

Soil Ciliate Community Structure Changes in Response to Different Slope Aspects in the Gannan Alpine Meadow (Postprint)

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Abstract

Soil ciliates are not only important components of soil ecosystems, but also crucial driving factors in ecosystem material cycling and energy flow processes. To investigate the characteristics of soil ciliate communities across different slope aspects in the Gannan subalpine meadow, a survey was conducted on five slope aspects (sunny slope, semi-sunny slope, west slope, semi-shady slope, and shady slope) of the same mountain from July 21-26, 2015. The results showed: (1) A total of 142 ciliate species were identified using the “non-flooded petri dish method”, belonging to 9 classes, 18 orders, 32 families, and 55 genera. The relationship among slope aspects in terms of species number and individual count exhibited the pattern: west slope > semi-sunny slope > sunny slope > semi-shady slope > shady slope. The dominant groups were Spirotrichea, Litostomatea, Oligohymenophorea, and Colpodea, with dominance values of 28.17%, 19.72%, 13.38%, and 12.68%, respectively. (2) Species number, individual count, and Shannon index of soil ciliates showed significant differences among different slope aspects ($P < 0.05$), indicating that soil ciliates in the Gannan subalpine meadow ecosystem are sensitive to changes in slope aspect as a microclimatic environmental factor. (3) Both species number and individual count of soil ciliates on each slope aspect exhibited obvious surface aggregation. (4) Pearson correlation analysis revealed that among the measured soil physicochemical factors, total nitrogen and organic matter showed significant positive correlations with ciliate species number and individual count ($P < 0.05$). Comprehensive analysis indicated that the main factors influencing the variation in soil ciliate community structure across different slope aspects in the Gannan subalpine meadow were total nitrogen, soil organic matter, and aboveground vegetation conditions.

Full Text

Preamble

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Response of Soil Ciliate Community Structure to Different Slope Aspects in an Alpine Meadow of Southern Gansu

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Abstract

Soil ciliates constitute a vital component of soil ecosystems and play fundamental roles in material circulation and energy flow processes. To determine how different slope aspects influence soil ciliate community characteristics in a South Gansu alpine meadow, we investigated five slope aspects—sunny, half-sunny, west, half-shady, and shady—on the same hillside between July 21 and 26, 2015. The results demonstrated that: (1) A total of 142 ciliate species were identified across the different slopes using the non-flooded petri dish method, belonging to 9 classes representing 18 to 55 genera and 32 families. The relationship between slope aspect and species/individual numbers followed the pattern: west slope > half-sunny slope > sunny slope > half-shady slope > shady slope. Dominant taxa included Heterotrichea (28.17%), Spirotrichea (19.72%), Litostomatea (13.38%), and Colpodea (12.68%). (2) Soil ciliate species and individual numbers varied significantly across slope aspects, with the Shannon diversity index showing significant differences ($p < 0.05$), indicating that soil ciliates in the Gansu alpine meadow ecosystem are sensitive to microclimatic environmental changes associated with slope aspect. (3) Both species and individual numbers exhibited obvious surface aggregation. Pearson correlation analysis revealed significant positive correlations ($p < 0.05$) between soil physicochemical factors and ciliate species/individual numbers, particularly with total nitrogen (TN) and organic matter. (4) Comprehensive analysis indicated that the primary factors influencing soil ciliate community structure changes across different slopes in the Gansu alpine meadow were TN, soil organic matter conditions, and above-ground vegetation status.

Keywords: alpine meadow; southern Gansu; slope aspect; soil ciliates; community diversity

Introduction

Soil ecosystems serve as the foundation for all terrestrial life and represent one of the most important natural resources for human survival [1]. Soil ciliates

are essential components of soil ecosystems, occupying a critical position in the soil microbial food chain and participating directly or indirectly in the decomposition of soil organic matter. They play significant roles in energy flow and material cycling within soil ecosystems. Therefore, elucidating the relationships between soil fauna and environmental factors is crucial for understanding the operational mechanisms of soil ecosystems [2]. Ciliates are unicellular protozoa characterized by small body size, large surface-area-to-volume ratios, rapid reproduction, and high sensitivity to environmental changes, making them valuable bioindicators for monitoring and predicting soil environmental changes [3].

Research on soil ciliate species diversity in China began relatively late, with representative works by Shen et al. [4], Song et al. [5], and Ning et al. [6-12]. However, few of these studies focused on subalpine meadow regions. For Gannan Prefecture, located on the eastern edge of the Qinghai-Tibet Plateau with an extensive grassland area of 2.723×10^6 hm², no research has been reported on the relationship between soil ciliate community structure characteristics and soil factors across different slope aspects in subalpine meadows. This study investigates soil ciliates in different slope aspects of subalpine meadow ecosystems in Gannan during summer, aiming to identify soil ciliate species diversity and the relationships between communities and environmental factors in this region. The results will enrich baseline data on soil ciliate species composition and community characteristics under local microclimates in western China, provide a scientific basis for assessing subalpine meadow degradation and health, and support environmental protection, sustainable ecotourism development, and economic growth in the region.

1. Study Area Overview

The study area is located at the Lanzhou University Subalpine Meadow and Wetland Ecosystem Research Station in Hezuo City, Gannan Tibetan Autonomous Prefecture, Gansu Province, on the northeastern edge of the Qinghai-Tibet Plateau. The region features a cold temperate humid plateau climate. According to local meteorological data, the site (34.55°N, 102.53°E) has an elevation of 2900-3050 m, mean annual temperature of 2.4°C, mean annual precipitation of 557.8 mm (reaching up to 1200 mm), mean annual evaporation of 1290 mm, and a warm, humid July with temperatures of 17.7°C. The coldest month (January) averages -8.9°C. The soil type is subalpine meadow soil, and the vegetation type is subalpine meadow. Dominant plant species include *Kobresia humilis*, with secondary species such as *Astragalus polycladus*, *Potentilla fruticosa*, *Artemisia desertorum*, *Gueldenstaedtia verna*, and *Potentilla anserina*. Vegetation species richness and coverage increase gradually from sunny to shady slopes.

Environmental factors and vegetation characteristics across different slope aspects

2. Plot Setup and Sampling

The study site was established on a hillside with distinct sunny and shady aspects near the research station. Slope direction and angle were measured using an electronic compass, and five aspects were delineated: sunny, half-sunny, west, half-shady, and shady (Table 1). In mid-July 2015, a 10 m × 10 m plot was established in the middle section of each slope aspect, subdivided into five 5 m × 5 m subplots. Within each subplot, surface litter and stones were removed before sampling. Soil samples were collected using a 5 cm diameter soil auger following the plum blossom five-point method at three depths: 0–5, 5–15, and 15–25 cm. Five replicate samples were taken per depth, yielding 150 total samples (5 aspects × 3 depths × 5 replicates × 2 for backup). Soil temperature and moisture were measured concurrently. The west slope had relatively gentle topography compared to other aspects, with significant differences among slope aspects.

3. Laboratory Methods

3.1 Sample Cultivation and Identification

Fresh soil samples were homogenized in the laboratory, with roots and stones removed. The non-flooded petri dish method was employed, wherein soil extract was added to petri dishes to moisten the soil without submerging it. Soil was placed in 9 cm diameter petri dishes and cultured in a light incubator. Species observation and identification were performed using an optical microscope until no new species emerged. Each soil sample underwent multiple cultivations. Identification techniques included live observation and fixation staining, following methods by Yin et al. [17–18], Song et al. [15], Foissner [19], Wilbert [16], and Fernandez-Galiano [14]. Quantitative analysis employed direct counting methods [20].

3.2 Classification of Dominant Groups and Species

Identified taxonomic units and species were statistically analyzed following Foissner et al. [19]. The order with the most species was defined as the dominant group, the second most as the subdominant group, and monotypic orders as rare groups [21]. Species with the highest frequency and abundance were designated as dominant species.

3.3 Data Analysis

Community diversity indices were calculated using standard formulas: Shannon-Weiner index ($H = -\sum P \ln P$), Simpson dominance index ($D = \sum P^2$), and Pielou evenness index ($J = H / \ln S$), where S is the number of taxa, N is the total number of individuals, and N_i is the number of individuals of species i . All data were initially stored in Excel and analyzed using SPSS 18.0 and Origin 8.0.

2. Results and Analysis

2.1 Species Composition

During summer 2015, 142 ciliate species were identified in the Gannan subalpine meadow. Community structure analysis revealed Heterotrichea as the dominant class (28.17%), followed by Spirotrichea (19.72%), Litostomatea (13.38%), and Colpodea (12.68%).

2.2 Diversity Dynamics

Soil ciliate community diversity indices varied across slope aspects (Figure 1). Species and individual numbers increased initially then decreased from sunny to shady slopes, peaking on the west slope. Shannon diversity indices differed significantly among slope aspects in the surface soil layer (0-5 cm) ($F = 460.26$, $p < 0.01$), while Simpson ($F = 161.63$, $p < 0.01$) and Pielou ($F = 7.028$, $p < 0.05$) indices also showed significant variation. This indicates that slope aspect significantly affects summer soil ciliate community diversity in Gannan subalpine meadows. With increasing soil depth, Shannon, Simpson, and Pielou indices showed fluctuating patterns. No significant correlations were found between diversity indices and slope aspect changes in deeper layers ($p > 0.05$).

[Figure 1: see original paper] Dynamics of soil ciliate community diversity across slope aspects in the Gannan alpine meadow (Mean \pm SD)

2.3 Vertical Distribution Dynamics

Soil ciliate species and individual numbers generally decreased with soil depth, showing significant vertical distribution differences across slope aspects (Figure 2). Species numbers were highest on west slopes and lowest on shady slopes in the 0-5 cm layer, with no significant differences between 5-15 cm and 15-25 cm layers. Individual numbers followed the same pattern. Two-way ANOVA revealed significant differences in species and individual numbers among slope aspects within the same soil layer ($p < 0.01$). Further correlation analysis showed that species and individual numbers were significantly correlated with soil organic matter and total nitrogen ($p < 0.05$), but not with soil temperature, slope angle, or light intensity ($p > 0.05$). The factors influencing vertical distribution may be organic matter and total nitrogen content, though specific mechanisms require further investigation.

[Figure 2: see original paper] Changes in vertical distribution of soil ciliates across slope aspects in the Gannan alpine meadow (Mean \pm SD)

2.4 Correlations Between Community Parameters and Environmental Factors

Pearson correlation analysis between ciliate community parameters and environmental factors revealed significant positive correlations ($p < 0.05$) between

species numbers, individual numbers, and SOC, TN in the surface soil layer (Table 2). This indicates that soil physicochemical factors strongly influence ciliate community structure across different slope aspects in Gannan subalpine meadows during summer.

Correlation analysis between structural parameters of ciliate communities and soil factors

2.5 Relationship Between Vegetation and Ciliate Communities

Ciliate species and individual numbers were closely related to local vegetation conditions across slope aspects (Figure 3). As plant richness and coverage increased from sunny to shady slopes, ciliate species and individual numbers initially increased then decreased, reaching maxima between half-sunny and west slopes, with west slopes approaching the peak. The fitted curve equations demonstrated that west slopes represent the most suitable habitat for ciliates. Within the same region, ciliate species diversity generally corresponded with vegetation richness, and as vegetation coverage increased, ciliate diversity also increased.

[Figure 3: see original paper] Relationship between vegetation characteristics and ciliate species/individual numbers across slope aspects

3. Discussion

3.1 Effects of Slope Aspect on Soil Ciliate Communities

Our results demonstrate that soil ciliate community composition changes significantly with slope aspect. The west slope supported the highest species and individual numbers, followed by half-sunny slopes. ANOVA confirmed significant differences in species and individual numbers across slope aspects ($p < 0.01$), indicating that slope aspect significantly influences summer soil ciliate community diversity in Gannan subalpine meadows. Correlation analysis revealed significant positive correlations between ciliate species/individual numbers and organic matter and total nitrogen ($p < 0.05$). These findings align with previous research showing that soil fauna density correlates negatively with soil bulk density but positively with organic matter, phosphorus, and potassium content [25-26]. The study area's local microclimate results in minimal differences in climatic factors across slopes, making soil physicochemical properties and vegetation more influential. Higher plant diversity and coverage increase surface litter and soil nutrient content, thereby enhancing ciliate diversity [27-28]. Although half-shady and shady slopes had high vegetation species richness and coverage, excessive soil moisture likely limited ciliate diversity by inhibiting populations, similar to findings that high moisture suppresses nematodes [29-32].

3.2 Vertical Distribution Dynamics Across Slope Aspects

Soil ciliate species and individual numbers in the Gannan subalpine meadow ecosystem exhibited surface aggregation characteristics, with aggregation degree paralleling species/individual abundance trends. Previous studies indicate that soil fauna vertical distribution is generally influenced by soil physicochemical properties and nutrient status [33]. The 0-10 cm soil layer represents the primary root distribution zone, where vegetation structure and soil properties determine relative stability in vertical distribution [34-35]. Research also shows that temperature variations can affect vertical distribution of meso- and micro-soil fauna in grassland ecosystems [36]. Our findings that vertical distribution of ciliates across slope aspects is influenced by organic matter and total nitrogen are consistent with these studies, though specific mechanisms warrant further investigation.

3.3 Comparison of Diversity Indices Across Slope Aspects

Ciliate species diversity indices did not consistently align with species richness or individual numbers. Correlation analysis revealed no significant positive relationships between diversity indices and evenness or dominance indices. Shannon diversity and evenness indices showed significant positive correlations with temperature ($p < 0.05$), while Simpson dominance index correlated negatively with evenness. These patterns may result from exposed ground surfaces on sunny slopes where water retention is poor, combined with shallow soils underlain by rock that limit ciliate habitats. Additionally, calculation of diversity indices may be affected by the taxonomic resolution of ciliate classification. The inconsistent patterns likely reflect both environmental constraints and methodological considerations in diversity measurement.

References

[1] [2] [3] [4] [5] [6] [7] [8] [9] [13] [14] [16] [17] [18] [19] [20] [21] [22] [23] [24] [25] [26] [27] [28] [29] [30] [31] [32] [33] [34] [35] [36] [37]

Note: The reference list contains both Chinese and English sources as cited throughout the text, including works by Shen et al., Song et al., Ning et al., Foissner, Fernandez-Galiano, Wilbert, Yin et al., and others.

Note: Figure translations are in progress. See original paper for figures.

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