

Postprint: Dynamic Characteristics and Driving Factors of Community-Level Forest Landscape Patterns

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Abstract

Based on high-resolution SPOT-5 imagery, TM imagery, household survey data, and relevant ancillary data, Shixing Village in Sanxing Township, Shizhu County—a typical forest-rich county in the Three Gorges Reservoir Area—was selected as the study area. Employing landscape pattern indices and Logistic regression analysis, this study examined the dynamic characteristics of forest landscape patterns and their influencing factors from 1994 to 2014, aiming to enrich understanding of community-level forest landscape dynamics and provide a scientific basis for formulating forest landscape restoration and sustainable management strategies. The results indicate: The forest landscape consistently dominated the landscape matrix throughout the 20-year period. Spatially, degraded primary forests were concentrated in the low mountainous and deep hilly regions of the central-eastern part, while secondary forests, degraded forestlands, and plantations exhibited a mosaic pattern dispersed within the dominant matrix landscape; Over the 20-year period, the forest landscape displayed an overall “U-shaped” pattern of initial decrease followed by increase, manifesting as two contrasting processes—degradation during 1994–2004 and recovery during 2004–2014—with these processes primarily occurring at interfaces between forest landscapes and paddy fields, drylands, residential areas, and roads; The evolution trend during 2004–2014 was generally opposite to that during 1994–2004; spatially, forest landscape recovery during this stage primarily occurred in areas that had experienced degradation during 1994–2004; Over the 20-year period, forest landscapes exhibited significant heterogeneous distribution at the patch level. The overall ranking of fragmentation degree across the three cross-sectional years was consistently: degraded forestland > plantation > secondary forest > degraded primary forest, with degraded primary forests, secondary forests, and degraded forestlands all showing identical fragmentation trends of initial increase followed by decrease; At the landscape level, forest landscape fragmentation exhibited a trend of initial intensification followed by weakening,

with the fragmentation degree in 2014 recovering to a level lower than that in 1994, further demonstrating that during post-degradation forest landscape recovery, the restoration rate of ecological integrity is far slower than the rate of fragmentation; Socioeconomic factors exerted the most prominent influence on forest landscape changes over the 20-year period. The most critical factor was population density change; its increase-then-decrease pattern caused corresponding fluctuations in ecological pressure, thereby driving forest landscape degradation and recovery. The second most important factor was change in per capita net income of farmers, particularly the income increase during 2004–2014, which facilitated energy structure transformation and reduced dependence on and disturbance to forest landscapes. Spatial distance exerted a stable and persistent influence, with residents' disturbances to forest landscapes largely mediated through distance factors. Natural factors controlled the broad geomorphological pattern and had limited impact on forest landscape changes in the medium-short term; however, secondary forests and degraded forestlands, being located in marginal zones suitable for development, were more significantly affected by natural environmental conditions.

Full Text

Preamble

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Forest Landscape Pattern Dynamics and Its Driving Factors at the Community Level

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Abstract: To better understand the dynamic characteristics of forest landscapes and provide scientific foundations for forest landscape restoration and sustainable development at the community level, this study analyzed the dynamic characteristics and influencing factors of forest landscapes from 1994 to 2014 using landscape metrics and logistic regression analysis. Based on high-resolution SPOT-5 imagery, TM images, household survey data, and related auxiliary data, Shixing Village in Sanxing Township, Shizhu County—a typical forest-rich county in the Three Gorges Reservoir Area—was selected as the sampling site. The results revealed that: (1) Forest landscape has been the dominant landscape matrix in the sampling area for the past two decades, with

degraded primary forest mainly distributed in the hills and low mountains of the central and eastern parts of the study site, while secondary forest, degraded forest land, and plantations showed a mosaic pattern distributed within the matrix of the major landscape. (2) Forest dynamics during these two decades reflected an initial reduction followed by an increase, constituting a U-shaped trend. The landscape evolution from 1994 to 2004 showed an inverse process to that from 2004 to 2014, occurring mainly in contiguous areas between forest landscape and paddy fields, dryland, human settlements, and roads. In terms of spatial pattern, the recovery area during 2004–2014 was almost identical to the degraded area during 1994–2004. (3) At the patch level, the forest landscape was significantly heterogeneously distributed and has been for the past 20 years. The total ranking of forest landscape fragmentation across three time points was: degraded forest land > plantation > secondary forest > degraded primary forest. Additionally, degraded primary forest, secondary forest, and degraded forest land showed the same fragmentation tendency of increasing first and then decreasing. (4) At the landscape level, the forest landscape fragmentation tendency was the same as that at the patch level, with the degree of fragmentation in 2014 lower than that in 1994, indicating that the speed of ecological integrity recovery was slower than the speed of degradation. (5) Socio-economic factors had a significant influence on forest dynamics from 1994 to 2014. First, the most important factor was the change in residential population density. Fluctuation in population density directly affected ecological pressure and led to forest landscape degradation and recovery. The second critical factor was the change in farmers' net income, especially the increase from 2004 to 2014, which resulted in transformation of the energy structure and reduction of dependence and interference in the forest landscape. The spatial distance factor had a steady effect on forest landscape dynamics, as human disturbance factors affected forest landscape via accessibility based on spatial distance. Overall, natural factors controlled the entire landscape pattern of the forest but only slightly affected forest landscape in the short term. Secondary forest and degraded forest land were influenced by the natural environment due to their location in developing suburban areas.

Keywords: community level; forest landscape; dynamic evolution; driving factors; mountainous area

1. Regional Overview

The sampling site, Shixing Village, is located in the central-eastern part of Sanxing Township, Shizhu County (108°04 34 -108°09 43 E, 29°52 00 -29°54 00 N). The terrain slopes from high in the east to low in the west, with low mountains and gentle hills as the main landforms. The total area is 1172.46 hm², featuring both mountainous and hilly landscape characteristics. The region has a subtropical humid monsoon climate with an average annual temperature of 17.6°C and elevation ranging from 630 to 1380 m. The soil is primarily yellow

soil, and vegetation consists mainly of subtropical evergreen broad-leaved forest and deciduous broad-leaved forest. Forest coverage reaches 60.71%. According to the International Tropical Timber Organization (ITTO) classification standards [19-20], the sampling area contains degraded primary forest (454.97 hm²), secondary forest (121.79 hm²), degraded forest land (72.95 hm²), plantation (62.09 hm²), dryland (253.27 hm²), paddy field (181.90 hm²), human settlements (22.50 hm²), and water bodies (2.99 hm²). The village comprises 4 villager groups with a permanent out-migrant labor force.

2. Data Sources

Data used in this study primarily involved two categories: basic data and survey data. Forest resource inventory data were obtained from the Shizhu County Forestry Bureau. SPOT-5 imagery was sourced from the Chongqing Forestry Planning Institute. The 2010 second national land survey data, 1:10,000 topographic maps, administrative boundaries, and road distribution maps were obtained from the Shizhu County Land and Resources Bureau. TM imagery was sourced from the Chinese Academy of Sciences' Resource and Environmental Science Data Center. Agricultural economic reports from 1994 to 2014 were obtained from the Sanxing Township government and relevant functional departments. Participatory farmer interviews were conducted by the author's research team, involving 50 households. Questionnaire content covered population, per capita cultivated land area, fuelwood demand, willingness regarding land use, and perceptions of forest changes.

3. Data Processing

3.1 Forest Landscape Pattern Extraction

The extraction of forest landscape patterns for 2002 and 2010 followed this process: geometric correction, image mosaicking, and clipping of remote sensing images were performed with software support. These were then unified with auxiliary interpretation data (2002 forest resource inventory sub-compartment data, 2010 second land survey data, 1:10,000 topographic maps, and administrative boundary vector maps) under Xi'an 80 projection. SPOT-5 10-meter panchromatic and multi-spectral band images were fused. Human-computer interactive interpretation and sub-compartment division were conducted, referencing the ITTO classification standards [19-20], field surveys, and farmer interviews to establish interpretation criteria for forest landscape elements in the sampling area. Based on the 2002 forest inventory sub-compartment maps and interpreted forest landscape patterns, field verification and validation were conducted at the sub-compartment level. Using the indoor-interpreted sub-compartments as base maps, local residents were engaged to trace back each sub-compartment, and the traced results were verified against high-resolution imagery to improve accuracy. Random sub-compartments were selected for each forest landscape type to verify interpretation and tracing results. For degraded

primary forest, secondary forest, and plantations in 1994, 2004, and 2014, 13, 27, and 19 sub-compartments were respectively selected, with accuracy rates of 95.5%, 89.7%, and 91.3%. For 2004 and 2014, 9, 21, and 24 corresponding sub-compartments were selected, with accuracy rates of 93.9%, 91.6%, 88.3%, 95.1%, and 90.9%, all meeting the precision requirements of this study. The three-phase forest landscape pattern interpretation results are shown in Figure 2

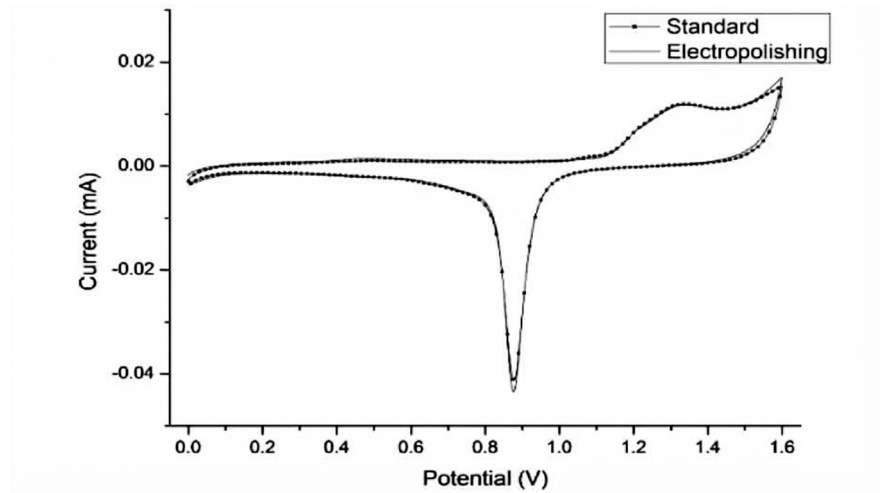


Figure 1: Figure 2

Because this study operates at the community level and aims to trace forest landscape evolution to specific land parcels, using only TM imagery for interpretation would yield coarse granularity and large relative errors. Conversely, relying solely on participatory farmer interviews would make it difficult to precisely trace forest landscape changes to specific years, introducing significant uncertainty. Therefore, this study combined both methods: using conventional remote sensing image processing for geometric and projection correction of TM imagery as auxiliary data for 1994 forest landscape pattern extraction, while using 2004 and 2014 interpreted forest landscape maps as base maps for local residents to trace back each sub-compartment, with TM imagery used to verify tracing results and improve accuracy.

3.2 Landscape Pattern Analysis

Landscape pattern indices are simple quantitative indicators reflecting landscape spatial configuration characteristics and composition, and are the most commonly used static quantitative methods for characterizing landscape patterns [21]. They are divided into patch level, class level, and landscape level. To

study the response of forest landscape patterns to natural environment, human disturbance, and socio-economic development changes during 1994–2014, seven landscape metrics were selected at class and landscape levels [22–23]: patch density (PD), edge density (ED), mean patch size (MPS), largest patch index (LPI), area-weighted mean shape index (AWMSI), contagion index (CONTAG), and Shannon’s diversity index (SHDI). PD and ED indicate higher fragmentation and heterogeneity; MPS indicates the proportion of the largest patch area; LPI shows larger proportion of maximum patch area with less disturbance; AWMSI indicates more complex and diverse spatial patterns; CONTAG shows higher density of various elements; and SHDI indicates higher diversity.

Landscape index calculations were implemented using ArcGIS as the data input platform and Fragstats 3.3 software. Logistic regression models were used to identify driving factors influencing forest landscape pattern evolution [24–25]. Model predictive capability was evaluated using maximum likelihood estimation. When regression coefficients were positive, the probability of the dependent variable increased with the explanatory variable. Wald statistics indicate each variable’s relative weight, evaluating its contribution to the event [26]. Variables with significance levels less than 0.05 were retained, otherwise removed. The Hosmer-Lemeshow (HL) test was used for goodness-of-fit evaluation [26–27], with $HL > 0.05$ indicating good model fit.

3.3 Dependent Variable Construction

To analyze influencing factors of various forest landscape changes, this study selected changes in degraded primary forest, degraded forest land, and plantations as dependent variables. “1” indicated forest landscape change (conversion from other types to this forest type or vice versa), while “0” indicated no change. The study period was 1994–2014. Under ArcGIS support, adjacent temporal forest landscape interpretation vectors were overlaid to obtain dynamic change vector maps for 1994–2004 and 2004–2014, which were then converted to raster format at 10m resolution according to coding values.

3.4 Independent Variable Construction

Forest landscape patterns in the sampling area changed significantly under combined natural and human drivers. Considering data scientific rigor and availability, 12 influencing factors closely related to spatiotemporal forest landscape changes were selected across three dimensions: natural background, socio-economics, and spatial distance. These represent direct and indirect impacts of natural and human factors on forest landscape dynamics. Elevation and slope served as natural background variables. Changes in permanent population density, fuelwood demand, cultivated land per laborer, and farmers’ net income were socio-economic variables selected considering rural characteristics. Distances from sub-compartments to roads, settlements, and water bodies reflected spatial human activity impacts. Considering different influence capacities of roads, settlements, and water bodies, and the large relative elevation difference in the

sampling area, distance calculations were modified based on road impact index research [28]:

$$D = L \times E + H$$

Where D is the modified distance from sub-compartment to roads, settlements, or water bodies; L is the influence coefficient of different road, settlement, or water body levels; E is the minimum linear distance; and H is the relative elevation difference. Higher levels or closer proximity indicate stronger disturbance. Road levels were categorized: township roads and above as level 1, production paths as level 2. Settlements were categorized: contiguous residential area $\geq 0.5 \text{ hm}^2$ as level 1, $< 0.5 \text{ hm}^2$ as level 2. Water bodies were categorized by irrigation capacity.

3.5 Data Extraction and Analysis

Distances to settlements, roads, and water bodies were calculated using the above formula in a raster calculator at 10m resolution. Socio-economic data were spatialized by villager group. To avoid spatial autocorrelation, random sampling selected n uniformly distributed points. ArcGIS' s Create Random Point tool generated points, and Extract Value to Point assigned dependent variable attributes. Selected points' independent variable values were averaged to retain original information while eliminating dimensional effects. SPSS 17.0 performed binary Logistic regression with forward stepwise selection at 0.05 significance level.

shows the driving factor index system for forest landscape pattern evolution.

4. Results

4.1 Landscape Pattern Characteristics

Forest landscape has dominated the sampling area' s matrix for nearly 20 years, exceeding 60% of total area in all three time points. Degraded primary forest occupied the dominant landscape position in all three years, with cumulative proportions of 41.90%, 33.46%, and 36.46% respectively, comparable to secondary forest. Spatially, degraded primary forest was mainly distributed in low mountains of central-eastern areas, while paddy fields and dryland were concentrated in western shallow hill areas. Other landscape types showed mosaic patterns scattered within the dominant matrix landscape. In distribution morphology: degraded primary forest showed contiguous patch distribution, degraded forest land showed banded distribution, plantations showed point distribution, and dryland showed contiguous areal distribution.

4.2 Conversion Dynamics

4.2.1 Overall Pattern Conversion During 1994-2014, forest landscape showed a U-shaped trend of first decreasing then increasing, with net increase

of 19.39 hm². Its proportion of total area decreased from 60.71% to 52.05% during 1994–2004, then increased to 60.71% by 2014. This reflected two opposite processes: degradation during 1994–2004 and recovery during 2004–2014. Secondary forest trends matched the overall pattern, while degraded forest land and plantations continuously increased. Degraded primary forest net decreased by 36.33 hm², while degraded forest land and plantations net increased by 99.02 hm² and 62.69 hm² respectively. In spatial pattern, forest landscape evolution occurred mainly in areas accessible to human activities, particularly at interfaces with paddy fields, dryland, and roads, where human disturbance fluctuated with regional economic development.

During 1994–2004, forest landscape reduction occurred mainly in central areas where degraded primary forest bordered paddy fields, dryland, and settlements, and in eastern areas where paddy fields were embedded within degraded primary forest. Driven by economic interests, large forest areas were converted to dryland, degraded forest land, or plantations. With industrialization and urbanization, large numbers of young laborers migrated out, reducing disturbance and facilitating forest recovery. The first areas to recover were those last disturbed.

4.2.2 Pattern Conversion Trajectories During 1994–2004, main conversion types were: degraded primary forest to secondary forest (70.43 hm²), secondary forest to degraded forest land (32.86 hm²) and dryland (34.21 hm²). Degraded primary forest mainly converted to secondary forest, then to degraded forest land, with only small portions directly converted to dryland. Degraded forest land conversion to dryland occurred mainly in central-western settlement areas, showing inverse relationships with distance to these features.

During 2004–2014, forest landscape evolution showed reverse trends. Secondary forest ecological integrity improved to degraded primary forest, degraded forest land recovered to secondary forest or plantation, and dryland was abandoned to secondary forest (62.69 hm²). This stage also saw large paddy fields converted to dryland (50.89 hm²). Forest landscape recovery occurred in areas degraded during 1994–2004, with area increases of 63.11 hm², 25.68 hm², and 12.78 hm² respectively. The recovery was driven by rural residents' retreat from forest areas due to rising non-farm wages and opportunity costs of farming, leading to labor reallocation and land use shifts toward less labor-intensive practices.

and show landscape composition and transfer matrices for 1994–2004, while shows the 2004–2014 transfer matrix.

4.3 Patch-Level Characteristics

Forest landscape showed heterogeneous distribution at the patch level across all years, with distinct distribution patterns for different types. Degraded primary forest dominated central-eastern high-elevation mountainous areas, secondary forest increased with elevation and was scattered in central-western areas, de-

graded forest land concentrated in transition zones from low mountains to hills, and plantations were distributed near residential areas for management convenience.

Fragmentation ranking across the three time points was consistently: degraded forest land > plantation > secondary forest > degraded primary forest. Degraded primary forest, secondary forest, and degraded forest land showed identical fragmentation trends—increasing then decreasing—indicating human disturbance intensity that first increased then decreased. This pattern resulted from intensive development during 1994–2004 followed by abandonment and natural recovery during 2004–2014. Plantations showed opposite trends, with fragmentation decreasing then increasing as residents planted more economic forests near settlements when labor decreased.

[FIGURE:3] illustrates patch-level index changes.

4.4 Landscape-Level Characteristics

During 1994–2004, landscape-level fragmentation increased: patch density rose from 58.94 to 63.29 per 100 hm^2 , edge density increased from 170.27 to 179.62 m/hm^2 , while mean patch size decreased from 1.70 to 1.58 hm^2 . The largest patch index declined from 35.27% to 32.08%, and the area-weighted mean shape index increased from 4.15 to 4.63, indicating more complex shapes. Shannon's diversity index rose while contagion fell, showing increased heterogeneity.

During 2004–2014, fragmentation decreased: patch density and edge density fell to 56.90 per 100 hm^2 and 161.45 m/hm^2 respectively, while mean patch size increased to 1.76 hm^2 . Contagion increased and shape complexity decreased. However, the 2014 fragmentation level remained lower than 1994, and degraded primary forest area was still below 1994 levels, indicating that ecological integrity recovery lags far behind fragmentation recovery.

summarizes landscape-level changes.

4.5 Driving Factors of Forest Landscape Evolution

4.5.1 Degraded Forest Land In the 1994–2004 Logistic model (HL = 10.667, $P = 0.221$), socio-economic factors significantly influenced degraded forest land change. Permanent population density change was the most important factor ($\beta = 2.83$, Wald = 50.33), with higher population density increasing change probability. The sampling area's ethnic minority characteristics and high natural population growth rate caused continuous population density increases, raising ecological pressure through expanded cultivated land and fuelwood collection. Cultivated land per laborer was the second factor ($\beta = -0.26$, Wald = 27.72), with inverse relationship to change probability.

In the 2004–2014 model (HL = 7.323, $P = 0.502$), only cultivated land per laborer entered the model ($\beta = 1.13$, Wald = 15.26), showing positive correlation. Spatial distance factors were consistently important: distances to settlements

($\beta = -2.13$) and roads ($\beta = -0.51$) negatively correlated with change probability, while distance to water bodies positively correlated ($\beta = 1.13$). Natural factors became significant only in the second period, with elevation ($\beta = -3.90$, Wald = 48.70) as the primary explanatory variable, indicating higher change probability at lower elevations.

presents the driving factor analysis.

4.5.2 Plantation Due to small change area during 2004-2014, the plantation model only analyzed 1994-2004 changes (HL = 14.798, P = 0.063). Two factors entered the model: distance to settlements ($\beta = -1.63$, Wald = 25.62) as the most important, and population density change ($\beta = -0.96$, Wald = 13.80). Plantation change probability increased with proximity to settlements and decreased with population density, as labor reduction led residents to plant low-labor, high-value plantations near settlements.

shows the plantation driving factor analysis.

4.5.3 Secondary Forest In the 1994-2004 model (HL = 8.987, P = 0.343), population density change was the primary factor ($\beta = 2.90$, Wald = 60.58), positively correlated with change probability. Spatial distances to settlements ($\beta = -1.45$), water bodies ($\beta = -1.08$), and roads ($\beta = -0.73$) also significantly influenced changes.

In the 2004-2014 model (HL = 7.172, P = 0.518), farmers' net income change became the primary factor ($\beta = 1.80$, Wald = 56.25), with income increases reducing fuelwood dependence and allowing forest recovery. Distance to settlements ($\beta = -0.75$) and roads ($\beta = -0.40$) remained significant, while slope ($\beta = -0.39$) entered as the third factor, indicating that steeper slopes were more likely to recover.

presents the secondary forest driving factor analysis.

4.5.4 Degraded Primary Forest In the 1994-2004 model (HL = 6.919, P = 0.545), population density change was the key factor ($\beta = 1.75$, Wald = 862.44). Spatial distances to water bodies ($\beta = -2.07$) and settlements ($\beta = -1.64$) were also significant. In the 2004-2014 model (HL = 3.089, P = 0.378), population density change remained important ($\beta = 1.39$, Wald = 28.65), with farmers' net income change ($\beta = -1.13$, Wald = 26.76) also entering. Spatial distance factors were excluded in the second period because nearby degraded primary forests had been exhausted in the first period.

shows the degraded primary forest driving factor analysis.

5. Conclusion

- (1) Forest landscape dominated the sampling area's matrix during 1994-2014, with degraded primary forest occupying the absolute dominant po-

sition across all three time points. Spatially, degraded primary forest was concentrated in central-eastern low mountains, showing contiguous patch distribution, while degraded forest land, secondary forest, and plantations formed mosaic patterns within the dominant matrix.

- (2) Forest landscape showed a U-shaped trend of first decreasing then increasing, reflecting opposite processes of degradation (1994–2004) and recovery (2004–2014). Spatially, evolution occurred mainly at interfaces between forest landscape and paddy fields, dryland, roads, etc., where human activities fluctuated with economic development.
- (3) During 1994–2004, main conversion types were degraded primary forest to secondary forest, secondary forest to degraded forest land and dryland, and degraded forest land to dryland. Conversions occurred near settlement edges or existing dryland edges, with rates increasing as distance to settlements, roads, or water bodies decreased.
- (4) During 2004–2014, forest landscape recovery showed reverse trends to the previous period, with recovery occurring in previously degraded areas. At the patch level, forest landscape was heterogeneously distributed, with fragmentation ranking consistently: degraded forest land > plantation > secondary forest > degraded primary forest. Fragmentation trends for degraded primary forest, secondary forest, and degraded forest land all increased then decreased, indicating disturbance intensity that first rose then fell.
- (5) At the landscape level, fragmentation first increased then decreased during 1994–2014, with 2014 fragmentation lower than 1994. However, ecological integrity recovery lagged far behind fragmentation recovery, requiring long-term reduction of disturbance to high-quality forest resources.
- (6) Socio-economic factors most prominently influenced forest landscape changes. Permanent population density change was the primary factor, with its fluctuation directly affecting ecological pressure and causing degradation/recovery cycles. Farmers' net income change was the second factor; income increases after 2004 promoted energy structure transformation and reduced forest dependence. Spatial distance factors had stable, persistent effects, as human interference was largely mediated through distance. Natural factors controlled broad geomorphological patterns but had limited short-term impact. Secondary forest and degraded forest land were more influenced by natural environment due to their location in marginally developable areas.

These results align with forest landscape evolution patterns in Xituo Town, northwestern Shizhu County [10], indicating that since the mid-1990s, China's key forest regions have experienced similar development (pre-2000) and recovery (post-2000) processes with comparable driving mechanisms [31–33]. Community-level studies are essential for understanding forest landscape evolution mechanisms and developing sustainable restoration strategies, as they reveal how

residents' livelihoods and welfare drive landscape changes.

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Figures

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Figure 2: Figure 1

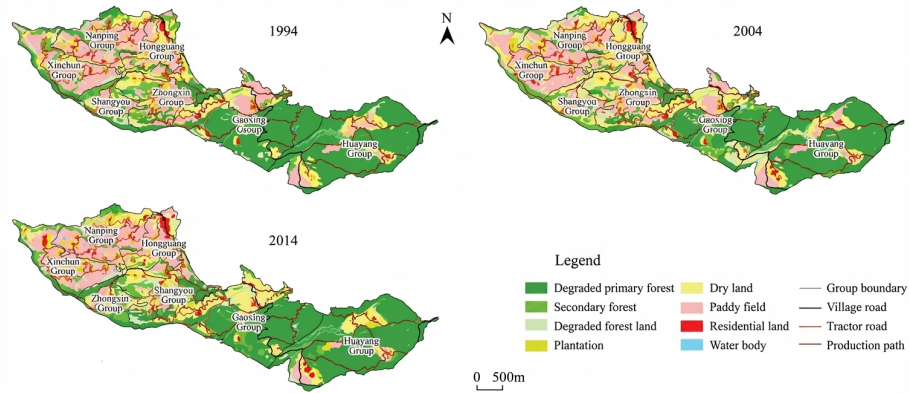


Figure 3: Figure 10

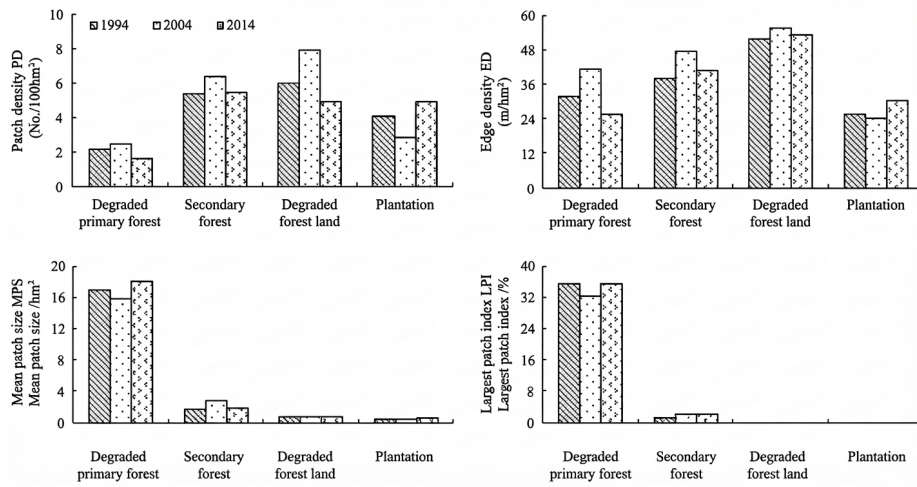


Figure 4: Figure 11