

Effects of Environmental Factors on the Distribution and Species Composition of Bryophytes on Lake Islands: Postprint

Authors: Luo Xianzhen, Xiong Yuanxin, Xia Xin, Cao Wei, Zhong Shimei, Cui Zaining, Tan Hongying, Liu Liangshu

Date: 2017-04-18T00:00:00+00:00

Abstract

Bryophytes exhibit high sensitivity to environmental conditions, along with broad adaptability and strong reproductive capacity, playing an important role in ecological environment monitoring and ecological restoration. Through field plot survey methods, regression analysis and canonical correspondence analysis (CCA) were employed to explore the effects of environmental factors on species distribution and composition, while partial CCA calculated the total and net effects of each environmental factor on species composition. The results showed that bryophyte species richness and similarity in species composition increased extremely significantly with increasing island area and island altitude, and decreased significantly with increasing island shape index and nearest distance from island to mainland. Eight environmental factors collectively explained 35.6% of the variation in species composition, among which substrate, slope, herbaceous coverage, aspect, canopy closure of tree and shrub layers, human disturbance, air humidity, and altitude exhibited significant net effects on species composition ($P < 0.05$), but their effect intensity decreased sequentially. Eurohypnum leptothallum was the most dominant species, being less affected by environmental factors, achieving a coverage of 19.2% in 77.7% of the sampled quadrats where it occurred.

Full Text

Effects of Environmental Variables on Species Composition and Distribution of Bryophytes on Lake Islands

Luo Xianzhen¹, Xiong Yuanxin¹, Xia Xi¹, Cao Wei¹, Zhong Shimei¹, Cui Zaining¹, Tan Hongying¹, Liu Liangshu² ¹College of Life Sciences,

Guizhou University, Guiyang 550025, China ²College of Forestry, Guizhou University, Guiyang 550025, China

Abstract

Bryophytes are highly sensitive to environmental changes, exhibit strong adaptability and reproductive capacity, and play important roles as bioindicators in ecological monitoring and restoration. This study investigated the relationships between species composition and environmental variables through field surveys, regression analysis, and canonical correspondence analysis (CCA) on islands in Hongfeng Lake. Partial CCA was used to calculate the gross and net effects of each environmental variable on species richness. The number of bryophyte species and species composition similarity increased significantly with island area and elevation, but decreased significantly with increasing island shape index and nearest distance to mainland. Eight environmental variables collectively explained 35.6% of the variation in species composition. The net effects of canopy cover, air moisture, and altitude on species composition were significant ($P < 0.05$), though their influence decreased sequentially. *Eurohyppnum leptothallum* was the most dominant species, exhibiting minimal environmental sensitivity, occurring in 77.7% of sample plots with a coverage of 19.2%.

Keywords: Island; Bryophytes; Ecology; CCA; Environmental factors

Funding: National Natural Science Foundation of China (31360041); Guizhou University Graduate Innovation Fund (2016001) **Received:** 19 November 2015; **Online publication date:** 30 August 2016 **Corresponding author:** E-mail: xiongyx@vip.sin.com

1 Study Site

Hongfeng Lake is an artificial lake located at the watershed between the Yangtze River and Pearl River systems in Guizhou Province. The study area, situated at 106°33' -106°47' E, 26°23' -26°61' N, features multiple islands of varying sizes. The lake has a normal water level elevation of 1240 m, a surface area of 57.2 km², and a perimeter of 92.7 km, representing typical characteristics of a deep mountain reservoir. The region is a low-latitude, high-altitude area with an average annual temperature of 15.3 °C, historically ranging from -9.5 °C to 39.5 °C, and annual precipitation of approximately 1200 mm.

2 Sampling and Data Collection Methods

Nine islands with relatively minimal human disturbance were selected for investigation: Yeijpo, Gantianbian Island 1, Xinzhuang Island 1, Hongfeng River Island 1, Yuanyang Island 1, Yuanyang Island 2, Hongfeng River Island 2, Xinzhuang Island 2, and Ganbiantian Island 2. On each island, the quadrat method was employed, with three 20 m × 20 m large quadrats established per

island. Each large quadrat contained five $1\text{ m} \times 1\text{ m}$ small quadrats for detailed survey.

Environmental variables measured in each small quadrat included: - Longitude and latitude (using GPSmap 60CSx) - Canopy cover of trees and shrubs - Herbaceous layer coverage - Slope aspect (converted using the formula $\text{TRASP} = (1 - \cos((\text{aspect}-30)/180))/2$, where larger values indicate hotter/drier habitat conditions) - Slope gradient - Air humidity (measured with HH314A hygrometer) - Altitude

Human disturbance (HD) was calculated based on four vegetation characteristics: relative vegetation coverage, relative species richness, relative plant height, and relative dominance of anthropophilic species, following the disturbance assessment standards of Liu et al. for subalpine meadows in Beijing's Dongling Mountain.

3 Analysis of Bryophyte Diversity and Environmental Factors

Regression analysis using Preston's model (1962) examined relationships between bryophyte species richness/composition similarity and island area, shape index, and nearest distance to mainland. Jaccard similarity coefficient was used to calculate similarity between island and mainland bryophyte compositions. Island shape index (SI) was calculated using a circle as the reference geometric shape.

4 Ordination

Detrended correspondence analysis (DCA) revealed a maximum gradient length of 6.793, indicating substantial heterogeneity in species composition data and suitability for unimodal models in direct gradient analysis. Canonical correspondence analysis (CCA) was therefore employed to explore environmental influences on species composition. Variance inflation factors (IFs) were calculated for all environmental variables to assess multicollinearity; all IFs were sufficiently low to be negligible.

The species data matrix (18×73) consisted of species importance values, calculated as: $(\text{relative coverage} + \text{relative frequency})/2$. The environmental data matrix comprised eight variables: moisture, altitude, matrix, canopy cover, herbaceous coverage, human disturbance, aspect, and slope. Monte Carlo tests (9999 permutations) assessed significance of all ordinations. Statistical analyses were conducted using CanoDraw for Windows 4.5 and Excel 2013.

5 Island Data Analysis

Island baseline parameters (area, perimeter, altitude, nearest distance to mainland) were digitized from 1:10,000 topographic maps of Hongfeng Lake and cal-

culated using ArcView 3.2 software. Table 1 presents the basic characteristics of surveyed islands and their bryophyte species counts.

6 Regression Analysis of Bryophyte Species Richness and Island Geographic Factors

Correlation analysis revealed highly significant relationships between bryophyte species richness/composition similarity and island characteristics:

Island Area: Species richness and composition similarity showed extremely significant positive correlations with island area ($r = 0.8944$, $P < 0.01$; $r = 0.822$, $P < 0.01$). Regression equations: - Species richness: $\ln(S) = 0.2691 \ln(A) + 3.3227$ ($r = 0.8944$, $P < 0.01$) - Composition similarity: $\ln(CS) = 0.1916 \ln(A) + 2.6071$ ($r = 0.822$, $P < 0.01$)

Island Altitude: Significant positive correlations were found ($r = 0.9011$, $P < 0.01$; $r = 0.833$, $P < 0.01$). Regression equations: - Species richness: $\ln(S) = 5.3214 \ln(H) - 34.286$ - Composition similarity: $\ln(CS) = 3.9128 \ln(H) - 25.049$

Island Shape Index and Distance: Species richness and composition similarity decreased significantly with increasing shape index and nearest distance to mainland. As shape index increases, islands deviate more from circular geometry, intensifying edge effects. Regression equations: - Species richness vs. shape index: $\ln(S) = -0.7498 \ln(SI) + 7.831$ ($r = 0.7209$, $P < 0.01$) - Composition similarity vs. shape index: $\ln(CS) = -1.2772 \ln(SI) + 3.6666$ ($r = 0.9141$, $P < 0.01$) - Species richness vs. distance: $\ln(S) = -0.4956 \ln(D) + 5.5908$ ($r = 0.7216$, $P < 0.01$) - Composition similarity vs. distance: $\ln(CS) = -1.0718 \ln(D) + 2.8859$ ($r = 0.9209$, $P < 0.01$)

Figures 1-4 [FIGURE:1-4] illustrate these relationships.

7 Sub-plateau Island Bryophyte Communities

A total of 73 bryophyte species were identified and recorded across all sample plots. Table 2 details the environmental conditions of the 18 large quadrats.

8 Canonical Correspondence Analysis of Bryophyte Distribution and Environmental Factors

The CCA revealed that eight environmental variables collectively explained 35.6% of species composition variation. Monte Carlo random permutation tests showed high significance ($P = 0.0004$), indicating strong species-environment relationships. The first four canonical axes explained 12.8%, 9.9%, and subsequent portions of this variation.

Axis 1 was significantly negatively correlated with moisture, altitude, and canopy cover, but positively correlated with human disturbance and slope. Axis 2 primarily reflected the altitude gradient, while Axis 3 represented human

disturbance. Table 3 presents correlation coefficients between environmental variables and the first four CCA axes.

9 Effects of Environmental Factors on Bryophyte Species Composition

Eurohypnum leptothallum was the most dominant species, occurring in 77.7% of sample plots with 19.2% coverage, followed by *Thuidium kanedae* and *Trichostomum brachydontium*. Species distribution patterns were clearly reflected in the CCA biplot [Figure 5: see original paper]:

- Species in the upper right (e.g., *Eurhynchium laxirete*, *Claopodium rugulosifolium*) occurred in habitats with high human disturbance, dense herbaceous cover, and hot/dry aspects.
- Species in the lower portion (e.g., *Rhynchostegium subspeciosum*, *Brachythecium velutinum*) preferred cool/moist aspects, high canopy cover, and high altitude with minimal disturbance.
- Central species (e.g., *Weissia edentula*) showed relatively low environmental sensitivity, occurring across most plots.

Table 4 quantifies the gross and net effects of environmental variables. All eight variables showed significant gross effects ($P < 0.05$). Matrix (substrate) explained the most variation in net effects, followed by canopy cover, moisture, and altitude.

10 Relationship Between Bryophyte Distribution and Environmental Factors

Species richness and composition similarity increased with island area and elevation—a pattern consistent with island biogeography theory where larger areas provide more suitable habitats. However, these metrics decreased with increasing distance from mainland, as water poses a nearly insurmountable barrier to bryophyte spore dispersal, reducing colonization opportunities. Similarly, increasing shape index (greater deviation from circular geometry) intensified edge effects, leading to fewer species and lower composition similarity.

11 Relationship Between Species Composition and Environmental Factors

The cumulative explanatory power of all canonical axes demonstrated significant species-environment relationships ($P < 0.001$). Environmental factors influenced species composition through multiple pathways: substrate affected moisture, shading, and light conditions; canopy cover, moisture, and altitude influenced temperature, precipitation, and habitat conditions. The CCA biplot clearly illustrated these influences, with central species showing relative environmental insensitivity.

12 Conclusion

Bryophyte species richness and composition similarity increased with island area and elevation, but decreased with island shape index and nearest distance to mainland. CCA revealed significant correlations between species and environment, with canopy cover, moisture, and altitude showing significant net effects ($P < 0.05$) in decreasing order of importance. *Eurohypnum leptothallum* was the most dominant species, occurring in 77.7% of sample plots with 19.2% coverage.

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