Landscape Pattern Changes in Hainan Tropical Rainforest National Park, 2015–2020: Postprint

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Abstract

Hainan Tropical Rainforest National Park is abundant in forest resources. Investigating the spatiotemporal evolution characteristics of landscape patterns in this region holds significant importance for maintaining the ecological security barrier of Hainan Island. This study, based on land cover data of Hainan Tropical Rainforest National Park from 2015 and 2020, establishes a landscape distribution pattern system, and employs methods including landscape pattern indices, landscape dynamic degree, and transfer matrix to analyze the landscape pattern change characteristics of ten land cover types in Hainan Tropical Rainforest National Park and explore the influencing factors of these changes. The results indicate: (1) From 2015 to 2020, the overall landscape fragmentation of Hainan Tropical Rainforest National Park exhibited a decreasing trend, spatial aggregation increased, the comprehensive dynamic degree was relatively low, and landscape types remained generally stable. (2) The area of evergreen broad-leaved forest, the dominant species in the rainforest, continuously increased with reduced fragmentation, demonstrating a positive growth trend; the areas of coniferous forest and shrubland decreased; some water bodies were converted to wetlands, resulting in area reduction; other landscape types accounted for relatively small proportions and changed in accordance with natural succession. (3) The evolution of landscape patterns was primarily driven by natural succession of the rainforest, secondarily influenced by a combination of policy, climate, and other factors. In summary, since the initiation of the Hainan Tropical Rainforest National Park system pilot, its landscape pattern has tended toward stability. Policy guidance plays a crucial positive role, and targeted conservation and restoration efforts for tropical rainforest landscapes contribute to the sustainable development of Hainan Tropical Rainforest National Park.

Full Text

Preamble

Landscape Pattern Changes of Hainan Tropical Rainforest National Park from 2015 to 2020

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Abstract

Hainan Tropical Rainforest National Park is rich in forest resources, and investigating the spatiotemporal evolution characteristics of its landscape pattern holds significant importance for maintaining the ecological security barrier of Hainan Island. This study established a landscape distribution pattern system based on land cover data from 2015 and 2020 for the park, employing landscape pattern indices, landscape dynamic degree, and transfer matrix methods to analyze the landscape pattern change characteristics of ten land cover types and explore their influencing factors. The results indicate: (1) From 2015 to 2020, the overall landscape fragmentation of Hainan Tropical Rainforest National Park showed a decreasing trend, spatial aggregation increased, the comprehensive dynamic degree was relatively low, and landscape types remained generally stable. (2) The area of evergreen broad-leaved forest, the dominant rainforest species, continuously increased with reduced fragmentation, demonstrating positive growth; the areas of coniferous forest and shrubland decreased; some water bodies converted to wetlands, resulting in reduced water area; other landscape types accounted for relatively small proportions and changed according to natural succession. (3) Landscape pattern evolution was primarily driven by natural rainforest succession, with secondary influences from policy, climate, and other factors. In conclusion, since the pilot establishment of Hainan Tropical Rainforest National Park, its landscape pattern has tended toward stability. Policy guidance has played an important positive role, and targeted conservation and restoration efforts for tropical rainforest landscapes will contribute to the sustainable development of the park.

Keywords: landscape pattern, evolution, Hainan Tropical Rainforest National Park, influencing factors

Introduction

Landscape pattern refers to the spatial arrangement of landscape mosaics of varying sizes and shapes, representing both the concrete manifestation of landscape heterogeneity and the combined effects of natural and anthropogenic factors across space and time (Cao et al., 2021; McGarigal et al., 2023). Frequent urbanization activities and global climate change represent important driving factors affecting global landscape change (Plieninger & Bieling, 2012). As human activities accelerate environmental changes, ecological landscapes tend toward fragmented development. Once this exceeds the ecosystem's carrying capacity, various ecological functions and self-healing capabilities are significantly reduced (Beller et al., 2019), leading to issues such as soil quality degradation and biodiversity loss (Scheffer et al., 2015; Li et al., 2020; Zhang et al., 2020). Strengthening research on the spatiotemporal variation of landscape patterns and widely conducting landscape change monitoring and conservation is crucial for maintaining regional ecological security (Manolaki et al., 2021).

With the development of remote sensing technology and geographic information systems, numerous scholars have employed landscape pattern indices to quantitatively describe and monitor changes in landscape structure (Turner & Ruscher, 1988; Szilassi et al., 2017), analyze the driving mechanisms of landscape change (Tzanopoulos & Vogiatzakis, 2011; You et al., 2023), or utilized the CLUE model for multi-level, multi-scale dynamic simulation of land use change (Das et al., 2019) to comprehensively explore spatiotemporal evolution characteristics of landscape patterns. However, due to the inherent complexity of tropical rainforests and the difficulty of in-depth investigation, existing research on landscape evolution in tropical rainforest regions remains limited.

In his important speech on April 13, 2018, President Xi Jinping emphasized the need to "actively carry out pilot programs for the national park system, establish national parks such as tropical rainforest parks, and build a natural protected area system with clear ownership, well-defined rights and responsibilities, and effective supervision." Currently, research on national parks in China is still in its infancy, focusing primarily on management system establishment and legal mechanism improvement (Huang et al., 2018), while some unresolved issues and challenges remain (Zang et al., 2020). Therefore, drawing on excellent domestic and international experiences to conduct detailed assessments of landscape fragmentation in national parks (Muhammed & Elias, 2021; Zhang et al., 2022) is essential for maintaining the integrity of typical ecosystems. Hainan Tropical Rainforest National Park was selected as one of China's first batch of national parks on October 12, 2021. Previous research has primarily focused on community plant composition and diversity change patterns (Chen et al., 2014; Liu et al., 2020), with landscape pattern studies mainly targeting various national-level nature reserves or major forest areas (Lan et al., 2020), monitoring land use structure and landscape patterns to macroscopically grasp dynamic evolution laws of forest land (Xiao et al., 2010; Liu, 2010b; Song et al., 2013), using spatial analysis methods to investigate landscape vulnerability of protected areas (Wei & Meng, 2015), and analyzing correlations between land use change and ecosystem service value in the tropical rainforest national park (Li et al., 2022). However, previous studies have lacked discussion on the driving forces of landscape pattern evolution in Hainan Tropical Rainforest National Park and have neglected comprehensive landscape pattern analysis of the entire region connecting various protected areas. Evergreen broad-leaved forest is the dominant population in Hainan Tropical Rainforest National Park. Identifying vulnerable areas in forest landscapes, conducting targeted conservation efforts, and quantitatively assessing the impacts of natural and anthropogenic factors on landscape fragmentation constitute important foundations for tropical rainforest ecological restoration.

Based on this, our study takes the entire Hainan Tropical Rainforest National Park as the research object, relying on fine land cover products from 2015 and 2020, and employing landscape pattern indices and landscape dynamic change models to address the following questions: (1) What are the change characteristics of the landscape pattern in the tropical rainforest national park in recent five years? (2) What factors influence landscape changes in the tropical rainforest national park? The aim is to provide scientific references for the planning and sustainable development of Hainan Tropical Rainforest National Park.

1.1 Study Area Overview

Hainan Tropical Rainforest National Park (hereinafter referred to as the study area) is located in the central mountainous region of Hainan Province (108°44 - 110°4 E, 18°33 - 19°14 N), extending from Diaoluo Mountain National Forest Park in the east to Jianfengling National Nature Reserve in the west, from Maogan Township, Baoting County in the south, to Limu Mountain Provincial Nature Reserve in the north. It represents the only "continental island-type" tropical rainforest in the transitional zone between Asian tropical rainforest and world monsoon evergreen broad-leaved forest, with a total area of approximately 4,000 km^2 (about one-seventh of Hainan Island's land area). The climate is tropical maritime monsoon, characterized by high temperatures and abundant rainfall year-round, with an average annual temperature of 24.67 °C and precipitation of 1,759 mm. Soils are primarily latosols and red soils. The terrain is high in the center and low around the periphery, with Wuzhi Mountain and Yingge Ridge as the highest core areas, gradually decreasing in elevation, reaching a maximum of 1,867 m at Wuzhi Mountain. The area possesses rich flora and fauna species and germplasm resources, including Hainan endemic species such as *Cycas hainanensis* and *Nomascus hainanus*, with a forest coverage rate as high as 95.56%.

1.2 Data Sources and Processing

This study selected two periods of global 30-meter fine land cover products (GLC_{FCS30}-2015 and GLC_{FCS30}-2020) from before and after the national park establishment. The data were obtained from the research team of Professor Liu Liangyun at the Aerospace Information Research Institute, Chinese Academy of Sciences. Meteorological data such as rainfall and temperature were sourced from the China Weather Network; typhoon data were obtained from the National Environmental Information Center; and the study area boundary was generated through vectorization of the planning boundary from the Hainan Tropical Rainforest National Park Master Plan (2019-2025).

The base data were imported into ENVI 5.3 for geometric correction and image mosaicking, then clipped according to the Hainan Tropical Rainforest National Park vector boundary using ArcGIS to obtain land cover type maps for 2015 and 2020. Referring to the international IGBP LUCC classification system and the 30 land cover types of GLC_{FCS30}, and combining the actual landscape conditions and research objectives of the study area, landscape types were classified into ten categories: rainfed cropland, herbaceous plant, irrigated cropland, evergreen broad-leaved forest, deciduous broad-leaved forest, needle-leaved forest, shrubwood, wetland, impervious layer, and water body, as shown in Figure 1 [Figure 1: see original paper].

Figure 1 Landscape types of Hainan Tropical Rainforest National Park in 2015 and 2020

1.3.1 Landscape Pattern Index

Landscape pattern reveals the spatial arrangement of landscape elements with varying shapes and sizes. Landscape pattern indices employ quantitative analysis methods to highly condense and summarize dynamic change characteristics of landscape spatial structure (Yu & Li, 2020; Jia et al., 2020). Based on the landscape vegetation characteristics of the study area, this research was conducted at both class and landscape scales. At the class level, the following metrics were selected: Percentage of Landscape (PLAND), Number of Patches (NP), Patch Density (PD), Mean Patch Area (AREA_{MN}), Largest Patch Index (LPI), Landscape Shape Index (LSI), and Cohesion Index (COHESION). At the landscape level, NP, Contagion Index (CONTAG), Aggregation Index (AI), Shannon's Diversity Index (SHDI), and Shannon's Evenness Index (SHEI) were selected. All calculations were completed using Fragstats 4.2.

1.3.2 Landscape Dynamic Change Model

Landscape dynamic change analysis can comprehensively reflect landscape pattern changes within a certain time range and plays a positive role in comparing regional differences in landscape pattern changes and predicting future trends (Li et al., 2020). To fully investigate the landscape pattern change characteristics of the study area over the five-year period, this study introduced single landscape dynamic degree and landscape transfer matrix to construct a landscape dynamic change model.

The single landscape dynamic degree can accurately reflect the activity level and quantitative changes of landscape changes within a certain time range (Wang, 2000). Its calculation formula is:

$$K = \frac{U_b - U_a}{U_a} \times \frac{1}{T} \times 100\%$$

where: K is the single dynamic degree of a certain landscape during the study period; U and U_b are the areas of a certain landscape type at the beginning and end of the study period, respectively (km^2); T is the length of the study period in years.

The landscape transfer matrix simulates the dynamic process of landscape transition from one state to another, quantitatively explaining the specific conversion directions among various landscape patterns and holding significant statistical importance (Yang et al., 2020). Its mathematical expression is:

$$S = \begin{pmatrix} S_{11} & S_{12} & \cdots & S_{1n} \\ S_{21} & S_{22} & \cdots & S_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ S_{n1} & S_{n2} & \cdots & S_{nn} \end{pmatrix}$$

where: S is the area of each landscape; n is the number of landscape pattern types before and after transition; i and j represent landscape types at the beginning and end of the study period, respectively.

2.1 Landscape Structure Characteristics of Hainan Tropical Rainforest National Park

The study area features a typical tropical rainforest environment with rich landscape types. The dominant landscape is evergreen broad-leaved forest, followed by shrubwood, with their combined proportion increasing from 89% to 94%. In both 2015 and 2020, evergreen broad-leaved forest accounted for over 50% of the area, indicating a significant growth trend as protection efforts strengthened, with an area increase of 531.38 km^2 over the five-year period. The main change areas were in the core protection zones of Wuzhi Mountain and Diaoluo Mountain and the surrounding areas of Mihou Ridge. The proportion of shrubwood decreased, converting to evergreen broad-leaved forest, with an area reduction of 294.74 km^2, primarily distributed in Kangyun Ridge and Shizhai Ridge of Wuzhi Mountain. Deciduous broad-leaved forest, wetland, and impervious layer showed rapid growth trends, while rainfed cropland, herbaceous plant, irrigated cropland, needle-leaved forest, and water body landscape areas tended to decrease. Wetland landscape had the smallest proportion, mainly distributed in the Daguangba Reservoir and Changhua River basin. In 2020, the landscape type area ranking was: evergreen broad-leaved forest > shrubwood > needle-leaved forest > water body > rainfed cropland > irrigated cropland > herbaceous plant > deciduous broad-leaved forest > impervious layer > wetland.

Table 1 Landscape area and proportion of Hainan Tropical Rainforest National Park in 2015 and 2020

2.2 Landscape Index Change Characteristics of Hainan Tropical Rainforest National Park

At the class scale, NP and PD in the study area generally showed a decreasing trend over the five-year period, with only slight increases in deciduous broad-leaved forest, wetland, and impervious layer, indicating increased landscape fragmentation for these three types. Evergreen broad-leaved forest showed a significant decrease in NP while its area increased annually, with the highest growth in AREA_{MN}, indicating that patches became connected and concentrated, reducing heterogeneity and fragmentation. Herbaceous plant PD showed a downward trend, decreasing landscape fragmentation. Water body had the largest AREA_{MN} with a growth trend, mainly distributed in the Daguangba Reservoir, but its NP was relatively small, indicating that water body patches tended to concentrate. Evergreen broad-leaved forest had the largest LPI with the fastest growth rate, indicating it is the main landscape type in the study area with strong resistance to disturbance. Shrubwood had the second-highest LPI, but its area tended to decrease over the five-year period, with LPI significantly decreasing and landscape dominance weakening, suggesting that external disturbances such as human activities had some impact on shrubwood succession. Shrubwood had the highest LSI, indicating irregular patch shapes with significant edge effects. However, except for deciduous broad-leaved forest, wetland, and impervious layer, LSI for all landscape types showed a decreasing trend over the five-year period, with patch shapes becoming more regular and reduced potential for interaction with the external environment. Except for wetland, all landscape types in the study area had relatively high COHESION values, with evergreen broad-leaved forest and water body approaching 100%, indicating extremely high landscape connectivity. Wetland landscape was more dispersedly distributed with weaker connectivity.

At the landscape scale, influenced by the dominant evergreen broad-leaved forest, the overall NP of the study area significantly decreased, reducing landscape fragmentation. The overall landscape CONTAG and AI were relatively high and showed an increasing trend over the five-year period, indicating enhanced spatial aggregation of landscape in the study area, with the dominant evergreen broad-leaved forest connecting the overall landscape to form high connectivity. SHDI and SHEI values were relatively low and showed a decreasing trend over the five-year period, indicating enhanced proportional differences among landscape types, low landscape richness, and increased dominance.

Table 2 Class-level landscape indices of Hainan Tropical Rainforest National Park in 2015 and 2020

Table 3 Landscape-level indices of Hainan Tropical Rainforest National Park in 2015 and 2020

2.3 Overall Landscape Type Dynamic Transfer in Hainan Tropical Rainforest National Park

From the perspective of landscape type conversion directions: (1) Evergreen broad-leaved forest had the largest transfer amount, mainly converted from shrubwood and needle-leaved forest, with conversion areas of 512.97 km^2 and 203.97 km^2, accounting for 17.05% and 6.78% of the total transfer amount, respectively. Needle-leaved forest conversion areas were mainly concentrated in the former site of Ya'en Village and the core protection zones of Wuzhi Mountain and Diaoluo Mountain. (2) Irrigation of farmland near water bodies led to hardening of nearshore water areas, with water bodies converting to wetland, rainfed cropland, and irrigated cropland, with conversion areas of 0.58 km^2, 1.94 km^2, and 2.34 km^2, and conversion proportions of 0.89%, 2.99%, and 3.60%, respectively, mainly distributed along both banks of the Daguangba Reservoir and the Shiyun Township section of the Changhua River. (3) Herbaceous plants mainly converted to shrubwood, with a conversion area of 37.58 km^2 and a proportion of 76.49%, primarily distributed in the core area of Bawangling, Baisha County. (4) Some rainfed cropland and evergreen broad-leaved forest converted to deciduous broad-leaved forest, with conversion areas of 1.41 km^2 and 1.72 km^2, and proportions of 21.83% and 26.59%, respectively. (5) Rainfed cropland mainly interconverted with shrubwood. Transfer changes in irrigated cropland and impervious layer were relatively small.

From the perspective of area change and dynamic degree: (1) Evergreen broad-leaved forest, shrubwood, and needle-leaved forest dominated, with relatively small area changes in other landscapes. The absolute area change ranking from largest to smallest was: evergreen broad-leaved forest > shrubwood > needle-leaved forest > herbaceous plant > rainfed cropland > deciduous broad-leaved forest > water body > irrigated cropland > impervious layer > wetland. (2) The absolute dynamic degree ranking from highest to lowest was: wetland > deciduous broad-leaved forest > impervious layer > herbaceous plant > needle-leaved forest > evergreen broad-leaved forest > shrubwood > irrigated cropland > rainfed cropland > water body. Dynamic degree is influenced by initial area, with only evergreen broad-leaved forest, deciduous broad-leaved forest, wetland, and impervious layer showing positive growth and positive dynamic degree values. Wetland had the highest dynamic degree change value, while water body had the smallest.

Calculating the comprehensive dynamic degree allows for overall analysis of landscape type changes in the tropical rainforest national park and its various reserves. The comprehensive dynamic degree of the tropical rainforest national park from 2015 to 2020 was 2.45%. Referring to relevant research by Liu et al. (2014), the study area's comprehensive dynamic degree falls into the extremely slow change category, indicating slow landscape type changes, basically stable landscape types, minimal human disturbance, natural vegetation succession, and good ecosystem stability.

Table 4 Dynamic degree of landscape type changes in Hainan Tropical Rainforest National Park, 2015-2020

Table 5 Landscape transfer matrix for Hainan Tropical Rainforest National Park, 2015-2020

3.1 Policy Factors

Since the implementation of the "Natural Forest Protection Program" in Hainan in 1998, the province's natural forests have been effectively protected, with forest volume and coverage rates rising continuously. In 2013, the Hainan Provincial Government issued the "Hainan Province Green Hainan Great Action Engineering Construction Master Plan," further strengthening natural forest protection. Additionally, Hainan established a local ecological forest compensation mechanism in 2006, with compensation standards rising annually from 3 yuan/mu in 2006 to 18 yuan/mu in 2017, greatly enhancing farmers' enthusiasm for participating in ecological conservation. To provide ecological security for stable growth of natural forests in protected areas and effectively prevent and control major dangerous forestry pests that threaten forestry development, in April 2015, forest pest control stations in four surrounding cities and counties including Wuzhishan jointly signed the "Joint Prevention and Control Agreement for Forestry Pests." Since 2016, Hainan Provincial Courts have successively established circuit courts in protected areas such as Yinggeling and Bawangling, providing strong judicial protection for rare tropical rainforest environmental resources and wildlife. A series of policy measures have demonstrated the Hainan government's determination and perseverance in protecting rainforest ecological environments, leading to 逐年减少的违法砍伐现象 and orderly ecological restoration work, with continuously increasing natural forest area, landscape patches connecting into continuous areas, and reduced fragmentation.

Furthermore, to address the issues of food source plant supplementation and habitat fragmentation for rare wildlife such as gibbons, since 2013, Hainan forestry departments have used artificial intervention to construct ecological corridors in Bawangling Nature Reserve, transforming 400 mu of pine forest in the Nancha River area by planting gibbon food source plants and establishing mixed forest zones (Peng et al., 2022). This is also one of the important reasons for the increase in broad-leaved forest area in the study area, particularly in the Bawangling region.

3.2 Climate Factors

Based on monthly average precipitation and temperature data from nine counties in the study area from 2015 to 2020, climate change in Hainan Tropical Rainforest National Park was analyzed. Statistics show that the average annual temperature in the study area was 24.55 °C in 2015, with annual precipitation of 130.89 mm, while in 2020 the average annual temperature was 24.80 °C with precipitation of 145.97 mm. Overall, both rainfall and temperature showed upward trends during the five-year period, with an average warming of 0.25 °C and an average precipitation increase of 15.08 mm, which to some extent facilitated hydrothermal conditions promoting vegetation growth. Moreover, the soil in the study area is primarily organic-rich red soil, which is conducive to positive succession of evergreen broad-leaved forest, the dominant population in the tropical rainforest landscape. On the other hand, severe climate events such as typhoons have negative impacts on rainforest vegetation growth, including canopy layer destruction, creating numerous gaps, windthrow, and landslides. Between 2015 and 2020, three strong tropical storms swept through Hainan Tropical Rainforest National Park, including Typhoon "Yinhe" (No. 3) in 2016 and Typhoon "Shanshen" (No. 9) in 2018, which accompanied by level 8-9 winds and heavy rainfall crossed the core protection zones of Wuzhi Mountain and Jianfengling from east to west, causing damage to large-diameter tree layer plants and even changing regional landscape dominant species. This may be one of the reasons for the reduction of needle-leaved forest in the Wuzhi Mountain area. Meanwhile, gaps formed by typhoon passages promoted growth of sapling and understory vegetation to some extent, facilitating rainforest vegetation renewal (Xu, 2010).

Table 6 Annual average precipitation and temperature of meteorological stations in 2015 and 2020

3.3 Terrain Factors

Overlay analysis of the study area's elevation map with landscape transfer maps revealed that the total area of needle-leaved forest converting to evergreen broad-leaved forest was 203.92 km^2, with higher conversion rates in the 800-1,400 m elevation zone, totaling 173.53 km^2 and accounting for 85.09%, mainly distributed in the core protection zones of Wuzhi Mountain, Bawangling, and Diaoluo Mountain, as well as Qingchun Ridge, Wa Ridge, and Mihou Ridge. The total area of shrubwood converting to evergreen broad-leaved forest was 512.45 km^2, primarily distributed in low-altitude mountains at 200-800 m, with an area of 409.87 km^2 accounting for 79.98%. The total area of herbaceous plants converting to shrubwood was 37.45 km^2, with higher conversion rates in low-altitude hilly areas below 400 m, totaling 22.00 km^2 and accounting for 58.74%. These conversion distributions are relatively consistent with natural vegetation growth patterns. Slope and aspect analysis of the study area showed that in gentle slopes, northwest-facing aspects, and leeward slopes of low-altitude mountains with relatively small rainfall, conversion from shrubwood to rainfed cropland was more significant. The terrain of the study area is complex. Compared with slope and landform, elevation had a greater impact on landscape type changes, and the interactions among the three factors all showed nonlinear enhancement characteristics.

Table 7 Landscape pattern transformation and elevation analysis

3.4 Human Activity Factors

Human activities within the tropical rainforest national park range are relatively limited. This study selected residential point and road distribution patterns to represent human activity intensity and explore impacts on landscape pattern changes. Multi-ring buffer analysis was conducted on 18 concentrated residential points in the study area to represent influences of different human activity intensities (Figure 2 [Figure 2: see original paper]A). A 1 km × 1 km fishnet was created within the study area to extract various roads and railways within and 5 km around the study area in 2020 for road density analysis, calculated as "road density = road length/grid area" (Figure 2B). Weighted analysis of residential point and road impacts yielded a comprehensive human activity intensity level distribution map (Figure 2C). Results showed that high-intensity human activity areas were mainly located in Shiyun Township, Qiantie Village, Tongjia Village, and other areas with convenient transportation and low altitude. In these areas, conversion mainly occurred between rainfed cropland and shrubwood. Taking Shiyun Township as an example, located at the foot of Yingge Ridge with flat terrain and surrounded by important transportation routes such as National Highway G224 and Hai-San Expressway G9811, the area suffers severe human disturbance, where significant conversion from shrubwood to rainfed cropland, herbaceous plants, and irrigated cropland occurs, and ecosystems tend toward reverse succession. Conversely, positive succession from shrubwood to evergreen broad-leaved forest mainly occurred in high-altitude areas with medium-low human activity intensity such as Wa Ridge.

Figure 2 Analysis of human activity intensity in Hainan Tropical Rainforest National Park

4.1 Evolution Patterns of Landscape Pattern in Hainan Tropical Rainforest National Park

Hainan Tropical Rainforest National Park features a typical tropical rainforest environment, with evergreen broad-leaved forest as the main dominant landscape (Li et al., 2022), followed by shrubwood. As protection and publicity policies continue to strengthen, the area of Hainan's tropical rainforest has increased annually, primarily manifested as: area growth of evergreen broad-leaved forest in the core protection zones of Wuzhi Mountain and Diaoluo Mountain and surrounding areas of Mihou Ridge, enhanced landscape dominance, reduced fragmentation, and concentrated distribution of connected patches. Evergreen broad-leaved forest mainly converted from shrubwood and needle-leaved forest, leading to significant reductions in shrubwood and needle-leaved forest areas. Among these, shrubwood area in Kangyun Ridge and Shizhai Ridge of Wuzhi Mountain was substantially reduced, but its landscape shape index remained the highest, with irregular patch shapes and significant edge effects. Under the guidance of Hainan's ecological compensation and indigenous ecological relocation policies, rainfed cropland positively succeeded to shrubwood and broad-leaved forest; nearshore water areas of the Daguangba Reservoir negatively converted to wetland, farmland, and other landscapes. Wetland landscape had the highest single dynamic degree, indicating active change and significant positive growth, but wetland landscape was dispersedly distributed with poor connectivity and increased fragmentation. Water body landscape slightly decreased but patches tended to aggregate.

Previous scholars have investigated landscape patterns in Hainan Island, with studies showing that forest area in regions such as Bawangling is slowly increasing (Liu et al., 2010a; Zhou & Zhou, 2015). This study focuses on the five-year period before and after the establishment of the Hainan Tropical Rainforest National Park pilot zone, providing a detailed investigation of landscape pattern change rules in the study area and further demonstrating that under macro-level policy regulation, Hainan's tropical rainforest has received good protection, with continuously decreasing landscape fragmentation and enhanced rainforest ecological restoration capacity.

4.2 Analysis of Factors Influencing Landscape Pattern Changes in Hainan Tropical Rainforest National Park

Landscape pattern evolution in Hainan Tropical Rainforest National Park is primarily influenced by policy factors, followed by climate, terrain, and human activity disturbances. Over the past decades, due to the continuous emergence of economic forestry booms (Feintrenie & Levang, 2009), primary tropical rainforests worldwide are disappearing at a rate of 2%-20% annually (Potapov et al., 2017). Indonesia's tropical rainforests have suffered severe pollution (Sahide et al., 2015), while artificial economic forest area in Xishuangbanna has increased more than 20-fold, with broad-leaved and needle-leaved forest areas significantly decreasing by 30%, rainforest carbon storage plummeting, and natural forest landscape patterns becoming fragmented (Liu et al., 2017). Benefiting from Hainan's Natural Forest Protection Program and Green Hainan Action, continuous protection through natural forest closure has significantly increased broad-leaved forest area. Under China's Grain for Green policy, indigenous residents have been relocated out of the core zone of Hainan Tropical Rainforest National Park, avoiding impacts of human activities on rainforest ecosystems. Through self-healing of the rainforest ecosystem (Priyadarshini & Abhilash, 2020), original cultivated land in the study area has gradually converted to forest land. Mountain rainforests at higher altitudes are dominated by positive natural succession, with continuously increasing forest area and enhanced spatial aggregation. In areas with frequent human activities, rainforest ecosystems tend toward reverse succession with severe landscape fragmentation, which is consistent with tropical forest landscape changes in Xishuangbanna (Wei et al., 2018). Unlike Asian regions, the main driving factor for landscape changes in the Congo tropical rainforest is climate, as African regions are severely affected by precipitation, where minor precipitation changes can lead to conversion between rainforest landscape and grassland (Giresse et al., 2020). Inappropriate human activities are also one of the important factors causing rainforest crises in Africa (Berhanu et al., 2023). Establishing national parks is an important step in China's ecological civilization construction. Through policy regulation, gradually reducing human interference in tropical rainforest landscapes and ensuring the authenticity of Hainan tropical rainforest ecosystems holds certain reference and guiding significance for future ecological environmental protection and development in China.

Conclusions and Recommendations

The Hainan Tropical Rainforest National Park system pilot was established in 2019 and later selected as one of China's first batch of national parks. Hainan Province has continuously strengthened publicity and promotion of the tropical rainforest national park. On one hand, extensive science education and publicity have raised public awareness of tropical rainforest landscape protection; on the other hand, ecological recreation planning and construction will be put on the agenda. The study area will tend toward diversified development in the future, with core protection zones emphasizing strict protection of rainforest ecosystems following natural succession laws, while general control zones will be open to the public to a certain extent to explore the ecological economic value of green mountains and clear waters. To balance the relationship between protection and utilization, it is necessary to strengthen real-time monitoring and management of landscapes in Hainan Tropical Rainforest National Park, advocate protective and ecological development, strictly prohibit all construction activities that may damage rainforest landscapes, and promote ecological livable development in general control zones. It is essential to explore HML (human modified landscapes) structures with conservation potential at different scales, optimize landscape composition, explore critical ecological thresholds for tropical rainforest protection (Wies et al., 2021), learn from excellent international experiences, introduce forest governance mechanisms such as payment for ecosystem services, and reduce disorderly destruction of rainforests from legal and institutional perspectives (Edwards & Giessen, 2014; Berhanu et al., 2023).

The tropical rainforest national park is the source of Hainan's three major rivers and possesses Hainan's second-largest reservoir, the Daguangba Reservoir, with abundant water resources. However, water body landscape area in the study area showed a decreasing trend over the five-year period, inconsistent with the annually increasing precipitation. Protection efforts for river source areas should be strengthened, water source protection zones established, and water conservation layout optimized to enhance landscape integrity and connectivity (Wang et al., 2020). Additionally, in areas with strong human activity such as Shiyun Township and Maorui, where the ecological environment is relatively fragile, vegetation environments around construction land such as expressways should be restored as soon as possible, establishing green belts and other forms of road buffers to form ecological security barriers and reduce impacts on the ecological environment. The tropical rainforest national park is rich in biodiversity and is a crucial tropical germplasm gene bank in China, hosting nationally protected flora and fauna such as *Tylototriton hainanensis* and *Cycas changjiangensis*, and the Bawangling Reserve is the only habitat for the globally endangered primate, the Hainan gibbon (*Nomascus hainanus*) (Du et al., 2020). To further improve rainforest vegetation richness and provide high-quality habitats for rare animals, ecological restoration systems should be continuously improved, landscape ecological corridors constructed, tree species with good protection benefits planted, and connectivity among various reserves strengthened to form a continuous forest ecological network.

This study covers only a five-year period before and after the establishment of the tropical rainforest national park, which cannot fully reveal the evolution characteristics and influencing factors of the study area's landscape pattern. Future research will consider extending the time span to discuss landscape conditions before the establishment of various reserves in the 1990s and comprehensively explore the overall conservation effectiveness of the study area. On the other hand, as the study area is a key protected region in Hainan Province, some detailed meteorological and vegetation data are difficult to obtain, while policy and human activity influencing factors are difficult to quantify and statistically analyze. Subsequent research will expand indicator selection, increase field investigations, and further explore driving factors of landscape pattern evolution in the study area.

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Note: Figure translations are in progress. See original paper for figures.