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Evaluation of Spatial Functions and Scale Effects of "Production–Living–Ecological" Space in Hainan Island

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Abstract: The identification, evaluation, and spatial distribution of "Production–Living–Ecological" space (PLEs) have been widely studied, but there is still little attention paid to whether their distribution characteristics will vary with scale changes. This article takes the organic whole of the PLEs composed of production space, living space, and ecological space on Hainan Island as the research object. Starting from the perspective of spatial heterogeneity, it quantitatively evaluates its spatial functions and explores the regularities of its aggregation and coordination characteristics with changes in scale, revealing the evolution of its distribution pattern with changes in scale. The results show that: (1) The distribution of PLEs in Hainan Island has obvious heterogeneity. The functional values of production and living space are distributed in a pattern of high in the south and north, low in the middle; The ecological space shows a high distribution pattern in the middle and low around it. (2) The PLEs in Hainan Island is significantly affected by scale effects. The degree of aggregation decreases as the scale increases, with the ecological space showing the most obvious downward trend, the living space showing a weaker downward trend and the production space being moderate. (3) The overall level of coupling-coordination of PLEs in Hainan Island is low, which decreases as the scale increases, with 500 m × 500 m being the peak value. The research results of this article indicate that there are scale effects in the functional distribution characteristics of PLEs, which can provide decision support for the national spatial planning at different scales.

Keywords: "Production–Living–Ecological" space (PLEs); scale effect; heterogeneity; spatial aggregation; coupling and coordination; Hainan Island

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1. Introduction

With the rapid changes in urban–rural industrial structure, the expansion of urban space, and the increasing contradictions between agricultural production, ecological protection, and urban–rural development, the Chinese government has proposed an overall optimization layout of "Production–Living–Ecological" space (PLEs) to explore new ideas for land use and environmental protection, and requires administrative units at all levels to achieve the unity of economic, social, and ecological benefits. Here, production space refers to specific functional areas where people engage in production activities; living space refers to spaces used for daily living activities; and ecological space refers to territorial spaces with ecological protection functions that can provide ecological products and services. However, in the practical process, there are certain differences in the attention paid to the PLEs scale by administrative units at different levels. It is still unclear whether the distribution characteristics at different scales will change, leading to conflicts of interest among different levels of administrative units. To properly coordinate the interests of administrative units at all levels and promote sustainable economic and social development, it is necessary to clarify whether there are differences in the PLEs with changes in scale and explore the evolution laws with changes in scale, thus providing decision support for the optimization of the territorial spatial pattern of Hainan Island and even China.

Currently, research on PLEs is mainly carried out along the following framework: "connotation definition–analysis framework construction–functional evaluation–zoning optimization". Existing research has defined the PLEs based on spatial functions in the spatial function theory [1], based on land use in the spatial land use theory [2], and based on human practical activities in the spatial practice theory [3]. On this basis, building on these theories, logical theory [4] and economic theory [5] have been introduced to explore the construction of an analytical framework for quantitative evaluation of PLEs functions. The evaluation scope ranges from traditional land carrying capacity to residents' behavior [6]. The research areas are divided into national [2], regional [7], provincial [8], municipal [9], and county levels [10] according to administrative divisions or specific needs. The functional evaluation mainly adopts two methods: quantitative measurement and merging classification. The former establishes an indicator system based on the functional attributes of the PLEs and calculates the functional values of different plots. However, many social and economic factors, such as population density and nighttime light image, cannot be clearly reflected as numerical variables in many research processes. The latter can effectively connect land use classification and the evaluation of PLEs functions, clarify the relationship between different types of evaluation units, but cannot reflect the spatial differences in the same land type. In addition, the main theoretical support for the optimization of the PLEs functional space comes from the theories of regional resource and environmental carrying capacity and the coupling of urbanization and ecological environment, forming the optimization idea of relative agglomeration of production space, relative concentration of living space, relative collection of ecological space, and relative integration of the PLEs [11]. Based on this idea, there are two research trends: one is spatial optimization based on adaptive assessment, which evaluates at both macro [12] and micro scales [13]; the other is "integration of multiple plans" spatial optimization, which is carried out according to the national, provincial, and municipal county-level spatial planning systems [14].

Existing research on scale effects mainly focuses on landscape ecology, which takes the evolution of landscape patterns as the research focus and explores the characteristics and laws of landscape pattern evolution with scale changes, mainly on ecological space and covering risk assessment [15], ecological security assessment and restoration [16], and ecological fragility [17]. The selected scales are mainly specific grid scales, township scales, and city, county, and provincial scales. Among them, the research on special grid scale effects involves land use [18], water resource carrying capacity [19], landscape pattern [20], and ecosystem [21]. The township scale includes the functional evaluation [22], spatial distribution pattern, and heterogeneity characteristics [23]. At macro scales such as cities, counties, and provinces, the granularity and amplitude effects of different scales are compared and analyzed, and the multi-scale characteristics [24] and the temporal and spatial changes in landscape patterns [25] are analyzed.

However, there are still some shortcomings in existing research. Firstly, the research on scale effects is often influenced by the research ideas of landscape ecology, focusing on the current situation of landscape fragmentation [26], composition, and evolution in a single area [27], and the attention to production and living spaces is insufficient. Secondly, although existing research has effectively explored spatial patterns at different scales, it has not proven whether scale effects will have an impact on the PLEs spatial patterns and revealed their evolution patterns, there is currently no consensus on whether their distribution characteristics will have functional changes with scale changes [28]. Finally, the theoretical basis for setting scale gradients is still weak. A significant feature of landscape scale effect research is the diversity of scale levels. In order to make the research results of different research work comparable, it is necessary to establish a theoretical basis for scale setting.

In summary, this article first uses the merge classification method and multi-source spatial data correction method to quantitatively evaluate the spatial functions and heterogeneity of PLEs; secondly, using bilinear interpolation method, spatial resampling of

spatial heterogeneity evaluation results is performed to obtain ten evaluation results at different scales; thirdly, establish a spatial autocorrelation model to explore its scale effects from the characteristics and differences of aggregation distribution; and fourthly, establish a coupling coordination degree model to explore its scale effects from the characteristics and differences of coupling coordination.

The structure of this article is as follows: the second part introduces the overview of the research area and the data and methods used, specifically including: spatial heterogeneity evaluation, resampling, constructing spatial autocorrelation models and coupling-coordination models; the third part explores the results of spatial heterogeneity evaluation and scale effects; the fourth part discusses the spatial heterogeneity evaluation and scale effect analysis mentioned earlier, and proposes effective policy recommendations; and the final section provides concluding observations.

2. Materials and Methods

2.1. Overview of the Study Area

Hainan Island is the second largest island in China and the core region of Hainan Province. The island has a high middle and low surrounding terrain, a good ecological environment, and abundant tropical biological resources, making it China's first ecological civilization demonstration zone. Due to the influence of topography and location, the social and economic development of the north and south poles of Hainan Island is faster, the development of the eastern coastal area is moderate, and the development of the central and western regions is slower, showing significant regional differences. Since China proposed the construction of the Hainan Free Trade Zone (Port) in 2018, the social and economic development of Hainan Province has made significant progress. As of the end of 2022, the province's permanent population was 10.27 million, with a total GDP of 681.822 billion yuan, and the proportion of the tertiary industry structure was 60.0%. In the context of Hainan Province's vigorous promotion of the ecological civilization demonstration zone and the construction of the free trade port, objectively grasping the basic pattern of production, living, and ecological space on Hainan Island and revealing its pattern characteristics with scale changes is conducive to providing decision support for the layout and optimization of the PLEs on Hainan Island at different scales, and promoting the coordinated development of ecological protection and resource development across the island.

2.2. Data Sources and Preprocessing

The basic data used in this study mainly include land use data, land cover data, and other multi-source spatial data. The former are based on the 2018 remote sensing monitoring data of land use and land cover in Hainan Island, sourced from the Resource and Environment Science and Data Center of the Chinese Academy of Sciences, with a spatial resolution of 30 m and reliable interpretation accuracy [29]. The latter include the 2018 normalized difference vegetation index (NDVI) with a spatial resolution of 30 m, the VIIRS nighttime light image with a spatial resolution of about 400 m, vector data of road networks (including expressways, national highways, provincial highways, county roads, rural streets, and urban roads), and Landsat 8 images with a spatial resolution of 30 m, which are used to calculate RSEI. Among them, NDVI, VIIRS, and Landsat 8 images are obtained through the Google Earth Engine cloud platform, and road network vector data are obtained through web scraping of Baidu Maps.

The above basic data are projected to the same spatial coordinate system to ensure consistent location information. At the same time, due to limitations in the basic data, VIIRS nighttime light image data are resampled to 30 m. When using road network vector data for road density analysis, its spatial resolution is also set to 30 m, in order to evaluate the PLEs function values of Hainan Island at a resolution of 30 m $\times$ 30 m. The overall ideas and technical roadmap of this article are as follows (Figure 1).

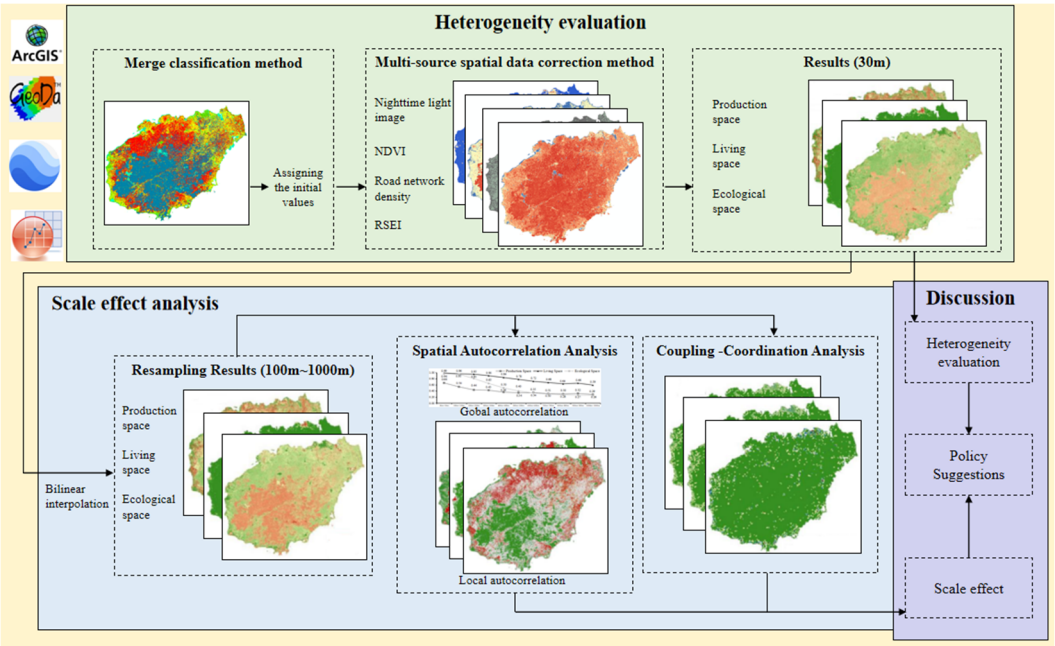

Figure 1. General idea and technology roadmap.

2.3. Evaluation of Heterogeneity in PLEs Spatial Functions

To effectively carry out a spatial heterogeneity evaluation of the PLEs spatial patterns on Hainan Island at a 30 m × 30 m scale, laying the research foundation for scale effects. Firstly, the merging classification method is used to classify different land types into corresponding production, living, and ecological spaces, and the initial values of the production, living, or ecological space functions are assigned based on the differences in land type characteristics, namely the initial values of the PLEs functions (Figure 2). Specific details can refer to the research results of scholars such as Liu Jilai [30] and will not be elaborated on here.

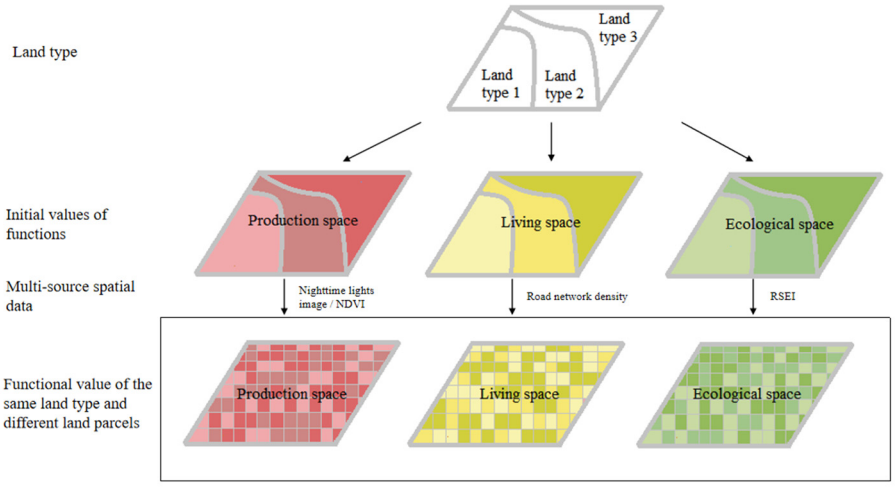

Figure 2. Flow chart of spatial heterogeneity evaluation of PLEs.

Secondly, multi-source spatial data are introduced, and the proportional transformation method is used to evaluate the spatial heterogeneity of the initial values of the PLEs functions based on land classification, following the idea that "the higher the value of the multi-source spatial data, the higher the corresponding position's functional value" [31]. In

this way, the PLEs function values of "same land type, different land parcels" are obtained, as follows:

$$V_{ij} = V_i \times X_{ij} / \overline{X_i} \quad (1)$$

where "V_{ij}" is the PLEs function value of the "j" land parcel in the "i" land type; "V_i" is the initial value of the PLEs function of the "i" land type; "X_i" is the measured value of a specific indicator of a particular multi-source spatial data corresponding to the "j" land parcel in the "i" land type; "$\overline{X_i}$" is the average value of the specific multi-source spatial data corresponding to the "i" land type.

Based on the connotation of the PLEs and its functions, appropriate multi-source spatial data are determined. For production space, it can be further divided into urban production space and rural production space based on the differences in the products and services they provide. Urban production space mainly provides industrial products and service products, and its function size is positively correlated with the output of urban construction land. Relevant studies have also shown that there is a strong correlation between the brightness of nighttime lights and the output of urban construction land [32]. Therefore, the VIIRS nighttime light image is selected to evaluate the heterogeneity of the function of urban production space. The ability of agricultural production space to provide agricultural products is closely related to the biological productivity of the land, and the normalized difference vegetation index (NDVI) can effectively characterize the high and low biological productivity of the land [33]. Therefore, the NDVI is selected to evaluate the heterogeneity of the function of agricultural production space; For living space, it provides necessary spatial conditions for human habitation and public activities, and road network density reflects the intensity of resident activities to a certain extent [34]. Therefore, the road network density is selected as the correction coefficient to evaluate the heterogeneity of the function value of living space; For ecological space, it is of great significance in maintaining regional ecological security and sustainable development, The remote sensing based ecological index (RSEI) can reflect the quality of the ecological environment system to a certain extent. Therefore, the RSEI is selected to evaluate the heterogeneity of the function value of ecological space.

2.4. Spatial Resampling

In order to obtain the spatial heterogeneity evaluation results of PLEs at different scales and effectively conduct spatial autocorrelation and coupling-coordination analysis. Using bilinear interpolation, spatial resampling analysis was conducted on the spatial heterogeneity evaluation results of 30 m × 30 m. Referring to the existing literature with a gradient of 100 m [35], ten different scales of results were obtained, including 100 m × 100 m, 200 m × 200 m, . . ., 1000 m × 1000 m.

2.5. Spatial Autocorrelation Model

The PLEs functions exhibit clustering distribution patterns [31]. To reveal the clustering distribution characteristics and their differences at different scales, the spatial autocorrelation model is used for analysis. First, global spatial autocorrelation is calculated using Moran's I index for the PLEs functions on Hainan Island at different scales, as follows:

$$I = \sum_{\propto=1}^{n} \sum_{\beta \neq \alpha}^{n} W_{\alpha\beta}(\nu_\alpha - \overline{\nu})(\nu_\beta - \overline{\nu}) / S^2 \sum_{\propto=1}^{n} \sum_{\beta \neq \alpha}^{n} W_{\alpha\beta} \quad (2)$$

where "I" is the Moran's I index, which reflects the strength of spatial autocorrelation of the variable, with a value range of $[-1, 1]$. Under the premise of significance level testing, a value closer to 1 indicates a stronger positive spatial correlation of the variable, a value closer to -1 indicates a stronger negative spatial correlation, and a value of 0 indicates a random distribution in space. "v_α" and "v_β" are the measured values of the spatial variable (production, living, or ecological function values) in spatial units "α" and "β", respectively. "$\overline{v}$" and "S^2" are the mean and variance of the spatial variable, respectively. "n" is the

number of spatial units, and "$W_{\alpha\beta}$" is the spatial weight matrix that reflects the spatial adjacency between different spatial units ("α" and "β").

Secondly, local spatial autocorrelation analysis is conducted to obtain the Moran scatter plot of the PLEs functions on Hainan Island at different scales, and the clustering characteristics of functions are divided into four quadrants. Quadrants one and three represent high–high (HH) and low–low (LL) clustering, indicating positive spatial autocorrelation. Quadrants two and four represent high–low (HL) and low–high (LH) clustering, indicating negative spatial autocorrelation.

2.6. Coupling-Coordinated Model

There are coupling or coordination characteristics among the PLEs functions [36]. In order to reveal the mutual coupling or coordination characteristics and their differences at different scales among production, living, and ecological spaces, a coupling-coordinated model is used to analyze the interactions and influence of functions at different scales, as follows:

$$\begin{cases} C = \sqrt[3]{\frac{X \times Y \times Z}{[(X+Y+Z)/3]^3}} \\ D = \sqrt{C \times T} \\ T = aX + bY + cZ \end{cases} \quad (3)$$

In the coupling-coordinated model, "C" represents the coupling degree with a value range of $(0, 1]$. "X", "Y", and "Z" represent the functional values of production, living, and ecological spaces in the same grid. To facilitate the next calculation, "X", "Y", and "Z" are normalized separately. Then, the coupling-coordinated model is calculated, with "D" as the coupling-coordinated degree and "T" as the coordination index of the PLEs functions. "a", "b", and "c" are undetermined coefficients, assuming that the importance of production, living, and ecological spaces is equal, with "$a = b = c = 1/3$".

Based on the existing literature, the following grading standards are determined for the calculated results [37]: $0 < D \leq 0.2$ indicates barely coordinated type; $0.2 < D \leq 0.4$ indicates primary coordination type; $0.4 < D \leq 0.5$ indicates intermediate coordination type; $0.5 < D \leq 0.8$ indicates highly coordination type and $0.8 < D \leq 1$ indicates super coordinated type.

3. Results

3.1. Evaluation Results of PLEs Functions in Hainan Island

The spatial heterogeneity evaluation results show that the PLEs function values in Hainan Island at a resolution of 30 m × 30 m have significant regional differences in distribution (Figure 3). The production space function values on the entire island range from 0 to 14.21, with an average value of 1.63. They show a distribution pattern of "high in the south and north, low in the central part; high along the coast, low inland", which is consistent with the basic pattern of economic growth and industrial development mainly concentrated in Haikou, Sanya, and eastern coastal cities and counties. It also reflects the phenomenon of regional economic production imbalance to some extent. The living space function values on the entire island range from 0 to 5.22, with an average value of 0.29. They show a distribution pattern of "high at both ends and low throughout", with high-value areas mainly concentrated in the urban areas of Haikou and Sanya, and most areas having weak living space functions, exhibiting typical spatial regional differences, and reflecting the uneven distribution of residents' living standards on the entire island. The ecological space function values on the entire island range from 0 to 12.28, with an average value of 3.48. They show a distribution pattern of "high in the central part and low around the four sides", which is consistent with the current basic situation of good ecological environment, low population density, and low development level in the central part of the island, and reflects the excellent environmental protection effect in most areas of the entire island.

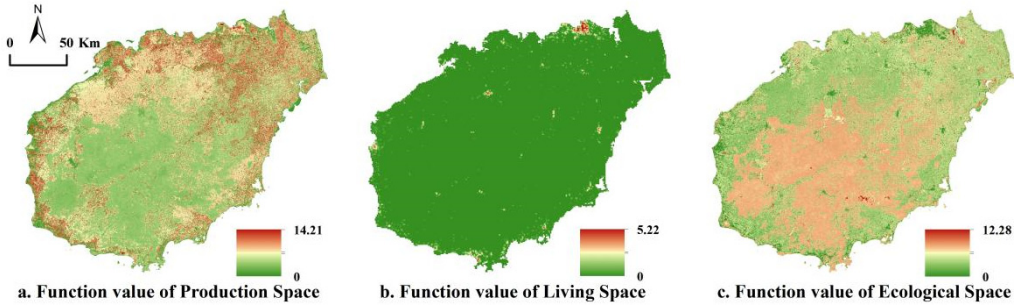

Figure 3. Evaluation Results of the Spatial Function Value of PLEs in Hainan Island in scale of 30 m × 30 m.

3.2. PLEs Function Values and Their Scale Response Characteristics in Hainan Island

Overall, the spatial distribution characteristics of the functional values of PLEs on Hainan Island are generally consistent at different scales (Figure 4), the characteristics gradually weaken as the scale increases, and the peak of the functional values on the whole island decreases with the increase in scale.

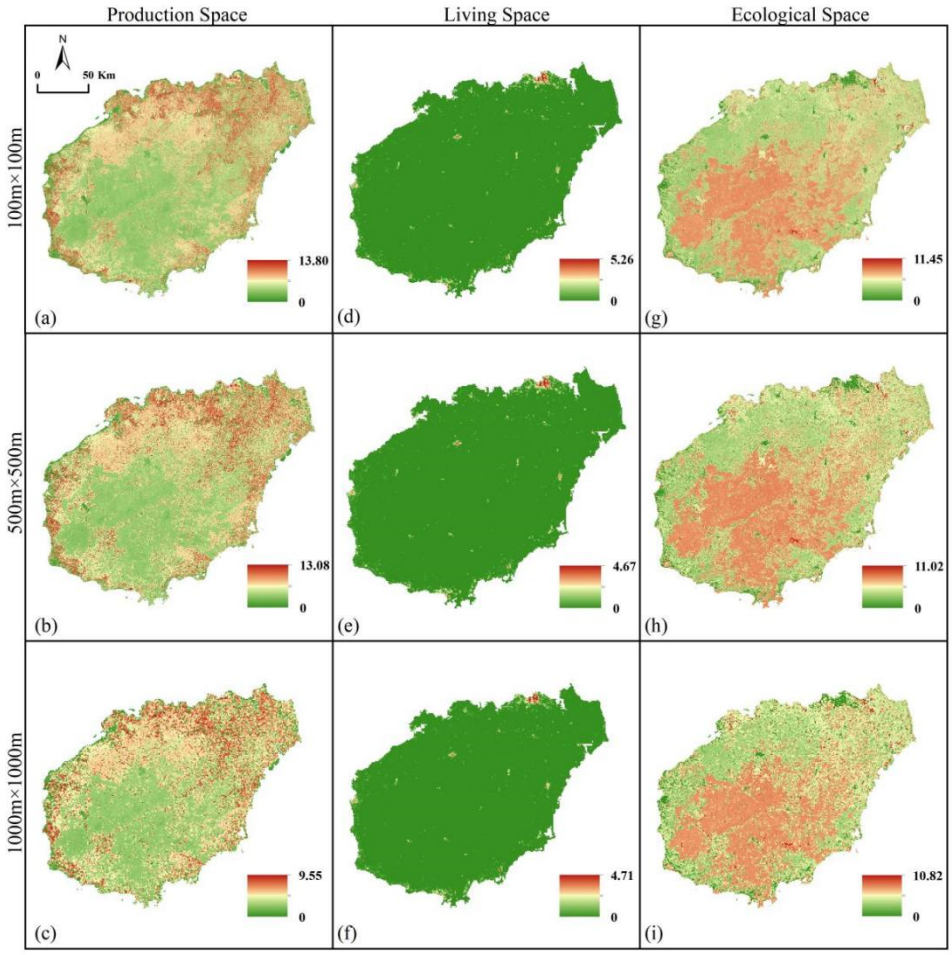

Figure 4. Spatial multi-scale distribution pattern of PLEs in Hainan Island. Note: Due to space limitations, the evaluation results at only three scales, 100 m × 100 m, 500 m × 500 m, and 1000 m × 1000 m, are shown in the figures.

The production space function values in Hainan Island show a distribution pattern of "high in the south and north, low in the middle; high along the coast, low inland", and as the scale increases, the peak values in the north and south gradually decrease, and

the low values in the middle part gradually increase (Figure 4a–c). The main reason is that with the increase in scale, the addition of large peripheral urban patches leads to a significant decrease in the function values and landscape fragmentation in the north and south, while the low-value areas in the middle part are influenced by surrounding urban patches, resulting in a continuous increase in function values. Therefore, the weakening of distribution characteristics is most evident, and is most strongly affected by scale changes.

The living space function values in Hainan Island show a distribution pattern of "high in the south and north, low in the middle", and as the scale increases, the peak value areas in the north and scattered high-value areas in the middle part show a decreasing trend (Figure 4d–f). The reason is that living space is usually closely related to roads, and road landscapes have the characteristics of linearity, wide coverage, and strong connectivity, and their landscape shape is the most complex. With the increase in scale, low-value areas around the road network are affected, and the differences are further reduced. The weakening of distribution characteristics is more evident, and is more strongly affected by scale changes.

The ecological space function values in Hainan Island show a distribution pattern of "high in the middle, low around the four sides", and as the scale increases, the peak value area in the middle part slowly decreases, while the low-value areas around the four sides show no significant changes (Figure 4g–i). The main reason is that the ecological environment in Hainan Island is well-protected, and the overall differences are small, and the distribution pattern of green landscape is widespread. The weakening of the feature pattern reflected by the increase in scale is not obvious, and is less affected by scale changes.

3.3. Spatial Aggregation of PLEs and Its Scale Response Characteristics in Hainan Island

The global spatial autocorrelation analysis results show that the Moran's I index of PLEs function values in Hainan Island is always positive at different scales, and it shows a decreasing trend as the scale increases, and the local autocorrelation also shows a gradually decreasing trend. This indicates that the PLEs in Hainan Island shows a positive spatial aggregation characteristic at different scales, but its degree of aggregation shows a decreasing trend both globally and locally as the scale increases (Figure 5).

For production space, its Moran's I index decreased from 0.66 to 0.29, and the overall decline was relatively low. Among them, when the scale was less than or equal to 300 m × 300 m, the decline of Moran's I index was significant. However, after exceeding that scale, the decline of Moran's I index gradually slowed down. This indicates that the production space on the entire island shows a positive spatial aggregation characteristic at different scales, but this feature is greatly affected by scale changes within the scale range of 300 m × 300 m. After that, it is less sensitive to changes in scale. Further analysis of local spatial autocorrelation results shows that as the scale increases, the downward trend in positive and negative autocorrelation areas is most evident. Among them, the distribution area of positive autocorrelation (HH, LL) is widespread and mainly concentrated in the coastal areas, while the distribution area of negative autocorrelation (HL, LH) is relatively small and mostly concentrated in the northeast region (Figure 5a–c).

For living space, its Moran's I index decreased from 0.99 to 0.59, and the overall decline was relatively moderate. Among them, when the scale was between 200 m × 200 m and 800 m × 800 m, the decline of Moran's I index was significant, while the decline of Moran's I index was relatively slow at other scales. This indicates that the living space maintains a strong positive spatial aggregation characteristic at different scales, and it is greatly affected by scale changes between 200 m × 200 m and 800 m × 800 m, while it is less sensitive to changes in scale at other scales. The local spatial autocorrelation analysis results show that there is no significant downward trend in positive and negative autocorrelation areas as the scale increases. Among them, most areas are distributed with positive autocorrelation, and negative autocorrelation areas are only sparsely distributed in the north and south regions (Figure 5d–f).

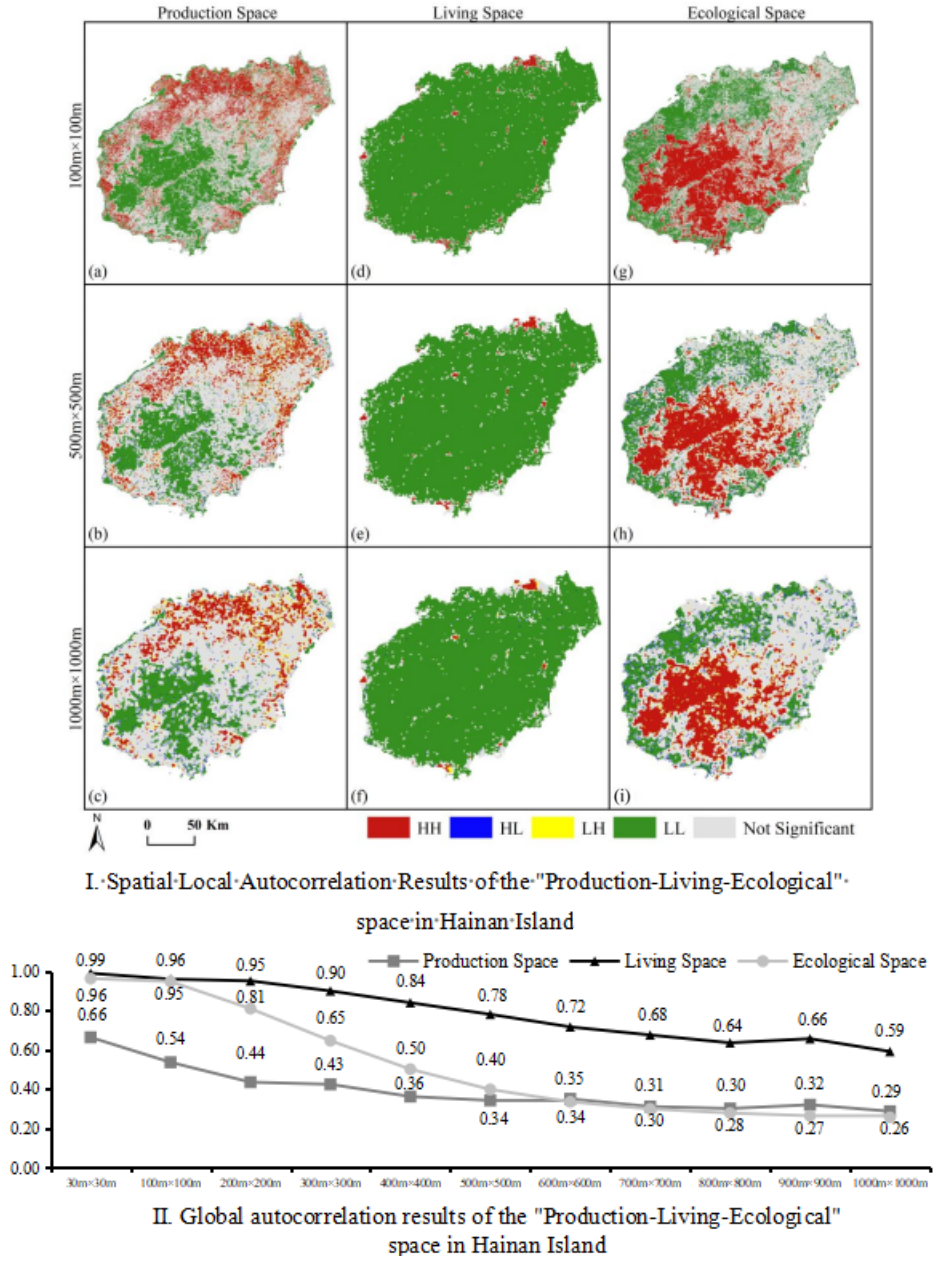

Figure 5. Spatial autocorrelation analysis results of the PLEs in Hainan Island. Note: Due to space limitations, the evaluation results at only three scales, 100 m × 100 m, 500 m × 500 m, and 1000 m × 1000 m, are shown in the figures.

For ecological space, its Moran's I index decreased from 0.96 to 0.29, and the overall decline was relatively large. Among them, when the scale was between 100 m × 100 m and 700 m × 700 m, the decline of Moran's I index was significant, while the decline of Moran's I index was relatively slow at other scales. This indicates that the positive spatial aggregation characteristic of ecological space fluctuates greatly at different scales, and it is greatly affected by scale changes between 100 m × 100 m and 700 m × 700 m, while it is less sensitive to changes in scale at other scales. The local spatial autocorrelation analysis results show that the downward trend in positive and negative autocorrelation areas is relatively moderate as the scale increases. Among them, the distribution area of positive autocorrelation is the most extensive, while the distribution area of negative autocorrelation is only staggered in the middle and eastern regions (Figure 5g–i).

In summary, there is a significant spatial scale effect in the PLEs in Hainan Island, and the overall stability is strong. The smaller the spatial scale, the stronger the response of Moran's I index and the stronger the local autocorrelation. The degree of aggregation is relatively high within the scale of 400 m × 400 m, indicating that when studying the spatial scale effect of landscape patterns, the image resolution selected should not be lower than 400 m × 400 m, and the higher, the better. As the spatial scale increases, the landscape patches will experience certain fragmentation, loss, and recombination, resulting in the results being less reflective of reality.

3.4. Coupling-Coordination Degree and Its Scale Response Characteristics of PLEs in Hainan Island

The overall level of coupling-coordination degree in the PLEs in Hainan Island is relatively low, mostly in the category of barely coordinated (Figure 6). Among them, the low-value area is widely distributed and concentrated in the middle region, while the high-value area is mainly concentrated in the north and south regions, and the middle region is sparsely distributed in a point-like pattern. Overall, the coupling-coordination degree shows a spatial pattern of "high in the north and south, low in the middle", with significant regional differences.

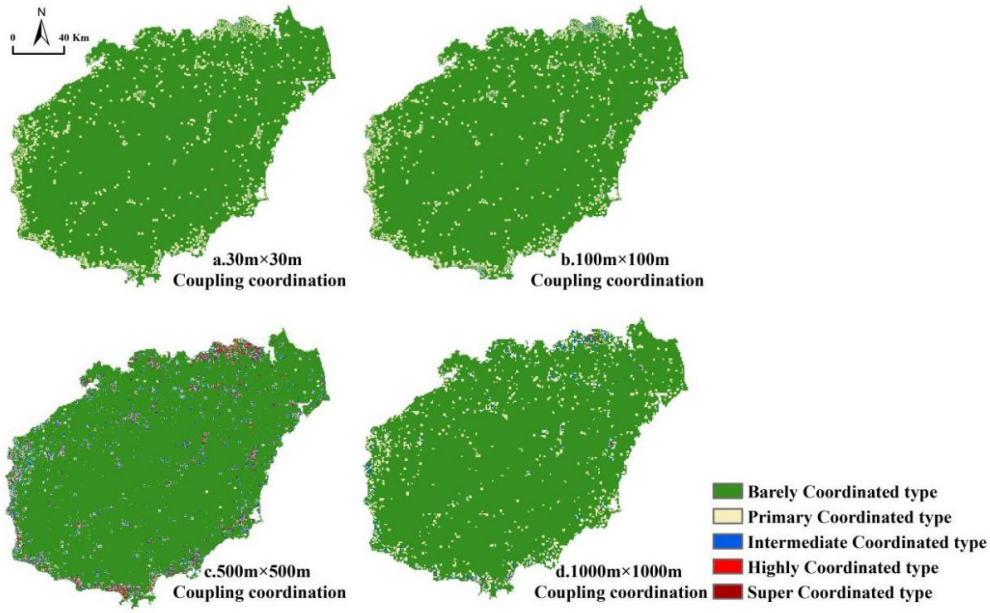

Figure 6. Measurement results of multi-scale coupling-coordination development level in the PLEs of Hainan Island. Note: Due to space limitations, the evaluation results at only four scales, 30 m × 30 m, 100 m × 100 m, 500 m × 500 m, and 1000 m × 1000 m, are shown in the figures.

Specifically, the comprehensive evaluation index, coupling degree, and coupling-coordination degree of the PLEs in Hainan Island show a slow upward trend in the range of 30 m × 30 m to 500 m × 500 m, and a fluctuating downward trend after 500 m × 500 m. The 500 m × 500 m scale is the peak value among all scales in terms of the comprehensive evaluation index and coupling-coordination degree. This indicates that when the scale is less than 500 m × 500 m, the coupling-coordination degree gradually increases as the scale increases, and reaches its peak at 500 m × 500 m. When the scale is larger than 500 m × 500 m, the coupling-coordination degree gradually decreases with the increase in scale, and conflicts become more intense. Therefore, when conducting the spatial coupling-coordination analysis of the PLEs in Hainan Island, it is recommended to select less than or equal to 500 m × 500 m scale, and 500 m × 500 m resolution is optimal.

4. Discussion

4.1. Discussion on the Evaluation of Spatial Functional Heterogeneity of PLEs

By using the merging classification method to assign values to different land types and utilizing existing indicator systems combined with multi-source spatial data for correction, the study on the spatial heterogeneity of Hainan Island's "Three Lives" can effectively leverage the advantages of the merging classification method and organically combine land use classification with the evaluation of spatial functions of the "Three Lives".

By using the merging classification method to assign values to different land types and modifying them with existing indicator systems and multi-source spatial data to study the heterogeneity of PLEs in Hainan Island, which can fully utilize the advantages of the merging classification method and organically combine land use classification with the evaluation of PLEs functions. Moreover, by correcting the functional values of PLEs using coupling nighttime light image data, normalized difference vegetation index, road network density, and remote sensing ecological index, factors such as social economy, natural ecology, and human living conditions are fully integrated, overcoming the disadvantage that numerical variables cannot be effectively reflected in quantitative measurement methods.

However, there are shortcomings in the spatial heterogeneity evaluation. The use of road network density data to correct the value of living space function is highly influenced by road network density, ignoring the fact that the population density around some highways is low, which leads to a lack of adaptive consideration of the study of living space. In the future, various data such as population distribution density and household population can be combined to correct the value of living space function, in order to achieve an adaptive approach and further deepen the study of the distribution pattern of living space.

4.2. Discussion on the Scale Effect of PLEs

The scale effect is an important concept in the field of landscape ecology. The macroscopic scale effect includes time scale and spatial scale. The spatial scale focused in this article usually shows that with the increase in scale, different types of minimum patches appear in the landscape and the minimum patch area gradually increases, while the landscape diversity index decreases with the increase in scale. A certain spatial structure characteristic can only be manifested at a certain scale.

As an objective entity in the landscape, PLEs not only includes the "ecological space" focused by traditional landscape ecology research, but also includes the "production" and "living" spaces that directly provide material services for human production and living, forming an organic whole. With the increase in scale, the patches within the production, living, and ecological spaces will also change. From the perspective of each system, there are fluctuations with peaks and decreases with aggregation. From the overall perspective, the coupling-coordination type between the three will also change. Therefore, PLEs also exhibits different spatial structure characteristics at different scales, and the results show that the scale effect can also be applied to the study of which.

4.3. Discussion on the Research Ideas of This Article

Theoretically speaking, exploring the scale effect in the spatial distribution of PLEs can not only broaden our understanding of it, but also expand the diversity of research ideas. It can also help to move the research on scale effect beyond the scope of a single ecological space. In addition, the influence of scale effect exists in many regions [38]. The research ideas of this article can provide theoretical basis for the selection of scales in the study of PLEs spatial distribution in other regions. Practically speaking, fully recognizing the scale effect inherent in the PLEs is beneficial for different levels of government in different countries to make scientific decisions, coordinate the common interests of different countries and administrative units at different levels, and ultimately serve the national spatial planning.

The shortcoming of this article is the lack of exploration of the temporal scale, as it did not consider the dynamic changes based on the temporal scale. In the future, spatial autocorrelation and coupling-coordination analysis can be further conducted based on the spatial distribution patterns of PLEs at different scales over a long period of time.

4.4. Policy Suggestions

Based on the results of the spatial heterogeneity evaluation and scale effect study of PLEs in Hainan Island, the following policy suggestions are proposed:

For large scale areas (over 700 m × 700 m), the aggregation and coupling-coordination degree of PLEs is relatively low. Therefore, in overall planning, the optimal layout of PLEs should be coordinated to play a harmonizing role. To address the characteristic of production space being severely influenced by peripheral large patches, industry layout should be relocated outside the city center to alleviate industrial pressure. To address the weak distribution pattern of living space, population density should be increased outside the urban area, promoting the convergence of population in remote rural areas towards central villages, and improving the cost-effectiveness of infrastructure and public services. To address the characteristic of the lowest aggregation and weak distribution pattern of ecological space, we should tailor the development of unique landscape patterns according to the natural geography features such as regional humidity and hydrology, and utilize the climate advantages of being located in a tropical region on Hainan Island to enhance the richness of landscape patterns.

For medium scale areas (between 400 m × 400 m and 700 m × 700 m), the aggregation degree of PLEs drops significantly, and the coupling-coordination degree first rises and then falls, requiring measures to slow down the decline. To address the production space, we should reasonably plan the industry layout within the area at the medium scale and plan land use according to the characteristics of different industries, avoiding excessive concentration of the same industry, causing resource waste and environmental pollution. To address the living space, we should vigorously promote the transformation of old residential areas in various urban areas and the relocation compensation and resettlement work in rural areas, maintain and repair infrastructure, increase public space and green space, and improve the quality of the living environment. To address the ecological space, we should focus on improving the habitat quality of ecological protection zones and natural conservation areas, strengthening the protection and restoration of marine, forest, wetland, and other ecosystems, forming a concentrated and contiguous high-value area of ecological space and constructing an overall coordinated ecological space pattern with clear local features.

For small scale areas (below 400 m × 400 m), the aggregation degree of PLEs is the highest, and the coupling-coordination degree is increasing. We should give full play to its advantages. To address production space, we should layout industrial parks within the area reasonably, fully utilize the production advantages and aggregation effects of high-value industrial parks and improve the intensive utilization of production space. To address living space, we should consider appropriately reducing the population density of the peak value area in the north and south, guiding the orderly transfer of excessively concentrated resource elements, and forming a linkage development trend with surrounding satellite cities, suburban new towns, and other regions. The functional value and aggregation degree of ecological space are relatively high, indicating that the ecological environment quality is excellent at a small scale, and we should continue to attach importance to ecological environmental protection.

5. Conclusions

Based on the evaluation of the heterogeneity characteristics of PLEs in Hainan Island and exploring the distribution pattern, spatial aggregation characteristics, and coupling-coordination characteristics at different scales, the following conclusions are drawn:

(1) The spatial distribution of the PLEs in Hainan Island shows significant heterogeneity. The functional values of production and living space show a high distribution pattern in the north and south and low in the middle; the ecological space shows a characteristic of being high in the middle and low around, and the ecological environment protection effect on the whole island is relatively good.
(2) The PLEs in Hainan Island is significantly affected by the scale effect. With the increase in scale, the distribution pattern weakens, the aggregation degree decreases, and the decline accelerates after the scale is greater than 400 m × 400 m. Among them, the downward trend in ecological space is the most obvious, the downward trend in living space is relatively weak, and the trend in production space is moderate.
(3) The overall level of coupling-coordination degree of PLEs in Hainan Island is relatively low, with significant regional differences. With the increase in scale, it shows a trend in first rising and then falling, with 500 m × 500 m as the peak value of coupling-coordination degree.

In summary, this article reveals the characteristics of PLEs spatial distribution as it changes with scale, explores the differences in production space, living space, and ecological space with scale, and summarizes the scale effect of PLEs provides explanations for its underlying reasons. Based on this, future research can focus on the following two aspects: (1) Empirically analyze the driving factors and differences behind the characteristics of PLEs spatial distribution at different scales, and further demonstrate and explain the reasons and mechanisms behind the scale effect. (2) Explore the temporal changes in the scale effect of PLEs and reveal the evolutionary rules of its scale effect, thereby providing decision-making support for the rational layout and planning of its spatial distribution.

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