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Ecological Zoning Management Strategies in China: A Perspective of Ecosystem Services Supply and Demand

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Abstract: Ecological zoning management aims to ensure ecological functions and improve environmental quality, serving as an essential means to optimize the development and protection of territorial space. However, comprehensive research on ecological zoning management that combines human needs with natural resources is still relatively scarce. In this study, we selected water yield (WY), food provision (FP), and carbon sequestration (CS) as the critical ecosystem services (ES) in China. An InVEST model, ecosystem services supply–demand index (ESI), random forest (RF), and geographically and temporally weighted regression (GTWR) were used to analyze the spatiotemporal characteristics and influencing factors of ES supply and demand, and the four-quadrant model was used to analyze the spatial matching patterns. The results showed that: (1) from 2005 to 2020, the supply and demand of WY, FP, and CS increased. Among them, WY, FP, and CS supply increased by 16.06%, 34%, and 22.53%, respectively, while demand increased by 5.63%, 12.4%, and 83.02%, respectively; (2) the supply of WY and CS follow a "high in the southeast and low in the northwest" pattern, while all of the demands exhibit a "high in the east and low in the west" pattern; and (3) the average ecosystem service supply–demand index (ESI) values for WY, FP, and CS in China are 0.45, 0.12, and −0.24, respectively, showing an overall upward trend. The study identified three dominant functional zones for WY, FP, and CS, and four classification management zones, including protection zones, conservation zones, improvement zones, and reconstruction zones. These research findings provide a scientific basis for future territorial space planning in China and the application of ecosystem service supply and demand in sustainable development.

Keywords: ecosystem services; supply–demand; spatial matching patterns; ecological zoning management strategy

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1. Introduction

China has proposed the concept of ecological civilization to address the challenge of economic structural adjustment [1], among which territorial spatial planning is regarded as an essential approach to further reconciling economic development and environmental protection [2,3]. The core issue in spatial planning is how to coordinate human activities with the protection of ecological patterns and resources [4]. Thus, spatial planning practices have begun to emphasize protecting the supply of sustainable natural resources as well as ecosystem structure and function, and as such, the environmental suitability and carrying capacity of natural resources are required as the foundation of multi-level spatial

planning [5]. However, solely relying on the indicator approach [6,7], previous studies on the carrying capacity of natural resources and environments cannot inform territorial spatial planning due to their lack of spatial features and insufficient consideration of human demands [8]. Ecosystem services (ES) have emerged as a key concept in linking natural ecosystems and human well-being; therefore, they can serve as a critical vehicle for valuing natural resources [9,10]. The latest national spatial planning framework proposes agricultural zones, ecological preservation zones, and urban development zones, highlighting water yield, carbon sequestration, and food provision as fundamental ES for human survival and development [11]. Considering the often unbalanced spatial distribution of ES supply and demand, fully understanding the spatiotemporal patterns of ES supply and demand is critical [12,13] for optimizing spatial layout and structural adjustment to ensure the rational allocation of resources among regions [14].

Early studies on ecosystem services focused on their monetization, calculating the value of ES through methods such as market substitution and value equivalency. To address the spatial limitations and scientific shortcomings of these valuation methods, later scholars integrated ecological principles and employed ecosystem process models, such as InVEST and CASA [15,16]. These models spatially and quantitatively reflect the supply levels of various services, providing effective tools for ecological zoning [17,18]. Currently, research on ecological zoning primarily selects indicators related to regional ecological conservation and economic development. Techniques such as matrix analysis [19,20], cluster analysis [21], multi-criteria decision analysis [22], and dynamic analysis [23] are employed to delineate ecological zones and determine their dominant functions and management measures. While methodological and conceptual studies prevail, there remains a scarcity of applied case studies related to policy [24]. Meanwhile, traditional ecological zoning predominantly focuses on safeguarding the scale and quality of ecosystems passively; in other words, most current research emphasizes the supply of ES, factors influencing them, and the trade-offs and synergies among these services, with less emphasis on assessing ecosystem service demands [25–28]. From a supply–demand perspective, strictly focusing on long-term protection from the supply side alone would hinder the effective realization of ecological spatial value, thereby impeding its crucial support for economic development. Conversely, prioritizing development solely from the demand side could lead to unregulated overuse of ecological spatial value, potentially resulting in irreversible degradation or even loss of ecological spaces, exacerbating the conflict between economic development and ecological conservation. Matching the supply and demand of ES couples natural ecosystems with socio-economic systems, accurately identifying imbalanced areas and enabling the planning of governance measures based on their spatial relationships.

Factors influencing ES supply–demand balance, directly or indirectly, encompass both natural ecological and socio-economic factors. Natural ecological factors are critical for ES supply capacity, covering aspects of land use and natural conditions [29]. For example, terrain affects water supply capacity, crop yields, and the spatial distribution of human activities [30,31]. Climate directly influences ecosystem services by altering ecological structures and biophysical processes [32–34]. Socio-economic factors are associated with human activities, including economic growth, industrial structure, and population, influencing ES demand levels [35]. Human activities indirectly impact ES supply functions by disturbing ecosystem components, structures, and processes [36]. Changes in natural ecological environments due to socio-economic development alter ES supply–demand relationships. For instance, population growth increases pressure on land use, triggering various land changes [37]. Changes in land use reflect human resource utilization [38], a direct manifestation of human impact on ecosystems and a key factor influencing changes in ecosystem services [39,40]. Socio-economic factors such as GDP and population are closely related [41]; GDP often has negative impacts on ecosystem services [42]. Therefore, a comprehensive framework is needed to deepen the study of ecosystem service supply–demand dynamics, explore influencing factors, and provide better scientific guidance for

national spatial planning. This is crucial for achieving a win-win situation with regards to ecological conservation and high-quality development.

Based on data availability and socioeconomic needs, this study aims to investigate the spatial patterns and driving factors of water yield (WY), food provision (FP), and carbon sequestration (CS) supply and demand in China from 2005 to 2020. Specifically, the objectives are to (1) elucidate the spatial patterns of ES supply and demand, (2) identify spatial mismatches between ES supply and demand and associated key environmental and social factors, and (3) clarify ecological management zones and propose management strategies. This research provides scientific guidance for improving policies related to ecosystem management and territorial spatial planning under different ES matching models.

2. Materials and Methods

Combining ecosystems and human systems, this study developed a research framework of "integrated assessment of supply and demand, matching of supply and demand, drivers analysis, and zoning and classification management" from the perspective of ES supply and demand (Figure 1). The work involved: (1) assessing the supply and demand of WY, FP, and CS, and analyzing the drivers of ES from the supply side in 31 provincial administrative regions in mainland China (Figure 2); (2) quantitatively and spatially analyzing their matching characteristics based on quadrant models and ESI; and (3) formulating zoning and classification management strategies based on the results of the ESI and the four-quadrant model.

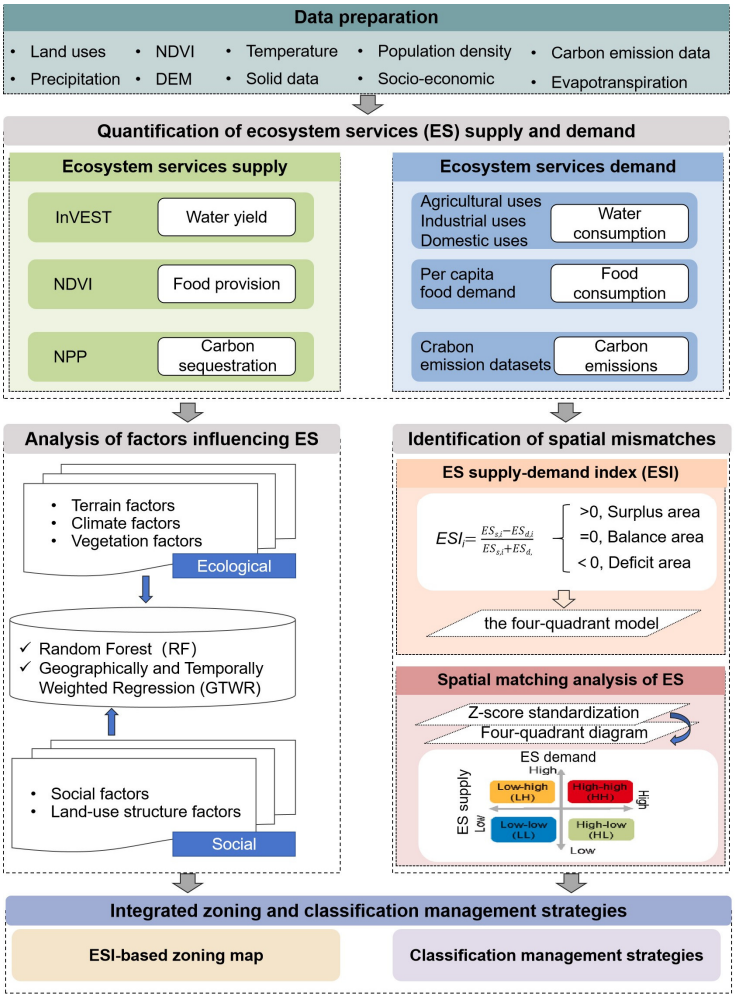

Figure 1. Research framework.

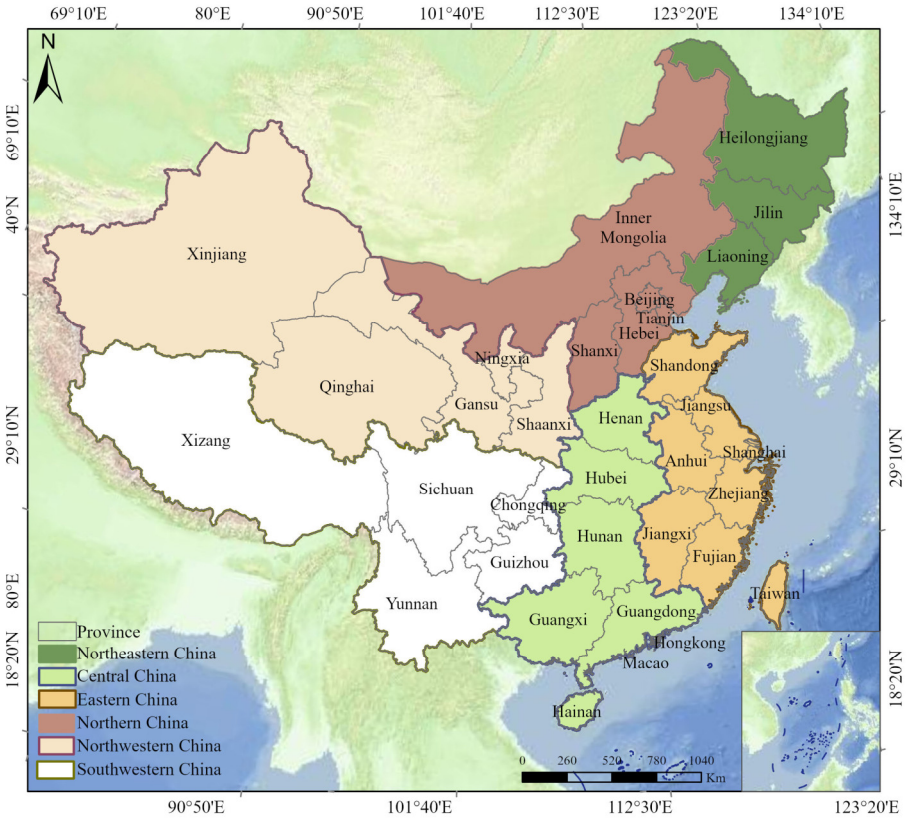

Figure 2. Study area.

2.1. Data Sources

The data employed in this study include: (1) Population data from WorldPop (https://www.worldpop.org/, accessed on 10 September 2023). Potential evapotranspiration data were derived from the Global Aridity and PET Database, with China-specific data selected from the global potential evapotranspiration distribution map. (2) Land use/land cover data, NDVI, precipitation data, temperature data, and DEM data from the Resource and Environmental Science Data Center (https://www.resdc.cn, accessed on 21 July 2023). (3) GDP, food provision, food demand, and water demand data from statistical yearbooks and water resources bulletins of provinces (https://www.stats.gov.cn/, accessed on 13 January 2024). (4) Carbon emissions data from the China Emission Accounts and Datasets (CEADs). All raster data were uniformly resampled to 1 km spatial resolution.

2.2. Quantifying ES Supply and ES Demand

Using ecological and socio-economic models, this study spatially mapped the supply and demand of three ES: water yield (WY), food provision (FP), and carbon sequestration (CS).

WY supply was obtained using the InVEST 3.14.1 model's water production module [30]. According to the hydrothermal balance principle, the module considers the difference between actual evapotranspiration and precipitation as the water supply service quantity. The consumption of water resources for human activities and daily life, including agricultural, industrial, domestic, and ecological purposes, constitutes the demand for WY [31]. Given the spatial heterogeneity of WY demand, it is calculated based on the water consumption per capita and population density at the grid scale. Detailed formulae for the InVEST model and WY demand are provided by [32].

The spatial distribution of crop production is primarily based on total food output and the crop yield per unit area of cultivated land [33]. However, it does not account for the impact of farmland quality, water, soil, and management on food provisions. Therefore, this study allocated food to each grid according to the proportion of each cultivated land grid's

vegetation condition index (VCI) across the research area [34]. VCI was calculated based on NDVI. FP demand was calculated by multiplying the food consumption per capita by the population density [43]. We depicted the distribution of food demand by multiplying food consumption per capita by population density.

Net primary productivity (NPP) is an essential indicator of plant ecological function and ecosystem carbon sequestration capacity. The regional carbon sequestration capacity was calculated from NPP, commonly used to assess carbon sinks and sources [44]. Similar to FP, the demand for CS was calculated using carbon emissions per capita and population density.

2.3. Analysis of the Influence of Environmental and Social Factors on ES

2.3.1. Variable Selection

Synthesizing previous studies [38–41,45–49] and considering China's socio-economic and natural background, we selected nine variables that have direct or indirect effects on ES to clarify the key factors influencing ecosystem services supply and the spatiotemporal differentiation of these factors (Table 1).

Table 1. Variables used to study the influencing factors on ecosystem services supply.

Types	Subtypes	Driving Factors	Code
Natural factors	Terrain factors	Elevation	DEM
		Terrain slope	Slope
	Climate factors	Annual average precipitation (mm)	Pre
		Annual average temperature (°C)	Temp
	Vegetation factors	Normalized differential vegetation index	NDVI
Anthropogenic factors	Social factors	Economic density (10^4 yuan/km^2)	GDP
		Population density (person/km^2)	POP
	Land use structure factors	Construction land proportion (%)	CLP
		Forest land proportion (%)	FLP

2.3.2. Random Forest

Regression analysis is a standard method for identifying influences, categorized into "global" and "local" regression [50]. However, it does not enable the comparison of the importance of significant influential factors. To address this limitation, we employed the random forest (RF) method. RF is a machine learning technique designed to enhance classification and regression trees by generating and averaging a series of de-correlated trees [51]. It has been widely utilized to predict the importance of explanatory variables to the target variable. The importance of variables is reflected by the degree to which the decrease in data accuracy affects the accuracy of prediction results [52]. We used RF to detect the relative importance of drivers (the independent variables) in each ES supply and demand relationship (dependent variable) with the "Random Forest" package in R version 3.6.3 [51]. In this analysis, 80% of the dataset was used as the training set and 20% as the test set.

2.3.3. Geographically and Temporally Weighted Regression

The geographically and temporally weighted regression (GTWR) method introduces the temporal dimension into the geographically weighted regression (GWR), effectively overcoming the limitation of considering only spatial effects [53]. GTWR reveals the heterogeneity of variables over time and space, providing a better explanation of the spatiotemporal relationship between variables and dependent variables [54]. Therefore, this study employs GTWR to capture the spatiotemporal heterogeneity of factors influencing ES. Adaptive bandwidth was used for more accurate results, utilizing the AICc criterion implemented in ArcGIS 10.3.

2.4. Analysis of Matching ES Supply and Demand

2.4.1. Quantitative Matching Analysis

ES supply and demand exhibit spatial heterogeneity, characterized by spatial mismatch. The ecological supply–demand index (ESI), linking the actual supply of ES and human demand, can be used to reveal the nature of surpluses or deficits [55]. ESI is calculated according to the following formula:

$$ESI_i = \frac{ES_{s,i} - ES_{d,i}}{ES_{s,i} + ES_{d,i}} \quad (1)$$

where $ES_{s,i}$ and $ES_{d,i}$ are the supply and demand of ES, respectively. When $ESI_i > 0$, supply exceeds demand, indicating a surplus; when $ESI_i = 0$, there is balance; and when $ESI_i < 0$, it indicates a deficit.

2.4.2. Spatial Matching Pattern Analysis

While ESI is valuable for visualizing mismatched states, it introduces a "patchiness effect" [56]. It is more feasible for stakeholders to implement management measures within an administrative area than for a grid cell. In this study, a four-quadrant model was used to explore the pattern of ecosystem service supply and demand in city-level administrative regions. The supply and demand of ES were first normalized by z-scores [57], and a two-dimensional coordinate system was constructed with normalized supply as the *X*-axis and demand as the *Y*-axis to obtain four matching patterns: high supply–high demand (high–high), high supply–low demand (high–low), low supply–low demand (low–low), and low supply–high demand (low–high) [58].

2.4.3. Integrated Zoning and Classification Management Strategies

In this paper, an integrated zoning model for ES management is proposed, which combines the matching relationship and pattern between ES supply and demand. By comparing the ESI values of WY, FP, and CS through spatial overlay techniques [57], the region is divided into three functional areas. Then, they are divided into four categorical strategic regions based on the results of the four-quadrant model, and classification management strategies are proposed [59]. This approach highlights the dominant functions and the balance of supply and demand in the regional space, thus improving the effectiveness of regulation [60].

3. Results

3.1. Spatiotemporal Changes in ES Supply and Demand

3.1.1. Spatial-Temporal Changes in ES Supply

Temporally, from 2005 to 2020, the supply of WY and FP in China initially increased and then stabilized, while the supply of CS continuously grew (Table 2). Specifically, the supply of WY increased from 1909.15 to 2331.80 billion m^3, marking a growth of 16.06%. The supply of FP rose from 584.18 to 782.84 million tons, an increase of 34%. Additionally, the supply of CS grew from 4470.00 to 5476.90 million tons, an increase of 22.53%. These changes in the supply of the three ES exhibited evident spatial heterogeneity (Figure 3(a5,b5,c5)). There was a significant decrease in WY along the southern coast. Increases in the supply of WY and FP were mainly concentrated in the Yangtze River Basin, while the increase in the CS supply was primarily concentrated in central China.

Figure 3(d1–d3) show the varying performances of the three ES at the provincial scale. Significant variation among provinces regarding resource supply reflects regional disparities in economic development and natural resource endowment. Based on the comparison of the average supply values (Figure S1), the lowest WY values were found in Beijing (1.29 billion m^3), Tianjin (1.53 billion m^3), and Ningxia (1.80 billion m^3), while the highest provinces were in Sichuan (190.97 billion m^3), Xizang (154.79 billion m^3), and Guangxi (154.11 billion m^3). Regarding FP, Henan, Heilongjiang, Shandong, and Sichuan

were the top suppliers during the study period, with averages of 693.85, 573.54, 567.35, and 430.51 million tons, respectively, reflecting their roles as major agricultural regions. Provinces with lower food supply were mainly located in high-altitude, semi-arid regions of Northwest China, such as Xizang (12.86 million tons) and Qinghai (16.46 million tons), and economically developed regions, such as Beijing (11.59 million tons) and Shanghai (13.14 million tons). For CS, the top three provinces were Yunnan, Sichuan, and Heilongjiang, with values of 618.01, 478.90, and 355.04 million tons, respectively, while the bottom three were Shanghai, Tianjin, and Ningxia, with values of 0.51, 4.05, and 10.23 million tons, respectively.

Table 2. Supply and demand of water yield, food provision, and carbon sequestration in China.

Year	Water Yield (Billion m^3)		Food Provision (Million Tons)		Carbon Sequestration (Million Tons)	
	Supply	Demand	Supply	Demand	Supply	Demand
2005	2009.15	799.07	584.18	521.61	4470.00	5398.28
2010	2315.72	849.61	670.62	554.05	4556.04	7904.55
2015	2237.09	880.65	782.00	547.20	5217.85	9253.50
2020	2331.80	844.07	782.84	586.29	5476.90	9879.75

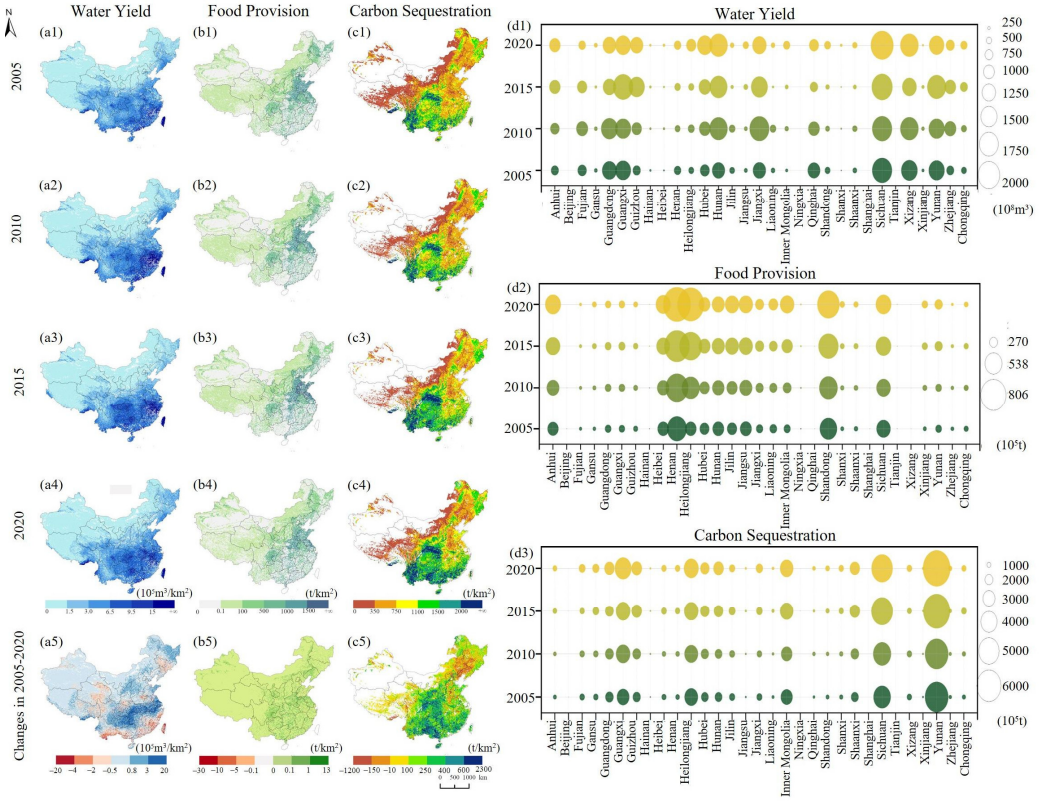

Figure 3. Spatial patterns and changes in the supply of (**a1**–**a5**) WY, (**b1**–**b5**) FP, and (**c1**–**c5**) CS in China, and (**d1**) WY, (**d2**) FP, and (**d3**) CS by province. WY: water yield; FP: food provision; CS: carbon sequestration.

Spatially, there was little difference in the spatial differentiation patterns of ES across different periods, but there were significant differences among different ES (Figure 3). The WY supply demonstrated a spatial pattern of "high in the south and low in the north" (Figure 3(a1–a4)), directly related to the average annual precipitation and the topography of the watershed. High-value areas for FP were mainly located in the Northeast Plain, the North China Plain, the Middle-lower Yangtze Plain, and river-loop irrigation areas (Figure 3(b1–b4)). CS was significantly higher and expanding slightly over time in the

southeastern hills, the Yunnan-Guizhou Plateau, and the Sichuan Basin (Figure 3(c1–c4)), where the climatic conditions are suitable for vegetation and low-intensity human activities.

3.1.2. Spatial-Temporal Changes in ES Demand

Temporally, the demand for the three ES increased during the study period (Table 2), indicating a growing dependence on ES for regional development. The demand for WY remained relatively stable, increasing from 799.07 to 844.07 billion m^3. The demand for FP rose from 52.16 to 58.63 million tons, with a modest growth rate of 12.4%. The demand for CS increased significantly, from 5398.28 million tons in 2005 to 9879.75 million tons in 2020, reflecting an 83.02% growth rate. Notably, the growth rate of CS demand decreased from 46.43% (2005–2010) to 17.07% (2010–2015) and further to 6.78% (2015–2020), closely related to the implementation of the carbon emission reduction policy in China. Figure 4(d1–d3) illustrate the varying demands for the three ES across provinces. Almost all provinces experienced increases in demand for the three ES. According to average values during the study period (Figure S2), Guangdong, Shandong, and Sichuan were high-demand regions for FP, with demand values of 411.87, 375.92, and 374.2 million tons, respectively. Provinces with smaller populations, such as Xizang, Qinghai, and Ningxia, had lower demand values of 13.07, 20.74, and 26.21 million tons, respectively. The highest demand for CS was concentrated in populous provinces and provinces rich in mineral resources: Shandong, Hebei, Jiangsu, and Liaoning had carbon demands of 1132.280, 1102.864, 865.070, and 717.645 million tons, respectively. Due to its developed livestock industry, Inner Mongolia also had high carbon emissions, reaching 925.871 million tons.

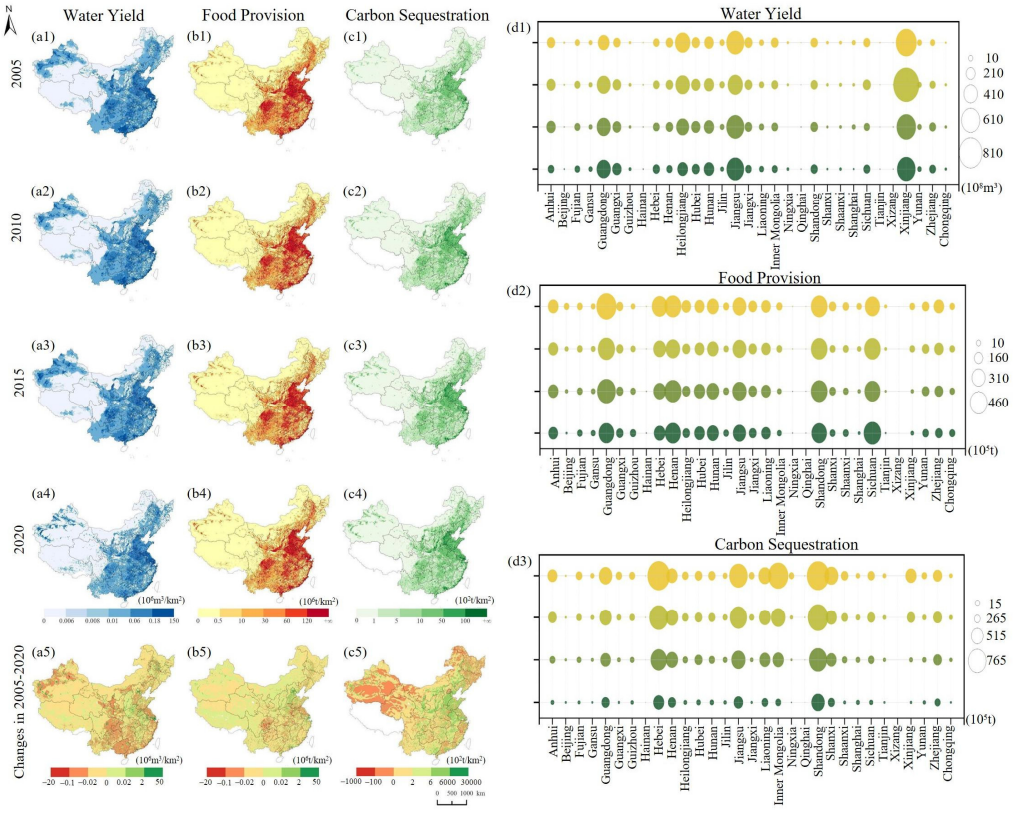

Figure 4. Spatial patterns and changes in the demand for (**a1–a5**) WY, (**b1–b5**) FP, and (**c1–c5**) CS in China, and (**d1**) WY, (**d2**) FP, and (**d3**) CS by province. WY: water yield; FP: food provision; CS: carbon sequestration.

Spatially, the demand for the three ES in China displayed a distribution pattern of "high in the east and low in the west" (Figure 4). The areas with high demand for ES were mainly distributed in the regions with large populations and high levels of urbanization,

especially for WY and FP. The high-demand areas for CS are expanding, gradually radiating outward from initial high-demand points.

3.2. The Influence of Environmental and Social Factors on ES

3.2.1. Importance of Factors Influencing ES

Random forest regression was introduced to analyze the importance of factors influencing ES in China from 2005 to 2020. To avoid the effect of covariance, factors with a variance inflation factor (VIF) greater than 10 were excluded (Table S1), and the importance of the remaining factors is shown in Figure 5. In terms of variable importance, the significance of Slope consistently ranked among the top three. For WY, the importance of Pre, Slope, and Pop consistently ranked among the top three. For FP, GDP, Slope, and Pre consistently held the top three positions in importance. The importance of NDVI for both WY and FP decreased. Regarding CS, the influence of Pop was consistently the highest, followed by NDVI and Slope, with the importance of Temp and Pre increasing.

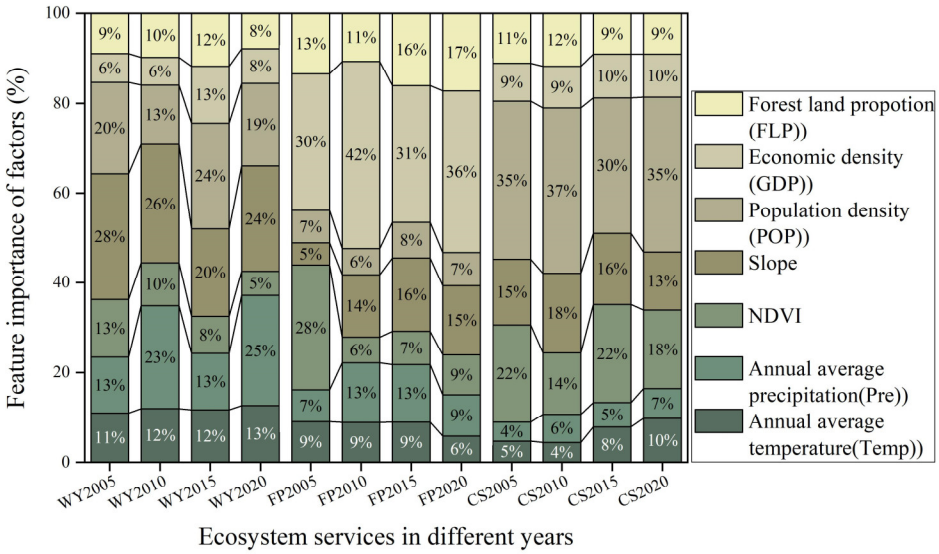

Figure 5. Importance of factors influencing ecosystem services supply in China from 2005 to 2020. WY: water yield; FP: food provision; CS: carbon sequestration.

3.2.2. Implications of GTWR Model Results on Factors Influencing ES

The GTWR model was used to analyze the spatial and temporal differentiation of the influencing factors from 2005 to 2020. A comparison with traditional models (OLS and GWR) in terms of AICc and R2 showed a better fit for GTWR (Table S2). An important feature of GTWR is the ability to estimate local regression coefficients. The regression coefficients of all research units were significant ($p < 0.05$) at the $\alpha = 0.01$ level. To enhance the comparability of the results, the same segmentation points were used for the regression coefficients of the same variable in different years. The spatial distribution of GTWR coefficients in China from 2005 to 2020 is described in Figures S3–S5, clearly showing the spatiotemporal variations in the relationships between ES and their influence factors. In terms of WY, the GTWR coefficients for precipitation in all provinces were positive, indicating that precipitation has a positive impact on water production, while the impact of slope is negative. For FP, the GTWR coefficients for NDVI in all provinces were positive. The number of provinces negatively affected by GDP has increased, while those affected negatively by temperature and slope have decreased. Regarding CS, the GTWR coefficients for NDVI in all provinces were also positive. Between 2005 and 2010, the number of provinces positively affected by slope increased, and then stabilized. By 2020, GDP mainly had a negative impact. The impact of slope and precipitation has remained relatively stable.

3.3. Supply–Demand Matching Characteristics of ES

3.3.1. Spatial-Temporal Characteristics of ESI

The supply–demand matching model was used to measure the ESI in China and calculate the average value over the study period (Table 3). Overall, the average ESI values of the three ES in China, from greatest to least, were as follows: WY (0.45) > FP (0.12) > CS (−0.24). The average ESI values of WY and FP were greater than 0, indicating an oversupply of water yield and food provision during the period that satisfied internal demand. In contrast, CS was undersupplied. Specifically, the ESI value of FP increased from 0.06 in 2005 to 0.14 in 2020, an increase of approximately 2.5 times, although it still indicated a "tight balance". For CS, the ESI declined from −0.19 in 2005 to −0.29 in 2020, a reduction of nearly three times. However, since 2010, the values have stabilized between −0.27 and −0.29, with no further deterioration.

Table 3. ESI of ES in China from 2005 to 2020.

Ecosystem Services	2005	2010	2010	2020	Average
Water yield	0.43	0.46	0.44	0.47	0.45
Food provision	0.06	0.10	0.18	0.14	0.12
Carbon sequestration	−0.09	−0.27	−0.28	−0.29	−0.24

During the study period, the spatial distribution pattern of ESI remained stable within the same ES (Figure S4), whereas it varied significantly among different ES (Figure 6). The deficit areas of WY were mainly distributed in northwestern China. For FP, the surplus areas were primarily located in northeastern, northern, and central China, covering the major grain-producing areas, while the deficit areas were south of the Yangtze River and northwestern China. The deficit areas of CS were mainly situated in the northern regions. At the provincial level, the average ESI values of the three ES showed varying degrees of surplus, balance, and deficit (Figure 7). For WY, all provinces except for seven, including Ningxia, Shanghai, and Beijing, were in surplus. Regarding FP, nearly half of the provinces were in deficit, with Guangdong, Zhejiang, and Fujian being the most severe. Provinces lacking grain mainly fall into two categories: those with high population density, frequent human activities, and high environmental material demand, such as Beijing and Shanghai, and those limited by climate and arable land area, predominantly consisting of sloped farmland with low per-unit grain yields, such as Qinghai and Xizang. For CS, the ESI showed varying degrees of deficit, but most provinces showed a mitigating trend after 2010, including Shanghai, Tianjin, and Beijing.

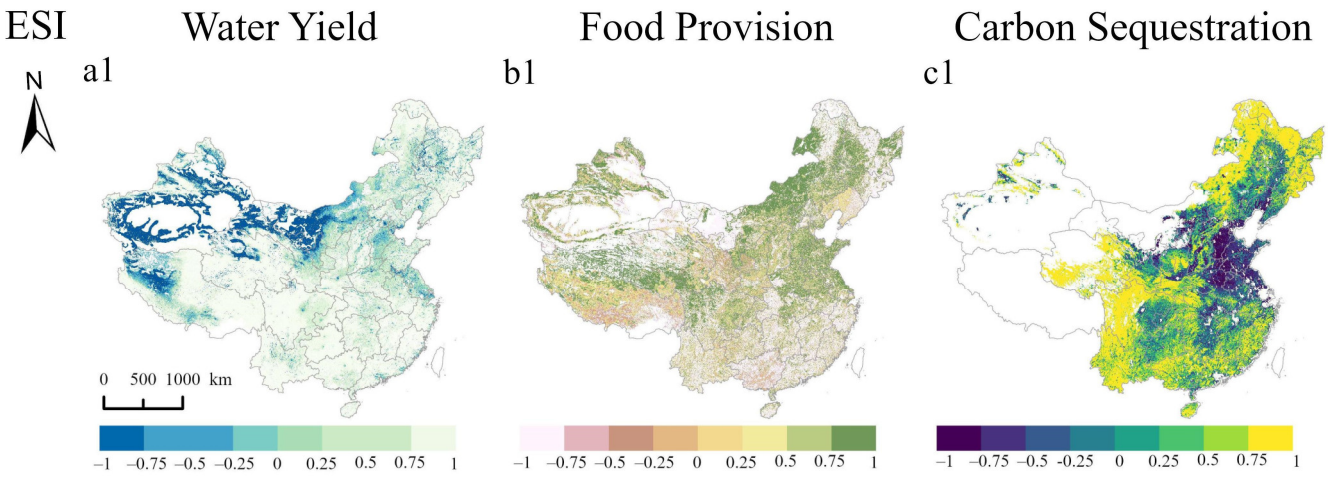

Figure 6. Spatial patterns of the ESI averages for Water yield (**a1**), Food provision (**b1**), and Carbon sequestration (**c1**) in China during the study period.

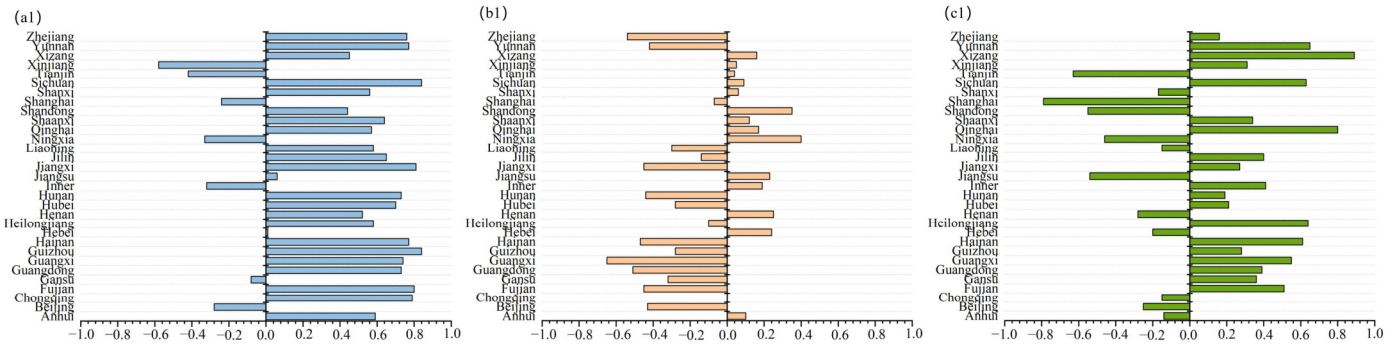

Figure 7. The average values of ESI for (**a1**) water production, (**b1**) food provision, and (**c1**) carbon sequestration for each province in China during the study period.

3.3.2. Spatial Matching and Integrated Zoning

Using the four-quadrant model, we analyzed the supply–demand matching patterns of ES (Figure 8a–c) and counted the number of cities in each pattern. Based on these city counts, the primary spatial matching patterns for the ES were identified (Figure 8d). WY was dominated by low–low spatial matches, followed by low–high spatial mismatches, involving 166 and 79 cities, respectively (Figure 8a). High–high spatial matching areas were mainly located in central, southern, and northeastern China, while low–high spatial dislocation areas were concentrated in coastal regions like Tianjin, Hebei, and Jiangsu, as well as agricultural and pastoral development areas such as Inner Mongolia, Henan, and Xinjiang. High–low spatial dislocation areas were primarily found in southern regions with numerous rivers. FP primarily exhibited low–low spatial matching, covering 181 cities, mainly in western China (Figure 8b). The second most common pattern was high–high spatial matching, with 93 matching cities, mainly in central, northern, and northeastern China. Although these cities have high FP supply levels, their large populations result in food provision shortages. Therefore, these cities should be monitored, as their rapid urban land expansion may continue encroaching on agricultural land. CS was primarily characterized by high–high matching areas, followed by high–low spatial dislocation areas (Figure 8c). There were 121 cities in high–high spatial matching areas, mostly in regions with high forest coverage and some desertification control areas, such as Xinjiang, where industrial and agricultural activities are intensive. High–low spatial dislocation areas were mainly located in regions with rich forest resources and good ecological environments, but relatively low economic development and low levels of industrialization and urbanization, such as Heilongjiang, Yunnan, Guizhou, and Gansu.

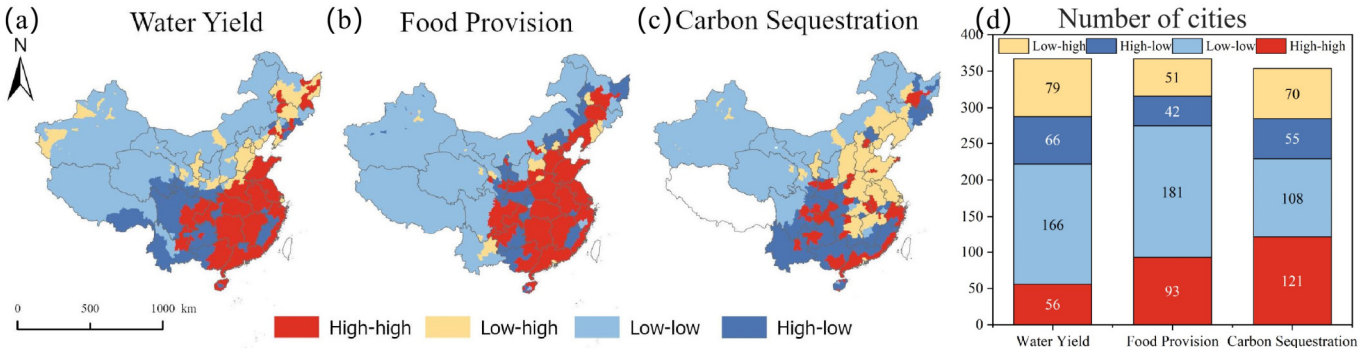

Figure 8. Spatial matching patterns of (**a**) WY, (**b**) FP, and (**c**) CS in China, and (**d**) number of cities for each pattern.

Zoning based on the ESI (Figure 9a) led to the derivation of further classification management strategies from the matching patterns. By integrating the three ES, an integrated management model was obtained (Figure 9c). China was divided into three main functional

zones: water production area, food provision area, and carbon sequestration area, which broadly align with China's functional zoning. The area proportions of WY, FP, and CS were 54%, 30%, and 16%, respectively. Regarding classification management strategies (Figure 9b), protection zones primarily included central, northern, and northeastern China, where the ES supply–demand matching type was predominantly high-high. This area is characterized by plains and hilly terrain, with land use types mainly comprising arable land and construction land, and a high intensity of human activity. Conservation zones have high topography and excellent ecological environments, providing a solid ecological barrier. With slow urbanization, low economic development and population density, and minimal human development and construction activities, the capacity to supply ecosystem services is usually higher than the level of demand. Improvement zones are characterized by a simple industrial structure, a weak economic base, and limited ecological resources, leading to low ecological supply and demand. Reconstruction zones are mainly concentrated in the core areas of major cities. These zones are densely populated, with high levels of economic development and urban development intensity, but with scarce ecological resources and a weak ecological carrying capacity, making it difficult to meet the demand for ecosystem services.

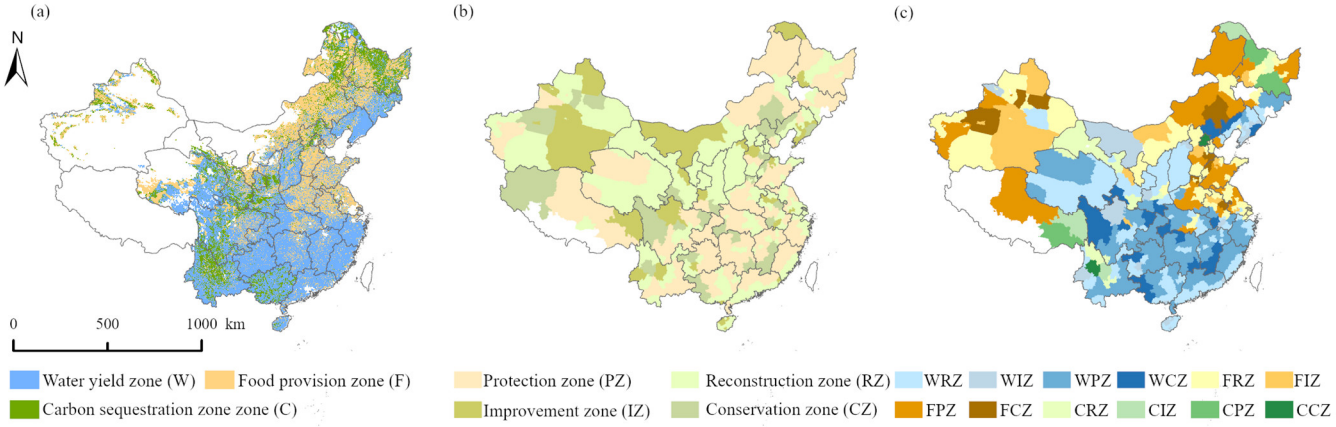

Figure 9. Functional zones (**a**), classification management strategies (**b**), and environmental management zoning (**c**) in China. The first letter of the WRZ in (**c**) represents the functional area type in (**a**): water yield zone (W). The last two letters represent the protection strategy in (**b**): reconstruction zone (RZ), and similarly for others.

4. Discussion

4.1. The Mismatching of ES Supply and Demand

To demonstrate the robustness of our ecosystem service results, we compared them with findings from relevant studies and reports. The water yield computed in this study aligns with the surface water resources quantity announced by the Water Resources Bulletin of China, with $R^2 = 0.94$. Additionally, the spatial distribution trend of water yield aligns with the previous findings [61], indicating the feasibility of our simulations. For ES demand assessment, one approach relies mainly on expert opinion-based scoring [62–64]. This method has relatively low data requirements and can easily depict various ES supply and demand levels in specific regions, but it can only provide relative values. Another approach involves using indicators such as population density, GDP, and land use as proxies to assess overall ecosystem demand [64]. However, these indicators may not fully represent the ES demands of different regions and populations. To improve the accuracy of our results, we selected quantitative indicators for different services. The findings indicate a spatial pattern of ecosystem service demand characterized by "higher in the east and lower in the west", which is consistent with the overall pattern of ecosystem demand in China [65].

Due to the influence of natural endowment and human activities, there is a widespread spatial mismatch between the supply and demand of ES [66,67]. This supply–demand

matching pattern tends to be regional, often manifesting as mismatches within a particular natural area or between artificially defined administrative regions. This study found that the supply–demand conflict in China is mainly reflected in the difference in supply levels between the north and south directions and the difference in demand levels between the east and west, with the largest ESI value for WY.

For WY, most of China's cities have already balanced their supply and demand due to sufficient water sources. However, northern China, especially in northwestern regions such as Ningxia and Gansu, still faces challenges in meeting water demand due to insufficient water supply, particularly in the context of rapid urbanization in northwestern China. Therefore, ES shortages in some cities can be addressed through internal redeployment. Protecting ecological land from being converted to construction land is a better option to solve the deficit.

Regarding FP, while China's current food supply is adequate overall, there is a noticeable regional imbalance. Based on Figure 3, it is evident that the high-yield food production areas in the northern regions are expanding, while Figure 4 indicates an increasing demand for food provision in the southern regions. These trends exacerbate the supply–demand imbalance in the southern regions (Figure 6), suggesting the potential formation of a "north-to-south grain diversion" pattern. This pattern puts immense pressure on manpower and transportation capacity in the production areas during harvest and transport seasons and leads to increased consumption of natural resources in the north, further exacerbating economic and environmental imbalances between the northern and southern regions.

In terms of CS, between 2005 and 2020, the supply increased in most regions but fell far short of meeting the demand for CS. Developed regions like Shanghai and Jiangsu exhibited poor ESI, identifying them as demand hotspots, primarily due to significant industrial emissions, indicating the regions as priority areas for reducing carbon emissions. The CS deficit can be addressed by reducing internal emissions, increasing internal supply, or using ecological compensation plans (such as through the PES scheme). China's total ESI values have increased, attributed to policies such as ecological restoration projects and optimizing energy structures (NFGA, 2021).

4.2. Ecological Zoning Management Strategies Based on ES

Spatially, China exhibits significant imbalances in ES supply and demand, particularly in developed urban clusters. Therefore, it is essential for managers to understand the surplus and deficit areas of ES supply and demand, addressing supply–demand deficits as a priority in ecological management. This requires formulating localized ecological management measures to ensure the orderly development of natural resources and the rational allocation of industrial development [68]. The delineated ecological management zones are broadly consistent with China's major function-oriented zoning, validating the rationality of the findings. Based on our analytical results, the following suggestions are proposed to address regional supply–demand deficits:

(1) As demonstrated in Section 3.2, driving factors have varying impacts across different times and spaces. Regional ecological management strategies need to consider this spatiotemporal heterogeneity to effectively address the unique conditions of each locality [45,69]. Slope and socioeconomic factors (GDP, population) have a significant impact on ES. Steep slopes restrict human activities, providing safe spaces for ecosystems to self-reinforce. Conversely, in areas with gentle slopes, such as plains, human land development efficiency is higher [70], making ecosystems more vulnerable to damage, hence the need for prioritized protection of plain regions. Socioeconomic factors play a crucial role in the supply and demand mechanisms for ES [71]. For instance, the economic development of large urban clusters like the Pearl River Delta and the Beijing-Tianjin-Hebei region often comes at the expense of the ecological environment, failing to achieve synergy between economic development and ecosystem services. Therefore, curbing the disorderly expansion of urban and rural construction areas is urgent.

(2) Based on the ES supply–demand matching characteristics, regional balance can be achieved by increasing or reducing demand. We propose different management strategies for the four classifications (Table 4). Protection zones have high levels of socio-economic development, high ecological backgrounds, and ecosystem service demands. With their economic and ecological advantages, realizing a win-win situation for regional ecological protection and economic development is crucial. Maintaining and protecting the current ecological base while enhancing its service functions and ecological benefits through ecological restoration is essential. Integrating ecosystem assessment with urban planning will guide the orderly layout of industries and populations, reducing pressure on ecosystems from new development and construction activities.

Table 4. Differentiated ecological zoning management strategies based on ecosystem services.

Classification	Characterization of Ecosystem Services	Ecological Zoning Management Strategies	Example
Protection zones	high supply, high demand	1. Integrating urban planning with ecosystem services, guiding the orderly distribution of industries and population. 2. Reconstructing or transforming ecological node spaces, combining local humanities and commercial resources to promote eco-tourism and cultural tourism industries.	Weifang develops leisure and sightseeing agriculture; Wenzhou builds the green ecological trail.
Conservation zones	high supply, low demand	1. Promoting ecotourism development by relying on characteristic scenic resources. 2. Implementing strict protection of large ecological sources within the zone, restricting development and construction to ensure the function of the green ecological barrier.	Cangzhou develops ecotourism; Chengde provides ecological security for Beijing-Tianjin-Hebei.
Improvement zones	low supply, low demand	1. Establishing nature reserves or ecological parks. 2. Protecting and restoring natural vegetation through ecological restoration; constructing artificial forests and wetlands to diversify ecological land use. 3. Leveraging agricultural and tourism resources to foster green ecological industries.	Baoding develops green agriculture; Chamdo supplements ecological land through artificial forestation.
Reconstruction zones	low supply, high demand	1. Building more greenways to connect ecological nodes into green corridors and rings, etc., forming a complete and continuous green ecological network. 2. Appropriately releasing land for construction or converting inefficient industrial land to expand urban blue-green space. 3. Strengthening the construction of street green space, thematic pocket parks, and promoting three-dimensional greening. 4. Increasing investment in technology and engineering to upgrade the ecological efficiency and service capacity of green spaces.	Shanghai implements green roofs, vertical greening, greening along the mouth, and trellis greening projects; Beijing adds new urban green spaces, recreational parks, urban forests, pocket parks, and small micro green spaces.

(3) Conservation zones have slow urbanization, and low economic development and population density. They possess robust ecological foundations with minimal human disturbance, providing high-quality ecosystem services to their surroundings and playing a crucial role in regional regulation and buffering [48,72]. Establishing urban development boundaries is essential to prevent natural lands from being converted into artificial landscapes, thereby maintaining ecosystem integrity. These regions are less efficient in developing and utilizing ecological resources. Therefore, managing and protecting ecological source areas while moderately utilizing scenic resources for eco-tourism is wise.

(4) Improvement zones have a relatively simple industrial structure, weak economic foundations, and limited ecological background and ecosystem service demands. For these regions, management strategies should focus on preserving existing ecosystem services,

avoiding unnecessary development and destruction. Firstly, this can be achieved through establishing nature reserves or ecological parks. Secondly, through ecological restoration, natural vegetation can be protected and restored, while artificial forests and wetlands can be constructed to diversify ecological land use. Finally, further adjustments and the development of existing ecological spaces should prioritize eco-economic considerations. This could include, for instance, leveraging agricultural and tourism resources to foster green ecological industries, ensuring these activities do not adversely impact ecosystem services, and promoting sustainable resource utilization.

(5) Reconstruction zones are characterized by high population density, intense urban development, severe scarcity and fragmentation of ecological land, and a significant imbalance between supply and demand. Large-scale construction of urban ecological land is impractical due to high building density and scarce land resources. Therefore, it is necessary to strictly control the blind expansion of construction land strictly and reduce demand from the source. Moreover, increasing technological and engineering investments to enhance the ecological benefits and service capabilities of green spaces within the region is crucial. Optimizing the use of existing scattered and linear informal green spaces and unused areas through initiatives like street green space construction, themed pocket park development, and three-dimensional greening promotion is essential to expand urban green space coverage through "filling in the gaps".

(6) Based on the refinement of ecosystem service supply and demand, establishing an ecological compensation mechanism can balance ecological conservation and socioeconomic development. On the one hand, the spatial heterogeneity of ES supply and demand often leads to ecological surplus and deficit situations even within the same region. Interregional ecological compensation is an effective mechanism to address imbalances in ES supply and demand across different areas. On the other hand, using the quantity of ES supply and demand as a reference for ecological compensation helps determine the scope and financial standards for compensation and reallocates compensation funds between service beneficiary and provider areas, promoting social equity and ensuring the coordination of ecological interests [73,74].

4.3. Limitations and Prospects

This paper focuses solely on exploring the matching of supply and demand for WY, FP, and CS, contributing to comprehensive information for ecological management decisions. However, there are limitations to this study that can be further improved upon. Firstly, future research should comprehensively explore various types of ES, such as soil conservation and habitat quality, to enrich the study of ecosystem supply–demand matching patterns and integrated management. Secondly, although this study reveals relationships between ES and various influencing factors, it does not imply causality. The mechanisms of their interactions need further investigation. Lastly, the supply and demand of ES are influenced by the existing ecological systems of cities and their degree of development. Achieving a complete balance of ES supply and demand solely within modern cities is challenging, and self-sufficiency may not be the optimal solution. ES mismatches can be addressed through trade, transportation, and other measures. Therefore, while the study categorizes different types of regions, it is recommended that future research introduce ES flow to reveal the patterns of flow and transfer of ES from supply to demand areas.

5. Conclusions

This paper quantified the spatiotemporal characteristics and matching patterns of WY, FP, and CS supply and demand in China from 2005 to 2020, further dividing the ecological zones based on this analysis. Supported by RF and GTWR models, key influencing factors and their impacts across temporal and spatial scales were identified. The main findings were as follows: (1) the supply and demand of these three ES in China have increased during the study period. Spatially, the supply of WY and CS exhibits a "high in the south, low in the north" pattern, while the supply of FP shows a "high in the north, low in the

south" pattern. The demands for all three types of ES show a "high in the east, low in the west" pattern. (2) The ESI values of WY and FP show an increasing trend, while the ESI values of CS stabilize after a significant decline from 2005 to 2010. (3) The importance of the social factors was generally higher than that of the environmental factors. Slope consistently ranked among the top three in terms of importance for the three ecosystem services, with predominantly positive impacts on WY and CS, and negative impacts on FP. (4) Spatial matching patterns vary, with WY primarily showing low–low and low–high matches, while FP and CS primarily exhibited high–high and low–low matches. Based on these supply–demand characteristics, three main functional zoning areas and four management strategies were proposed. These results have important practical significance for improving the ES management of China in accordance with local conditions, which will inform China's future territorial spatial planning given evidence from a science-based study of natural resources and assessment of environmental carrying capacity. This study also showcases the potential implications of in-depth supply–demand analysis of ecosystem services for various fields of sustainable development.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/land13071112/s1, Figure S1: Average values of water yield (WY), food provision (FP), and carbon sequestration (CS) supply by province; Figure S2: Average values of water yield (WY), food provision (FP), and carbon sequestration (CS) demand by province; Figure S3: Spatial distribution of GTWR coefficients of factors influencing water yield in China from 2005 to 2020; Figure S4: Spatial distribution of GTWR coefficients of factors influencing food provision in China from 2005 to 2020; Figure S5: Spatial distribution of GTWR coefficients of factors influencing carbon sequestration in China from 2005 to 2020; Figure S6: Spatial patterns of ESI of Water yield, Food provision, and Carbon sequestration in China during 2005–2020; Table S1: VIF of driving factors; Table S2: Assessment of GTWR model.

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