LAND USE TRANSFORMATION AND ECOSYSTEM SERVICE VALUE FROM THE PERSPECTIVE OF "PRODUCTION-LIVING-ECOLOGICAL SPACE": A CASE STUDY OF HEILONGJIANG PROVINCE (CHINA)

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Abstract. Analyzing changes in land use and estimating ecosystem services is essential to directing the wise use of local land resources and encouraging environmental preservation. This study focuses on Heilongjiang Province (China), utilizing remote sensing data from 2000, 2010, and 2020 as the primary data source. A "Production-Living-Ecological Space" framework is established, encompassing four dimensions: ecological space, ecological production space, production ecological space, and living production space. Land use transition features of the study area were thoroughly examined, as well as temporal shifts in ecosystem service value based on Xie Gao Di's and other researchers' guidance. Based on our research, the following shows: (1) Over the past two decades, the area of ecological production space in Heilongjiang Province initially expanded and subsequently declined, while the areas of production ecological space and living production space consistently increased. Nonetheless, the overall trend stabilized in the ecological space area. (2) During this period, the total value of ecosystem services in the study area exhibited a downward trend, with a cumulative decrease of 162.392 billion yuan. The value of land ecological services in ecological space, living, and production space decreased, whereas the value of ecological production space initially increased and later declined. Conversely, the value of production ecological space showed an upward trend. (3) The complementary pattern of ecosystem service values in Heilongjiang Province underscores the significant role of forest land, a critical component of ecological space, in maintaining the overall ecosystem service value. (4) To preserve the stability and health of the ecosystem, Heilongjiang Province has to focus on the coordinated development of "Production-Living-Ecological Space". Through scientific and rational land use planning and policy adjustment, it is important to balance the relationship between economic development and ecological protection, and promote the sustainable development of ecological system.
Keywords: *Production-Living-Ecological Space, land use transformation, ecosystem service value, Heilongjiang Province, spatial changes*

Introduction

Land use transition is one of the manifestations of land use/cover change (LUCC) research. (Long, 2015), referring to the temporal changes in regional land use patterns that occur during different economic and social development stages (Long and Li, 2002). In order to advance green development and foster harmonious coexistence between humans and nature, the report of the 20th National Congress of the Communist Party of China places a strong emphasis on the integration of mountains, rivers, forests, fields, lakes, grasslands, and deserts into a comprehensive protection and systematic governance system. It also promotes the idea of ecological priority, conservation, intensification, and green and low-carbon development. It is evident that land use and ecological protection have become one of the major concerns at present. The "Production-Living-Ecological Space" has become an important foundation for optimizing the rational allocation of land and ecological civilization construction (Huang et al., 2017). The value of ecological services is a crucial metric for assessing

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how sustainable the transformation is, while the Production-Living-Ecological Space serve as land use's functional framework and land use transformation is its dynamic adjustment process. They work together to establish the resilience and balance of regional development through the interplay of "function-structure-value." Combining the "Production-Living-Ecological Space" with regional transformation contributes to the overall optimization and upgrading of regional land use, which has significant practical implications for improving regional ecological and environmental protection.

The "Production-Living-Ecological Space" represents a new land use spatial pattern where the development pattern of territorial space shifts from being dominated by production space to a coordinated development of production, living, and ecological spaces (Zhang et al., 2024). Regarding the categorization and identification of the "Production-Living-Ecological Space," researchers mainly classify it according to the various spatially prominent functions of land (Ben and Yu, 2022), the reorganization of land use status classification (Liu et al., 2017), and quantitative indicators and model-based classification methods (Sui et al., 2020). Land use transformation was introduced into Chinese land use research by Long et al. based on Grainger's concept of forest transformation (Long and Li, 2002). Existing research primarily focuses on the concepts and theories of land use transformation (Long and Qu, 2018; Song, 2017), characteristics of land use transformation (Liu and Long, 2016; Zhang and Zheng, 2018; Chen, 2015; Ge, 2018), the relationship between land use transformation and land functions (Chen et al., 2018), the transformation of single land types, and the interaction between land use transformation and the ecological environment (Chen et al., 2023a; Dong et al., 2023; Liu et al., 2023). Land use transformation has a certain impact and driving effect on the regional ecological environment, and the corresponding changes in land use patterns have significant implications for the regional economy, society, and ecological environment. The present study benefits from the substantial research undertaken by domestic and international scholars on land use change and ecosystem service value, which has yielded invaluable references and foundations.

Although Heilongjiang Province's land use trends, such as large-scale mechanized agriculture, the creation of ecological spatial networks, the contraction of urban governance, and other common challenges, show some convergence with European and North American models in terms of agricultural intensification, urbanization and expansion, and ecological protection, the implementation paths differ greatly because of the disparities in institutional environments. The core of Heilongjiang is government-led strict control, with a focus on ecological restoration and food security. Examples of this include the "three zones and three lines" planning and black land protection initiatives. However, the institutional context greatly differs from the implementation paths: While Europe and the US rely more on market-based tools like carbon trading and conservation leasing, Heilongjiang emphasizes the "national system" for ecological restoration and food security and has strict government-led controls like the "three zones and three lines" plan and the Black Land Protection Project (Zandebasiri et al., 2023). In addition to adding to the theory of the global land use transition, this study serves as a guide for creating sustainable development strategies in various institutional settings.

It is apparent that most current research focuses on analyzing the spatial-temporal patterns of land use transformation. However, there is a lack of research on the dynamic process of spatial-temporal redistribution of land resources in the "Production-Living-Ecological Space" and its impact on ecosystem service value. Due to the differences in

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economic, social, and ecological development among different regions in China, studying land use transformation and the ecological environment in multiple locations can provide valuable insights for the comprehensive development of land use in similar regions.

Heilongjiang Province is an important commodity grain production base and an old industrial base in Northeast China. There have been notable changes in Heilongjiang Province’s land use patterns due to the acceleration of urbanization and rapid economic development. Heilongjiang Province is the research area used in this study. This study examines the spatial-temporal features of land use transition from 2000 to 2020 based on the development of a classification system for the “Production-Living-Ecological Space” in the research region. It calculates the ecosystem service value of the research area by referring to the unit area ecosystem service value equivalent table proposed and analyzes the change patterns of its ecosystem service value. The purpose of this study is to provide scientific evidence and backing for achieving sustainable land development, protecting the ecological environment, and promoting economic development.

Materials and methods

Study area

Heilongjiang Province is located in the northeastern part of China, making it the northernmost and highest-latitude province in the country. It spans the geographic coordinates between 121°11′E and 135°05′E longitude, and 43°26′N and 53°33′N latitude. The province has a cold temperate and temperate continental monsoon climate, characterized by distinct seasons and significant regional differences in temperature and precipitation. The average yearly temperature is between -5°C and 5°C, and the precipitation falls mostly between 400 mm and 650 mm, with higher levels in the central mountainous areas, followed by the eastern regions, and less in the western and northern parts (Xu, 2019).

Heilongjiang Province’s terrain generally tends to be lower in the northeast and southwest and higher in the northwest, north, and southeast. Its landforms can be summarized as “five mountains, one water, one grassland, and three parts of farmland.” Specifically, the province is composed primarily of mountains, platforms, plains, and water surfaces. As of the end of 2024, the province had a total population of 30.29 million, governing 12 prefecture-level cities and 1 regional administrative office (*Fig. 1*).

Heilongjiang Province boasts rich land resources. According to the bulletin of the main data of the Third Land Survey of Heilongjiang Province: cultivated land makes up around 13% of China’s total cultivated land area and 37% of the province’s total surveyed land area. However, considering factors such as ecological construction and economic and social development needs, the regional ecosystem has been impacted to some extent by the conversion of land use types. The natural ecosystem has been severely disrupted by problems including soil erosion, the depletion of black soil layers, and the unchecked growth of area used for urban construction.

Data

This study primarily selected three periods of Landsat TM/ETM remote sensing images from 2000, 2010, and 2020 as data sources. With the support of the “Resource

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and Environmental Sciences Data Center of the Chinese Academy of Sciences," a land use database was generated through manual visual interpretation. ArcGIS 10.2 software was used to establish a "production-living-ecological space" classification scheme (*Table 1*) for the study area according to its actual conditions.

Other data collected for this study include administrative boundary data for Chinese cities and prefectures, the "Heilongjiang Provincial Statistical Yearbook" (2001-2021), the "Heilongjiang Provincial Almanac" (2001-2021), and statistical yearbooks from other cities and prefectures, among others, to support in-depth analysis and conclusion drawing.

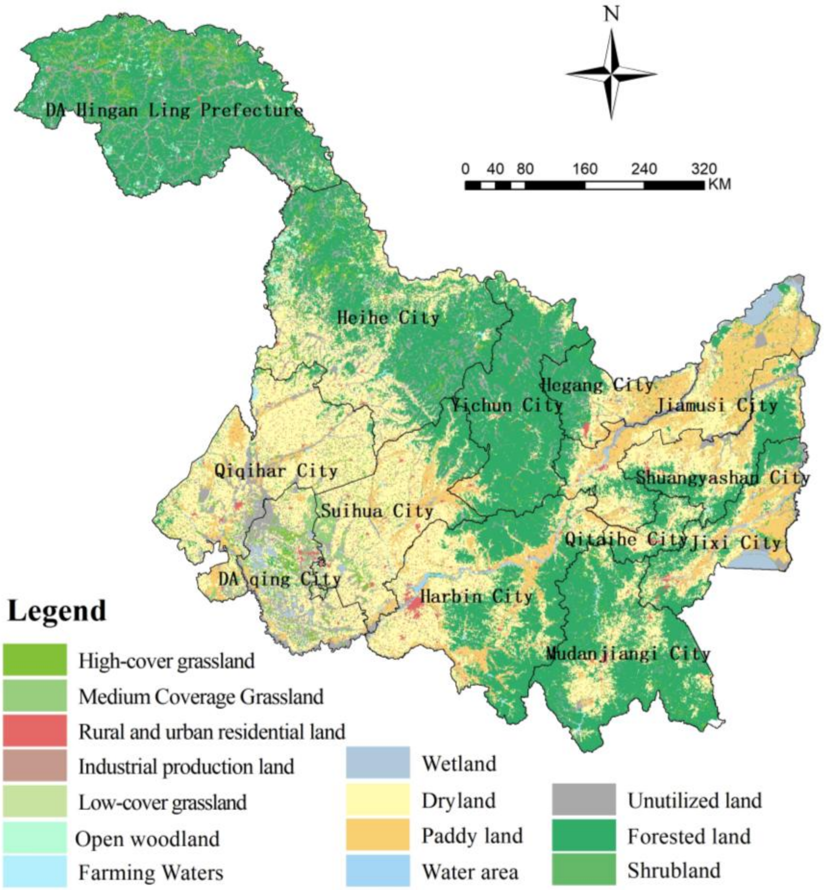

Figure 1. *Administrative division and land use status of Heilongjiang Province in 2020*

Methods

Construction of the classification system for "Production-Living-Ecological Space"

A scientifically reasonable classification system for "Production-Living-Ecological Space" serves as an essential foundation for this study. The term "Production-Living-Ecological Space" describes the fundamental spaces that support human social and economic activity. These spaces include ecological, living, and production spaces. According to the Land Use Status Classification (GB/T21010-2017), the third national land resources survey classification standard, this paper combines the land use characteristics of Heilongjiang Province and refers to relevant studies by scholars (Dai et al., 2018; Wen and Chen, 2022; Zhang et al., 2022). A classification scheme for the

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“Production-Living-Ecological Space” is established in the study area from the perspectives of ecological space, ecological production space, production-ecological space, and living-production space (*Table 1*). Among them, ecological space is a region whose main goals are to rigidly preserve the integrity of natural ecosystems, minimize human interference, and give priority to the preservation of essential ecological services like carbon sinks, biodiversity, and water conservation. The goal of ecological production space is to maintain ecological functions while permitting sustainable and low-intensity production activities. It also aims to strike a balance between resource exploitation and ecological preservation. Production functions dominate the production ecological space, but there are also places where ecological rehabilitation, technology advancement, or even active ecosystem restoration can lower environmental costs. Typically found in traditional villages or urban-rural transition zones, living and production space is a spatially mixed structure of residential life and production activities that emphasizes functional complexity and intense utilization of resources.

Table 1. *“Production-Living-Ecological Space” classification system of Heilongjiang Province*

Primary classification	Secondary classification	Corresponding land use type	Meaning
Ecological space	Key ecological land	Forested land (01)	Refers to natural forests and artificial forests with a degree of closure > 30%. Encompassing mature woodlands such as lumber forests, economic forests, protection forests, and others
		Wetland (02)	Lakes, mudflats
	General ecological land	Shrubland (03)	Alludes to short woodland and scrub woodland with a degree of depression > 40% and a height of less than 2 m
		Open woodland (04)	Refers to forest land with 10%-30% tree closure and unforested afforestation land, remnants, nurseries, and several kinds of gardens (mulberry, tea, orchard, thermoculture forest, etc.)
	Eco-hostile land	Water area (05)	Rivers and canals
		Low-cover grassland (06)	Refers to natural grassland with a cover of 5-20%. This type of grassland lacks moisture, has sparse grass cover, and is poorly utilized for pastoralism
		Unutilized land (07)	Sandy land, saline land, marshy land, bare land, bare rocky land
Ecological production space	Land for pasture production	High-cover grassland (08)	Describes the region that is covered by more than 50% of mowed areas, improved grasslands, and natural grasslands. This kind of grassland often features dense grass growth and ideal moisture conditions
		Medium coverage grassland (09)	Refers to natural grassland and improved grassland with > 20%-50% cover, which generally have insufficient moisture and sparse grass cover
	Water production land	Farming waters (010)	Reservoir Pit Ponds
Production and ecological space	Agricultural production land	Dryland (11)	Refers to arable land without irrigation water sources and facilities, which relies on natural precipitation to grow crops. Dryland farming land with water sources and irrigation facilities that can normally be irrigated in average years. farmland used mostly for growing vegetables. Fallow land and recreational land rotate regularly
		Paddy land (12)	Cultivated land with guaranteed water sources and irrigation facilities that can be irrigated normally in a normal year for growing rice, lotus root and other aquatic crops, including cultivated land practicing the rotation of rice and dryland crops
Living and production space	Urban and rural residential land	Rural and urban residential land (13)	Land for rural settlements and towns
		Industrial production land (14)	Other construction land

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Research method for land use transformation

The quantitative depiction of system states and state transitions in system analysis is where the land use transition matrix gets its start. It is able to comprehensively and specifically analyze the quantitative structural characteristics of regional land use change and the direction of change in each land use type (Lu et al., 2007; Li et al., 2014). This paper utilizes the transition matrix to analyze the studied area's temporal features of variations in the amount of cultivated land resources.

The transition matrix can be used to precisely and thoroughly characterize the features of regional land use change, as well as the composition and direction of transformation of each type of land use. Its expression in mathematics is:

$$S_{ij=}\begin{bmatrix} S_{11} & \cdots & S_{1n} \\ \vdots & \ddots & \vdots \\ S_{n1} & \cdots & S_{nn} \end{bmatrix} \quad \text{(Eq.1)}$$

where S stands for each land type's area; The number of land use kinds is represented by n; The land use types at the start and conclusion of the study period are represented by the letters i and j. When there are fewer than ten different types of land usage, for any two-period land use type maps and the transition matrix for the two periods can be obtained using the following map algebra method:

$$C_{i\times j} = A_{i\times j}^{k} \times 10 + A_{i\times j}^{k+1} \quad \text{(Eq.2)}$$

Where is the land use change map from period k to period $k+1$, representing the type and spatial distribution of land use changes.

Evaluation method for land ecological service value

Without making any substantial overall changes, this study mostly refers to the findings of ecological service value computations for different land use types in the unit area ecological service value equivalency table by academics like Xie et al. (2015a, b) and Costanza (1997). Among them, wetlands, shrubland, dryland, and paddy fields correspond to the corresponding types in the ecological service value equivalent table by scholars; high-coverage grassland, medium-coverage grassland, and low-coverage grassland correspond to the value equivalents of shrubs, meadows, and grasslands. Since the forest vegetation in Heilongjiang Province is mainly coniferous and broad-leaved mixed forests, the value of wooded land is taken as the value equivalent of coniferous and broad-leaved mixed forests. Based on the differences in canopy density between shrubland and sparse woodland, the value equivalent of sparse woodland is appropriately reduced proportionally. Water areas and aquaculture water areas are valued according to water systems. The value equivalents for urban and rural residential land and industrial production land refer to the research results of scholars, resulting in the ecological service value equivalent factor table for various land use types in the "Production-Living-Ecological Space" in Heilongjiang Province (*Table 2*).

The average yield per unit area of grain in Heilongjiang Province from 2000 to 2020 was 4626.75 kg/hm^2. During the same period, the average yield per unit area of grain nationwide in China was 5305.56 kg/hm^2. In 2010, the ecosystem's value per unit in China was valued at 3406.50 yuan/hm^2. After modifying the parameter system for land ecosystem service value in Heilongjiang Province, the calculated value of the value

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equivalent factor coefficient was 0.87, determining the ecological service value equivalent data in Heilongjiang Province as 3915.52 yuan/hm^2.

Table 2. *Factor table of ecological service value equivalent per unit area of ecosystems in Heilongjiang province*

Ecosystem classification	Ecosystem service value equivalent	Ecosystem classification	Ecosystem service value equivalent
Forested land	21.95	High cover grassland	17.33
Wetland	51.84	Medium-cover grassland	10
Shrubland	14.9	Farmed waters	125.61
Open woodland	9.31	Dryland	3.66
Water	125.61	Paddy field	2.42
Low-cover grassland	4.83	Urban and rural residential land	-12.71
Unutilized land	0.74	Industrial production land	-15.83

Using the data on land use and the revised value equivalent factor table of Heilongjiang Province for different years, the changes in the land ecosystem service value in the study area were calculated using the following formula:

$$ESV = \sum(A_k \times VC_k) \quad \text{(Eq.3)}$$

where ESV represents the total value; The area of the *k*th land use category is represented by A_k; and VC_k stands for the *k*th land use type's land ecosystem service value coefficient (yuan·hm^{-2}).

The ESV assessment can precisely identify the distinct effects of ecological space compression (e.g., reduction of forested land), production space expansion (increase of arable land), and living space encroachment (increase of construction land) on regional ecosystems. It is also compatible with the “three living spaces” classification system. It offers Heilongjiang Province a quantitative foundation for implementing the ecological priority program.

Analysis of the variation contribution rate of land use transformation to ecosystem service value

The variation contribution rate analysis is a quantitative analysis method used to reveal the relative contribution of different land types to the total change in ecosystem service value over a specific period. By calculating the percentage of the change in ecological service value of each land type in the total changed value, we can gain a deep understanding of the contribution degree of each land type to the change in ecosystem service value, thereby assessing its impact depth. The calculation formula is:

$$C_i = \frac{ESV_{ib} - ESV_{ia}}{\sum_{i=1}^{n}(ESV_{ib} - ESV_{ia})} \quad \text{(Eq.4)}$$

where *Ci* represents the variation contribution rate of the *i*th land system to the total service value of the regional ecosystem. The ecological service values of the *i*th land type at the start and finish of the study period are represented by ESV*ia* and ESV*ib*.

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If $Ci > 0$, the change trend of the *i*th land type is consistent with the total value of ecosystem services, increasing or decreasing simultaneously; if $Ci < 0$, it indicates that the change trend of the *i*th land type is opposite to the total value of ecological services, one increasing and the other decreasing. The larger the absolute value of *Ci*, the greater the contribution rate of the *i*th land type to the total value of ecological services, indicating a deeper impact (Hu et al., 2013).

Results

Examination of the study area's land use transformation's temporal and spatial features

Temporal change characteristics

In the land use transformation of "production-living-ecological" spaces in Heilongjiang Province, the area of ecological space remained relatively stable, with a decrease of 554,423 hm^2 over 20 years. The area of ecological-production space showed a trend of first increasing and then decreasing, with an increase of 46,124 hm^2 from 2000 to 2010 and a decrease of 949,636 hm^2 from 2010 to 2020, resulting in a net decrease of 27.71% over 20 years. Production-ecological space and living-production space areas kept growing, with increases of 1,293,822 hm^2 and 230,315 hm^2 over 20 years, representing increases of 8.08% and 26.8% respectively (*Figs. 2* and *3*). From 2000 to 2020, there were also changes in the secondary land types of the "production-living-ecological" spaces in the study area. Specifically, key ecological land showed a pattern of initially decline and then rise, with wetlands being the primary kind of land that decreased and forested land being the main type that increased. General ecological land continued to decrease, with shrubland experiencing a significant decrease of 1,847,935 hm^2 from 2010 to 2020, and open woodland experiencing a slight increase in the first 10 years but still a decrease of 344,673 hm^2 from 2010 to 2020. Ecological accommodation land showed a pattern of initial decline followed by increase, mainly due to the decrease and increase in unused land area. Grazing land for production decreased significantly from 2010 to 2020, with both high-coverage grassland and medium-coverage grassland experiencing decreases of 738,354 hm^2 and 259,549 hm^2 respectively. Water areas for production increased slightly, but the increase was not significant, with an increase of 48,267 hm^2. Agricultural production land area continued to increase, but the area of dryland decreased by 658,622 hm^2, while the area of paddy fields increased by 1,952,444 hm^2. Urban and rural living land area continued to increase, with a significant increase of 220,309 hm^2 from 2010 to 2020 (*Table 3*).

Table 3. *Area and change of secondary land classes in the study area from 2000 to 2020 (hm^2)*

Year	Priority ecological land	General ecological land	Ecological accommodation land	Land for pasture production	Water production land	Agricultural production land	Urban and rural living land
2000	18697187	3065806	3170935	3143190	117792	16019962	859332
2010	18505508	3165654	3048051	3175678	131428	16178646	869338
2020	18838188	973046	4568271	2177776	179695	17313784	1089647
2000-2010	-191679	99848	-122884	32488	13636	158684	10006
2010-2020	332680	-2192608	1520220	-997902	48267	1135138	220309

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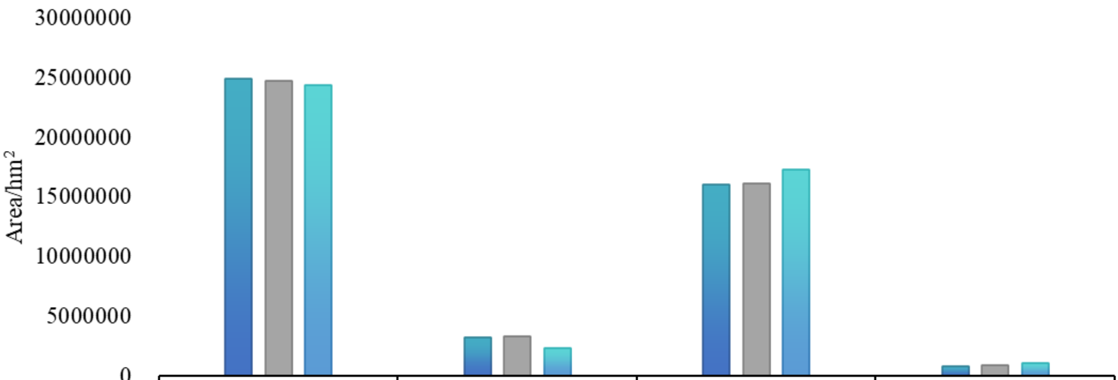

	Ecological space	Ecological production space	Production and ecological space	Living and production space
2000	24933928	3260982	16019962	859332
2010	24719213	3307106	16178646	869338
2020	24379505	2357470	17313784	1089647

Figure 2. *Change of land class area of "Production-Living-Ecological Space" in the study area from 2000 to 2020*

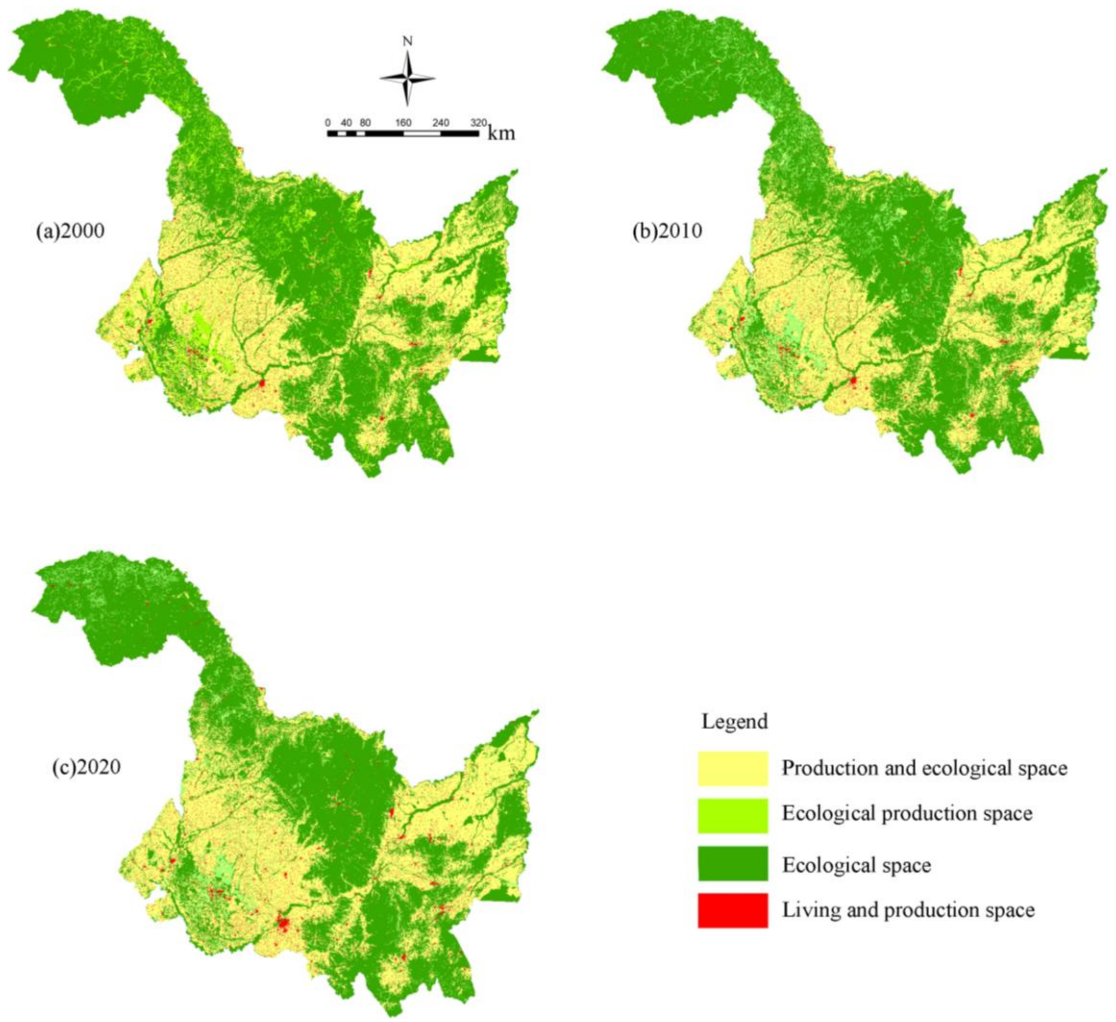

Figure 3. *Pattern of "Production-Living-Ecological Space" in Heilongjiang Province from 2000 to 2020*

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Spatial change characteristics

This study utilizes a land use transfer matrix to analyze the spatial change characteristics of land use in the “production-living-ecological” spaces in Heilongjiang Province (*Fig. 4; Table 4*). The “production-living-ecological” spaces observed a decrease in the areas of ecological space and living-production space between 2000 and 2020. This decrease was mostly caused by the encroachment of production-ecological space, which accounted for 70.84% and 83.66% of the area reduction, respectively. This indicates that production-ecological space played a crucial role in the overall area reduction. Further analysis of production-ecological space reveals that the outflow of agricultural production land, a secondary classification, was mainly due to its transition to key ecological land, accounting for approximately 35.50% of the transition area. This transition process reveals the dynamic balance and spatial reconfiguration between ecosystems. The area’s decline of key ecological land was closely related to the loss of wetlands and forested land. The decrease in wetlands was mainly due to the expansion of dryland and unused land, while the decrease in forested land was more often replaced by the increase in shrubland. The loss of ecological space was the primary cause of the outflow of production-ecological and ecological-production space. Specifically, 71.97% of the decrease in the area of ecological-production space originated from ecological space, and 62.28% of the decrease in the area of production-ecological space was also attributed to ecological space. This suggests that ecological space plays a central role in maintaining the overall ecological system balance. Among the outflows from ecological space, the decrease in the area of key ecological land was mainly due to the loss of agricultural production land and ecological accommodation land. Of these, land for agricultural production accounted for 36.49% of the reduced area, while ecological holding land accounted for 34.99%. This indicates that these two types of land are essential for maintaining the integrity of ecological space. The reduction in the area of land used for agricultural production is mainly due to the gradual conversion of unutilized land into dryland and the inter-conversion between dryland and paddy land. This conversion reveals the dynamic nature of land use and the combined effect of natural and anthropogenic factors. The decrease in the area of ecologically accommodated land, on the other hand, involves a number of factors. The loss of wetlands is mainly due to their conversion to water, but this conversion is only 33% of the area. In addition, the gradual transformation of dry and unutilized land into low-cover grassland, and the gradual transformation of forested land into unutilized land, all contribute to the decrease in the area of ecologically accommodated land.

The spatial transfer of various land uses in the “Production-Living-Ecological Space” is characterized by the increase in the area of ecological space and living-production space, which is primarily attributed to the expansion of production-ecological space. This increase reflects the dynamic balance and mutual support among the various components of the ecosystem. The increase in agricultural production land, representing production-ecological space, is sourced from the augmentation of key ecological land and ecological accommodation areas. Among them, the increase in key ecological land accounts for 32.65% of the total increase, while the increase in ecological accommodation areas accounts for 27.22%. Within the key ecological land, the expansion of forestland is primarily due to the conversion of dryland, indicating that in some regions, dryland is gradually being transformed into forestland, enhancing the forest coverage of the ecosystem. Meanwhile, the

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increase in wetland area is primarily sourced from the transfer of unused land, suggesting that unused land is gradually being developed for wetland protection and restoration. In ecological accommodation areas, the expansion of water areas is primarily derived from the transfer of unused land, indicating that unused land is gradually being utilized for water protection and restoration. Additionally, the increase in low-coverage grassland is a result of the transfer of high-coverage grassland, demonstrating that the grassland ecosystem is undergoing self-adjustment and optimization while maintaining its ecological functions. Finally, the expansion of unused land originates from the transfer of dryland, indicating that dryland is gradually being developed for various non-agricultural purposes.

In summary, the movement of space of various land uses in the “Production-Living-Ecological Space” exhibits a complex yet orderly pattern. This transfer not only reflects the combined influence of natural and human factors, but also provides us with profound insights into the spatial layout and interrelationships of ecology, production, and living.

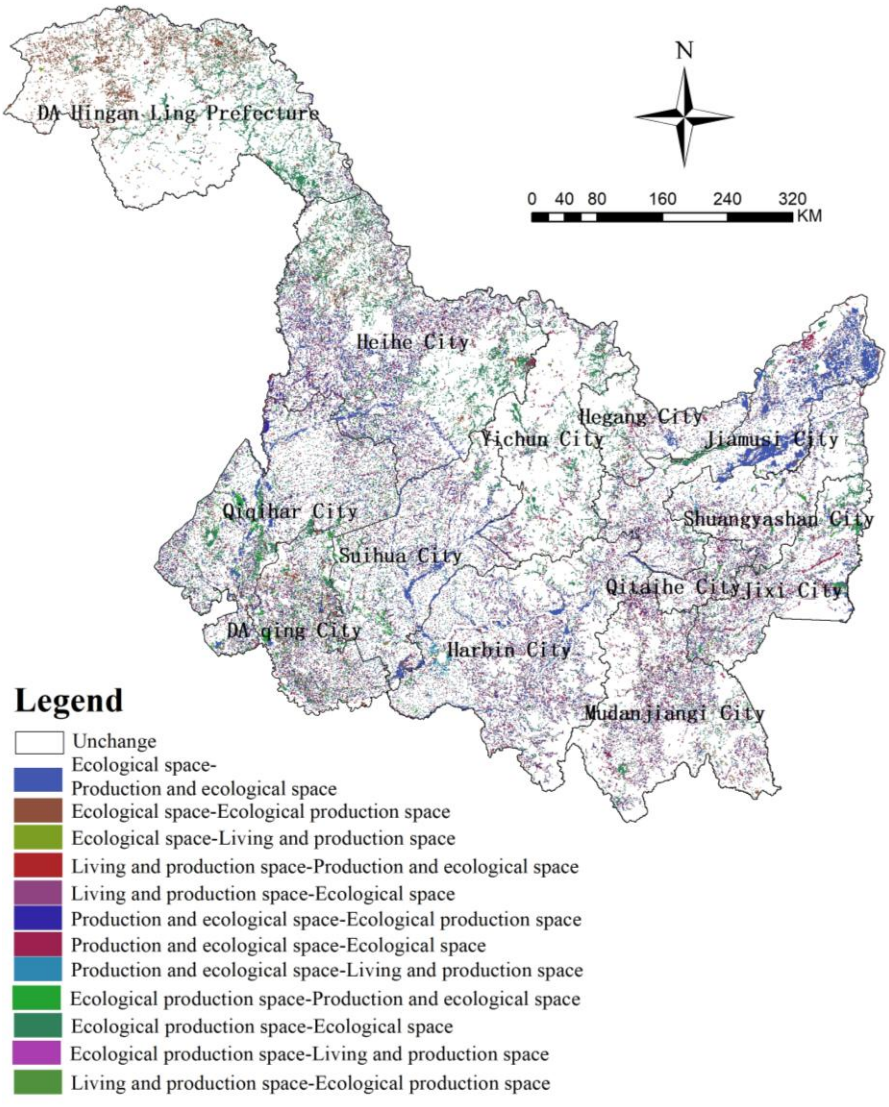

Figure 4. *Spatial change characteristics of “Production-Living-Ecological Space” in Heilongjiang Province from 2000 to 2020*

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Table 4. *Land use transfer matrix of "Production-Living-Ecological Space" in Heilongjiang Province from 2000 to 2020 (hm^2)*

Name of land category	Transfer area (hm^2)														Land area in 2000
	Urban and rural residential land	**Low-cover grassland**	**High-cover grassland**	**Industrial production land**	**Shrub lands**	**Dry land**	**Wetland**	**Open woodland**	**Shui Tin**	**Watersheds**	**Unutilized land**	**Farmed waters**	**Forested land**	**Medium-cover grassland**	
Urban and rural residential land	189566	800	13616	4420	7399	455273	5806	584	87222	3646	27430	3212	31988	7162	838124
Low-cover grassland	880	6232	2672	184	84	6052	300	0	804	0	5360	116	1000	6416	30100
High-cover grassland	20336	1768	232587	6620	52454	376817	22562	24907	92747	12936	548653	6823	831050	80486	2310746
Industrial production land	8780	0	568	1180	116	5512	100	0	200	32	664	132	3600	216	21100
Shrublands	13588	84	232649	4241	89678	224919	49258	51764	157009	27154	433306	2548	1182490	15292	2483979
Dry land	585701	5852	305165	28852	200788	9085220	91062	18167	1870900	26038	497755	46472	948151	105845	13815967
Wetland	11219	1188	23448	3485	6707	177951	327003	400	101308	55960	309272	12589	22519	13222	1066272
Open woodland	5500	0	31784	852	32297	122446	12596	25033	44144	1148	46448	814	250397	6974	580433
Shui Tin	84872	100	18817	3656	15008	628243	13184	584	1280370	4955	74866	5192	66597	4304	2200748
Watersheds	4993	84	7708	232	6366	39394	24519	834	5471	71053	51953	194	21277	588	234666
Unutilized land	29781	5728	98611	5732	33685	751580	89639	9256	404910	13204	1072350	21886	280481	82731	2899573
Farmed waters	2468	100	2808	116	836	24561	5980	0	4200	884	7656	52228	15312	632	117781
Forested land	40940	852	547392	14300	192483	1084550	8256	187892	85346	21142	1000930	25739	14358400	52662	17620883
Medium-cover grassland	12116	4712	69604	3232	9140	168241	9868	4436	17680	1066	176269	1396	142111	211347	831218
Land Area in 2020	1010740	27500	1587429	77102	647040	13150760	660133	323857	4152310	239218	4252911	179339	18155373	587878	45051590

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Variation in ecosystem service values over time and space in the research area

According to the land ecosystem service value formula, the ecosystem service values of the “production-living-ecological” spaces from 2000 to 2020 in the Province of Heilongjiang were calculated (*Table 5*). The analysis shows that over the previous 20 years, the study area’s ecosystem service values have been declining, with a cumulative reduction of 162.392 billion yuan. Notably, ecological space dominates among the four types of spaces, accounting for over 82% of the total service value in 2000, 2010, and 2020. This data underscores the significant impact of ecological space on the changes in ecosystem service values in the study area. Further examination from the viewpoint of “production-living-ecological” spaces indicates that both the land ecological service values of ecological space and living-production space have declined from 2000 to 2020. Conversely, the value of ecological production space has exhibited a trend of first increasing and then decreasing, while the value of production-ecological space has shown an upward trend. In-depth analysis of specific land use types reveals that industrial production land and shrubland are the primary types contributing to the decline in land ecological service values in the study area, with change rates of 73.90% and 267.28%, respectively. Conversely, paddy fields and unused land represent the two main land use types that enhance land ecological service values.

Table 5. *The change of ecosystem service value of “Production-Living-Ecological Space” in Heilongjiang Province from 2000 to 2020*

“Production-Living-Ecological Space”	Land use type	ESV (billion yuan) in 2000	ESV (billion yuan) in 2010	ESV (billion yuan) in 2020	Change in ESV (billion yuan) 2000-2020	Change rate (%) 2000-2020
Ecological space	Forested land	15150.92	15004.50	15620.10	469.18	3.10
	Wetland	2169.24	2125.95	1347.39	-821.85	-37.89
	Shrubbery	1449.90	1456.55	378.45	-1071.45	-73.90
	Sparse forest	211.65	243.89	118.24	-93.41	-44.13
	Water area	1181.39	1174.74	1347.61	166.22	14.07
	Low-coverage grassland	5.69	5.65	5.20	-0.49	-8.61
	Unused land	84.05	80.53	123.63	39.58	47.09
Ecological production space	High-coverage grassland	1568.59	1579.61	1078.59	-490.00	-31.24
	Medium-coverage grassland	325.59	331.96	230.33	-95.26	-29.26
	Aquaculture area	579.33	646.40	883.79	304.46	52.55
Production ecological space	Dry land	1980.32	1944.48	1885.93	-94.39	-4.77
	Paddy field	208.59	247.32	393.59	185.00	88.69
Living production space	Urban and rural residential land	-417.16	-419.00	-503.70	-86.54	-20.75
	Industrial production land	-13.08	-16.98	-48.04	-34.96	-267.28
Total	-	24485.03	24405.60	22861.11	-1623.92	-6.63

Utilizing the natural breaks method in ArcGIS software, the ecosystem service values in Heilongjiang Province in 2000, 2010, and 2020 were divided into five grades: extremely high value zone, high value zone, medium value zone, low value zone, and

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extremely low value zone (*Fig. 5*). Although spatial changes in the ecosystem service values of the study area have occurred during these 20 years, the overall trend is not significant. Extremely high-value areas for ecosystem services are primarily concentrated in the Greater Khingan Range, Yichun City, and Mudanjiang City, with their distribution highly consistent with the spatial distribution of forested land. Notably, the extremely high-value zone in Heihe City exhibited an expanding trend from 2010 to 2020, indicating the gradual improvement of ecosystem health in these areas. High-value areas are mainly distributed in Suihua City, Qiqihar City, the eastern part of Jixi City, and some areas of Harbin City, where land types with a large proportion of high-coverage grassland provide significant services to the ecosystem. Medium-value areas are concentrated in the northern section of Qiqihar City, the western part of Shuangyashan City, and the western part of Harbin City, where land types with a high proportion of dryland have a moderate impact on ecosystem service values. Low-value areas are more scattered and have a relatively small overall impact on the ecosystem service values of the study area. Extremely low-value areas are primarily distributed in cities such as Daqing City, Jixi City, Qitaihe City, and Hegang City, where the extraction of resources such as oil or coal has posed a threat to ecosystem health, resulting in low ecosystem service values.

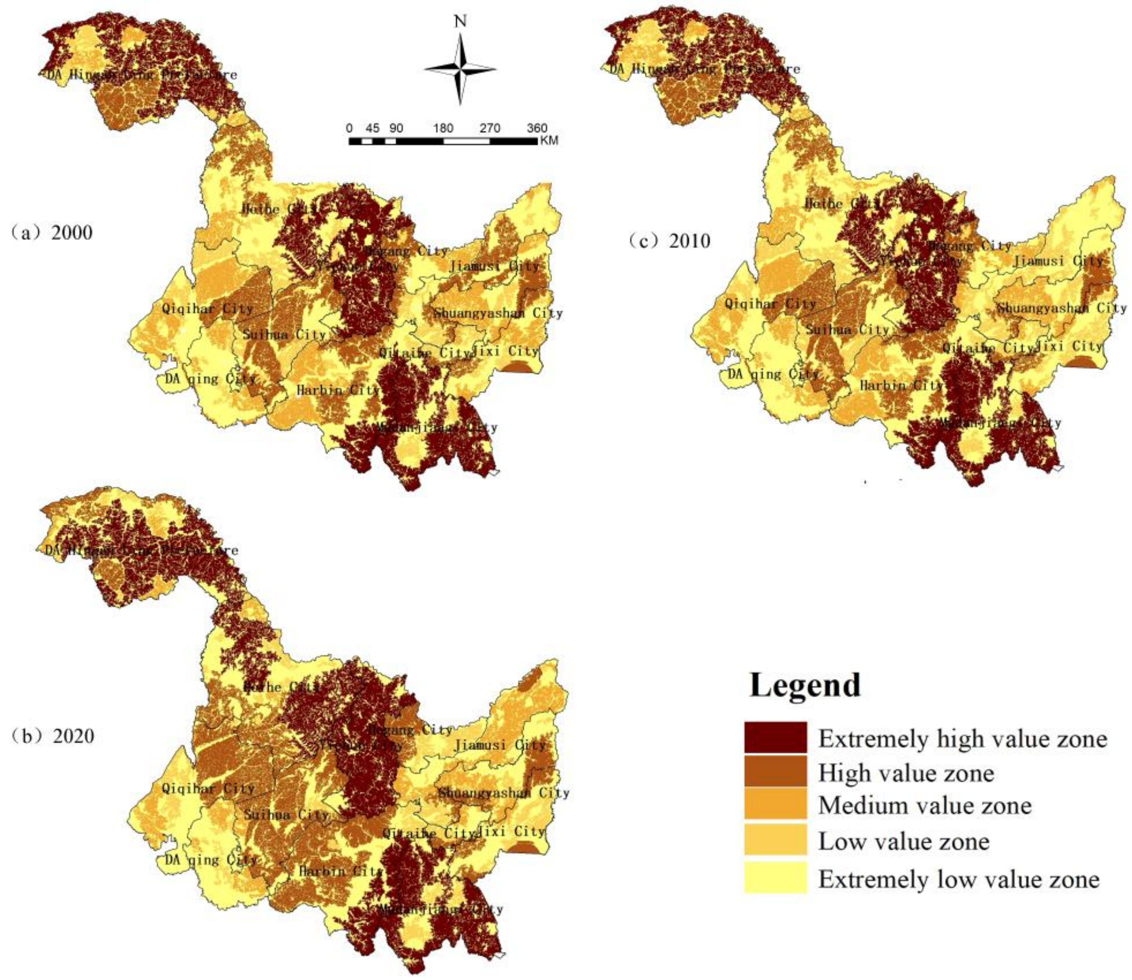

Figure 5. *Spatial and temporal zoning of ecosystem service value in Heilongjiang Province from 2000 to 2020*

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Impact of land use transformation in the study area on changes in ecosystem service value

The aforementioned research indicates that land use transformation in Heilongjiang Province from 2000 to 2020 played a crucial role in altering the value of ecosystem services. During this period, the mutual transformation of various spaces within the "Production-Living-Ecological Space" (ecological, production, and living) became the primary driver of changes in ecosystem service value. From the perspective of enhancing ecosystem service value (*Table 6*), it can be observed that the conversion of land use types within ecological spaces is a key path to promote the appreciation of ecosystem service value. Notably, the stability of forestland serves as the core driving force for this growth, with a contribution rate of 62.21%. This underscores the importance of forest resources in maintaining and enhancing ecosystem functions. China's implementation of the world's most stringent farmland protection policy directly led to the relative stability of cultivated land and paddy field areas and their spatial distribution in production-ecological spaces, thereby contributing to the improvement of ecosystem service value. As a type of cultivated land, dryland contributed 6.56% to the value of ecosystem services. Although the contribution rates of other land use type transformations in enhancing ecosystem service value may not be prominent, they are all moving towards positive directions, indicating that overall land use transformation is contributing to the improvement of the ecological environment and the enhancement of ecosystem service value.

From the perspective of reducing ecosystem service value (*Table 7*), during the 20-year period from 2000 to 2020, there was a transformation within ecological spaces from land types with high ecological service value to those with low ecological service value. These changes contributed 35.4% to the overall decline in ecosystem service value. Among them, the transformation of forested land into unused land had the most significant impact on the reduction of ecosystem service value, with a contribution rate of 13.09%. The encroachment of production-ecological spaces on ecological spaces also led to a significant decline in the ecosystem service value of the study area, with a contribution rate of 27.38%. This encroachment was primarily due to the transformation of forested land into dryland, while the transformation of wetlands into dryland and paddy fields also contributed to the reduction in ecosystem service value, with contribution rates of 5.29% and 3.09%, respectively. The transformation of production-ecological spaces into living-production spaces reflects the occupation of cultivated land by urban and rural residential land, contributing 6.7% to the reduction in ecosystem service value. Additionally, the transformation of ecological-production spaces into ecological spaces reveals the unreasonable use of certain land use types with high ecological service values, turning them into unused land, resulting in a decline in the ecosystem service value of the study area, with a contribution rate of 8.19%. Among the transformations of ecological-production spaces into production-ecological spaces, changes in cultivated land space due to the impact of the policy of requisition-compensation balance also contributed to the reduction in ecosystem service value in the study area, with a contribution rate of 6.45%. Other transformations between "Production-Living-Ecological Space" also led to a decline in ecosystem service value, and the expansion of urban and rural residential land and its occupation of other land types are also significant factors contributing to the decline in ecosystem service value.

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***Table 6.** The main land use transformation ways and their contribution rates to increase the value of ecosystem services in Heilongjiang Province from 2000 to 2020*

Land use transition type		ESV difference (billion yuan)	Contribution rate (%)
Ecological space → ecological space	Forestland remains unchanged	12340.42	62.21
	Wetland remains unchanged	663.75	3.35
	Water area remains unchanged	349.46	1.76
	Shrubland → forestland	326.42	1.65
	Unused land → forestland	232.93	1.17
	Unused land → wetland	179.35	0.90
	Wetland → water area	161.64	0.81
	Sparse forestland → forestland	123.93	0.62
	Subtotal	14377.9	72.47
Production-ecological space → production-ecological space	Dryland remains unchanged	1301.98	6.56
	Paddy field remains unchanged	121.32	0.61
	Subtotal	1423.3	7.17
Production-ecological space → ecological space	Dryland → forestland	679.02	3.42
	Dryland → wetland	171.79	0.87
	Dryland → water area	124.33	0.63
	Subtotal	975.14	4.92
Living-production space → production-ecological space	Urban-rural residential land → dryland ecological-production space → ecological-production space	291.79	1.47
Ecological-production space → ecological-production space	Aquaculture water area remains unchanged	256.87	1.30
	High-coverage grassland remains unchanged	157.82	0.80
	Subtotal	414.69	2.1
Production-ecological space → ecological-production space	Dryland → aquaculture water area	221.90	1.12
	Dryland → high-coverage grassland	163.34	0.82
	Subtotal	385.24	1.94
Ecological-production space → ecological space	High-coverage grassland → forestland	150.33	0.76
Total	---	19441.69	90.83

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Table 7. *The main land use transformation modes and their contribution rates to reducing ecosystem service value in Heilongjiang Province from 2000 to 2020*

Land use transition type		**Change in ESV (billion yuan)**	**Contribution rate (%)**
Ecological space → ecological space	Forest land → unused land	-831.25	13.09
	Wetland → unused land	-618.80	9.75
	Water area → unused land	-254.01	4.00
	Shrubland → unused land	-240.24	3.78
	Forest land → sparse forest	-92.99	1.46
	Water area → forest land	-86.36	1.36
	Water area → wetland	-70.82	1.12
	Forest land → shrubland	-53.13	0.84
	Subtotal	-2247.6	35.4
Ecological space → production-ecological space	Forest land → dryland	-776.70	12.24
	Wetland → dryland	-335.70	5.29
	Wetland → paddy Field	-196.04	3.09
	Water area → dryland	-188.11	2.96
	Shrubland → dryland	-98.99	1.56
	Shrubland → paddy field	-76.72	1.21
	Forest land → paddy field	-65.26	1.03
	Subtotal	-1737.52	27.38
Production-ecological space → living-production space	Dryland → urban-rural residential land	-375.42	5.91
	Paddy field → urban-rural residential land	-50.28	0.79
	Subtotal	-425.7	6.7
Ecological production space → ecological space	High-coverage grassland → unused land	-356.40	5.61
	Medium-coverage grassland → unused land	-63.91	1.01
	Cultivated water → forest land	-62.15	0.98
	Cultivated water → unused land	-37.43	0.59
	Subtotal	-519.89	8.19
Ecological production space → production-ecological space	High-coverage grassland → dryland	-201.69	3.18
	Cultivated water → dryland	-117.28	1.85
	High-coverage grassland → paddy field	-54.15	0.85
	Low-coverage grassland → dryland	-41.76	0.66
	Subtotal	-414.88	6.54
Ecological space → ecological production space	Forest land → high-coverage grassland	-99.02	1.56
	Water area → high-coverage grassland	-32.68	0.51
	Wetland → high-coverage grassland	-31.68	0.50
	Subtotal	-163.38	2.57
Living-production space → living-production space	Urban-rural residential land remains unchanged	-94.33	1.49
Production-ecological space → production-ecological space	Dryland → wetland	-90.84	1.43
Production-ecological space → ecological space	Dryland → unused land	-56.91	0.90
Ecological space → living-production space	Forest land → urban-rural residential land	-55.56	0.88
Total		-5806.61	91.48

Over the past 20 years, the ecosystem service value in Heilongjiang Province has exhibited a complementary trend. However, from an overall perspective, land use transformation has led to a reduction in ecosystem service value. Notably, the improvement of ecosystem service value in Heilongjiang Province relies heavily on the

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support of forested land types. In contrast, the implementation of farmland protection policies leading to the transformation of some high-ecological-value land types into cultivated land, as well as the continuous expansion of urban and rural residential land, are the main reasons for the decline in ecosystem service value. To maintain the stability and healthy development of the ecosystem, we must attach considerable emphasis to and strengthen the protection of land types with high ecological service value, while avoiding overexploitation and unreasonable utilization to ensure the sustainable utilization of land resources and the long-term health of the ecosystem.

Conclusions

In order to give theoretical support for the optimization of land space, this study builds a three-dimensional analysis framework of “Production-Living-Ecological Space,” which creatively reveals the law of spatial and temporal heterogeneity of land use transformation in Heilongjiang Province in China. According to the study, (1) the ecological production space exhibits an evolutionary trajectory of “expansion - contraction,” suggesting a dynamic game relationship between agricultural production and ecological protection; (2) the ongoing expansion of the living production space and production ecological space reflects the profound reconstruction of the “human-land relationship” during the urbanization process; (3) the total value of ecosystem services decreased by 162,392 million yuan, but the production ecological space’s value increased against the trend, exposing the spatial replacement effect of ecological factors and production factors.

Practically speaking, the red line must be used to protect forest land, which is the primary carrier of ecological service value, in accordance with the farmland protection policy. The establishment of an “ecological occupancy and compensation balance” mechanism is necessary to counteract the loss of ecological value brought on by urban and rural expansion.

Future studies could concentrate on (1) building a multi-dimensional ecological service evaluation system that incorporates carbon sink value; (2) creating a decision-making model for spatial optimization based on ecological thresholds.

This study supports the use of the primary functional area plan and offers a scientific foundation for balancing ecological and food security.

Discussion

The findings of this study offer valuable insights into the dynamics of land use transformation and its effects on ecosystem service value in Heilongjiang Province. The robust classification system for “Ecological-Production-Living Spaces” provides a clear framework for analyzing these changes. The notable shift in space configuration suggests a complex interplay between ecological preservation, economic activities, and urbanization. The decline in ecosystem service value raises concerns about the sustainability of current land use practices, particularly the conversion of high ecological value land into farmland driven by farmland protection policies. This highlights the potential conflicts between agricultural development and ecological conservation, and the need for policymakers to balance these competing interests.

Furthermore, the study emphasizes the importance of a balanced approach to land use planning, considering the needs of ecological, production, and living spaces. This

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requires comprehensive consideration of various factors, including ecological sustainability, economic development, and social welfare. The findings highlight the criticality of safeguarding land types with high ecological service values to mitigate overexploitation and irrational utilization. To achieve sustainable development in Heilongjiang Province, it is imperative to integrate scientific and prudent land use planning with policy revisions, ensuring that the needs of the ecosystem are prioritized alongside economic and social development.

It is advised that a synergistic governance framework consisting of "zoning control + ecological compensation" be developed in order to address these problems. The implementation of dynamic early warning through satellite remote sensing monitoring should be the first step. In ecologically fragile areas, a permanent ecological protection red line should be drawn. Arable land occupation and compensation balance projects should not be allowed to extend beyond the red line. In order to ensure food production capacity in the Songnen Plain's black soil area, the second step is the implementation of a grading management system for the quality of arable land (Chen et al., 2023b). This system places low-quality or high ecological service-value but low-yielding arable land into the ecological fallow plan and gradually restores it to grassland or wetland. This is done in tandem with the construction of high-standard farmland. Thirdly, a market-based ecological compensation system should be put in place to allow the value of ecological goods to be incorporated into the local government's GDP assessment system and to offer ecological subsidies to farmers who preserve wetlands based on the quantity of carbon stored.

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