Responses of Soil Macrofaunal Community and Diversity under Different Types of Vegetation on Soil Nutrient Pools in winter in Emei Mountain, China

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Abstract. To study its community characteristics under different types of vegetation in winter, soil macro fauna were collected and identified by hand picking in Emei Mountain in December, 2016. Soil nutrient pools and the amounts of microbial biomass were measured, and the diversity indices of soil macro fauna were calculated. We identified 667 soil macro fauna individuals belonging to 26 orders, 11 classes, and 4 phyla. The highest values of the Pielou (J) and Shannon-Wiener (H') diversity indices were established in the 0–5 cm soil layer of the evergreen broad-leaved forest (2.22 and 0.76, respectively). The lowest values these indices had in the 5–10 cm soil layer of the coniferous and broad-leaved mixed forest (0.51 and 0.17, respectively). The correlation analysis results showed that the numbers of soil macro fauna group were significantly correlated to soil temperature and MBC contents, and the number of soil macro fauna individuals was significantly correlated with soil water content. Therefore, vegetation type and soil microbial dynamics have a strong effect on the diversity of soil macro fauna communities, which further affect the soil nutrient cycle and ecological processes.

1. Introduction

The study of soil ecological processes is the frontier of biological research in the 21 st century. Soil fauna exerts essential functions in soil ecological processes. The species, size, way of life, and the relationships of soil fauna with soil nutrients affects many important processes in the soil, such as soil organic matter decomposition, nutrient cycling, and soil structure. Therefore, the studies on the taxonomic structure and diversity of soil animals are of substantial practical importance.

Vegetation not only affects soil nutrient changes and material cycling, but also leads to changes in soil ecological environment, which inevitably influences the structure and function of soil animals [1]. The research on soil fauna composition and dynamics under different vegetation types is scarce and limited mainly to examinations of the effects of a single type of vegetation [2-3]. Moreover, the growing season changes have been predominantly investigated, whereas studies on the non-growing season are extremely rare [4].

Investigations of soil ecology during the growing season are commonly performed in alpine ecology research, but the understanding of soil ecological processes in cold and long winters is

insufficient. However, increasingly more studies have revealed that the life processes in winter and even in the ice and snow environments are still vigorous, in which soil animals play an irreplaceable role [5]. Mount Emei is located on the southwest edge of the Sichuan Basin in China. The East and the North of Mount Emei approach the West Sichuan Plain, and the West and South are connected through the Qinghai Tibet Plateau. The vegetation types in Mount Emei are highly diverse. In this study, the effects of community structure and diversity characteristics of soil macro fauna on soil ecological processes in typical vegetation types in Mount Emei were explored in winter.

2. Study area and study methods

2.1. General information of study area
Mount Emei (3,099 m above sea level) is located in the humid subtropical monsoon climate zone in Sichuan Province, China. The average annual rainfall in Mount Emei is approximately 1,480.5 mm, and the annual relative humidity is about 80%. Different vegetation types are present in Mount Emei has at different altitudes that can be divided into four typical vegetation zones: broad-leaved evergreen forest (0– 1,500 m), evergreen and deciduous broad-leaved mixed forest (1,500– 2,100 m), coniferous and broad-leaved mixed forest (2,100–2,800 m), and boreal coniferous forest (2, 800–3,099 m) [6]. The soil freezing period in winter is about 120 d in the high altitude area, and the soil freezing depth is up to 20–30 cm.

2.2. Plot setting and sample collection
In December 2016, two replicate plots were set in the four typical vegetation belts in Mount Emei. The size of the plots was 20 m × 20 m (each 2 plots in Broad-leaved evergreen forest, Evergreen and deciduous broad-leaved mixed forest, Coniferous and broad-leaved mixed forest, and boreal coniferous forest). Next, three sampling points were set randomly at more than 5 m apart in each of the soil plots. Soil macro fauna individuals with a body length greater than 2 mm in an area of 0.5 m × 0.5 m were collected by hand-picking in different soil layers (0–5 cm, 5–10 cm, and 10–15 cm). Each of the collected soil macro fauna specimens was placed in a centrifuge tube which contained 75% alcohol and was transferred to the laboratory for identification. In addition, soil samples were collected by a soil sampler and their contents of soil organic matter (OM), ammonium nitrogen (NH_4^+-N), nitrate nitrogen (NO_3-N), total nitrogen (TN), total phosphorus (TP), total potassium (TK), microbial biomass carbon (MBC), and microbial biomass nitrogen (MBN) were determined.

2.3. Determination method
The classification and counting of soil macro fauna were conducted by a stereoscopic microscope [7]. Soil temperature and soil water content at a soil depth of 5 cm were measured by a portable soil temperature and humidity detector. NH_4^+-N and NO_3^--N contents were analyzed by indophenol blue colorimetry and ultraviolet spectrophotometry, respectively. MBC and MBN contents were determined by the chloroform-fumigation direct-extraction (CFE) technique. The OM, TN, TP, and TK contents were analyzed by the acid-dichromate oxidation method, the semi-micro Kjeldahl method, ammonium moly date spectrophotometry and flame photometry, respectively [8-9].

2.4. Data processing and analysis
The formulas for the calculation of community diversity indices (*H′*, *J, C*) are as Tan [10].

Microsoft Excel 2010 was used for data processing, and one-way ANOVA was conducted by SPSS 13.0. Values of $p < 0.05$ were considered statistically significant.

3. Results and analysis

3.1. Soil temperature and soil water content

Different values of the soil temperature were measured under different vegetation types, which, in general, decreased gradually with elevation. The soil temperature of the temperate coniferous forest (-0.12°C) with the highest elevation was the lowest (at 5 cm below the ground level), whereas the soil temperature of the evergreen broad-leaved forest belt with the lowest elevation was the highest (6.38°C). The soil water content showed an irregular trend with elevation increase. The soil water content of the evergreen and deciduous broad-leaved mixed forest at an intermediate altitude was the highest, reaching 24.52%, whereas in the high altitude of the coniferous forest, the the water content of the soil (11.82%) was the lowest (Figure 1).
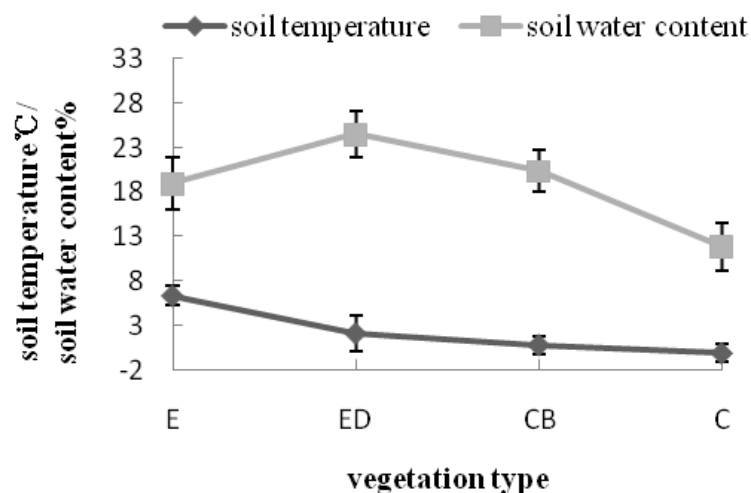

Figure 1. Soil temperature and soil water content under different vegetation types. "E" denotes broad-leaved evergreen forests; "ED" evergreen and deciduous broad-leaved mixed forests; "CB" coniferous and broad-leaved mixed forests; "C" stands for boreal coniferous forest. The same legend has been used in the text and figures below.

3.2. Soil nutrient pools and microbial biomass

As can be seen from Fig. 2, soil TN and MBC contents have the same change trend, exhibiting a gradual increase with altitude elevation. The results of ANOVA analysis showed that the impact of vegetation type on soil TN and MBC contents had reached significant levels ($P_{TN} = 0.008$, $P_{MBC} = 0.003$). The soil TK content showed a trend of irregular change and was the highest in the evergreen and deciduous broad-leaved mixed forests, reaching 30.300 g/kg, which was significantly higher than those of the other vegetation types ($p = 0.002$). The TP content changed slightly, and no significant differences were observed among the four vegetation types ($p = 0.137$). The contents of NH_4^+-N and OM reached their maximum levels under the coniferous and broad-leaved mixed forests, 10.8717 and 166.1333g/kg, respectively, and both reached a statistically significant level ($P_{NH4+-N} = 0.000$, $P_{OM} = 0.035$). The MBN and NO_3-N contents did not change regularly with the change of the vegetation types, and no significant difference was found ($P_{MBN} = 0.133$, $P_{NO3-N} = 0.334$).
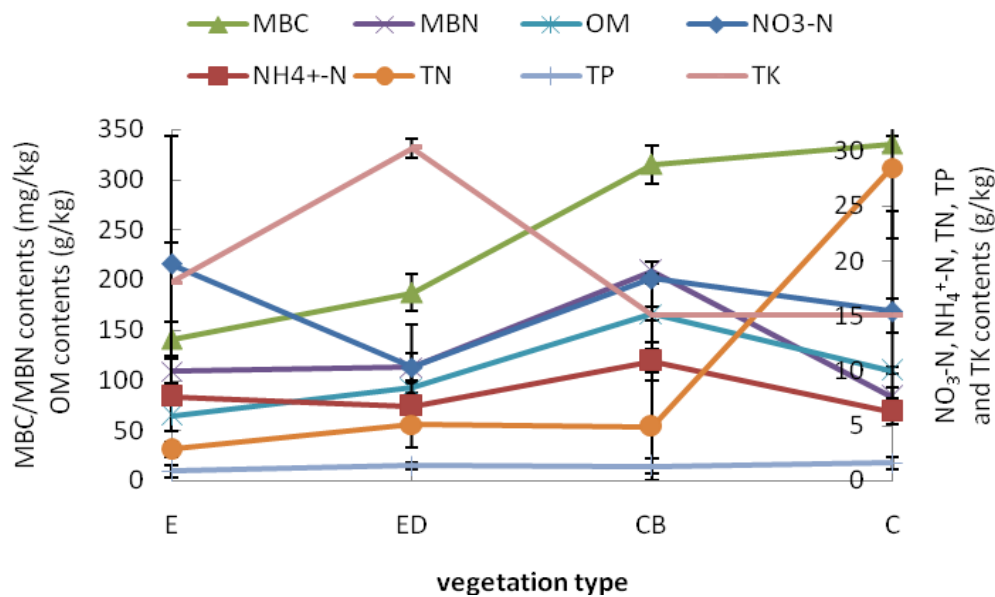
Figure 2. Soil nutrient pools and microbial biomass under different vegetation types.

3.3. Soil macro fauna composition

A total of 667 soil macro fauna individuals were found in the four vegetation belts of Emei Mountain in winter, which belonged to 4 phyla, 11 classes, and 26 orders. There were 132 soil macro fauna individuals in the evergreen broad-leaved forests, belonging to 4 phyla, 9 classes, and 19 orders. The number of soil macro fauna representatives was the largest (58) in the 0–5 cm soil layer and decreased gradually with the increase of soil depth. Nematodes and collembolan adults were the dominant groups in the evergreen broad-leaved forests, accounting for 40% and 13%, respectively. A total of 204 soil macro fauna individuals were identified in the evergreen and deciduous broad-leaved mixed forest, belonging to 3 phyla, 9 classes, and 19 orders. In the 0–5 cm soil layer, the group number of soil macro fauna representatives was 13 and that of the individuals was 113, both of which decreased with the increase of soil depth. The numbers of Sinentomata (Protura) adults were predominant in the evergreen and deciduous broad-leaved mixed forest, accounting for 28%. The adults of Enchytraeidae (Oligochaeta, Microdrileoligochaetes), larvae of Diptera (Insecta), and larvae of Oniscomorpha (Diplopoda) were the dominant groups, accounting for 16%, 13%, and 18% respectively. The number of soil micro-fauna individuals detected in the coniferous and broad-leaved mixed forest was 214, which belonged to 3 phyla, 6 classes, and 7 orders. The number of soil micro-fauna representatives showed no regularity with the change of soil depth, and the most of them were found in the 5–10 cm soil layer, reaching 104. Geophilomorpha (Chiropody) adults and Diptera (Insecta) larvae were the dominant groups in the coniferous and broad-leaved mixed forest, accounting for 47% and 37%, correspondingly. A total of 117 soil macro fauna individuals were found in the boreal coniferous forest, belonging to 2 phyla, 6 classes, and 7 orders, which were detected mostly in the 5–10 cm soil layer, where their number reached 83. The larvae of Diptera (Insecta) were absolutely dominant in the boreal coniferous forest, accounting for 68% (Table 1, Fig. 3).

Table 1. Composition of the soil macro fauna in Emei Mountain in winter.

Soil macrofauna group	Broad-leaved evergreen forests	Evergreen and deciduous broad-leaved mixed forests	Coniferous and broad-leaved mixed forest	Boreal coniferous forest
Nematoda	+++	+	++	-
Chilopoda, Lithobiomorpha	++	+	-	-
Chilopoda, Geophilomorpha	++	++	+++	++
Chilopoda, Scutigeromorpha	-	+	-	-
Chilopoda, Scolopendromorpha	+	-	-	-
Diplopoda, Oniscomorpha	-	++	-	-
Diplopoda, Oniscomorpha (Larva)	-	+++	-	-
Diplopoda, Julida	++	++	-	-
Diplopoda, Sphaerotheriida	++	-	-	-
Gastropoda, Pulmonata, Stylommatophora	+	-	-	+
Symphyla, Scolopendrellidae	++	-	-	-
Protura, Sinentomata	++	+++	-	-
Protura, Eosentomata	-	-	+	+++
Malacostraca, Isopoda	++	+	-	-
Malacostraca, Amphipoda	+	-	-	-
Oligochaeta, Microdrileoligochaetes, Enchytraeidae	++	+++	++	-
Oligochaeta, Megadrileoligochaetes, Lumbricida	+	+	-	++
Insecta, Diptera (Larva)	++	+++	+++	+++
Insecta, Coleoptera (Larva)	++	++	+	++
Insecta, Collembola	+++	++	-	-
Insecta, Homoptera (Larva)	+	-	-	-
Insecta, Hymenoptera	++	+	++	-
Insecta, Deramptera	-	+	-	-
Insecta, Lepidoptera (Larva)	+	+	-	-
Arachnida, Pseudoscorpiones	-	-	++	-
Arachnida, Araneae	-	+	-	+
Hirudinea, Rhynchobdellida	-	++	-	-
Hirudinea, Arhynchobdellida	-	-	-	+

Note [6]: "+++" dominant species (>10%), "++" common species (1%–10%), "+" rare species (<1%), "-" not found
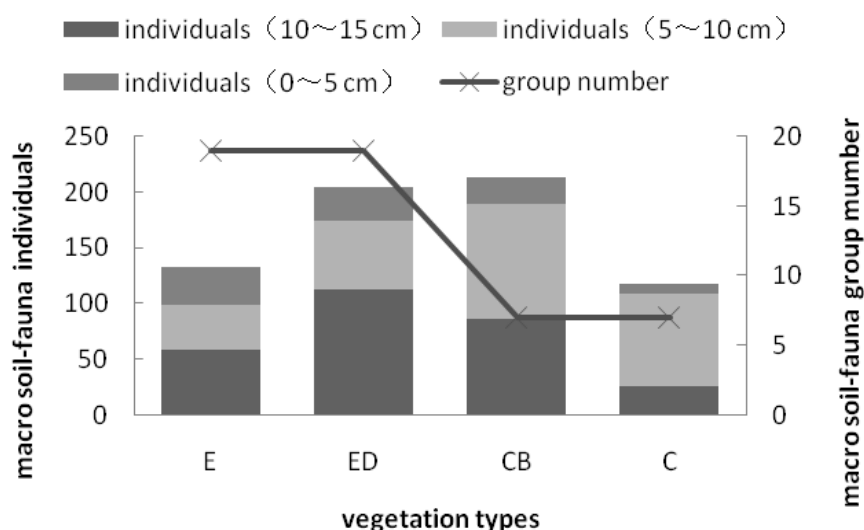
Figure 3. Number of soil macro fauna groups and individuals under different vegetation types in Emei Mountain in winter.

3.4. Soil macro fauna diversity indices

The three diversity indices (H', J, and C) characterizing the soil macro fauna in the four typical vegetation types of Emei Mountain showed a regular dynamic change in winter (Fig. 4). The H' index was the highest in the evergreen broad-leaved forest, followed by that in the evergreen and deciduous broad-leaved mixed forest, and was the lowest in the coniferous and broad-leaved mixed forest and the boreal coniferous forest. In addition to the boreal coniferous forest, the H' indices of the other three vegetation belts were the highest in the 0–5 cm soil layer. The J index showed a trend similar to that of the H' index. The C indices of the coniferous broad-leaved mixed forest belt and the boreal coniferous forest belts were the highest, especially in the 5–10 cm soil layer; whereas it had the lowest values in the evergreen broad-leaved forest, especially in the 0–5 cm and the 10–15 cm soil layers. The results of the multiple comparison tests showed that the three diversity indices of soil macro fauna were affected by the different vegetation types, and this effect was statistically significant in the 0–5 cm soil layer ($p < 0.05$).
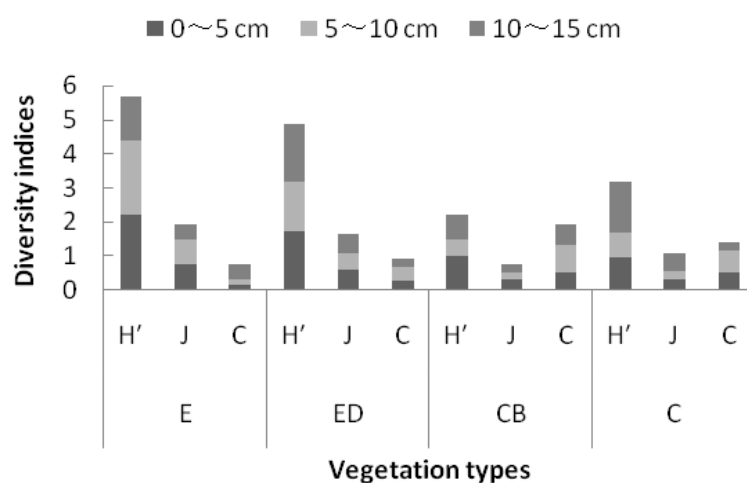

Figure 4. Diversity indices of the soil macro fauna under different vegetation types in Emei Mountain in winter. "H'" denotes the Shannon-Wiener diversity index; "J" the Pielou index; and "C" the Simpson diversity index.

3.5. Correlation analysis results of soil nutrient and soil macro fauna

The results of the analysis of the correlation between the soil nutrient levels and soil macro fauna changes showed that the numbers of soil macro fauna groups were highly significantly correlated with the soil MBC contents, and were significantly correlated with soil temperature. The correlation coefficient between soil macro fauna individuals and soil water content was 0.6465, reaching a statistically significant level (Table 2).

Table 2. Correlation analysis results of soil nutrient pools, microbial biomass, and soil macro fauna under different vegetation types.

Soil macro fauna	OM	Soil temperature	Soil water content	TN	TP	TK	MBC	MBN	NO$_3$-N	NH$_4^+$-N	C/N
Group numbers	-0.3411	0.6168*	0.3793	-0.3668	0.3993	0.5255	-0.9537**	0.1361	0.0671	-0.1449	0.0056
Individuals	0.3203	0.0541	0.6465*	-0.3692	0.0066	0.186	0.0004	0.5644	0.1037	0.3751	0.4965

Note: "**"$P < 0.01$, "*"$P < 0.05$

4. Discussion

Macro fauna is a group of animals that exert important effects on the dynamics of soil organic matter and litter decomposition process [11]. In several previous examinations [12-15], soil fauna was found to be one of the essential soil features that can be used for evaluation of its quality and health as the abundance and biology of macro-fauna individuals can be affected by various biotic and abiotic factors.

Abiotic factors refer mainly to the habitat ecological conditions in which plants survive, including temperature, moisture, soil nutrients, soil status, etc. [16-18]. Soil organisms have a lower activity and even enter a dormant state under the influence of low temperatures or soil freezing [10]. Moreover, a large number of studies have confirmed that soil animals migrate to deeper soil layers or trunks and overwinter in a larval form [19-21]. However, soil freezing substantially limits the survival of soil animals, and low numbers and taxa are maintained during the winter. In this study, the numbers of soil macro fauna species under different vegetation types varied significantly: they were higher in the evergreen and deciduous broad-leaved mixed forests with a higher temperature and humidity, whereas their amounts were the lowest in the boreal coniferous forest, characterized by the lowest temperature, humidity, and freezing soil. Gongalsky et al. revealed that soil humidity was the most effective factor that influenced soil invertebrate abundance [21]. Jalilvand and Kooch also found a positive and significant correlation between soil abundance, macro fauna biomass, and some other soil features, such as temperature and moisture [20]. Habitats with warm and humid soil play an important role in return of nutrients to the soil and are more appropriate for the survival and growth of detritivore and macro fauna species [19].

Moreover, there is a significant negative link between the numbers of soil macro fauna groups and MBC content, indicating that lower MBC values cause an increase in their group numbers. Inconsistent with the findings of this study, a significant positive link between the number of worms and the amount of microbial biomass was found in several studies [22-23]. Previous investigations have been carried out in the growing season, when intense competition may be present between microorganisms and soil animals because of the lack of nutrients, resulting in a shift in this study. Soil carbon and nitrogen contents are considered major variables that determine soil fertility and have important impacts on the survival, growth, and composition of soil macro fauna communities [17-18, 24]. Jalilvand and Kooch claimed that there was an inverse correlation between earthworm abundance and carbon content [20]. The results of our study are not completely consistent with those of previous investigations. In the cold winter, the changes of soil temperature and humidity were large or regular under the different vegetation types in Mount Emei, whereas the changes of soil C, N, and other soil

nutrients were small or irregular. Therefore, the numbers of groups and individuals of soil animals were more related to the temperature and humidity, rather than to soil nutrients.

In general, because of the presence of abundant nutrients, sufficient litter, space, as well as proper ventilation and structure of the soil, the highest numbers of macro fauna individuals were detected at a depth of 0–10 cm, and their number and groups declined with the increase in soil depth [19, 22, 25]. Rahmani and Zare Maivan suggested that deeper in depth would cause less in identity indices [26]. A similar phenomenon was observed in the broad-leaved evergreen and deciduous broad-leaved mixed forests in this study. However, the surface soil layers of the coniferous and broad-leaved mixed forest and the boreal coniferous forest were frozen, and thus the numbers and diversity indices of soil macro fauna were both lower than those in the deeper soil layers. Soil freezing, which is accompanied by a decrease in soil temperature and humidity, causes the death and transfer of some soil animals, an effect that is more pronounced in surface soil.

Biological factors mainly refer to the effects of vegetation, whose complex processes lead to changes in soil biological, physical, and chemical characteristics, which in turn affects to some degree the communities and numbers of soil animals [19, 27-28]. Li et al. studied the community and diversity of soil animals in the vertical vegetation zones of Gongga Mountain, China [4]. These researchers found that the community composition, diversity, and functional structure of soil animals were obviously different from those of the four typical vegetation types: evergreen broad-leaved forest, deciduous broad-leaved forest, coniferous and broad-leaved mixed forest and dark coniferous forest. Consistent with previous results [29-30], this study also found that the vegetation types significantly affected the composition and number of soil macro fauna communities. The rich vegetation and high species diversity of the broad-leaved evergreen forest and the evergreen and deciduous broad-leaved mixed forest composed by species, such as *Cupressus funebris* Endl.*., Vitex negundo* L., and *Pinus massoniana* Lamb., was easy to use by soil animals. Hence, the numbers of soil macro fauna groups and individuals and diversity indices were exceedingly large. The boreal coniferous forest was dominated by *Abies*. The single vegetation and food, as well as the low food utilization rate, led to the lowest number and identity indices of soil macro fauna in the boreal coniferous forest. In winter, the dominant groups of soil macro fauna in Mount Emei varied under the different vegetation types. Collembola and Nematoda were the dominant animals in the evergreen broad-leaved forest, whereas Oniscomorpha (Larva), Sinentomata, Enchytraeidae, and Diptera (Larva) were prevalent in the evergreen and deciduous broad-leaved mixed forest. The representatives of Diptera (larvae) were the most abundant in both the coniferous and broad-leaved mixed forest and the boreal coniferous forest. These dominant taxa are the major soil macro fauna categories in the different vegetation belts in Mount Emei in winter, and they can play an extremely important role in the forest soil ecosystem processes during this period. On the other hand, the rest of the groups of soil macro-fauna may be more sensitive to the forest environment and can respond rapidly to the influence of the environmental factors. Only in certain periods or appropriate soil conditions, the numbers of soil macro fauna individuals can gradually increase, and they can become the dominant or common groups.

5. Conclusion

The results of this study indicate that soil macro fauna are still present in forest soils even in the cold winter. The changes in the vegetation type have a strong influence on soil macro fauna communities and significantly influence their structure and function, suggesting that the changes in soil macro faunal communities driven by the predominant type of vegetation may have important implications for understanding the ecological processes in forest soils in winter.

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