as park and city (Baró et al., 2015; Shen et al., 2017), to macro-scale, such as the mainland (Schulp et al., 2014; Ala-Hulkko et al., 2019). Studies have shown that human intervention (labor, technology, and capital) usually helps to maintain and enhance ecosystems, thereby enhancing ecosystem service supply through land-use management (Geertsema et al., 2016). Therefore, policy makers often want to maximize the ecosystem services supply to reduce the mismatch between supply and demand through land management. However, when some services are maximized at the expense of other services, ecosystem service trade-offs may occur, which will increase the mismatch between supply and demand of other services (Geijzendorffer et al., 2015). Moreover, social, governmental and cultural differences, as well as market price fluctuations, can lead to diversification of ecosystem services demand and may change over time and spatial scale (Wang et al., 2019b). In the future, the complex relationship of ecosystem services in the management process should be fully understood to reduce (or

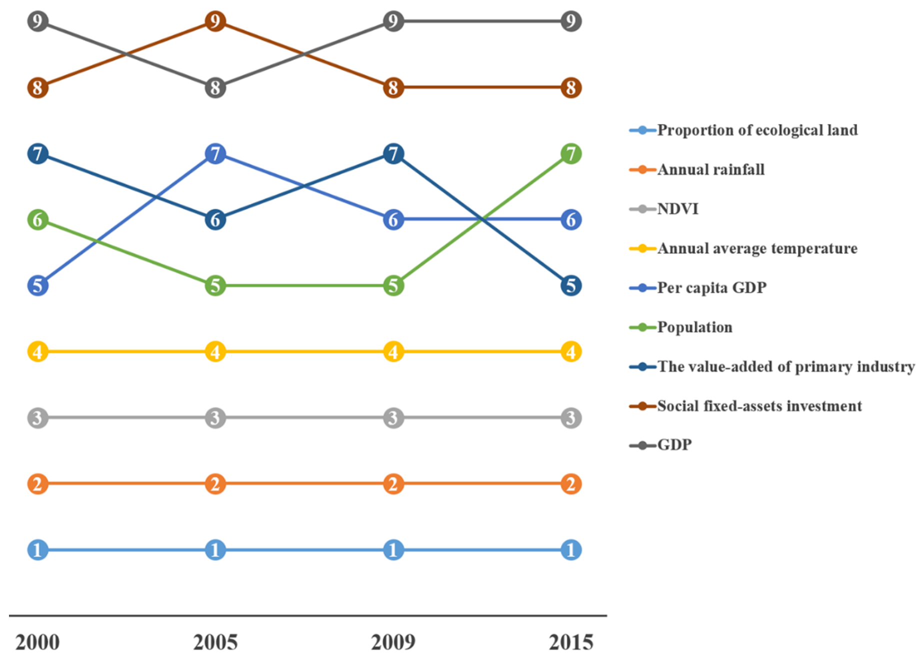

Fig. 5. Changes in the ranking of different impacting factors on ecosystem services supply-demand index in 2000, 2005, 2009 and 2015 in the coastal region in China.

possibly eliminate) trade-offs and achieve an exact match between ecosystem service supply and demand.

4.2. *The relationship between spatial imbalance in the supply-demand pattern of ecosystem services and environmental justice*

The results showed that there was a clear spatial imbalance in the supply-demand pattern of ecosystem services. Meanwhile, the spatial imbalance in the supply-demand pattern of ecosystem services caused serious environmental injustice. After the reform and opening up in China, the government created preferential policies to allow some coastal cities, like Shenzhen, to develop first, while western regions, among others, provided raw materials including water resources, minerals, and electricity. Although the factory-based economic models of some coastal cities in eastern China greatly promoted local economic development, the subsequent water pollution and air pollution caused the eastern coastal region to suffer from ecological disasters (Zhao et al., 2010; Wang et al., 2013). In addition, most of the western regions were ecologically fragile areas (economically impoverished areas), and it was necessary to sacrifice certain economic development interests for the sake of ecological protection while developing the economy (Yao and Xie, 2016). The benefits of ecological protection in these ecologically fragile areas (economically impoverished areas) were freely enjoyed and occupied by the coastal areas, generating environmental injustice.

With the economic development of coastal areas gradually entering mid- and post-industrialization stages, the degree of environmental pollution showed a declining trend year by year, and the impact to the ecosystem also gradually decreased. The implementation of some ecological restoration projects also played an important role in environmental improvement. Actually, the economic development model of eastern coastal areas in China was the same as that of developed countries, which was to develop the economy first and then to harness the environment. In the early years of economic development, developed countries, such as the United States (Driscoll et al., 2003; Matus et al., 2008), the United Kingdom (Anderson et al., 1996; Menz and Seip, 2004), France (Audry et al., 2004), and Japan (Harada, 1995; Ogawa et al., 2004), neglected the impact on the environment, resulting in ecological deterioration. Air pollution, water pollution and soil pollution frequently broke out. Until the 1970s, developed countries adopted a series of measures to control pollution problems, and the environment improved significantly (Sullivan et al., 2018). Other developing countries in the world, such as Brazil (Veado et al., 2006), India (Guttikunda et al., 2019) and Bangladesh (Hasan et al., 2019), were also experiencing this economic development model, and environmental pollution was very serious.

In addition, this study also found that the sequence between per capita GDP and ESSDI showed an inverted U-shaped change between 2000 and 2015. The results were similar to the Kuznets curve (Lin and Zhu, 2018; Song et al., 2013), which verified that the ecological environment of coastal areas had improved (Chapter 3.2). Wu et al. (2018) and his colleagues also found that most cities in East China reached the second inflection point of the inverted-N curve to step into the win-win stage. On the other hand, due to low labor costs, abundant resources and energy, weak awareness of environmental protection, and a broad space for economic development, many high-energy-consuming, high-pollution enterprises shifted and continue to shift to western China through the transfer of industries and trade. This was also a very important reason for environmental improvement in coastal areas. Zheng and Shi (2017) also found that during the period of 2004–2013, the annual average pollution discharge fee paid by each firm was 800,351 CNY in east coast regions, which was significantly higher than that in middle (497,235 CNY) and western (369,416 CNY) inland regions. Regional differences in economic instruments caused the polluting sector to relocate from the eastern region to the inland region. The pollution haven hypothesis was confirmed in China, which also caused environmental injustice to some extent (Sun et al., 2017). This phenomenon was also found in other developing countries. Due to the relatively low environmental standards in developing countries, most foreign investments were concentrated in high-pollution areas. For example, Ghana has developed a comparative advantage pollution-intensive industries and become one of the "havens" for the world's polluting industries (Solarin et al.,2017). In the Niger Delta, the local community bears most of the environmental costs of oil extraction, while the benefits of the oil industry hardly return to the Delta (Adekola et al., 2015). Several studies also show that inequities in park acreage, quality, and safety in many cities in the Global North and Global South, with Low-income ethnic minorities often do not have access to more ecosystem services (Boone et al., 2009; Macedo and Haddad, 2016; Rigolon, 2017; Rigolon et al., 2018). Nowadays environmental justice exists in different scales and different fields in the world.

4.3. Efforts to improve environmental injustice

Whether within coastal areas or between the coastal areas and western regions, the spatial imbalance in ESSDI caused serious environmental injustice due to natural background differences, national policy, development gaps, trade and industrial shifts. In order to solve the problem of environmental injustice, the Chinese government implemented many policies. To date, the Chinese government has invested a total of 21.9 billion CNY for wetland restoration and has launched a variety of coastal restoration projects. Some researchers found that China's total mangrove area increased, demonstrating the effectiveness of coastal eco-restoration projects (He et al., 2014; Liao and Zhang, 2014). During the latest round of the Grain for Green Project, a total of 447 million mu were completed. The total area of forest land and total forest volume increased by more than 15.4% and 10%, respectively (Wang et al., 2017). The per capita net income of farmers in the Grain for Green Project increased from 1945 CNY in 2000 to 7602 CNY in 2014. In 1996, the central government made a major policy decision regarding “cooperation between the East and the West for poverty alleviation”. From 1996 to 2015, the eastern region provided assistance funds totaling more than 16 billion CNY to the western poverty alleviation cooperation area, guided enterprises to actually invest 1.5 trillion CNY, and implemented a large number of support projects and livelihood projects. China’s poverty alleviation policies have achieved great success (Liu et al., 2017; Meng, 2013).

All the projects have achieved great results following implementation, and environmental injustice has improved (Yin et al., 2014; Zhang et al., 2012; Dai et al., 2017; Zhang et al., 2018; Zhou et al., 2018). At present, China has established the forest ecological benefit compensation fund system; the ecological compensation system for grassland, wetlands, and mines; the transfer payment system for key ecological functional areas; and the compensation mechanism for river basin ecological protection. In 2017, ecological compensation was included in the general plan for reform of the ecological civilization system and opinions on accelerating the construction of ecological civilization. The framework of the national ecological compensation system has been constructed and is constantly being extended.

The results noted in Section 3.3.2 indicate that the driving mechanisms of ESSDI were more reflected in the individual roles of various factors. Therefore, some measures can be taken to better solve the spatial imbalance of ESSDI. Some suggestions are provided: the government should play a more important role in the face of environmental injustice, increase the investment of ecological compensation funds, and further improve the ecological compensation mechanism. Meanwhile, the government needs to speed up the development of environmental laws and regulations, strengthen law enforcement of environmental protection, strengthen ability of environmental management, and enhance the voice of citizens and non-governmental organizations in environmental decision-making. In the long run, it is essential to carry out education for environmental protection, to study environmental theories, to establish environmental protection awareness, and to change people's understanding of nature ideologically.

In this study, the ecosystem services supply-demand index was proposed to achieve the coupling of ecosystem services supply and demand, and to analyze the relative imbalance of the spatial distribution of ecosystem services supply and demand. In other studies about the ecosystem services supply and demand, it was necessary to collect statistical data from different departments or conduct a questionnaire survey (Palomo et al., 2013; Bukvareva et al., 2017; Castillo-Eguskitza et al., 2018). The calculation process was complicated, and it was difficult to analyze the changes of ecosystem services supply and demand and reveal deep-seated problems. Using only land survey data and economic and demographic data, this study can quickly explain the changes in the supply-demand pattern of ecosystem services, find out the imbalance trend and its causes, and further reveal the environmental injustice caused by the spatial imbalance in the supply-demand pattern of ecosystem services. County was selected as the basic unit in this study, which can achieve the rapid monitoring and management of the ecosystem under the serious disturbance of human activities from the macroscopic scale. This has certain reference value for regional sustainable ecological management and environmental decision-making. In addition, studies on the supply-demand of ecosystem services and environmental justice are still relatively independent, and studies linking the two are still lacking (Villegas-palacio et al., 2016; Arbieu et al., 2017; Ala-Hulkko et al., 2019). This study is a meaningful attempt.

However, there are some limitations in this study, and several points warrant further discussion. For example, the supply-demand situation of ecosystem services is influenced by many factors, including physical geography and social economy, and there are great differences among different regions. In this study, only population density, economic density and the proportion of developed land were selected to represent the ecosystem services demand, which may not be able to comprehensively measure the ecosystem services demand. Meanwhile, the selection of county as the basic unit cannot achieve fine ecosystem management on grid scale like some countries (Burkhard et al., 2012; Kroll et al., 2012). This study was conducted at specific geographic boundaries, which largely ignored the flow of ecosystem services between regions. In the future, questionnaire survey or sampling survey method should be adopted in a small range to improve the analysis accuracy on the basis of collecting as much data as possible representing human demand, such as cellular signaling data. Through analyzing a large number of case studies and field observation data in different regions, the supply-demand pattern of ecosystem services will be studied to provide suggestions for improving the environmental injustice. Further, the study between ecosystem service flow and environmental justice should be strengthened.

5. Conclusions

Research results showed that the imbalance in the supply-demand pattern of ecosystem services was serious. However, the Moran’s I of ESSDI showed an upward trend, and the number of counties and cities experiencing High-High clustering increased while those experiencing Low-Low clustering decreased, confirming that the spatial imbalance in the supply-demand pattern of ecosystem services had improved. Compared with social factors, the correlation coefficient between natural factors and ESSDI was higher, but the development of the economy and the improvement of the quality of the population also played an important role in changes in ESSDI and improving environmental quality. Due to differences in natural background, national policies, development gaps, trade and industrial shifts, the spatial imbalance in ESSDI caused serious environmental injustice. However, the implementation of some projects, such as the Grain for Green Project, not only changed the spatial imbalance in ESSDI, but also relieved environmental injustice.

This study proposed a method to quickly understand the situation of a given ecosystem, achieve good coupling of ecosystem services supply and demand, and analyze the relationship between the supply-demand pattern of ecosystem services and environmental justice. This is of great significance to regional ecosystem management. However, there may be differences between different regions in terms of factors affecting the ecosystem services supply and demand. In the future, more accurate data should be obtained using questionnaires or sampling surveys for small-scale areas to improve the accuracy of the analysis. Our discussion of environmental justice at the regional scale must be expanded to include the global and rural scales. We need to explore the deep links between ecological supply and demand and environmental justice from a broader perspective.

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