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Spatial Conflict of Production–Living–Ecological Space and Sustainable-Development Scenario Simulation in Yangtze River Delta Agglomerations

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Abstract: Production–living–ecological space (PLES) is a recent research hotspot on land planning and regional sustainable development in China. Taking the Yangtze River Delta agglomerations as a case study, this paper establishes a spatial-conflict index to identify the PLES conflicts, and then builds a cellular-automaton (CA) Markov model to simulate the PLES pattern in 2030 and to evaluate the influence on PLES conflicts under two scenarios. Results showed that the ecological space (ES) and the living–productive space (LPS) of the Yangtze River Delta agglomerations showed a descending tendency in 2010–2015, whereas ecological–productive space (EPS) and productive–ecological space (PES) reflected a small increase. EPS and PES had squeezed ES and LPS with urbanization and industrial development in this region. Meanwhile, the spatial conflicts of PLES worsened during the period, with the average of the spatial-conflict index (SCI) shifting from 0.283 to 0.522, and seemed to gain momentum. On the basis of scenario analysis for 2030, it was concluded that the "ecological red line policy", appropriate restriction of urban expansion, and ecological management of the bank of the Yangtze River are helpful in alleviating PLES conflicts, and contribute to spatial structure and harmonizing. The results of this study are expected to provide valuable implications for spatial planning and sustainable development in the Yangtze River delta agglomerations.

Keywords: PLES; spatial conflict indices; CA Markov; scenario analysis

1. Introduction

1.1. Motivation and Literature Review

Landscapes are multifunctional, comprehensive systems that are used by people for multiple purposes to achieve economic stability but that also need to maintain and enhance environmental values. Land use classification (LUC) is the process of identifying and distinguishing the space unit of land use. It provides information on land cover and the way of utilization and transformation of the land by humans, reflecting the utilization form and function of the land [1]. Production–living–ecological space (PLES), the shortened form for productive space (PS), living space (LS), and ecological space (ES), is reclassified considering both land use functions and utilization types [2]. It was formally put forward in the 18th National Congress of the Chinese Communist Party in 2012, and its purpose is to optimize the spatial pattern of land uses by the overall co-ordination of PS, LS, and ES [3]. In recent years, agricultural and ecological lands have been heavily crowded out with the gradual expansion of urban land, and the spatial conflict between PS, LS, and ES is becoming worse, which has negatively influenced the harmonious and sustainable development of regional economies and societies. Thus, the recognition and optimization of spatial conflicts between PS, LS, and ES is an important problem for regional spatial planning.

Land use conflict is the process of competition and contradiction between land use subjects and stakeholders, with land in the same spatial location as core resource elements, and its connotation is the evolution of various interest conflicts and land use types [4]. It has attracted widespread attention from scholars and planners for promoting sustainable economic and social development. Baja et al. assessed land use conflict attributed to the unsuitable spatial location of existing land use with land use functions in spatial regulation at the provincial and regency scales [5]. Sinead et al. investigated the mechanism of land use conflict of a shared rural landscape that is simultaneously used as a working landscape, a rural idyll, a landscape of provision, and a living landscape in Upper Hunter Valley, NSW, Australia [6]. Zou et al. constructed an empirical model for land use conflict identification and intensity diagnosis, and also performed a scenario-optimization simulation on China's southeast coast [7]. Those studies have greatly contributed to land use conflict identification, but there is still a lack of published research on spatial conflict from the perspective of PLES.

PLES was first proposed by Chen and Shi (2005) based on the production–living–ecological function of land use, and was then formally confirmed as the national land classification method in the 18th National Congress of the Chinese Communist Party in 2012 [8]. Subsequently, the connotation and definition of PLES was systematically developed by Li and Fang [9]. Recently, Chinese scholars have done much research around PLES, and results are plentiful, including on the theoretical content and framework of PLES [10,11], the land-classification system on PLES [12,13], the bearing-capacity analysis of PLES [14–16], and the quantitative function identification and analysis of PLES [9]. However, the research perspective still needs diversity, and the studied scale needs to shift from macroscopic to regional geography. China is still a developing country, and the conflict between PS, LS, and ES could last for the next few decades in order to sustain social and economic development. Research on the evolution and optimization of spatiotemporal patterns of PLES is urgently needed, particularly for regions with prominent conflicts between humans and the environment.

The Yangtze River Delta agglomerations are located in the alluvial plain before the Yangtze River enters the sea, with Shanghai as the center (32°34′–29°20′ north latitude, 115°46′–123°25′ east longitude) (Figure 1) [17]. It is an important intersection zone between "one belt and one road" (an initiative proposed by China in 2013 that aims to enhance the economic links among countries, and might create new opportunities for global sustainable development) and the Yangtze River economic belt, and plays a significant strategic role in China's overall modernization [18]. However, in recent years, the ecosystem pattern of the Yangtze River Delta city cluster has changed dramatically due to rapid development and urbanization. Farmlands, forests, grasslands, rivers, lakes, wetlands, and other ecosystems have considerably decreased, and water and soil loss in the upper reaches is serious. The function of the wetland ecosystem has degenerated, and the conflict between ecological damage and land use has become increasingly prominent [19]. In 2019, the Chinese Government (the central government implements a system of control over the purposes of land use, and the local government may draw up overall plans for land utilization but should not be against the State's land use planning in China [20]) put forward building a "Beautiful Yangtze River Delta" by releasing the Developing Program for Regional Integration in the Yangtze River Delta [21]. However, PLES conflicts have restricted the development of the economic society and the ecological environment in the Yangtze

River Delta agglomerations. Therefore, it is necessary to perform conflict identification and optimize the spatial layout for PLES in this region.

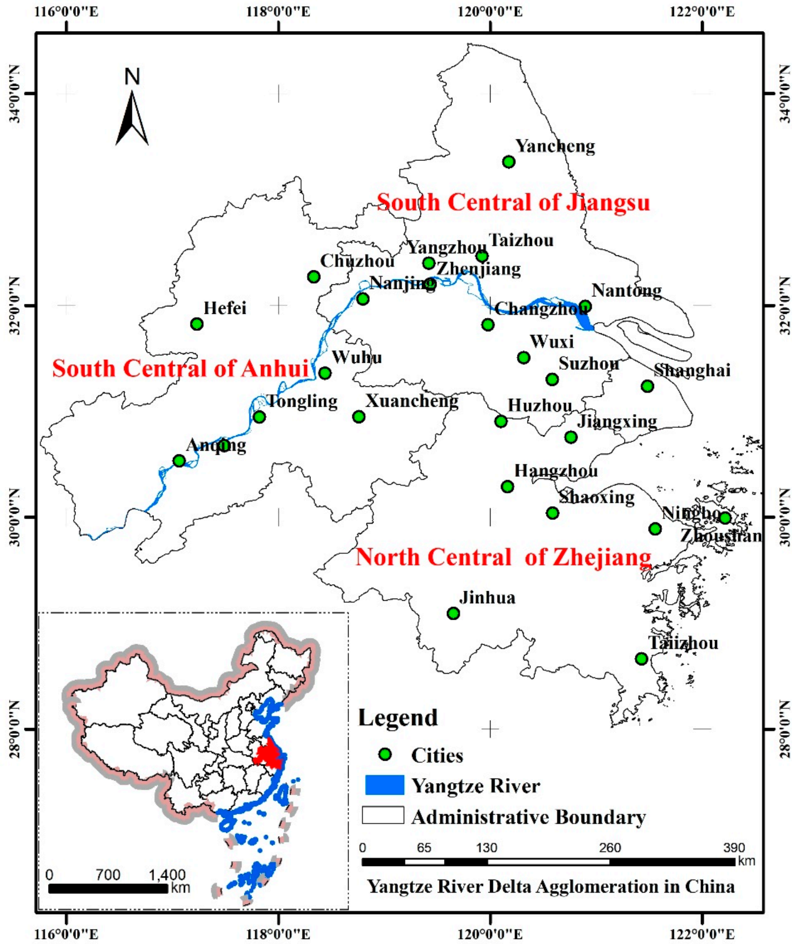

Figure 1. Location of study region in China.

1.2. Objective and Contribution

This study aims to explore the spatial-temporal characteristics of PLES, and analyze PLES conflicts by building a spatial-conflict index on the basis of the landscape-ecology method (the calculation of landscape indices based on the theory of landscape ecology analysis [22]). Then, a method based on cellular-automaton (CA) Markov is proposed for simulating sustainable PLES scenarios on the basis of conflict management. We expect it to provide valuable references for policy makers in conflict management and control in China.

2. Methodology

2.1. Research Framework

The research framework to identify PLES conflicts and simulate the PLES was developed using the following steps:

Step 1: Evaluate PLES spatiotemporal variation on the basis of PLES grid data at 1 × 1 km.

Step 2: Quantify PLES conflicts using a spatial-conflict index on the basis of the landscape-ecology method.

Step 3: Perform two scenario simulations for PLES in 2030 (an important programming year in the Yangtze River Delta agglomerations) on the basis of the cellular-automation (CA) Markov model.

2.2. Data Sources and Processing

PLES grid data at 1 × 1 km of the Yangtze River Delta agglomerations for 2010 and 2015 were obtained on the basis of reclassified land use products according to the land-classification system by Zhang et al. [2]. On the basis of the multifunctionality principle, PLES is classified into four categories, namely ecological space (ES), including biodiversity conservation, ecological capacity, flood regulation and storage, general adjustability, river bank protection, and water conservation land; living–productive space (LPS), including rural living, urban built-up, and industrial- and commercial-production land; productive–ecological space (PES), including cultivated and garden land; and ecological–productive space (EPS), including fishery culture and timber land.

2.3. Spatial-Conflict Index

The spatial-conflict index (SCI) was built on the basis of the study by Liao et al. (2017) that is referred to as the landscape-ecology method, which took into account the complexity, vulnerability, and stability of PLES [22]. SCI can be expressed as follows:

$$SCI = CI + FI - SI, \tag{1}$$

where CI represents the complexity index of PLES, calculated by the area weighted average block fractal index (AWABFI) [23]. FI represents the vulnerability index of PLES, which is used to measure the response of land use from external pressure and evolution processes [24]. SI represents the stability index of PLES, which is expressed by the landscape fragment [25]. According to the curve-distribution characteristics of the land use spatial-conflict index's cumulative frequency and inverted U-curve, the PLES can be divided into four levels: Stable and Controllable (level 1: 0–0.25), Basic Controllable (level 2: 0.25–0.5), Basic Out of Control (level 3: 0.5–0.75) and Seriously Out of Control (level 4: 0.75–1.00) [23,26].

2.4. Land-Use Scenario Simulation

In this paper, the CA Markov model was used to simulate future PLES. CA Markov combines the best of the time-dimension analysis of the Markov model and the spatial-dimension analysis of the CA model, which reduces the difficulty of the transformational rules and artificial factors [27–29]. It estimates the probability of event occurrence based on their current situations, taking time and space elements into account. The CA model is a dynamic grid model, charged with the simulation of the spatio-temporal evolution of land use, while the Markov model can assess the influence of random factors on land use and predict the future transition probability. Supported by Geographic Information System (GIS), the landscape pattern change can be simulated based on the calculation of transferred-area and -probability matrices of land use using the grid data. The simulation of PLES in 2030 was carried out using the IDRISI (an integrated GIS and Image Processing software solution) according to the following steps. First, the transferred-area and -probability matrices of PLES between 2010 and 2015 were calculated using the Markov model on the basis of an overlay analysis of PLES grid data. Second, a suitability atlas was built using the multicriteria-evaluation (MCE) modules of IDRISI. Suitability factors for the suitability atlas, which is used for assessment of the suitability of land use in this study, were confirmed on the basis of driving-force analysis of PLES. Elevation, slope, population density, and distance from roads were selected as the driving factors on the basis of the logistic-regression model, considering data accessibility, economic, and ecological conditions [30]. Third, the starting point of the CA Markov model was set in 2010 to simulate PLES 2015, and the cellular-filter size was 5 × 5. Then, the starting point was changed to 2015 to simulate PLES 2030 with scenario-analysis methods on the basis of high-precision prediction. Finally, the kappa coefficient was used for precision validation between simulation and observed results [31].

2.5. Scenario Settings

Scenario analysis, as an important means of implementing management and auxiliary decision-making, has been extensively used in resources, ecological environment, and regional development [32–35]. In this paper, two scenarios, business as usual (BAU) and a collaborative-development scenario (CDS), are proposed on the basis of ecological principals of the Yangtze economic belt and the coordinated development of PLES. BAU was set to simulate the normal evolution of PLES under the driving force of natural, economic, and social elements, simultaneously taking into account the red lines of basic farmland protection and of ecological protection [36], while CDS needs to be extended to coordinate PLES conflicts. The industrial, commercial, and urban lands of LPS were appropriately controlled, and ES was properly enlarged by adjusting the transfer probability. CDS also led to an increased focus on soil and water conservation and riparian ecological protection, setting them as the immovable region. CDS also needs to implement a returning-farmland-to-forest policy by setting the cultivated land of PES with a slope greater than 25% to convert to ES forestlands. Last and most importantly, the shoreline protection of the Yangtze River was considered in CDS by designing a buffer zone of 3 km as the ES.

3. Results and Discussion

3.1. Spatial–Temporal PLES Characteristics in the Yangtze River Delta Agglomerations

Figure 2 shows the spatial characteristic of PLES in the Yangtze River Delta agglomerations. In general, the ES of the Yangtze River Delta agglomerations dropped remarkably during the period from 2010 to 2015, with the proportion shifting from 23.39% to 20.73%. By contrast, EPS and PES saw a small increase from 14.63% and 51.67% in 2010 to 16.71% and 53.41% in 2015, respectively. The overall LPS extent were not large in this period.

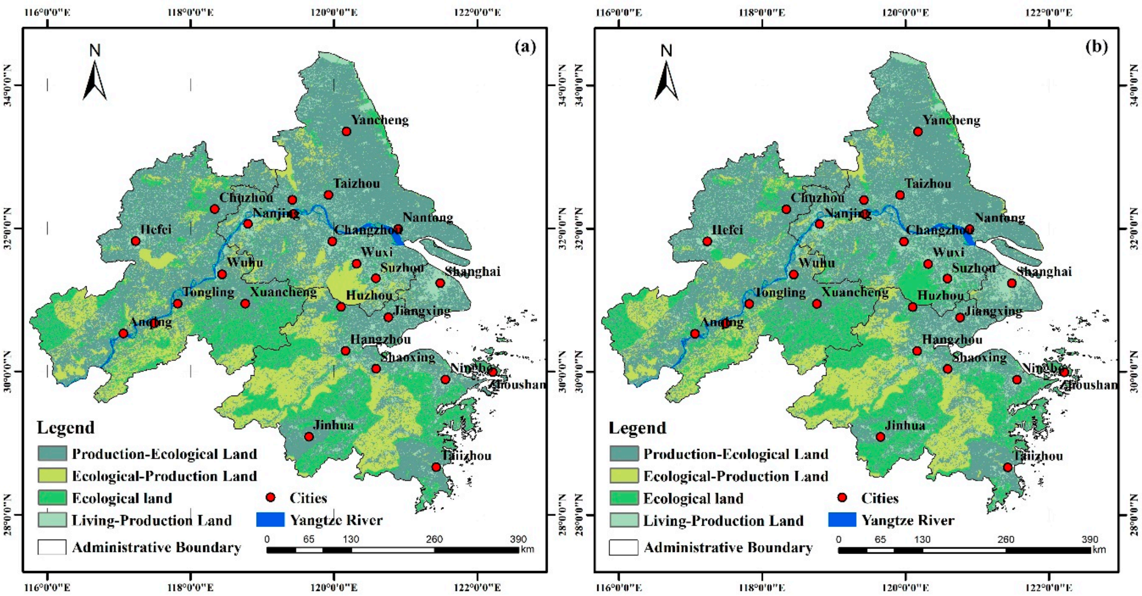

Figure 2. Production–living–ecological space (PLES) in the Yangtze River Delta agglomerations for (**a**) 2010 and (**b**) 2015.

Table 1 shows the transfer matrix of PLES from 2010 to 2015. EPS was the most variable of PLES, followed by ES and LPS, and PES was relatively stable. EPS was not vulnerable in spite of having the largest changes, since it mainly received land transformation from others. Thus, PLES vulnerability was, in order, EPS, LPS, PES, and ES, according to the transition-matrix analysis.

Table 1. Transfer-matrix analysis of PLES from 2010 to 2015 (km^2). ES: ecological space; EPS: ecological–productive space; PES: productive–ecological space; LPS: living–productive space.

2010	2015			
	ES	**EPS**	**PES**	**LPS**
ES	4180.98	4782.95	1749.97	86.24
EPS	620.75	29,413.42	162.39	22.12
PES	267.38	162.45	105,641	619.15
LPS	238.89	139.80	2729.93	18,173.32

Table 2 shows the calculated results of PLES spatial-conflict indices in the Yangtze River Delta agglomerations in 2010 and 2015. In 2010, they were mainly stable and controllable (Level 1) and basic controllable (Level 2), accounting for 94.24% of the total. The average value of spatial-conflict indices was approximately 0.283, which showed a good PLES condition. Conversely, however, things had become so bad in 2015 that the spatial-conflict indices of PLES in the Yangtze River Delta agglomerations were mainly in the levels of basic out of control and seriously out of control, accounting for 72.15% of the total. The average value rose to 0.522 from 0.283 in 2010, and PLES conflicts became a critical threat to regional sustainable development. As shown in Figure 3, the serious conflicts were mainly in Shanghai and near the Yangtze River region in the south-center of Jiangsu province. This is because the gradual expansion of urban land in these regions had despoiled much of ES, PES, and LPS, such as ecological regulation regions like cultivated land. Therefore, it is urgently needed to develop a scientific and reasonable spatial planning system for PLES in the Yangtze River Delta agglomerations.

Table 2. Calculated results of PLES spatial-conflict indices in Yangtze River Delta agglomerations in 2010 and 2015.

Level of Conflict	Cells		Percentage (%)	
	2010	**2015**	**2010**	**2015**
Level 1	61,767	0	29.88	0
Level 2	133,049	57,624	64.36	27.87
Level 3	11,911	136,510	5.76	66.03
Level 4	0	12,593	0	6.09
Average of conflict	0.283	0.522	/	/

Note: Stable and Controllable (Level 1: 0–0.25), Basic Controllable (Level 2: 0.25–0.5), Basic Out of Control (Level 3: 0.5–0.75) and Seriously Out of Control (Level 4: 0.75–1.00).

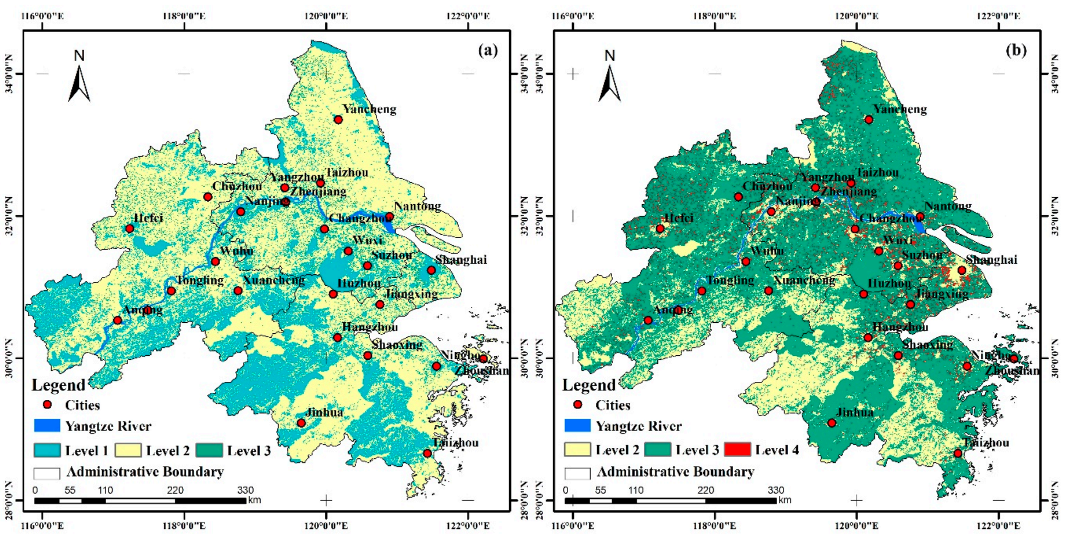

Figure 3. Spatial characteristics of PLES conflicts in the Yangtze River Delta agglomerations for (**a**) 2010 and (**b**) 2015.

3.2. Scenario Analysis of Sustainable PLES in Yangtze River Delta Agglomerations

We used the CA Markov module of IDRISI for simulation operations to obtain PLES in 2030. The kappa coefficient that was returned from the model by the crosstab of IDRISI was 0.86, indicating a better forecasting precision. Figure 4 shows the spatial characteristics of PLES in the Yangtze River Delta agglomerations for BAU and CDS. Overall, ES continues to fall on the basis of 2015 in BAU, covering about 15.15% of the total. The decline of PES is also visible in BAU, with the percentage reducing to 41.88% compared to 2015 (53.41%), whereas in the LPS in BAU, the growth trend is obvious, shifting from 9.15% in 2015 to 28.85% in 2030, due to the deregulation of the urbanization process in this scenario. The EPS variation trend was small when the change of the percentage was less than 3%. We then shifted focus to the spatial-conflict indices of PLES in BAU. As shown in Table 3, PLES conflicts were moderate compared to those in 2015; cells in Level 3 were greatly reduced, with a percentage of 34.83%, and 57.22% of the space cells already fell in Levels 1 and 2. However, the general situation is still not optimistic, with the average of the PLES conflict indices being 0.513, indicating a high risk of conflict in the Yangtze River Delta agglomerations.

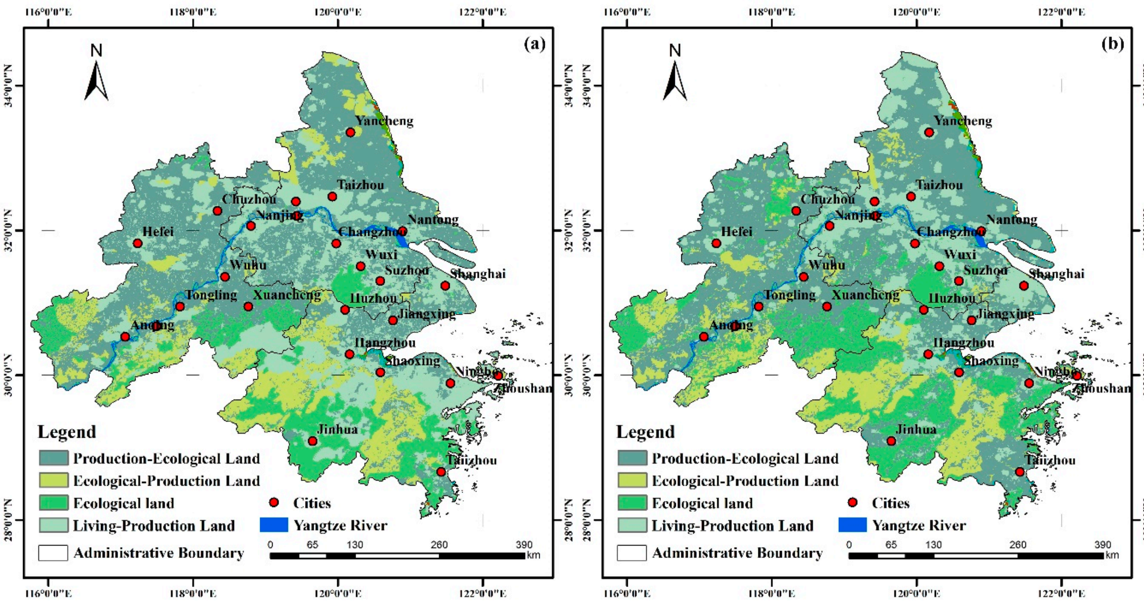

Figure 4. PLES in the Yangtze River Delta agglomerations for business as usual (BAU) and collaborative-development scenario (CDS).

Table 3. Calculated results of PLES spatial-conflict indices in the Yangtze River Delta agglomerations for BAU and CDS.

Level of Conflict	Cells		Percentage (%)	
	BAU	EPS	BAU	EPS
Level 1	31,145	132,598	15.07	64.14
Level 2	87,140	70,152	42.15	33.93
Level 3	72,014	3977	34.83	1.93
Level 4	16,428	0	7.95	0
Average of conflict	0.513	0.134	/	/

Note: Stable and Controllable (Level 1: 0–0.25), Basic Controllable (Level 2: 0.25–0.5), Basic Out of Control (Level 3: 0.5–0.75) and Seriously Out of Control (Level 4: 0.75–1.00).

The obvious contrast was with BAU. There could be a slight increase of ES in CDS compared to 2015, occupying about 21.14% of the total area. The area of EPS and PES in CDS would decrease with the scenario setting, coming down to 14.11% and 44.22%, respectively. Some were transformed to ES, and another part supported the LPS, increasing the covering area of LPS to 20.53%. However, growth is under control compared to the situation on BAU, due to the appropriate restriction to LPS in CDS. From a spatial-conflict point of view, the situation in CDS becomes very good. Most of the SCI of PLES fell to Levels 1 and 2, with percentages of 64.14% and 33.93%, respectively, and there was less than 2% in Level 3. Beyond that, the average conflict indices of PLES is 0.134, indicating a better advantage in the spatial layout of PLES. Further, the expansion of the ecological area could help relieve PLES conflicts in the Yangtze River Delta agglomerations, and restrictions to the transformation of LPS land also contribute to PLES collaboration.

3.3. Discussion of the Study

Constructing a world-class agglomeration on the Yangtze River Delta is inevitable for China in its efforts to speed up development and participate in international competition. However, the problems of disordered development of land use have become major concerns in this region with the increase of the urbanization process. On the basis of PLES conflicts, this study provides a new perspective for understanding the coordination and allocation of regional land use in the Yangtze River Delta agglomerations. Based on the remote sensing image data, Shen et al. explored the spatio-temporal evolution characteristics of urban construction land and landscape patterns in the Yangtze River Delta agglomerations [37]. The results showed that the expansion rate of urban land in 2010–2015 was significantly high in this region, and that farmland had been heavily crowded out, which is consistent with this study. Supported by GIS data, studies on land use classes transformation and land use conflicts are becoming increasingly diversified. Taking the North Brabant region in the Netherlands as a case study, Wang et al. developed a generic framework to analyze the industrial land transition using vector data [38]; the analysis procedure can not only help to find the neighborhood land use interaction rules for the CA model, but also help to formulate a sustainable policy on land uses [39]. A two-dimensional model of land use conflict was built to anticipate and identify the areas of potential land use conflicts using public participation GIS data in Australia [40]. The research assessed land use conflicts integrated in two dimensions: the importance or intensity of landscape values and the land use preference directionality.

There are still some limitations to this paper. The spatial resolution of PLES was 1×1 km, which might have ignored landscape details in local regions. Driving factors that were used for building the suitability atlas were still deficient due to data availability restrictions, and more factors remain to further improve. Thus, further studies need to be carried out if high-resolution spatial data can be obtained. Another limited point is that the landscape patterns in the "red line" areas were identified as the fixed region in the scenario simulation, which was inconsistent with the actual situation. The scenarios associated with policy planning assumed in the model also bring errors. This paper is nonetheless expected to provide valuable reference information for regional planning.

4. Conclusions

The collaborative layout of PLES is significant to build a rational spatial development mode, constructing a sustainable development framework of the world-class city group. Identifying the spatial conflict of PLES on the basis of ecological-landscape science is a feasible approach with important practical significance to harmonize the relationships between population and natural environment. This paper established spatial-conflict indices to identify PLES conflicts for the Yangtze River Delta agglomerations, which play a significant strategic role in China's overall situation of modernization, but serious contradictions of land use have occurred due to rapid development and urbanization. A CA Markov model was also built to simulate the PLES in 2030 under two scenarios, BAU and CDS, to evaluate the influence of policy implementation on PLES conflicts. The ES and LPS of the Yangtze River Delta agglomerations showed a descending tendency during the period from 2010 to 2015, whereas EPS and PES had a small increase. EPS and PES squeezed ES and LPS with urbanization and industrial development in this region. PLES spatial conflicts continued during the period and seemed to gain momentum. On the basis of the scenario analysis for 2030, we concluded that the "ecological red line policy", appropriate restriction of urban expansion, and ecological management of the banks of the Yangtze River would be helpful in alleviating PLES conflicts and contributing to spatial structure and harmonizing. The Overall Plan for The Integrated Development of Ecology and Green in Yangtze River Delta was released in 2019, and aimed to coordinate regional development by optimizing the PLES [41]. Based on the findings of this study, it is expected to achieve the coordinated development of ecological civilization and socio-economic development under the guidance of the planning in this region. However, the situation is complex and needs more analysis and study. Further research might possibly focus on the systematic optimization of PLES on the basis of the spatial heterogeneity and identification of the conflict mechanisms of PLES.

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