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Non-linear effect of habitat fragmentation on plant diversity: Evidence from a sand dune field in a desertified grassland in northeastern China

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ABSTRACT

Although a large number of empirical studies have documented the effect of habitat fragmentation on plant diversity, we are far from being able to draw effective conclusions due to a lack of a proper reference point and a large range of patch size. This study aims to test the hypothesis that the effect of habitat fragmentation on plant diversity is non-linear, i.e. there is a shift in the effect of habitat fragmentation on plant diversity from positive to negative (or from negative to positive) with intensifying fragmentation. A sand dune field in a desertified grassland in eastern Inner Mongolia, China, was used as the study site. Eighteen fragmented plots (inter-dune lowlands in the sand dune) and 14 continuous plots (different sizes of grassland) were selected. Plant diversity was estimated by species richness, functional groups and rare species. Logarithmic, power and exponential functions were used to analyze the relationship of species richness, frequency and abundance and plot area. There was a shift from positive to negative in the relationship between habitat fragmentation and species richness with the intensifying fragmentation. The number of plant functional groups increased due to habitat fragmentation, and different functional groups showed distinct responses to the degree of fragmentation. The effect of habitat fragmentation on rare species richness is non-linear, and the effect of habitat fragmentation on rare species population is negative. Our results indicate: (1) thresholds should be taken into consideration when drawing up plant diversity conservation plans; and (2) a single large reserve and several small reserves have different implications in plant diversity conservation.

1. Introduction

China central government has invested a huge amount of money for the biodiversity conservation and restoration of degraded ecosystems (Cao, 2008; Cao et al., 2011). Unfortunately, due to ignorance of some important issues, one of which is habitat fragmentation, biodiversity conservation has not been very successful (Cao et al., 2009, 2010; Gao et al., 2011; Wang and Cao, 2011). To know how habitat fragmentation is linked to species richness, functional groups and rare species is crucially important for biodiversity conservation in China.

Habitat fragmentation is considered as one of the major threats to biodiversity (Krauss et al., 2004; Fischer and Lindenmayer, 2007; Filgueiras et al., 2011; Ruell et al., 2012). Previous studies indicate that the effect of habitat fragmentation on plant diversity is linearly negative (Laurance et al., 2001) or positive (Dolt et al., 2005), or non-linearly negative (Digiovinazzo et al., 2010). We suspect that the effect of habitat fragmentation on plant diversity is non-linear, and that this non-linearity means a shift in the effect of habitat fragmentation on plant diversity from positive to negative with intensifying fragmentation, rather than the higher rates of loss in plant diversity indicated in previous studies (Drinnan, 2005; Lindenmayer and Luck, 2005; Digiovinazzo et al., 2010). Habitat fragmentation can lead to both habitat loss (Fahrig, 2003) and habitat creation (Tscharntke et al., 2002), and thus can sometimes serve to accommodate more exotic species whilst causing habitat loss for other, more common species. It seems that larger fragments tend to house more species than a plot of the same area in continuous habitat because the fragments collectively have a larger boundary, which allows more exotic species to colonize, and when a fragment is large enough its species number will likely reach saturation. Moreover, although environmental fluctuation in fragments allows species to coexist by “time-sharing” a niche (Roxburgh et al., 2004), small fragments are likely to have stronger environment variation (Metzger et al., 2009), which is unfavorable for species survival and causes the number of species to decline. Consequently, we anticipate a non-linear effect of habitat fragmentation on plant diversity.

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It is evident that how species richness, functional groups and rare species change with fragmentation intensity is a very important issue to be solved in biodiversity conservation.

Although a large number of empirical studies have documented the effects of habitat fragmentation on plant diversity (Bascompte and Rodriguez, 2001; Drinnan, 2005; Digiovinazzo et al., 2010), we are far from being able to draw effective conclusions on the patch level. This is due to: (1) no distinction between the effect of species–area law and that of habitat fragmentation on plant diversity; and (2) a failure to determine a shift in the relationship between habitat fragmentation and plant diversity in response to patch size.

An appropriate point of reference is critical in helping to draw conclusions about the impacts of habitat fragmentation on plant diversity (Fahrig, 2003). However, we are often misled by many previous studies, which mainly conclude that plant diversity decreases with a decrease in patch size, based on analyses of species–area relationships (Haig et al., 2000; Hill and Curran, 2003; Echeverría et al., 2007). Obviously, this approach is inadequate, as a decrease in area will lead to a decrease in species number, even in continuous habitat (Bröring et al., 2005; Tomsic et al., 2007). Since habitat fragmentation per se is a process in which continuous habitat breaks into isolated patches (Ewers and Didham, 2007), it is more appropriate to make a comparison between the fragments and the continuous habitat in evaluating the effects of habitat fragmentation on plant diversity. Consequently, selecting a proper reference point is essential before one can make inferences about the relationship between habitat fragmentation and plant diversity.

One of shortcomings of previous studies is that there were not enough patches to detect the relationship between habitat fragmentation and plant diversity (Zartman, 2003; Mayfield et al., 2005). Therefore, selecting a large range of patch sizes is crucial to elucidate the effect of habitat fragmentation on plant diversity.

Since a proper reference point and a large range of patch sizes are essential to uncover the effect of habitat fragmentation on plant diversity, finding an appropriate study area is very important, and a sand dune field in a desertified grassland is a good candidate. The fragmentation of grassland leads to the formation of sand dune fields, which are characterized by a mosaic distribution of sand dunes and inter-dune lowlands. Each inter-dune lowland area can be considered as a fragmented patch. Because the continuous grassland can be regarded as a reference point, and a large number of inter-dune lowland areas of different size can be found within the sand dune field, this type of habitat possesses the right set of criteria for evaluating the relationship between habitat fragmentation and plant diversity. Plant diversity can be evaluated by species richness (Wright, 2002), functional group (Ward et al., 2009) and rare species (Liu et al., 2007).

Based on the above, we chose to regard continuous natural grassland as the initial habitat, and inter-dune lowlands in the active dunes as fragments, to study the effect of habitat fragmentation on plant diversity in an area of northeastern China. By examining the change in total species richness, functional groups, and rare species in response to habitat fragmentation, we tested the hypothesis that the effect of habitat fragmentation on plant diversity is non-linear.

2. Materials and methods

2.1. Study site

The study site was located in the Wulanaodu region (119°39′–120°02′E, 42°29′–43°06′N; 480 m a.s.l.), northeastern Inner Mongolia, China. The region has a semi-arid, continental monsoon climate in the temperate zone. The annual average temperature is 6.3 °C. The average annual rainfall is ca. 340 mm, most of which falls during June to September. The windy season is from March to May, and the growing season lasts from late April to late September. The area was intensively grazed between the 1950s and 1980s, but has been fenced since the 1980s, with over-grazing being the major force leading to the transition from natural grassland to sand dunes (Li et al., 2000). The active sand dune areas, 15–35 m in height, are advancing at a speed of ca. 6–7 m year^{-1}, and, following the aforementioned fencing since the 1980s, are permanently closed off from the natural grassland (>600 ha). The natural grassland and the active sand dunes experience the same climatic conditions, i.e. similar rainfall, temperature, humidity etc. The vegetation before the intense grazing period was dominated by perennial grasses, such as *Phragmites communis* and *Calamagrostis epigeios*, whereas after the onset of grazing pasammophilous species, such as *Artemisia wudanica* and *Agriophyllum squarrosum*, became more established.

2.2. Experimental design and field sampling

We selected a sand dune field in a desertified grassland as the study site because it contained a suitable reference point as well as a wide range of habitat patches. We regarded grassland as the initial habitat, and the inter-dune lowlands of the active dunes as the fragments. From June to September 2010, we randomly selected eighteen inter-dune lowlands with areas ranging from 0.03 to 11.3 ha and fourteen natural grassland plots with areas ranging from 0.05 to 12 ha. Plot areas were measured using GPS.

To consistently and accurately reflect the true distribution of vegetation, we used grid sampling at a resolution of 10 × 10 m. We established transects divided into 10-m intervals in each plot, all running in the vertical direction of the prevailing wind, and then selected 1 × 1 m quadrats, 10-m-spaced, along each transect. This approach enabled us to include more species since it sampled greater microhabitat heterogeneity and contained more individuals occupying a greater area (Stiles and Scheine, 2010). Sampling intensity is an important aspect that must be taken into account in studies of this nature, especially for rare species, because the probability of encountering a new species early in the sampling process is high (Loya and Jules, 2008). Therefore, we took great care to ensure our sampling intensity was sufficiently strong in this study. Owing to the different size of the fragments, the number of sampling quadrats in each fragment depended on patch size. There were 5906 quadrats in all. Plant species composition and abundance were recorded in each quadrat. For bunchgrasses (e.g. *C. squarrosa*), we counted the number of clusters to obtain the abundance, whereas for clonal species (e.g. *S. gordejevii* and *P. communis*) we counted the number of ramets, and for discrete species (e.g. *A. squarrosum*) the number of individuals were counted. The frequency of each species was determined within each plot.

2.3. Data analysis

Curve-fitting was carried out using Microsoft Excel, with exponential, power and logarithmic functions used to assess the effect of habitat fragmentation on species richness, frequency and abundance. All the statistic analysis was conducted in SPSS software. Model selection was based on maximum R^2, and residual analysis showed that the model fit was adequate. After one-way ANOVA analysis was done, LSD's test was applied post hoc to distinguish species richness, frequency and relative abundance between the continuous and fragmented habitat at different plot sizes. Statistical significance was determined at $P = 0.05$. We analyzed the