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Species diversity of butterflies in Changbai Mountain in China

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ABSTRACT

Using a modified belt transect method, we investigated the butterfly communities in five different vertical vegetation belts of Changbai Mountain in China from 1992 to 2009; these belts were broadleaf deciduous forest, coniferous–deciduous mixed forest, coniferous forest, erman's birch forest and alp tundra. We determined the number of species and abundance of butterflies in each belt and in the coniferous–deciduous mixed forest belt, we also compared these parameters among different months. Preston's lognormal distribution was used to model the species abundance distributions and five indicators (Shannon–Wiener diversity index (H'), Pielou uniformity index (J), Simpson predominance centralization index (C), Margalef abundance index (E) and Jaccard similarity coefficients) were used to analyze the butterfly community diversity. We found four main results. (1) Across all five vertical vegetation belts, 9641 butterflies were collected, belonging to 7 families, 98 genera and 196 species. As altitude increased, the number of butterfly genera and species gradually reduced. There was a relationship between the distribution of dominant species and the total species between each belt and the distribution of vascular plants. (2) The species abundance distribution was successfully modeled as a Preston's lognormal distribution; the best fit was obtained when $\alpha = 0.326$, the determinant coefficient of the equation was 0.74798. The species abundance distribution indicates that Changbai Mountain provides a suitable environment for butterflies; there was high species richness and an even distribution of butterfly species. There were few very common and very rare species, with most species having an intermediate abundance. (3) As altitude increased, H' and E gradually became smaller, while C showed the opposite pattern, and J did not significantly change. The similarity coefficients analysis demonstrated a clear difference among belts; the farther apart any two belts, the smaller the similarity coefficient, indicating less similarity in the butterfly communities. The similarity coefficient between the deciduous forest and the coniferous–deciduous mixed forest belt was the largest (0.651) while that between the deciduous forest and the alp tundra was the smallest (0.141). (4) Comparison of the butterfly species communities among different months in the coniferous–deciduous mixed forest found that H' and E showed similar directional changes, while the opposite pattern was found with C; the changes in J did not necessarily reflect the actual change in diversity.

1. Introduction

Butterfly species are known to be good indicators of the ecological environment. For example, it is possible to predict changes in plant populations from knowledge of butterfly populations [1]. Within the Changbai Mountain region, changes to both plant community and butterfly taxa and abundance are evident with increases in altitude. From the 1980s, Chinese scholars have been investigating the taxonomy of butterflies within the Changbai Mountain region [2–10]. However, the number of butterfly species reported within these studies was inconsistent, there were a lot of errors made in regard to species identification, and there is a lack of studies on species diversity. This study aimed to investigate spatial variability of butterfly taxonomy and abundance among five vertical distribution belts within the Changbai Mountain region. The study area was restricted to the Linjiang, Changbai, Fusong and Antu Counties of the Jilin Province within the years 1992–2009. An objective of the study was to propose a model explaining the vertical distribution of butterfly taxonomy and abundance. To achieve this, we not only measured the abundance and diversity of butterfly communities, but also developed a model to estimate the total community of Changbai Mountain butterfly species, based on the assumption of a normal distribution.

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2. Research methods

2.1. Collection sites profile

Changbai Mountain which is located in the eastern part of China, in Jilin Province near the North Korean border, is the highest mountain in northeast China, with Baiyun Peak being 2,691m above sea level. Changbai Mountain is located at 127°42′55″–128°16′48″E, 41°41′49″–42°25′18N, and has a total area of 196,465 hm^2 [11]. Geographically, Changbai Mountain is divided into the North Slope and Southwest Slope, with Antu and Helong Counties located on the North Slope, while Fusong, Changbai and Lingjiang Counties are located on the Southwest Slope.

The flora of Changbai Mountain can be divided into five vertical distribution belts from bottom to top: (1) The broadleaf deciduous forest belt occurring below 500 m in elevation and consisting of secondary deciduous forest mixed with the distribution of agricultural land. Here the climate is warm and sunny, and the forest flora is complex and diverse. The main tree species include *Betula platyphylla*, *Populus davidiana*, *Quercus mongolica*, *Acer mono*, *Phellodendron amurense*, *Salix matsudana* and *Schizandrae chinensis*. (2) This belt consists of coniferous–deciduous mixed forest, 500–1100 m in elevation, and is one of the few large native coniferous–deciduous mixed regions in the world. The plant community structure of this region is complex and structured, consisting of a tree layer, shrub layer and herb layer. Species within the tree layer include *Pinus koraiensis*, *Picea koraiensis*, *Larix olgensis f. viridis*, *Tilia amurensis*, *Fraxinus mandschurica and Juglans mandshurica*. Plant species within the shrub layer include *Corylus mandshurica*, *Acanthopanax senticosus* and *Syringa reticulata var. amurensis*. Plant species within the herb layer include *Carex lasiocarpa*, *Equisetum hyemale* and *Brachybotrys paridiformis*. (3) The coniferous forest belt region occurs 1100–1800 m in elevation, has a cold and wet climate, and thin soil geology. This belt can be divided into two sub-belts. Light coniferous forest dominates from 1100 to 1500 m in elevation. Tree species occurring in this sub-belt are almost always conifers and include *P. koraiensis*, *Picea jezoensis var. microsperma*, *P. koraiensis* and *Abies nephrolepis*. The forest composition of this sub-belt is complex, with small amount of *B. platyphylla*. Dark coniferous forest dominates the sub-belt from 1500 to 1800 m in elevation. Tree species occurring here include *P. jezoensis*, *A. nephrolepis* and *P. koraiensis*. The forest in this sub-belt is gloomy, leading to shrub under-development, with only scattered occurrences of *Rosa davurica*, *Lonicera maackii* and *Sorbus pohuashanensis* among others. The moss layer in this region is well-developed, with thicknesses reaching up to 10 cm. (4) The erman's birch forest belt occurs at an elevation of 1800–2000 m. Weather conditions in this region are harsh, with cold temperatures and strong winds. Due to the weather conditions and barren soil, simple plant species dominate. Forests are composed of a single forest tree species, namely *Betula ermanii*. Herbaceous plants are more common in sunny forest areas where soil is moist, including, *Trollius chinensis*, *Sanguisorba sitchensis* and *Maianthemum bifolium*. (5) The Alpine tundra belt is the highest and coldest region of the Changbai Mountain, at over 2100 m in elevation. Winters in this region are long and summers are short. Weather conditions are similar to the polar environment, with large snowstorms and strong winds. Plant community structure in this region is simple, with a homogeneous layer consisting only of dwarf shrubs, perennial shrubs and cushion moss. A carpet of tundra vegetation occurs here, consisting of lichen species such as *Rhododendron aureum*, *Rhododendron bracteatum*, *Vaccinium uliginosum var. alpinum*, *Phyllodoce caerulea*, *Dryas octopetala var. asiatica*, *Aquilegia flabellata var. pumila*, *S. sitchensis and Gentiana algida*. Flowering of plants in this region occurs mainly in July–August [12,13].

2.2. Collection

Selecting representative locations in each vertical distribution belt and using a modified belt transect method [14], we collected specimens in Changbai, Linjiang, Fusong and Antu counties during 29 May–13 June 1992, 8 June–2 July 1996, 20 July–30 July 1998, 20 May–12 July 2001, 10 July–15 August 2002, 22 May–20 June 2006, 12 June–13 July 2008, 20 May–5 June 2009. Collecting was done between 9:00 and 11:30 every not rainy day in the field, by walking at a speed of 2000 m/h, and gathering butterflies within 2.5 m of either side of the route with a insect-collecting net. The total collection area covered was 0.025 km^2 per day. Total acquisition time was164 days [15].

2.3. Identification

After collection, we identified the specimens using a identification keys, reference books, manuals and illustrations [16–26]. For those which were difficult to identify from external morphology, identification was done under a stereomicroscope using slides of the genitalia.

2.4. Statistical analysis formula

The lognormal curve fitting formula [27] used was:

$$S(\hat{R}) = S_0 e^{-[\alpha(R-R_0)]^2}$$

The formula [28] for estimating the total number of species in the community used was:

$$S_T = S_0\sqrt{\pi}/\alpha$$

where $S(\hat{R})$stands for the theoretical species number in the R-th log interval, R for the log interval, S_0 for the species number at the highest point in the actual histogram (or actual curve) of the species abundance distribution, R_0 for the log interval corresponding to the highest point in the actual histogram (or actual curve) and α is determined according to both the determination coefficient (R^2) and the fitting effect for a theoretical curve in statistics.

The formula [29] for the determination coefficient (R^2) is shown as follows:

$$R^2 = 1 - \frac{\sum_{R=0}^{m}[S(R) - S(\hat{R})]}{\sum_{R=0}^{m}[S(R) - S(\bar{R})]}$$

$$S(\bar{R}) = \frac{1}{m+1}S(R)$$

where $S(R)$ stands for the actual butterfly species in R-th log interval, m for the number of log intervals in the fitting of the theoretical curve, while $S(\hat{R})$ and R represents the same as those in the preceding formula.

We analyzed the butterfly community diversity using five indicators:

The Shannon–Wiener diversity index (H'): $H' = -\sum Ni/N \ln Ni/N$.

The Pielou uniformity index (J): $J = H'/\ln S$.

The Simpson predominance centralization index (C): $C = \Sigma(N_i/N)^2$.

And the Margalef abundance index (E) : $E = (S-1)/\ln N$

where S represents species, Ni and N represent the individuals within butterfly species i and the total butterfly individuals respectively [30,31].

Using Jaccard similarity coefficients, we measured the similarity of the five vertical distribution belts as well as the different months