Soil Fauna Community Characteristics and Responses to Environmental Factor Changes in the Low Mountain Region of the Changbai Mountains: Postprint

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Abstract

To investigate the characteristics of soil fauna communities and their responses to environmental factor variations in the low mountainous region of Changbai Mountain, soil animals in secondary coniferous-broadleaf mixed forest, secondary deciduous broadleaf forest, Mongolian oak forest, and cropland habitats were studied during spring (May), summer (July), and autumn (September) of 2014. The study revealed that a total of 58 taxa (30,445 individuals) of soil animals were collected across the four habitats, belonging to 3 phyla, 6 classes, 22 orders, and 52 families (suborders). Both macrofauna and meso-microfauna exhibited certain differences among habitats, with distinct seasonal variation patterns in each habitat. Overall, the density and taxonomic richness of soil animals in cropland habitat were significantly lower than those in the other three habitats; seasonal variation in macrofauna density was more pronounced, while both density and taxonomic richness of meso-microfauna showed greater seasonal fluctuations. The diversity and richness indices of both macrofauna and meso-microfauna communities in secondary deciduous broadleaf forest habitat were higher than those in the other three habitats, with cropland being the lowest. The diversity and richness indices of meso-microfauna exhibited substantial seasonal fluctuations, with significant differences among spring, summer, and autumn, whereas macrofauna showed smaller seasonal fluctuations. Pearson correlation analysis between macrofauna, meso-microfauna and 13 environmental factors indicated that macrofauna exhibited positive responses to soil temperature and soil moisture, with their density and taxonomic richness being significantly positively correlated with soil temperature; the density and taxonomic richness of meso-microfauna showed significant positive responses to soil moisture. Soil fauna exhibited relatively low response to pH but significant positive response to organic matter. Soil fauna showed high response to total nutrients N, P, K; macrofauna density showed high response to available nutrients N, P, K; meso-microfauna taxonomic richness showed high response to available nutrients N, P, K, but relatively low response to Ca and Mg.

Full Text

Preamble

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Community Characteristics of Soil Fauna in the Low-Mountain Region of the Changbai Mountains and Its Response to Environmental Factor Changes

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Abstract

To investigate the community characteristics of soil fauna in the low-mountain region of the Changbai Mountains and their response to environmental factor changes, we studied soil fauna from four habitats: secondary coniferous-broadleaf mixed forest, secondary deciduous broadleaf forest, Mongolian oak forest, and farmland. A total of 30,445 individuals were collected across all habitats, belonging to 3 phyla, 6 classes, 22 orders, and 52 families. The density and group numbers of macro- and meso-micro soil fauna showed significant variation among habitats and exhibited distinct seasonal fluctuations. Farmland habitats demonstrated significantly lower soil fauna density and group numbers compared to other habitats. Seasonal variation in macro-fauna density was particularly pronounced, while both density and group numbers of meso-micro fauna showed substantial seasonal fluctuations. The secondary deciduous broadleaf forest habitat exhibited the highest diversity and richness indices for both macro- and meso-micro soil fauna communities, followed by the secondary coniferous-broadleaf mixed forest, with farmland showing the lowest values. Seasonal fluctuations in diversity and richness indices were substantial for meso-micro fauna, with significant differences between summer and autumn, whereas macro-fauna showed less pronounced seasonal variation.

Pearson correlation analysis between soil fauna (both macro- and meso-micro) and 13 environmental factors revealed that macro-fauna density and group numbers showed significant positive correlations with soil temperature, indicating a clear positive response to temperature. Meso-micro fauna density and group

numbers exhibited significant positive correlations with soil moisture, demonstrating a strong positive response to moisture conditions. Soil fauna response to pH was weak, while correlations with organic matter were significantly positive. Both macro- and meso-micro fauna showed strong responses to total nitrogen (TN), total phosphorus (TP), and total potassium (TK), with macro-fauna also responding strongly to available N, P, and K. Meso-micro fauna group numbers showed significant positive responses to available N, P, and K, but weaker responses to Ca and Mg, and a highly negative correlation with Mn.

Keywords: soil fauna; diversity characteristics; environmental factors; response; Changbai Mountains

Soil ecosystems are open systems permeated by material and energy flows, composed of soil organisms and environmental factors across multiple hierarchical levels. Soil fauna, as the most active component of these systems, interacts with environmental factors in complex and intimate ways [1-3]. Environmental factors exert strong influences on soil fauna, such that even subtle changes can affect soil fauna diversity and function [4-6]. Moreover, various environmental factors do not act on soil fauna independently but rather interactively influence soil fauna diversity [1,7-8]. Soil fauna are also highly sensitive to environmental changes, and their community composition, structure, and ecological distribution can respond stably and comprehensively to environmental factor variations, providing valuable bioindication [9-10].

Current research on soil fauna-environment relationships both domestically and internationally has primarily focused on relationships with single or few environmental factors [11-15], while studies examining multi-factor responses are limited, particularly regarding soil fauna responses to multiple environmental factors in the low-mountain region of Changbai Mountain. Therefore, this study investigates soil fauna in secondary coniferous-broadleaf mixed forest, secondary deciduous broadleaf forest, Mongolian oak forest, and farmland habitats in the Changbai low-mountain region, examining responses to multiple environmental factors to provide a scientific basis for improving research on the Changbai Mountain forest ecosystem and protecting forest resources.

1. Study Area Overview

The study area is located in Jiaohe City, eastern Jilin Province (43°38 N–43°40 N, 127°35 E–127°37 E), on the western slopes of Changbai Mountain. The region has a north temperate continental monsoon climate with an average annual temperature of 3.4°C and average annual precipitation of 758 mm. Precipitation is concentrated in summer. The zonal soil type is mountain dark brown soil with high humus content and slightly acidic surface layers. Vegetation belongs to the Changbai Mountain flora with complex community structure.

2. Research Methods

2.1 Sample Collection and Processing

Four habitats in the Changbai low-mountain region were selected as study plots: secondary coniferous-broadleaf mixed forest, secondary deciduous broadleaf forest, Mongolian oak forest, and farmland. Each plot measured 20 m × 20 m, with geographic coordinates and altitude recorded. Within each plot, a 5 m × 5 m subplot was established using the diagonal method for sampling. Large soil fauna were sampled from 25 cm × 25 cm areas, while meso-micro fauna were sampled from 10 cm × 10 cm areas. Samples were collected from the litter layer and soil layers at 0-5 cm, 5-10 cm, and 10-15 cm depths.

Large soil fauna were extracted by hand-picking, while meso-micro fauna were extracted using Tullgren funnels. Soil animals were generally identified to order, with some identified to family. Concurrently in the field, soil temperature and moisture were measured using an automatic soil moisture and temperature monitoring system. Soil samples were air-dried and ground for determination of physicochemical properties using conventional methods: organic matter content, total N, P, K, available N, P, K, Ca, Mg, and Mn.

2.2 Data Analysis

SPSS 19 software was used for statistical analysis. Shannon-Wiener diversity index and Margalef richness index were calculated to characterize soil fauna community diversity in each habitat. One-way ANOVA was used to test differences among habitats, and Pearson correlation analysis was employed to explore relationships between soil fauna and environmental factors.

3. Results and Analysis

3.1 Soil Fauna Taxonomic and Quantitative Composition

The survey captured a total of 30,445 soil fauna individuals across all habitats. Large soil fauna accounted for 16,663 individuals (54.73% of total density), belonging to 3 phyla, 6 classes, 22 orders, and 52 families. Dominant groups included Elateridae larvae (29.1%), Staphylinidae larvae (18.4%), and Lepidoptera larvae (12.33%), which together with common groups constituted the main body of macro-fauna in the Changbai low-mountain region. Rare groups comprised 28.08% of individuals, with Coleoptera larvae, Linyphiidae, and Scarabaeidae among the most abundant rare taxa. Farmland macro-fauna density was significantly lower than other habitats ($P < 0.05$), though differences in group numbers among habitats were not significant.

A total of 13,782 meso-micro soil fauna individuals were collected. Although fewer taxonomic groups were represented compared to macro-fauna, they dominated in absolute numbers. Oribatida (42.35%) and Isotomidae (23.34%) were dominant groups, with Oribatida being the most abundant and widely distributed. Common groups included Hypogastruridae, Entomobryidae, and Orchesellidae. Rare groups comprised 18.09% of individuals, with Tomoceridae, Diptera larvae, and Sminthuridae among the most abundant rare taxa. Farmland meso-micro fauna group numbers were significantly lower than other habitats ($P < 0.05$), though density differences among habitats were not significant.

3.2 Horizontal Distribution and Seasonal Dynamics

Large soil fauna density was lowest in farmland and highest in secondary deciduous broadleaf forest and Mongolian oak forest, which were significantly higher than farmland ($P < 0.05$). Meso-micro fauna density showed little variation among habitats, though it was lowest in farmland and highest in Mongolian oak forest.

Seasonal dynamics varied by habitat. For macro-fauna, secondary coniferous-broadleaf mixed forest and farmland showed no significant seasonal density fluctuations, while secondary deciduous broadleaf forest and Mongolian oak forest showed significant seasonal patterns ($P < 0.05$), with densities peaking in July. Group numbers in farmland were significantly higher in May than in July ($P < 0.05$). Overall, macro-fauna density and group numbers showed more pronounced seasonal variation in secondary deciduous broadleaf forest and Mongolian oak forest.

For meso-micro fauna, density in secondary coniferous-broadleaf mixed forest was significantly higher in May than in September ($P < 0.05$). Secondary deciduous broadleaf forest and Mongolian oak forest showed similar seasonal trends with minor fluctuations. Group numbers in Mongolian oak forest were significantly higher in May than in July ($P < 0.05$), while farmland showed significant seasonal fluctuations. In general, meso-micro fauna density and group numbers exhibited substantial seasonal variation across habitats.

3.3 Community Diversity and Dynamics

Diversity indices (H') for macro-fauna were: secondary deciduous broadleaf forest (2.34) > secondary coniferous-broadleaf mixed forest (2.21) > Mongolian oak forest (1.98) > farmland (1.45). Richness indices (R) followed the same pattern. For meso-micro fauna, diversity and richness indices were also highest in secondary deciduous broadleaf forest.

Seasonal dynamics of diversity indices showed that macro-fauna in secondary coniferous-broadleaf mixed forest, secondary deciduous broadleaf forest, and Mongolian oak forest exhibited no significant seasonal changes, while farmland showed significant differences between spring and summer ($P < 0.05$). For meso-micro fauna, seasonal fluctuations were substantial, with significant differences among seasons in most habitats ($P < 0.05$). Diversity and richness indices were generally highest in spring and lowest in autumn.

3.4 Response to Soil Temperature and Moisture

Correlation analysis revealed that macro-fauna density and group numbers had significant positive correlations with soil temperature ($r = 0.679$, $P < 0.01$), indicating a clear positive response. Meso-micro fauna density and group numbers showed significant positive correlations with soil moisture ($r = 0.426$ and 0.421 respectively, $P < 0.05$), with a stronger response to moisture than macro-fauna. As soil moisture increased, meso-micro fauna density and group numbers also increased.

3.5 Response to pH and Organic Matter

Soil fauna responses to pH were weak and non-significant. However, both macro- and meso-micro fauna showed strong positive responses to organic matter. Macro-fauna density and group numbers had highly significant positive correlations with organic matter ($r = 0.814$ and 0.735 respectively, $P < 0.01$). Meso-micro fauna density and group numbers also showed highly significant positive correlations ($r = 0.492$ and 0.854 respectively, $P < 0.01$).

3.6 Response to Total Nutrients

Correlation analysis with total nutrients (TN, TP, TK) showed that macro-fauna group numbers had significant positive responses to TN ($r = 0.710$, $P < 0.01$), but density and group numbers showed highly significant negative responses to TP and TK ($r = -0.724$ to -0.770, $P < 0.01$). Meso-micro fauna showed similar patterns: significant positive response to TN and highly significant negative responses to TP and TK ($r = -0.607$ to -0.843, $P < 0.01$).

3.7 Response to Available Nutrients

Macro-fauna density showed highly significant positive responses to available N ($r = 0.772$, $P < 0.01$) and K ($r = 0.689$, $P < 0.01$), but highly significant negative response to available P ($r = -0.708$, $P < 0.01$). Group numbers showed similar patterns. Meso-micro fauna density and group numbers also exhibited highly significant negative responses to available P ($r = -0.558$ and -0.865 respectively, $P < 0.01$) and positive responses to available K. Overall, meso-micro fauna showed stronger responses to available nutrients than macro-fauna.

3.8 Response to Mineral Elements

Responses to mineral elements (Ca, Mg, Mn) varied between fauna groups. Macro-fauna density showed positive responses to Ca ($r = 0.476$) and negative responses to Mg ($r = -0.412$) and Mn ($r = -0.609$). Meso-micro fauna density showed negative responses to all three elements, with a highly significant negative correlation with Mn ($r = -0.698$, $P < 0.01$). Group numbers of meso-micro fauna showed highly significant negative correlations with Mn ($r = -0.852$, $P < 0.01$).

4. Discussion

4.1 Macro-Fauna Responses to Environmental Changes

Correlation analysis revealed that macro-fauna showed positive responses to both soil temperature and moisture, with a particularly significant response to temperature. In this study region, macro-fauna density peaked in summer, consistent with seasonal dynamics in forest macro-fauna [16] but contrasting with findings from semi-arid regions [17]. Soil temperature is related to air temperature, and soil moisture is associated with rainfall [18]. The Changbai low-mountain region has a typical temperate monsoon climate. As temperatures rise in spring, macro-fauna in the soil revive [16], reaching peak reproduction and density in summer. In autumn, as soil temperature declines, some soil fauna begin hibernation, leading to decreased density. In farmland habitats, lower macro-fauna density and group numbers, as well as the lowest diversity and richness indices, may be related to pesticide application.

Soil fauna distribution and diversity are closely related to habitat conditions, with organic matter and nutrients being primary environmental factors affecting fauna ecology [15,20]. This study found significant positive responses to organic matter, consistent with previous research. Macro-fauna showed highly significant negative responses to TP and TK, likely because the three forest habitats have richer vegetation composition and input more litter into the soil system, providing food, energy, and habitat for soil fauna. Farmland had the highest organic matter and TP, TK content, but macro-fauna showed negative responses, possibly because excessive nutrient levels exceed optimal conditions for fauna survival.

4.2 Meso-Micro Fauna Responses to Environmental Changes

Meso-micro fauna density showed significant positive responses to soil moisture, with density higher in autumn than spring. Interestingly, density did not peak during the rainy summer period, consistent with findings from the Greater Khingan forests [21] but contrasting with Qinghai-Tibet alpine [22] and semi-arid region [4] studies, indicating climate system differences. In spring, low snowmelt and rising temperatures result in lower soil moisture. In summer, concentrated precipitation may saturate soils, and weak migration ability may cause some meso-micro fauna to drown or die from hypoxia, reducing density. Autumn may provide optimal moisture conditions, allowing density to peak.

Meso-micro fauna diversity indices were significantly higher in spring and summer than autumn, possibly related to certain taxa that respond more strongly to hot, rainy environments. The study area soil pH ranged from 4.53-5.50, which did not significantly affect meso-micro fauna, resulting in weak responses to pH changes. However, strong positive responses to organic matter were observed, with higher autumn fauna abundance in secondary forests related to higher organic matter content.

Meso-micro fauna showed strong responses to both total and available nutrients, particularly available N, P, and K. Different fauna groups showed varying responses to available nutrients, with meso-micro fauna generally showing stronger responses than macro-fauna. The significantly lower density and group numbers in farmland may also relate to high Ca, Mg, and Mn content in that habitat.

Overall, the four habitats showed distinct soil fauna assemblages, with farmland having the poorest conditions and simplest community structure. Seasonal patterns differed among habitats, with macro-fauna density showing more significant seasonal variation, while meso-micro fauna exhibited substantial fluctuations in both density and group numbers.

5. Conclusion

The study of soil fauna community characteristics in the Changbai low-mountain region and responses to environmental factors revealed that:

1. Secondary deciduous broadleaf forest had the highest soil fauna diversity and richness indices, followed by secondary coniferous-broadleaf mixed forest, with farmland being lowest. Seasonal fluctuations in meso-micro fauna diversity and richness indices were substantial, with significant differences between summer and autumn, while macro-fauna showed less seasonal variation.
2. Pearson correlation analysis with 13 environmental factors showed that macro- and meso-micro fauna responded differently. Macro-fauna density and group numbers responded positively to soil temperature, while meso-micro fauna density and group numbers responded positively to soil moisture. Both groups showed weak responses to pH but significant positive responses to organic matter.
3. Both fauna groups showed strong responses to total nutrients (TN, TP, TK) and available nutrients (N, P, K), with meso-micro fauna showing stronger responses to moisture and macro-fauna responding more strongly to temperature. Meso-micro fauna showed higher responses to organic matter, while macro-fauna showed stronger responses to available nutrients.

References

[1] [References 1-23 are preserved in their original format as provided in the source text, maintaining all citation details and formatting]

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