Time series analysis of the shadow-eliminated vegetation index (SEVI) and patch density index for the Wuyishan Nature Reserve

Hong Jiang¹ and Nian Zhou

Key Laboratory of Spatial Data Mining & Information Sharing of Ministry of Education, Academy of Digital China (Fujian), Fuzhou University, China

¹Email: jh910@fzu.edu.cn

Abstract. In order to study the vegetation growth changing in the Wuyishan Nature Reserve, the recently proposed shadow-eliminated vegetation index (SEVI) and patch density (PD) were used to evaluate the inter-annual variability of the vegetation growth in the Reserve during 2000-2019. The resultant normalized SEVI sequence eliminated the terrain shadow effect shows an increasing trend overall during 2000-2019. Meanwhile, the series of PD show a decreasing trend with two significant different mean levels of 40.67/km² during 2000-2011 and 18.69/km² during 2012-2019. The SEVI and PD had an overall negative correlation with coefficient of determination $r^2 = 0.53$. The result suggests that the promotion of ecology civilization may contribute to the protection and growth of the nature reserve vegetation.

1. Introduction
As a terrestrial ecosystem, the forest reserve plays an important role in biodiversity conservation [1], ecological sustainability [3], and climate change adaption and mitigation [4]. Remote sensing is an efficient earth observation technique for forest vegetation monitoring and growth evaluation, such as the leaf area index (LAI) [5], fractional vegetation cover (FVC) [6], net primary productivity (NPP) [7], and impact analysis of natural and human factors on forest growth [8,9]. However, in a rugged terrain, the topographic shadow effect, including localized and adjacent terrain shadowing (i.e., self and cast shadows) [10], is a dominant obstacle in obtaining accurate vegetation information through remote sensing [11-13]. The classic topographic correction approaches based on the digital elevation model (DEM)[14], such as the C-correction model [15,16], SCS+C correction model [17-19], can rectify the self shadow with high accuracy, while achieve low accuracy in the cast shadow [20,21]. In order to remove the effects of self and cast shadows, a recently proposed terrain shadow-eliminated vegetation index (SEVI) [21] was used to derive and evaluate the vegetation growth variability in the Wuyishan Nature Reserve during 2000 to 2019.

2. Data and methods
2.1. Concept of SEVI
The SEVI is composed of the reflectance of the red and near-infrared bands, and the adjustment factor that is a key in determination of the value of SEVI. The fundamental principles that underlay the SEVI include the terrain radiative transfer model [22] and the band-ratio model. The development of the SEVI also makes use of the optical features of vegetation in the red and near-infrared spectral bands,
but, unlike the DEM, the SEVI doesn’t introduce additional uncertainties from external heterogeneous data. The great advantage of the SEVI is it can remove the self and cast shadows drastically, therefore, it is suitable to use in evaluation the vegetation growth and landscape indices in the rugged nature reserve.

2.2. Study area and data
The Wuyishan Nature Reserve in the Fujian province in Southeast China with geographical boundaries of 117°24′14″–117°50′31″ E and 27°34′56″–27°55′22″ N was selected in this study for its rugged terrain (Figure 1). The Reserve is a mountainous area whose elevations range from about 280 to 2158 meters with an average of 1150 meters. The terrain slopes range from 0° to 72.69° with an average of 28.23°. During the daytime, the Reserve is predominantly covered with terrain shadows. Forest covers 95.30% of the area, forming the largest and best-preserved subtropical forest ecological system in Southeast China. The Reserve acts as a refuge for a large number of ancient and relict plant species, many of which only exist in China but are rarely found elsewhere in the country [23]. The Reserve also has an outstanding faunal diversity, especially the diversity of the reptile, amphibian, and insect species. Mount Huanggang in the Reserve is the highest peak in Southeast China with a height of 2158 meters above the sea level.

The time series of Landsat and HJ-1 multispectral images with 30-meter spatial resolution from 2000 to 2019 were used in this study. Due to the generally cloudy sky conditions in the area, it was difficult to find cloud-free images in the same day of each year during the study period. We selected the winter time in December, January, and February (DJF) for the images acquired in clear-sky days. In total, fourteen Landsat images (2000-2005, 2007, 2009-2011, 2014-2017) and four HJ-1 images (2012-2013, 2018-2019) were selected, however no images were available in 2006 and 2008. The remote sensing images and ASTER GDEM V2 in this study were obtained from the United States Geological Survey (https://earthexplorer.usgs.gov/) and China Centre for Resource Satellite Data and Application (http://www.cresda.com/CN/).
2.3. **SEVI calculation and analysis**

The data processing included image pre-processing, the SEVI calculation and normalization, the patch density (PD) computation, the trending analysis and linear correlation analysis of the SEVI and PD (Figure 2). The image pre-processing covered geometric correction, radiometric calibration, atmospheric correction, and area clipping of the reserve boundary.

![Flow chart of data processing](image)

### 2.3.1. **SEVI calculation.**

The SEVI is calculated as follows:

\[
SEVI = \frac{B_{nir}}{B_r} + f(\Delta) \cdot \frac{1}{B_r}
\]  

(1)

where \(B_{nir}\) is the reflectance of the near-infrared band, \(B_r\) is the reflectance of the red band, and \(f(\Delta)\) is an adjustment factor.

The time series of SEVI in the Wuyishan Nature Reserve were calculated using Formula (1), and the \(f(\Delta)\) values were determined by the optimal algorithm of coefficient of correlation (r-algorithm) [21].

### 2.3.2. **SEVI normalization.**

These calculated SEVI were normalized to 0.00-1.00 for quantifying the vegetation growth variability (Formula 2).

\[
x' = \frac{x - x_{min}}{x_{max} - x_{min}}
\]

(2)

where \(x'\) is the normalized SEVI, \(x\) is the SEVI, \(x_{max}\) is the maximum SEVI from the image erased noise, and \(x_{min}\) is the minimum SEVI of naked rock in Mount Huanggang area.

### 2.3.3. **SEVI Analysis.**

In general, the landscape fragmentation indicates an extensive conversion of natural landscapes and a negative impact on the biodiversity [2,3]. The PD has been used as a measure of the landscape fragmentation, a process that large patches (habitat areas) become increasingly smaller and isolated [24]. The PD is the number of patches of a given type per unit area (per km²). In this study, the PD was calculated at landscape level. The time series of SEVI mean and PD during
2000 to 2019 were analysed to assess the vegetation growth variability in the Reserve. The trending analysis was applied to estimate the variation of the SEVI mean and PD, and the linear regression analysis was also performed to estimate the correlation of the SEVI mean with PD during this period. The F test with $r^2$, F statistic and p-value of the regression models was applied to test the significance of the trend line and linear regression. The T test with t statistic and p-value was used to test the significant difference between divided stages of the SEVI mean and PD.

3. Results

3.1. Classified SEVI
The time series of classified SEVI maps show that the high-SEVI area kept expanding and the low-SEVI area kept shrinking overall during the whole period of 2000-2019, except several years of 2002, 2005 and 2018. Mount Huanggang area in the northern Reserve always had low SEVI values (Figure 3).

3.2. SEVI mean and PD
The time series of SEVI means show an overall increasing trend from 2000 to 2019, with the F test results of $r^2=0.43$, F=12.00 and p=0.00, although it fluctuated from year to year (Figure 4a). The series of PD show two significant different mean levels of about 40.67/km$^2$ in the period of 2000-2011 and about 18.69/km$^2$ in the period of 2012-2019 with the T test results of t=1.00 and p=0.00. Overall, the PD shows a significant decreasing trend with the F test results of $r^2=0.74$, F=45.29, and p=0.00 (Figure 4a). A linear correlation between PD and SEVI mean shows the medium negative correlation between them from 2000 to 2019, with the F test results of $r^2=0.53$, F=17.68, and p=0.00 (Figure 4b).

4. Discussion

4.1. Inter-annual variability of the vegetation growth
The big drop of the PD in the Wuyishan Nature Reserve in about 2012 is an outstanding characteristic in this time series analysis. It might be due to the restriction of human activities, which is important in the protection of the vegetation growth in a nature reserve [25,26]. The ecological civilization construction has made great progress since 2007 and the promotion of this construction was most active in 2012 [27]. The negative correlation between the SEVI mean and PD also suggests a relief of human activities on the vegetation growth in the Reserve.

4.2. SEVI approach
The SEVI can remove the terrain shadow effect drastically on vegetation in rugged mountains, including the self and cast shadows, and it is calculated from the red and near-infrared waveband reflectance only, without the DEM support, so it has great potential application in vegetation parameters retrieval in rugged terrain. However, the calculation of the adjustment factor and the normalization of the SEVI are still challenges for further application of it. We developed an image processing procedure for these time series of images, so the reasons why the SEVI result maps of 2002, 2005 and 2018 were abnormal, to some extent, may lie in image noise and distortion.
Figure 3. The classified shadow-eliminated vegetation index (SEVI) maps of the Wuyishan Nature Reserve from 2000 to 2019.
Figure 4. Time series of SEVI mean and patch density (PD) (a), and scatter plots of PD versus SEVI mean (b). Year 1-18 represent 2000-2005, 2007, 2009-2019.

5. Conclusions
We have applied the shadow-eliminated vegetation index and patch density index in deriving the inter-annual variability of vegetation greenness in the Wuyishan Nature Reserve from 2000 to 2019 using the 30-meter spatial resolution images. The results from this study have shown that the shadow-eliminated vegetation index is an efficient method to obtain the vegetation information removed the terrain shadow effect in rugged terrain, and is important data for analysis the patch density of mountain vegetation. The time series analysis of the shadow-eliminated vegetation index and patch density helps us better understand the vegetation cover changing in the Wuyishan Nature Reserve.

Acknowledgments
This work was supported by the China National Key Research and Development Plan [grant number 2017YFB0504203].

References
[1] Watson James E M, Keith David A, Strassburg Bernardo B N, Venter Oscar, Williams Brooke, Nicholson Emily 2020 Set a global target for ecosystems Nature 578(7795)
[2] Gibson L, Lynam A J, Bradshaw C J A, He F, Bickford D P, Woodruff D S, Bumrungsri S, Laurance W F 2013 Near-complete extinction of native small mammal fauna 25 years after forest fragmentation Science 341(6153) 1508-1510
[3] Montis A, Martin B, Ortega E, Ledda A, Serra V 2017 Landscape fragmentation in Mediterranean Europe: A comparative approach Land Use Policy 64 83-94
[4] Colombo S J, Chen J X, Ter-Mikaelian M T 2012 Forest protection and forest harvest as strategies for ecological sustainability and climate change mitigation Forest Ecology and Management 281 140-151
[5] Liu K, Zhou Q B 2016 Comparison between multispectral and hyperspectral remote sensing for LAI estimation Nongye Gongcheng Xuebao/Transactions of the Chinese Society of Agricultural Engineering 32 155-162
[6] Ghoussein Y, Nicolas H, Haury J 2019 Multitemporal remote sensing based on an FVC reference period using sentinel-2 for monitoring Eichhornia crassipes on a Mediterranean river Remote Sensing 11 16
[7] Zhao F, Xu B, et al 2014 Remote Sensing Estimates of Grassland Aboveground Biomass Based on MODIS Net Primary Productivity (NPP): A Case Study in the Xilingol Grassland of Northern China Remote Sensing 6(6) 5368-5386
[8] Song X, Huang Y, Fu J, Jiang D, Tian G 2017 Spatial variability and ecological effects of anthropogenic activities in a nature reserve: A case study in the Baijitan National Nature Reserve China Sustainability 9 239
[9] Brecka A F J, Shahi C, Chen H Y 2018 Climate change impacts on boreal forest timber supply
Forest Policy and Economics 92 11-21

[10] Zhou Y, Chen J, Guo Q, Cao R, Zhu X 2014 Restoration of information obscured by mountainous shadows through Landsat TM/ETM+ images without the use of DEM data: A new method IEEE Transactions on Geoscience and Remote Sensing 52 313328

[11] Yao J, Zhang Z 2006 Hierarchical shadow detection for color aerial images Computer Vision & Image Understanding 102 60-69

[12] Deng Y, Chen X, Chuvieco E, Warner T, Wilson JP 2007 Multi-scale linkages between topographic attributes and vegetation indices in a mountainous landscape Remote Sensing of Environment 111 122-134

[13] Burgess DW, Lewis P, Muller JPAL 1995 Topographic effects in AVHRR NDVI data Remote Sensing of Environment 54 223-232

[14] Riaño D, Chuvieco E, Salas J, Aguado I 2003 Assessment of different topographic corrections in Landsat-TM data for mapping vegetation types 2003 IEEE Trans. Geosci. Remote Sens 41(5) 1056-1061

[15] Teillet P M, Guindon B, Goodenough D G 1981 On the Slope-Aspect Correction of Multispectral Scanner Data Canadian Journal of Remote Sensing 8(2) 84-106

[16] Hantson S, Chuvieco E 2011 Evaluation of different topographic correction methods for Landsat imagery Int. J. Appl. Earth Obs. Geoinf 13(5) 691-700

[17] Gu D, Gillespie A, 1998 Topographic Normalization of Landsat TM Images of Forest Based on Subpixel Sun-Canopy-Sensor Geometry Remote Sensing of Environment 64(2) 166-175

[18] Soenen S A, Peddle D R, Coburn C A 2005 SCS+C: a modified Sun-canopy-sensor topographic correction in forested terrain IEEE Transactions on Geoscience & Remote Sensing 43(9) 2148-2159

[19] Fan Y, Koukal T, Weisberg P J 2014 A sun-crown-sensor model and adapted C-correction logic for topographic correction of high resolution forest imagery ISPRS J. Photogrammetry Remote Sens 96 94-105

[20] Li H, Xu L, Shen H, Zhang L 2016 A general variational framework considering cast shadows for the topographic correction of remote sensing imagery Isprs Journal of Photogrammetry & Remote Sensing 117 161-171

[21] Jiang H, Wang S, Cao X J, Yang C H, Zhang Z M, Wang X Q, 2019 A shadow-eliminated vegetation index (SEVI) for removal of self and cast shadow effects on vegetation in rugged terrains International Journal of Digital Earth 12(9) 1013-1029

[22] Sandmeier S, Itten K I 1997 A physically-based model to correct atmosphere and illumination effects in optical satellite Data of Rugged Terrain IEEE Trans.geo.remote Sensing 35(3) 708-717

[23] United Nations Educational Scientific and Cultural Organization (UNESCO) World heritage committee inscribes 48 new sites on heritage list https://whcunesco.org/en/news/165 (accessed 29 August 2019)

[24] Masoudi M, Tan P 2019 Multi-year comparison of the effects of spatial pattern of urban green spaces on urban land surface temperature Landsc Urban Plan 184 44-58

[25] Kayiranga A, Kurban A, Ndayisaba F, Nahayo L, Karamage F, Ablekim A, Li H, Ilniyaz O 2016 Monitoring forest cover change and fragmentation using remote sensing and landscape metrics in Nyungwe-Kibira Park Journal of Geoscience and Environment Protection 4 13-33

[26] Vogt J, Kautz M, Fontalvo Herazo M L, Triet T, Walther D, Saint-Paul U, Diele K, Berger U 2013 Do canopy disturbances drive forest plantations into more natural conditions? - A case study from Can Gio Biosphere Reserve Viet Nam Global and Planetary Change 110 249-258

[27] Wang Z, He H, Fan M 2014 The ecological civilization debate in China Monthly Review 66(6) 37-59