Postprint of Vegetation Coverage Pattern Changes in Shennongjia Forest Area, 1998-2013, Based on SPOT-VEGETATION Data

Authors: Liu Jiayan, Xie Zongqiang, Shen Guozhen, Fan Dayong, Xiong Gaoming, Zhao Changming, Zhou Youbing, XU Wenting

Date: 2018-06-09T00:00:00+00:00

Abstract

Based on SPOT-VEGETATION normalized difference vegetation index (NDVI) data from 1998 to 2013, this study estimated the vegetation coverage in the Shennongjia Forest Region and Shennongjia National Nature Reserve using the dimidiate pixel model method, correlation analysis, and spatial analysis, combined with concurrent precipitation and mean temperature data, and analyzed the spatial patterns and influencing factors of vegetation coverage change. The results showed that during 1998-2013, the mean vegetation coverage in the Shennongjia Forest Region was 66.8%, the annual maximum vegetation coverage was 93.8%, and the maximum vegetation coverage inside the reserve was significantly higher than that outside the reserve; the change rate of vegetation coverage in the forest region was 1.45%, while that in the reserve was 2.26%, indicating an overall increasing trend in vegetation and effective conservation within the reserve. Temperature, precipitation, annual minimum temperature, and distance from roads and residential areas were important factors affecting vegetation coverage change, whereas elevation had no effect on vegetation coverage change.

Full Text

Dynamics and Analysis of Vegetation Fraction Changes in Shennongjia Forest District during 1998-2013 Using SPOT-VEGETATION NDVI Data

ACTA ECOLOGICA SINICA
Vol. 38, No. 11, June 2018
DOI: 10.5846/stxb201704240739

Authors: LIU Jiayan, XIE Zongqiang, SHEN Guozhen, FAN Dayong, XIONG Gaoming, ZHAO Changming, ZHOU Youbing, XU Wenting

Affiliations:
1. State Key Laboratory of Vegetation and Environmental Change, Institute of Botany, Chinese Academy of Sciences, Beijing 100093, China
2. University of Chinese Academy of Sciences, Beijing 100049, China

Corresponding Author: E-mail: xuwt@ibcas.ac.cn

Abstract

Fractional vegetation cover (FVC) is a critical parameter for describing forest vegetation dynamics and ecosystem processes. Remote sensing methods offer unique advantages for measuring FVC due to their broad spatiotemporal coverage. Shennongjia Forest District, one of the best-preserved primary forest regions in central China, possesses rich biodiversity and forest resources. However, the forest suffered extensive anthropogenic disturbance during the 1970s–1980s from rapid population growth and commercial logging. Since the establishment of the national nature reserve and implementation of protective policies, these disturbances have been substantially mitigated.

This study employed a dimidiate model to estimate FVC across Shennongjia Forest District from 1998 to 2013 using 1 km resolution, 10-day SPOT-VEGETATION NDVI composites. Correlation and spatial analyses were conducted incorporating annual precipitation, average temperature, elevation, and distances to residential areas and main roads to identify primary influencing factors. The district' s average annual FVC was 66.8%, with a maximum of 93.8%; FVC was significantly higher inside the national reserve than outside. During 1998–2013, FVC exhibited increasing trends both district-wide and within the reserve, rising by 1.45% and 2.26%, respectively, demonstrating effective protection within the reserve. Correlation analysis revealed that environmental factors (annual precipitation, average temperature, and extreme cold temperature) were positively correlated with FVC, whereas elevation showed no significant correlation. Socioeconomic factors, particularly distances to main roads and residential areas, substantially impacted FVC dynamics. FVC increased near residential areas due to urbanization and greening initiatives, while road proximity showed spatially variable effects from simultaneous road construction and afforestation. These findings reveal vegetation change patterns in Shennongjia and highlight that both natural and socioeconomic factors significantly influence FVC dynamics, providing a scientific basis for ecosystem management.

Keywords: normalized differential vegetation index; fractional vegetation cover; protecting efficiency; changing rate; influencing factors

---

Introduction

Vegetation, encompassing forests, grasslands, and crops covering the land surface, plays a vital role in terrestrial ecosystems [1]. Fractional vegetation cover (FVC), defined as the percentage of vegetation covering a unit area, is a crucial parameter for characterizing vegetation communities and ecosystems [3-6]. FVC directly influences ecosystem energy balance, carbon cycling, and productivity by altering surface reflectance, roughness, and soil evapotranspiration [7]. Monitoring FVC at multiple scales is essential for assessing grassland conditions in arid and semi-arid regions affected by livestock grazing and desertification [8], and has wide applications in hydrology, ecological surveys, soil erosion research, evapotranspiration studies, and land degradation assessments [9-12].

FVC monitoring methods fall into two categories: ground measurement and remote sensing [13]. Remote sensing has become the primary approach for FVC research due to its extensive data acquisition and continuous observation capabilities [14]. Satellite data products such as GIMMS (Global Inventory Modeling and Mapping Studies), MODIS (Moderate Resolution Imaging Spectroradiometer), and SPOT-VEGETATION have enabled long-term vegetation cover change studies. Previous research has demonstrated effective FVC estimation through various approaches: Shoshany et al. [15] established multivariate linear regression models with correlation coefficients reaching 0.88; Xiao and Moody [16] used linear regression equations with MODIS data in central New Mexico, achieving correlation coefficients of 0.89; Graetz et al. [17] calibrated Landsat data to monitor sparse rangeland vegetation in southern Australia, effectively tracking vegetation responses to drought and grazing stress; Boyd et al. [18] employed nonlinear regression models to estimate coniferous forest cover in the Pacific Northwest.

Pixel decomposition models have proven successful for regional-scale FVC estimation. Sun et al. [19] applied the pixel dichotomy model to the Beiyun River area, while Chen et al. [13] used FVC calculation models for dynamic remote sensing monitoring in Beijing' s Haidian District. These studies revealed severe vegetation degradation, with FVC declining by 25-50% and showing extensive east-to-west reduction, while northwestern mountainous areas exhibited continuous increasing trends, reflecting urbanization impacts. Li et al. [20] estimated FVC in the Miyun Reservoir watershed using the dimidiate pixel model, finding that low-elevation plains experienced greater anthropogenic disturbance, whereas high mountainous areas showed minimal FVC change with high estimation accuracy. Zhang et al. [21] studied spatial FVC differentiation in the Yiluo River Basin, while Detsche et al. [22] analyzed vegetation dynamics and seasonality using GIMMS data.

Despite these advances, few studies have examined vegetation cover changes in Shennongjia Forest District. Huang et al. [27] used MODIS EVI data to analyze vegetation dynamics and climate relationships, finding temperature as the primary controlling factor. Jiang et al. [28] used Landsat data to interpret land cover changes, reporting net forest area increases of 207.49 km² and 70 km² in two periods, but without quantifying FVC changes or addressing socioeconomic factors. This study addresses these gaps by applying the dimidiate model to SPOT-VEGETATION NDVI data to estimate FVC and its spatiotemporal patterns in Shennongjia, providing a basis for improved conservation of primary forests.

Study Area

Shennongjia Forest District (109°56 -110°58 E, 31°15 -31°75 N) is located in western Hubei Province, covering 3,250 km². It is China' s only county-level administrative region designated as a "forest district," preserving the only intact mid-latitude primary forest globally with 88.7% forest coverage. The district features the Daba Mountains' eastern section, with elevations decreasing from south to north. The highest peak, Shennongding (3,105.4 m), is Central China' s tallest summit. The region experiences a north subtropical monsoon climate with low temperatures, abundant rainfall (1,185 mm annually), and distinct vertical zonation. Vegetation zones include: subtropical evergreen broadleaf forest (400–1,000 m), north subtropical evergreen-deciduous broadleaf mixed forest (1,000–1,700 m), warm temperate deciduous broadleaf forest (1,700–2,200 m), temperate coniferous-broadleaf mixed forest (2,200–2,600 m), cold temperate coniferous forest (2,600–3,000 m), and subalpine shrub-meadow (>3,000 m).

The Shennongjia National Nature Reserve (769.5 km²) occupies the district' s southwestern portion. Established in 1986 following extensive logging in the 1970s–1980s, the reserve implemented logging bans and reforestation programs. Despite previous research on vegetation dynamics [27,28], quantitative FVC assessment and socioeconomic factor analysis remain limited.

Data Sources

1. Remote Sensing Data We used SPOT-VEGETATION 1 km resolution, 10-day NDVI composites from 1998–2013, obtained from the VITO website (http://www.vgt.vito.be). Data were processed using Maximum Value Composite (MVC) to minimize cloud, solar angle, and atmospheric scattering effects [29].

2. Meteorological Data Annual precipitation and average temperature data from Chinese meteorological stations (1998–2013) were downloaded from the China Meteorological Data Network (http://data.cma.cn). Using ArcGIS 10.1, we applied Kriging interpolation to generate 1 km resolution maps of average temperature, minimum temperature, and precipitation.

3. Species Data Community and tree species data across elevation gradients were extracted from published work by Zhao et al. [30]. Field surveys established 100 m^2 plots for complete tree inventories, recording diameter at breast height, crown width, elevation, latitude/longitude, and environmental factors for specific community types.

Methods

1. Vegetation Cover Calculation Remote sensing pixels typically contain multiple components. The pixel dichotomy model, the simplest decomposition approach, assumes each pixel comprises only vegetated and non-vegetated surfaces. Since NDVI is sensitive to soil background and varies with FVC and leaf area index, it can be used to retrieve FVC:

$$FVC = \frac{NDVI - NDVI_{soil}}{NDVI_{veg} - NDVI_{soil}}$$

where $NDVI_{veg}$ represents full vegetation cover and $NDVI_{soil}$ represents bare soil. For NDVI values between these extremes, FVC increases linearly. While other vegetation indices (e.g., GEMI, MSAVI) account for atmospheric and soil effects, NDVI remains widely applied due to its high vegetation sensitivity, wide detection range, and ability to reduce topographic and solar angle noise [32].

The key challenge lies in determining $NDVI_{veg}$ and $NDVI_{soil}$. Gutman and Ignatov [5] proposed using image-specific minima and maxima rather than fixed values to reduce interference. Li [34] simplified the model by using the 5% and 95% cumulative frequency values from NDVI histograms as $NDVI_{min}$ and $NDVI_{max}$:

$$FVC = \frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}}$$

This approach achieved high accuracy in the Miyun Reservoir watershed (correlation coefficient = 0.89) [34] and on the Loess Plateau (95.02% accuracy) [35]. We applied this method to calculate per-pixel FVC for each 10-day period, then averaged these to obtain annual mean FVC (hereafter referred to simply as FVC) for spatiotemporal analysis. Multi-year average FVC and annual maximum FVC were calculated per pixel and across the study area.

2. Vegetation Cover Change Rate Calculation To analyze the magnitude and spatial distribution of FVC changes during 1998–2013 while minimizing seasonal fluctuations, we calculated the change rate (FVC_{α}) using linear regression of growing-season averages against year [36]:

$$FVC_\alpha = \text{slope} \times 16 \times 100$$

where the slope represents the regression coefficient of growing-season mean FVC against year. All spatial analyses were conducted in ArcGIS 10.0.

3. Factor Analysis Using R [37], we analyzed correlations between FVC change rates and influencing factors: distance to nearest residential area, distance to nearest road, annual minimum temperature, elevation, precipitation, and average temperature.

4. Elevation Gradient and Species Richness Analysis We examined relationships between FVC dynamics, elevation gradients, and species richness across different altitudinal bands using R.

Results

1. Average Vegetation Cover in Shennongjia Forest District The multi-year average FVC for Shennongjia Forest District (1998–2013) was 66.8%, ranging interannually from 64.3% to 71.4%. The average maximum FVC was 93.8%, ranging from 92.5% to 94.5%. Inside the reserve, average FVC was 66.5% and maximum FVC was 94.3%, significantly higher than outside the reserve (average FVC = 66.8%, maximum FVC = 93.7%; paired t-test, $P < 0.01$) [Figure 2: see original paper].

[Figure 2: see original paper] Mean and maximum fractional vegetation cover inside and outside the Shennongjia National Nature Reserve (average ± standard deviation)

2. Spatial Distribution Patterns Spatial clustering analysis revealed distinct patterns: high FVC clusters occurred primarily in the Yinyu River, Jiuchong River, and Wen River basins, while low FVC clusters were concentrated in Dajiu Lake, Laojun Mountain, and along tourist roads within the reserve. The elevation gradient analysis showed highest FVC at 1,500–2,000 m ($R^2 = 0.185$, $P < 0.01$). FVC increased with elevation below 1,700 m, then decreased above 1,700 m. Combining our FVC estimates with species data from Zhao et al. [30], we found strong correlations between FVC and tree species richness ($R^2 = 0.953$, $P < 0.01$) and total species richness ($R^2 = 0.807$, $P < 0.01$) at 1,500–2,000 m, corresponding to the typical zonal vegetation (evergreen-deciduous broadleaf mixed forest) [Figure 4: see original paper].

[Figure 3: see original paper] The mean fractional vegetation cover pattern of Shennongjia Forest District (1998–2013)

[Figure 4: see original paper] The mean fractional vegetation cover altitude pattern of Shennongjia Forest District and relationship with species richness

3. Vegetation Cover Change Rates During 1998–2013, the district' s average FVC change rate was 1.45%, with significant differences between inside (2.26%) and outside (1.23%) the reserve (one-way ANOVA, $P < 0.01$). Areas with increased FVC included Dongxi Village and Xiangsiling Village in the reserve' s southwest, while decreases occurred mainly in Dacaoping and Songluo areas [Figure 5: see original paper].

[Figure 5: see original paper] The fractional vegetation cover change of Shennongjia Forest District (1998–2013)

4. Influencing Factors Correlation analysis revealed that FVC change rates were significantly influenced by distance to residential areas ($r = -0.16$, $P < 0.01$), distance to roads ($r = -0.09$, $P < 0.01$), annual minimum temperature ($r = 0.18$, $P < 0.01$), and precipitation ($r = 0.12$, $P < 0.01$). Elevation showed no significant correlation with FVC change rate ($r = -0.05$, $P > 0.05$) .

The relations between the changing rate of FVC and influence factors

---

Discussion

Shennongjia Forest District preserves the only extant primary forest in the global mid-latitude zone [23], with well-preserved natural vegetation showing distinct spatial heterogeneity. Primary forests are mainly distributed in the Yinyu, Wen, and Song River basins, yielding high FVC. In contrast, the western Dajiu Lake area contains extensive farmland, wetlands, and bare rock, resulting in low FVC. High-elevation areas like Laojun Mountain and northwestern tourist roads feature alpine meadows and shrubs with low coverage.

The 1.45% increase in FVC during 1998–2013 indicates positive vegetation recovery, consistent with Jiang et al. [28] who reported 207.49 km^2 net forest increase using Landsat data, and Huang and Xia [27] who found increasing MODIS EVI trends. The reserve' s 2.26% increase—nearly double the district rate—demonstrates effective protection. However, spatial heterogeneity existed: FVC increased near residential areas from urban greening, while road impacts were complex. National Road 209 showed decreased FVC from tourism infrastructure development, whereas Provincial Road 307 showed increased FVC from afforestation programs, consistent with Pauleit et al. [41] on urbanization effects.

The 2008 extreme cold event (minimum temperature -17.7°C) severely impacted evergreen-dominated vegetation at mid-low elevations, consistent with Ge et al. [42] on broadleaf tree dynamics after ice storms. Other disturbance factors included bark beetle outbreaks in *Larix kaempferi* plantations (since 2000) and reservoir construction near Pingqian Village. These results underscore that conservation management must address both anthropogenic and natural disturbances.

Elevation did not significantly affect FVC change rates, likely because protection policies uniformly restrict logging across elevations. However, the strong correlation between FVC and species richness at 1,500–2,000 m highlights this elevation band' s ecological importance for biodiversity conservation.

References

[1] Sitch S, Smith B, Prentice I C, et al. Evaluation of ecosystem dynamics, plant geography and terrestrial carbon cycling in the LPJ dynamic global vegetation model. *Global Change Biology*, 2003, 9(2): 161–185.

[2] Gitelson A A, Stark R, Grits U, et al. Vegetation and soil lines in visible spectral space: a concept and technique for remote estimation of vegetation fraction. *International Journal of Remote Sensing*, 2002, 23(13): 2537–2562.

[3] Deardorff J W. Efficient prediction of ground surface temperature and moisture, with inclusion of a layer of vegetation. *Journal of Geophysical Research: Oceans*, 1978, 83(C4): 1889–1903.

[4] Wittich K P, Hansing O. Area-averaged vegetative cover fraction estimated from satellite data. *International Journal of Biometeorology*, 1995, 38(4): 209–215.

[5] Gutman G, Ignatov A. The derivation of the green vegetation fraction from NOAA/AVHRR data for use in numerical weather prediction models. *International Journal of Remote Sensing*, 1998, 19(8): 1533–1543.

[6] Hirano Y, Yasuoka Y, Ichinose T. Urban climate simulation by incorporating satellite-derived vegetation cover distribution into a mesoscale meteorological model. *Theoretical and Applied Climatology*, 2004, 79(3/4): 175–184.

[7] Roy P, Tomar S. Landscape cover dynamics pattern in Meghalaya. *International Journal of Remote Sensing*, 2001, 22(18): 3813–3825.

[8] Purevdorj T, Tateishi R, Ishiyama T, et al. Relationships between percent vegetation cover and vegetation indices. *International Journal of Remote Sensing*, 1998, 19(18): 3519–3535.

[9] Adams J B, Sabol D E, Kapos V, et al. Classification of multispectral images based on fractions of endmembers: Application to land-cover change in the Brazilian Amazon. *Remote Sensing of Environment*, 1995, 52(2): 137–154.

[10] Dymond J, Stephens P, Newsome P, et al. Percentage vegetation cover of a degrading rangeland from SPOT. *International Journal of Remote Sensing*, 1992, 13(11): 1999–2007.

[11] (Reference omitted in original)

[12] (Reference omitted in original)

[13] Chen Y, Li J, Liu Y. Remote sensing estimation and change analysis of vegetation cover in Beiyun River area. *Research of Soil and Water Conservation*, 2006, 13(6): 97-99.

[14] (Reference omitted in original)

[15] Shoshany M, Kutiel P, Lavee H. Monitoring temporal vegetation cover changes in Mediterranean and arid ecosystems using a remote sensing technique: Case study of the Judean Mountain and the Judean Desert. *Journal of Arid Environments*, 1996, 33(1): 9-21.

[16] Xiao J, Moody A. A comparison of methods for estimating fractional green vegetation cover within a desert-to-upland transition zone in central New Mexico, USA. *Remote Sensing of Environment*, 2005, 98(2/3): 237-250.

[17] Graetz R, Pech R P, Davis A. The assessment and monitoring of sparsely vegetated rangelands using calibrated Landsat data. *International Journal of Remote Sensing*, 1988, 9(7): 1201-1222.

[18] Boyd D, Foody G, Ripple W. Evaluation of approaches for forest cover estimation in the Pacific Northwest, USA, using remote sensing. *Applied Geography*, 2002, 22(4): 375-392.

[19] Sun J, Li J, Liu Y. Remote sensing estimation of vegetation cover in Beiyun River area. *Research of Soil and Water Conservation*, 2006, 13(6): 97-99.

[20] Li M, Liu Q, Wang J. Remote sensing estimation of vegetation cover in the upper reaches of Miyun Reservoir. *Journal of Plant Ecology*, 2004, 26(4): 153-159.

[21] Zhang X, Liu L. Spatial differentiation of vegetation cover in Yiluo River Basin. *Journal of Geographical Sciences*, 2007, 17(4): 485-493.

[22] Detsche F, Otte I, Appelhans T, et al. Seasonal and long-term vegetation dynamics from 1-km GIMMS-based NDVI time series at Mt. Kilimanjaro, Tanzania. *Remote Sensing of Environment*, 2016, 178: 70-83.

[23] (Reference omitted in original)

[24] (Reference omitted in original)

[25] (Reference omitted in original)

[26] (Reference omitted in original)

[27] Huang J, Xia Z. Analysis of vegetation dynamic changes and its relationship with climate factors in Shennongjia Forest District using MODIS EVI data. *Meteorological and Environmental Sciences*, 2013, 36(3): 39-43.

[28] Jiang Z, et al. Land cover dynamic changes in Shennongjia Forest District interpreted from Landsat remote sensing images in recent years. *Journal of Yangtze River Scientific Research Institute*, 2016, 33(6): 150-154.

[29] Stow D A, Hope A, McGuire D, et al. Remote sensing of vegetation and land-cover change in Arctic Tundra Ecosystems. *Remote Sensing of Environment*, 2004, 89(3): 281-308.

[30] Zhao C M, Chen W L, Tian Z Q, Xie Z Q. Altitudinal pattern of plant species diversity in Shennongjia Mountains, Central China. *Journal of Integrative Plant Biology*, 2005, 47(12): 1431-1449.

[31] Carlson T N, Ripley D A. On the relation between NDVI, fractional vegetation cover, and leaf area index. *Remote Sensing of Environment*, 1997, 62(3): 241-252.

[32] (Reference omitted in original)

[33] Leprieur C, Kerr Y H, Mastorchio S, et al. Monitoring vegetation cover across semi-arid regions: Comparison of remote observations from various scales. *International Journal of Remote Sensing*, 2000, 21(2): 281-300.

[34] Li M. Research on remote sensing estimation methods of vegetation cover. *Graduate University of Chinese Academy of Sciences*, 2003.

[35] Li X. Estimation of vegetation cover on the Loess Plateau using the dimidiate model. *Remote Sensing Application Research*, 2011.

[36] (Reference omitted in original)

[37] R Core Team. *R: A Language and Environment for Statistical Computing*. Vienna, Austria: R Foundation for Statistical Computing, 2016.

[38] (Reference omitted in original)

[39] (Reference omitted in original)

[40] (Reference omitted in original)

[41] Pauleit S, Ennos R, Golding Y. Modeling the environmental impacts of urban land use and land cover change–a study in Merseyside, UK. *Landscape and Urban Planning*, 2005, 71(2/4): 295-310.

[42] Ge J L, Xiong G M, Wang Z X, et al. Altered dynamics of broad-leaved tree species in a Chinese subtropical montane mixed forest: The role of an anomalous extreme 2008 ice storm episode. *Ecology and Evolution*, 2015, 5(7): 1484-1493.

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