Ecological Indicators 78 (2017) 405–415

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

# Environmental vulnerability evaluation using a spatial principal components approach in the Daxing'anling region, China

Taohong Zou[a,*], Kunihiko Yoshino[b]

[a] Graduate School of System and Information Engineering, University of Tsukuba, Tsukuba, Ibaraki 3058577, Japan
[b] Faculty of Engineering, Information and Systems, University of Tsukuba, Tsukuba, Ibaraki 3058577, Japan

ARTICLE INFO

*Article history:*
Received 28 July 2016
Received in revised form 18 March 2017
Accepted 18 March 2017
Available online 30 March 2017

*Keywords:*
Environmental vulnerability evaluation
Spatial principal component analysis
Geographical information system
Daxing'anling area

ABSTRACT

Identifying environmentally vulnerable regions is an important aspect of forest resource management, especially in boreal forest ecosystems that exhibit sensitivity to climate change. In this study, an environmental vulnerability index was constructed to describe the vulnerability status of the ecosystem in the Daxing'anling region, Heilongjiang Province, China. Thirteen variables related to exposure, sensitivity and adaptive capacity of the ecosystem were selected and integrated into a comprehensive index using spatial principal component analysis. The vulnerability within each part of the study area was then classified into one of five levels, including potential, slight, light, medium and heavy vulnerability, based on the numerical values. Results showed that the degree of vulnerability was unevenly distributed throughout the Daxing'anling region. The highest environmental vulnerability index value was approximately 0.86 in the southern and central areas, suggesting that these regions are the most vulnerable to environmental changes. The lowest value was approximately 0.036 in the eastern region, which indicates a relatively high-quality environment that is less vulnerable to environmental changes. The results of the environmental vulnerability evaluation may be helpful for decision makers by providing a comparatively rational decision making tool for planning and implementing effective forest resource management.



## 1. Introduction

Forest ecosystems are under increased stress that has been linked to climate change (Mildrexler et al., 2015) resulting in the common problem of forest degradation in China (Xiao et al., 2004). The forest ecosystem of the Daxing'anling region in northeast China represents the southern-most part of the global boreal forest biome (Jiang et al., 2002), one of the most ecologically fragile and economically under-developed region in China (Huang et al., 2010). This region is particularly sensitive to changes in temperature and other environmental conditions (Luo and Xue, 1995). The ecosystem here plays important roles in biodiversity conservation and climate mitigation. However, it is affected by various types of natural and anthropogenic disturbance. In recent years, economic development and timber harvest operations have exacerbated the imbalance between environmental protection and economic development (He et al., 2002), which creates several problems related to the management of forest resources. Identifying vulnerable areas plays an important role in forest resource management, especially in fragile regions such as the Daxing'anling. To help decision makers formulate effective forest management strategies, conducting a comprehensive environmental vulnerability evaluation is imperative. This type of evaluation enables the identification of areas at risk of losing functions that will threaten future efforts related to sustainable land management (Song et al., 2015). However, scientists have found environmental vulnerability difficult to quantify because the qualitative nature of vulnerability indicators makes it difficult to develop precise and objective measurements of vulnerability.

The term of "environmental vulnerability" is related to the risk of damage to the natural environment or a particular ecosystem type. According to the Intergovernmental Panel on Climate Change (IPCC, 2014), vulnerability is the degree to which a system is susceptible to adverse effects caused by a specific hazard or stressor. Understanding the factors that affect vulnerability is critical to the process of evaluating environmental vulnerability (Burger, 1997). However, the mechanism of vulnerability evaluation varies from region to region because of regional environmental differences. Therefore, developing a location-based set of indicators that are suitable for the actual situation of each case study is necessary, because no uni-

* Corresponding author.
*E-mail address:* zoutaohong@gmail.com (T. Zou).

http://dx.doi.org/10.1016/j.ecolind.2017.03.039
1470-160X/

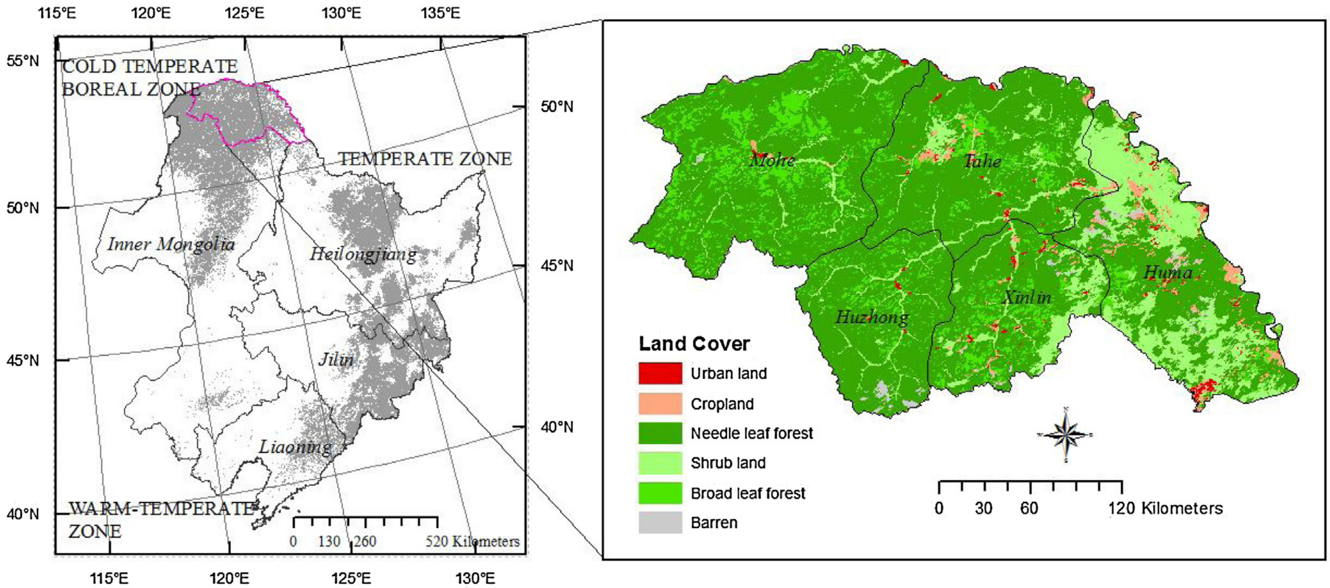


**Fig. 1.** Location of the Daxing'anling region in northeast China. A) Vicinity map showing northeast China and extreme northern Inner Mongolia Autonomous Region (grey color means vegetation covers); B) Land cover map of Daxing'anling Prefecture refer to (Zou and Yoshino, 2015).

versally applicable indicators currently exist (Beroya-eitner, 2016). Additionally, knowing how to correctly convert data from multiple sources, such as data related to climatic conditions, land cover, and socio-economic condition, into an integrated evaluation index is also important for vulnerability evaluation (Munda et al., 1994).

A variety of methods have been developed to evaluate vulnerability such as the fuzzy theory approach (Enea and Salemi, 2001), or the use of grey assessment models (Hao and Zhou, 2002), the artificial neural network approach (Park et al., 2004), and the analytical hierarchy process (Li et al., 2009). However, a certain degree of subjectivity cannot be avoided in index selection and index weight determination using these methods, because all of these methods mostly rely on the prior knowledge and experience of researchers. Principal component analysis is a type of statistical analysis that can be used to reduce the dimensionality of a dataset by converting a set of observed correlated variables into a set of linearly uncorrelated variables through orthogonal transformation (Hotelling, 1933), and can reduce this subjective influence to some extent. However, when considering the difficulty in finding a spatial relationship among different factors, the integration of geographic information system (GIS) data and PCA, defined as spatial principal component analysis (SPCA), was employed here. The goal was to detect the spatial tendencies of factors and use in a wide range of environmental reasearch for investigating the relationship between different indicators (Shi et al., 2009). In this study, we applied spatial principal component analysis to assess the environmental vulnerability caused by forest degradation in the Daxing'anling region, China. We combined remote sensing image data that can frequently provide updated information for inaccessible areas, where temporal and spatial variation of environmental vulnerability evaluation is needed, with PCA.

Our study builds a regional envrionmental vulnerability index (EVI) model using remote sensing, GIS, and a quantitative method based on SPCA to evaluate the environmental vulnerability in the Daxing'anling region, China. Next, the study area was regionalized into different vulnerability levels based on the EVI values. Then, alternative measures available for improving the environmental vulnerability of each area are proposed to help decision makers conduct effective forest resource management.

## 2. Materials and methods

### 2.1. Study site

The Daxing'anling region, located in northeast China (50°10′–53°33′N, 121°12′–127°00′E; Fig. 1), extends over $8.3 \times 10^4$ km$^2$ and occupies almost one sixth of the total territory of Heilongjiang Province. A cold temperate monsoon climate influences the region with total annual precipitation of approximately 460 mm; more than 65% of rainfall occurs between June and August. The annual average temperature falls between approximately −2 to 2 °C, and the monthly mean temperature ranges from approximately −40 °C in January to 28 °C in July. The typical cool temperate forests of the study area account for approximate 4.1% of the total forest area in China (Zhang et al., 2009). The total forest land, covering approximately 86% of the region, dominated by a larch species (*Larix gmelinii*) and mixed with birch trees (*Betula platyphylla*). The large forest area makes this region a green reservoir and eco-fence for the Northeast Plain. Additionally, the Daxing'anling region serves as one of the main timber production areas in China. The forest ecosystem in Northeast China holds a large C pool (Xing et al., 2015) and plays an important role in mitigating global climate change (Zhang et al., 2016).

Within the study area, extremely low winter temperatures help to develop an underground permafrost soil layer that can be envisioned as the southern edge of the Eurasian permafrost zone (Jin et al., 2007). The permafrost soil zone has strong effects on biogeochemical processes such as oxidation/reduction and decomposition (Ping et al., 2015). Moreover, the large amount of organic carbon that has accumulated in these soil layers make them prominent in global climate research (Bobrik et al., 2014) because thawing of this permafrost is predicted to release large amounts of greenhouse gas. However, the permafrost in the region is sensitive to climatic warming, which makes the forest ecosystem susceptible to climate change. The change of the permafrost soil layer can be seen as a sign of global climate change and once this permafrost is destroyed, recovery to its original state is considered difficult in the coming decades and centuries (Wang, 2005).