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Intensive land-use drives regional-scale homogenization of plant communities

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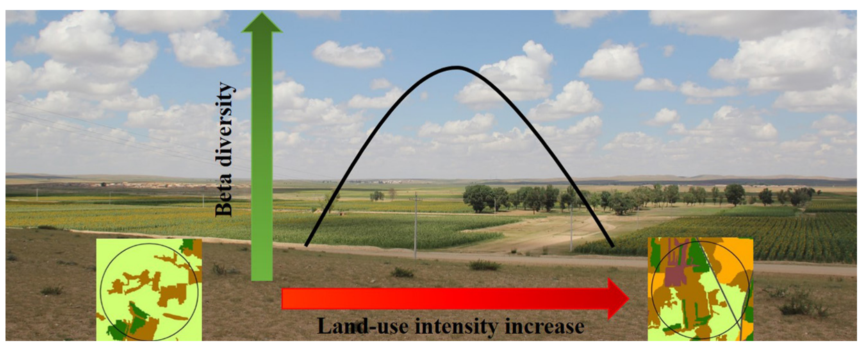
HIGHLIGHTS

- Alpha diversity was the dominant component of gamma diversity.
- With the increase of LUI, beta and gamma diversities showed hump-shaped relationships.
- Environmental heterogeneity was the primary factor in maintaining alpha diversity.
- Human activity primarily contributed to the maintenance of beta diversity.
- Intensive land-use drives homogenization of plant communities in this area.

GRAPHICAL ABSTRACT



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ABSTRACT

Intensive anthropogenic land-use causes habitat loss and landscape homogenization, which leads to the decrease of biodiversity and ecosystem degradation. Therefore, it is important to study the influence of landscape heterogeneity on biodiversity. In this study, vegetation surveys conducted at 53 sites in the Tabu River basin, located at the agro-pastoral ecotone of Inner Mongolia of China, revealed 146 species. Species diversity was evaluated at three scales: species richness within patches (alpha diversity), between patches (beta diversity) and at the landscape scale (gamma diversity). We analyzed landscape heterogeneity (LH_{total}) and its driving factors including environmental variables ($LHDF_{env\text{-}var}$, such as precipitation and altitude), environmental heterogeneity ($LHDF_{env\text{-}het}$) and human activities ($LHDF_{hum}$). We used structural equation modeling (SEM) to evaluate the response of species richness to landscape heterogeneity at three scales and determined the relative contribution of driving factors in explaining species diversity at these scales. The results of the study are summarized as follows: 1) Alpha diversity was the dominant component of gamma diversity in the Tabu River basin in Inner Mongolia. 2) There is no significant correlation ($P = 0.512$) between alpha diversity and LH_{total}; with the increase of LH_{total} beta and gamma diversities showed hump-shaped relationships. 3) $LHDF_{env\text{-}het}$ was the primary factor in maintaining alpha diversity, with heterogeneity of mean annual precipitation (MAP), temperature (MAT) and altitude (ALT) acting as three largest contributors. $LHDF_{hum}$ primarily contributed to the maintenance of beta diversity. 4) $LHDF_{hum}$ was the primary contributor to gamma diversity, and human activity exceeded threshold values for positive effects. Based on our findings we suggest liming agricultural use along the river to prevent reductions in species diversity.

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1. Introduction

In recent years, intensive human activities have aggravated the loss of biodiversity (Chapin et al., 2000). Changes in land use/cover and land-use intensification lead to habitat loss and landscape simplification, which further threaten regional biodiversity (Norris et al., 2010). Consequently, habitat loss and biotic homogenization caused by land use change are the primary reasons for the loss of biodiversity and ecosystem degradation (Wilson et al., 2016). Therefore, the influence of landscape heterogeneity on biodiversity has become a focus of recent research (Geri et al., 2010; Lundholm, 2009). Many studies have found that landscape heterogeneity and plant species richness (alpha and gamma diversity) are positively correlated (Dufour et al., 2006; Pausas et al., 2003). At a given spatial scale, increasing landscape heterogeneity is likely to increase the number and types of patches and the complexity of spatial heterogeneity, which is expected to provide more opportunities for species colonization and persistence and increase species diversity (Tscharntke et al., 2012). However, some studies have found that increasing landscape heterogeneity has adverse effects on species richness (alpha, beta and gamma diversity) (Steiner and Kohler, 2003; Tamme et al., 2010). In this scenario, the increase in the number of patches leads to reduction in the total area of suitable habitat and increase in patch isolation, which further reduces species diversity (Dufour et al., 2006; Fahrig, 2003). Two general trends can be derived from these studies. When the landscape is relatively homogeneous, increasing landscape heterogeneity leads to an increase in species diversity. However, such an increase is not monotonous leading to the eventual decline in species richness beyond a certain peak point. That corresponds to the area–heterogeneity trade-off hypothesis (Chocron et al., 2015), the trade-off between these positive and negative effects lead to a general hump-shaped relationship between species diversity and landscape heterogeneity (Fahrig et al., 2010; Redon et al., 2014).

Landscape heterogeneity is practiced in landscape ecology (Li and Reynolds, 1995), and environmental variables, environmental heterogeneity and human activity have always been considered to be the main factors affecting landscape heterogeneity (Chase and Leibold, 2002; Norris et al., 2010; Redon et al., 2014). Environmental variables are resource-related and topographic variables, such as precipitation and altitude. Spatial variation in environmental variables tends to be higher with higher environmental variables (Chase and Leibold, 2002), which further increases landscape heterogeneity. Environmental heterogeneity refers to spatiotemporal variability in environmental variables, is the component of landscape heterogeneity resulting from environmental gradients (Redon et al., 2014). For example, topography affects the redistribution of resources, such as precipitation, which further affects landscape heterogeneity. Human activities change landscape spatial patterns and subsequently affect landscape heterogeneity (Norris et al., 2010), especially high intensity and homogeneous land use (e.g. agricultural reclamation), it is a direct signal of the impact of human activities on terrestrial ecosystems which is also an important driver of landscape and habitat homogenization (Felipe-Lucia et al., 2014). At the same time species richness is significantly dependent on elements of landscape heterogeneity including patch area, connectivity, and amount or density of edges (edge effects). The effect of patch area on species diversity (alpha diversity) is known as the species-area relationship in which species richness increases with larger area, which is considered one of the important laws in ecology (Tscharntke et al., 2012). By contrast, fragmentation leads to the reduction in area and alpha diversity (Ewers and Didham, 2006). Landscape connectivity also affects species diversity (beta diversity) by determining whether organisms could disperse to unoccupied habitats. It also facilitates migration and persistence of metapopulations and influence the ability of species to respond to climate changes (Baguette and Dyck, 2007; Minor and Urban, 2008). Separate from these factors, edge effects also drive changes in species diversity by modifying biotic and abiotic conditions for organisms within individual patches (Woodroffe and Ginsberg, 1998). Depending on the response of particular species, edge effects can be either positive or negative. Additionally, edge effects are stronger when the patch area is small and irregularly shaped (Ewers et al., 2007; Ribeiro et al., 2015).

Although many studies have examined the effects of landscape heterogeneity on species diversity two problems still remain to be addressed. First, many studies were conducted at a single scale. However, species diversity can be analyzed at three different scales as identified by Whittaker (1960) alpha diversity (local species diversity), beta diversity (magnitude of changes in species composition), and gamma diversity (species diversity in a region). In the landscape context, alpha diversity refers to the species richness within patches, and beta diversity describes the differences in species composition between patches, namely, the species richness between patches. Gamma diversity is the species richness at the scale of the entire landscape. Landscape heterogeneity affects alpha and beta diversities, which is ultimately reflected in gamma diversity. The response of species diversity to landscape heterogeneity is largely scale dependent (With, 2016; Wu, 2013; Wu et al., 2015), and differences in diversity maintenance are exhibited across scales (Crawley and Harral, 2001; Wu et al., 2015; Zhang et al., 2014). Therefore, the influence of landscape heterogeneity on species diversity at different scales requires further research. Second, in many studies landscape heterogeneity is often assessed using a single thematic map of one ecological attribute (e.g., vegetation type, land use and cover type), making it impossible to determine the relative contribution of the three factors of landscape heterogeneity to diversity. Thus, distinguishing the effects of environmental variables, environmental heterogeneity and human activities should considerably improve our understanding of biodiversity and provide vital information for biodiversity conservation policies.

Natural ecosystems in the agro-pastoral ecotone of Inner Mongolia are characterized by high variability due to various natural and human disturbances. Intensification of anthropogenic activities is detrimental to those fragile ecosystems (Zhou et al., 2007). Therefore, understanding effects of landscape heterogeneity on species diversity is not only important for biodiversity conservation but can also improve the management of ecosystem services. Although many studies have examined the relationship between landscape heterogeneity and species diversity, a study that clearly defines the contribution of different factors of landscape heterogeneity to biodiversity at multiple scales is still lacking. The goals of our study were to reveal the responses of alpha, beta, and gamma diversities to landscape heterogeneity and to determine the composition of gamma diversity and the relative contributions of three drivers of landscape heterogeneity in this area. We also sought to provide a scientific basis for protecting biodiversity and maintaining ecosystem services in the Tabu River basin.

2. Materials and methods

2.1. Study area

This study was conducted in the Tabu River basin (41°2′–42°32′ N, 110°34′–112°11′ E) located in the Siziwang Banner of Inner Mongolia, China. The altitude of the basin ranges from 1360 to 1700 m. The climate of the region is temperate continental with the MAT varying from 1.5 to 5.0 °C and a MAP of 235 mm. The area has two types of landforms, low mountains and hills in the south and plateaus in the north. The zonal soil type is light chestnut soil. Zonal vegetation is comprised of grasses, *Stipa krylovii* and *S. breviflora*, that characterize the area as a typical transition zone of steppe and desert (Inner Mongolia-Ningxia Complex Expert Team of the Chinese Academy of Sciences, 1980). Tabu River is the largest in the Siziwang Banner. The river flows through the agro-pastoral ecotone from south to north. To determine the boundary of its watershed and the study area extent, ArcGIS 10.3 hydrology analysis modules were applied to the digital elevation model (DEM) obtained from ASTER satellite images at 30-m spatial resolution.