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ORIGINAL ARTICLE

Soil fauna effect on *Dryas octopetala* litter decomposition in an Alpine tundra of the Changbai Mountains, China

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Abstract

Soil fauna are critical for litter decomposition via physical fragmentation, chemical digestion, and changing activity of microorganisms, yet a few studies have been performed regarding the effects of soil fauna on alpine tundra litter decomposition. To better understand the effects of soil fauna on alpine tundra litter decomposition, we set up a litterbag experiment to determine the characteristics of the *Dryas octopetala* decomposition, and the diversity of the soil fauna in the litterbags, as well as the influence of the soil fauna on the decomposition in the tundra of the Changbai Mountains over a 36-month period. We found that the decomposition rate of the coarse mesh (2 mm) litterbags was faster than that of the fine mesh (0.01 mm) litterbags. The percentage of the mass lass of litter in the coarse mesh litterbags (2 mm) was 47.60%, while that in the fine mesh (0.01 mm) litterbags was 34.11% at the end of the experimental period (36th month of decomposition), and the contribution of soil fauna to the litter decomposition was confirmed to be 30.50%. The characteristics of litter decomposition exhibited some seasonal and annual differences. In addition, the diversity of the soil fauna in the litterbags was different during each of the years of the experiment. However, there were no significant differences observed during the same year. The effect of soil fauna on the litter decomposition was not obvious at the beginning of the experiment, and soil fauna contribution had a significant negative relationship with mass loss of litter. Our results provide experimental evidence that soil fauna can promote the decomposition of *Dryas octopetala* litter, but soil fauna contribution decreased with litter decomposition in the alpine tundra ecosystem.

Keywords Alpine tundra · *Dryas octopetala* · Soil fauna · Litter decomposition · Changbai Mountains

Introduction

Tundra environments are relatively harsh ecological systems, which are characterized by snow cover, short growing seasons, and low temperatures (Sistla et al. 2013). Therefore, tundra environments are unique and fragile ecosystems, and display sensitive responses to global changes (Yu et al. 2017; Loya and Grogan 2004). Litter decomposition is one of the most significant processes of material recycling and energy transformation in natural ecosystems (Soong et al. 2015; Loranger et al. 2002; Giardina and Ryan 2000; Melillo et al. 1982), and it plays a very important role in soil fertility and nutrient uptake (Ngatia et al. 2014; Parton et al. 2007). Some previous studies have revealed that, due to the low temperature environments, the rates of litter decomposition in tundra are relatively slow, and they respond to climate warming sensitively (Hobbie 1996; Liski et al. 2003; Yu et al. 2017). Therefore, a better understanding of litter decomposition

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in the tundra ecosystem is important for predicting global changes.

Soil fauna play important roles in the litter decomposition process (Garcia-Palacios et al. 2013; Vos et al. 2011; Hättenschwiler and Gasser 2005). On one hand, soil fauna can accelerate litter mass loss via physical fragmentation (Joly et al. 2018), excreting faeces (Coulis et al. 2016; Joly et al. 2018), and microbial modification (Joly et al. 2015), and, consequently, make critical contribution to litter decomposition (Yin et al. 2010; Christian and Alexer 2009). On the other hand, soil fauna communities are sensitive to environmental changes, and thus, their contribution to litter decomposition is affected by many kinds of factors, and some previous studies have shown that climate, litter quality, and soil condition have been identified as major drivers of litter decomposition (Hättenschwiler et al. 2005; García-Palacios et al. 2013). Meanwhile, other studies have found that, due to the differences in dietary requirements, soil fauna's diversity has a significant influence on litter decomposition (Cornelissen et al. 1999). In addition, Fujii et al. (2018) have revealed that the correlation between litter quality and contribution of mesofauna within elevation tended to be stronger at the higher elevations. Consequently, it is of concern to provide some insights into elucidating effects of soil fauna on litter decomposition in the alpine tundra ecosystem.

However, most of current research regarding tundra litter decomposition mainly focuses on Arctic tundra. In western Greenland, Blok et al. (2016) have revealed that deeper snow can accelerate shrub decomposition during the initial decomposition stages during winter. In the moist acidic tundra of northern Alaska, Mclaren et al. (2017) have observed that negative mixing effects exist in leaf decomposition during the early stages of shrub encroachment. Christiansen et al. (2017) have found that surface litter decay and nutrient turnover rates in both xeric and relatively moist tundra are likely to be significantly restricted by the evaporative drying associated with warmer air temperatures. In contrast, alpine tundra studies are rare relatively (Liu et al. 2016). Some previous studies have revealed that the solar radiation in alpine tundra is greater than that in Arctic tundra (Ledrew and Weller 1978; Körner 2003). It is known that the generalized positive effect of solar radiation exposure on subsequent microbial activity is mediated by increased accessibility to cell wall polysaccharides, and thus, the relatively higher solar radiation can promote the rates of litter decomposition (Austin et al. 2016). As a result, there are some difference in litter decomposition between alpine tundra and Arctic tundra (Liski et al. 2003; Gholz et al. 2000). In addition, most of current studies regarding tundra litter decomposition mainly focus on the rates of mass loss, nutrient release, and microbial activity, whereas studies regarding the effects of soil fauna on alpine tundra litter decomposition have been even fewer in number.

In this study, to better understand the effect of soil fauna on litter decomposition in alpine tundra, we selected the tundra of the Changbai Mountains as the experimental site, as it is one of the two alpine tundra areas in China. Then, a litterbag decomposition experiment in the tundra of the Changbai Mountains was conducted. This study used the litter of *Dryas octopetala*, which was determined to be the dominant species in the tundra of the Changbai Mountains (Wang et al. 2015a, b). Here, we hypothesized that (1) the decomposition rates of *Dryas octopetala* exhibits temporal variations, whereas these variations differ between the two mesh sizes; and (2) soil fauna affects the decomposition of *Dryas octopetala*, while the contributing effects are characterized by stages.

Materials and methods

Site description

The experiment in this study was carried out in the alpine tundra located on the northern side of the Changbai Mountains, Jilin Province, China (42°02′N, 128°03′E). The elevation of the study area was 2100 m above sea level. This area is situated the upper part of a volcano, and the volcanic and periglacial landforms have been typically developed. The climate was a typical alpine climate, with a mean annual temperature of − 7.3 °C. The mean number of snow-cover days accounted for more than 6 months per year. The mean annual precipitation was approximately 1100–1300 mm. The agrotype was alpine tundra soil, and the dominant species of the site was found to be *Dryas octopetala*.

Experimental setup

The leaf litter of the *Dryas octopetala* was collected during the peak litter-fall period in September, 2011. The leaf litter did not show any visible signs of decomposition, herbivory, or pathogens. All of the litter was cleaned by careful and gentle brushing, and then dried at room temperature. Litterbags (15 × 20 cm) with fine mesh (0.01 mm) were selected, which allowed for microbial activity only, as well as coarse mesh (2 mm), which allowed most of the soil fauna species to be active within the bags. To reflect a density similar to the local litter-fall, each of the litterbags was filled with 8.00 g of air-dried leaf litter.

Four replicated 5 m × 5 m plots were set in a flat site during October, 2011. The litterbags were placed on the soil surface of each of the plots. Each plot was spaced 10 m apart. Each plot was divided into a five row by twelve column sampling grid, and litterbags were placed at the center of each square of the grid. Some of the litter was used to cover the exposed surfaces of the litterbags to keep the litter decomposing naturally (Supplemental Fig. 1). Sixty litterbags (30 coarse mesh (2 mm) litterbags and 30 fine mesh (0.01 mm) litterbags) were randomly placed in each plot, for a total of 240 litterbags in the experiment. Following the placements in the field, some additional litterbags were collected from the site, and taken immediately to this study's laboratory for the purpose of calculating the mass loss of the litter during transit.

A coarse mesh (2 mm) litterbag, as well as a fine mesh (0.01 mm) litterbag, were collected from each plot on the 6th, 8th, 10th, 12th, 20th, 22nd, 24th, 32nd, 34th, and 36th months in each plot following the field placement. On every sampling date, each bag was carefully transported in a separate plastic bag to minimize the loss of any small litter fragments.

Foreign plant and soil fragments which were attached to the exteriors of the litterbags were carefully removed with forceps. Then, the contents of the 2 mm mesh-size litterbags were placed in the modified Tullgren extractors for the removal of the litter invertebrates. All of the extracted fauna samples were preserved in 75% ethanol, and identified at the order level. At this point, they were then counted under a stereoscopic microscope (OLYMPUS SZX16). Following the extraction of the soil fauna, all of the remaining litter in both sets of litterbags were gently rinsed with distilled water, oven-dried at 60 °C to a constant weight, and then weighed to determine the mass loss.

Data analysis

The mass loss of litter is calculated using $D = (W_0 - W_t)/W_0 \times 100\%$, where D is the mass loss of litter as a percentage; W_t is the litter-remaining mass at time t; and W_0 is the initial mass of the litter. The net loss of litter is calculated using $N = (W_t - W_{t+1})/W_t \times 100\%$, where N is the net loss of litter as a percentage; W_t is the litter-remaining mass at time t; W_{t+1} is the remaining mass at $t+1$. The rates of litter mass loss in the litterbags were estimated using Olson's formula (Olson 1963): $W_t = W_0\ \mathrm{e}^{-kt}$, in which W_t is the mass remaining at time t in years; W_0 is the mass at $t=0$; k represents the mean annual litter mass loss rate. The Shannon–Wiener diversity index was used to measure the relative diversity of the soil fauna community at the order level in all of the litterbags. The mass loss contributed by the soil fauna was calculated using the formula at each sampling: $L_{\mathrm{fauna}}/L_{\mathrm{total}} = (L_{2\mathrm{mm}} - L_{0.01\mathrm{mm}})/L_{2\mathrm{mm}}$, where $L_{2\mathrm{mm}}$ is the litter mass loss of the 2 mm mesh-size litterbags; $L_{0.01\mathrm{mm}}$ is the litter mass loss of the 0.01 mm; $L_{\mathrm{fauna}}/L_{\mathrm{total}}$ is soil faunal contribution to the litter decomposition (Irmler 2000; Seastedt 1984).

Generalized linear models (GLMs) were used to determine the effects of decomposition time on the mass loss of litter, Shannon–Wiener diversity index of the soil fauna, and litter mass loss contributed by the soil fauna. All count data metrics, abundance and richness of soil fauna, were not log-transformed and modelled with negative binomial distributed GLMs to determine the effects of decomposition time (O'Hara and Kotze 2010). We performed a linear regression model to test the relationship between the mass loss of litter (response or dependent variable) and the soil faunal contribution ($L_{\mathrm{fauna}}/L_{\mathrm{total}}$) (independent variable). We observed that there were four negative data points of soil faunal contribution at the 6th month. This indicated that the mass loss in the presence of soil fauna was much less than without fauna. However, the mass loss was much less at that time, and there was no significant difference between the remaining mass in the 2 mm and 0.01 mm mesh litterbags. As a result, the small differences in absolute values could lead to a high relative difference between the 2 and 0.01 mm mesh bags, which had no biological meaning. Consequently, these four negative data points were removed from this analysis. The significance of the coefficient of determination (R^2) for the linear regression analysis was tested using an F test ($p < 0.05$). Statistical analysis was performed using SPSS 22 (SPSS Inc., Chicago, IL, USA).

Results

Litter decomposition

Trends of litter decomposition

It was also found the mass loss of litter in the fine mesh (0.01 mm) litterbags was always lower than that of the coarse (2 mm) litterbags, with the exception of the first 6 months after the experiment initiation. The mass loss was much less at initial time, and there was no significant difference between remaining mass in 2 mm and 0.01 mm mesh litterbags. At the end of experimental period (36th month of decomposition), the percentage of the mass loss of litter in coarse mesh (2 mm) litterbags was 47.60%. Meanwhile, the same percentage in the fine mesh litterbags (0.01 mm) was determined to be 34.11% (Fig. 1).

Rates of litter decomposition

The decomposition rates were predicted using a single exponential model, as described by Olson (1963). In general, the decomposition rate of the coarse mesh (2 mm) litterbags was faster than that of the fine mesh (0.01 mm) litterbags (Table 1). According to the calculation, it took 36 months (3.0 years) for *Dryas octopetala* litter in the coarse mesh (2 mm) litterbags to decompose its initial mass to 50%, whereas 58 months (4.8 years) were needed in the fine mesh (0.01 mm) litterbags, which was 1.61 times that of the coarse mesh litterbags. Likewise, 158 months (13.1 years) were

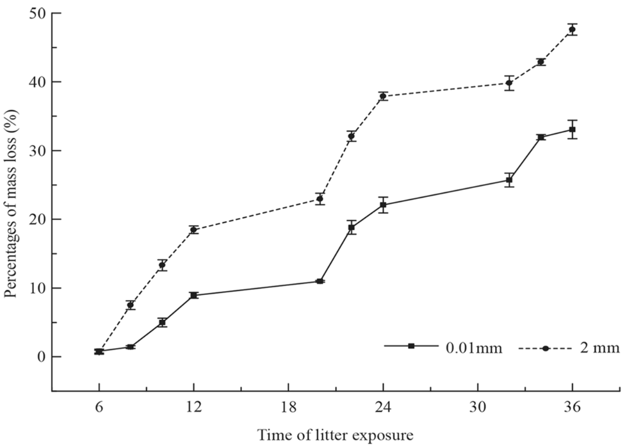

Fig. 1 Percentage of mass loss of *Dryas octopetala* litter in different mesh-size litterbags during the time of litter exposure. Means ± SE of four replicates

needed in the coarse mesh (2 mm) litterbags when 95% of its initial mass was decomposed, and 250 months (20.8 years) were spent in the fine mesh (0.01 mm) litterbags, which was 1.58 times that of the coarse mesh litterbags.

Seasonal and annual dynamics of litter decomposition

It was found that the percentage of net loss displayed distinctions in different years (Fig. 2). The percentage of net loss in the fine mesh (0.01 mm) litterbags increased year by year during the winter and spring (October to June), and there was no significant difference observed between the first 2 years (1.42% and 2.24%, respectively) ($p > 0.05$). However, a significant difference was found between the third year (4.62%) and the first 2 years ($p < 0.05$). During the summer and autumn seasons (June to October), the percentage of the second year (12.48%) was found to be significantly higher than that of the first year (7.62%) ($p < 0.05$). The percentage of net loss in the coarse mesh (2 mm) litterbags

Table 1 Decomposition parameters for *Dryas octopetala*

Mesh size	Decay model	k	R^2	p	$t_{0.5}$ (months/years)	$t_{0.95}$ (months/years)
0.01 mm	$W_t = 7.580e^{-0.012t}$	0.012	0.954	< 0.001	58/4.8	250/20.8
2 mm	$W_t = 7.520e^{-0.019t}$	0.019	0.963	< 0.001	36/3.0	158/13.1

k is the decomposition constant and R^2 is the regression coefficient

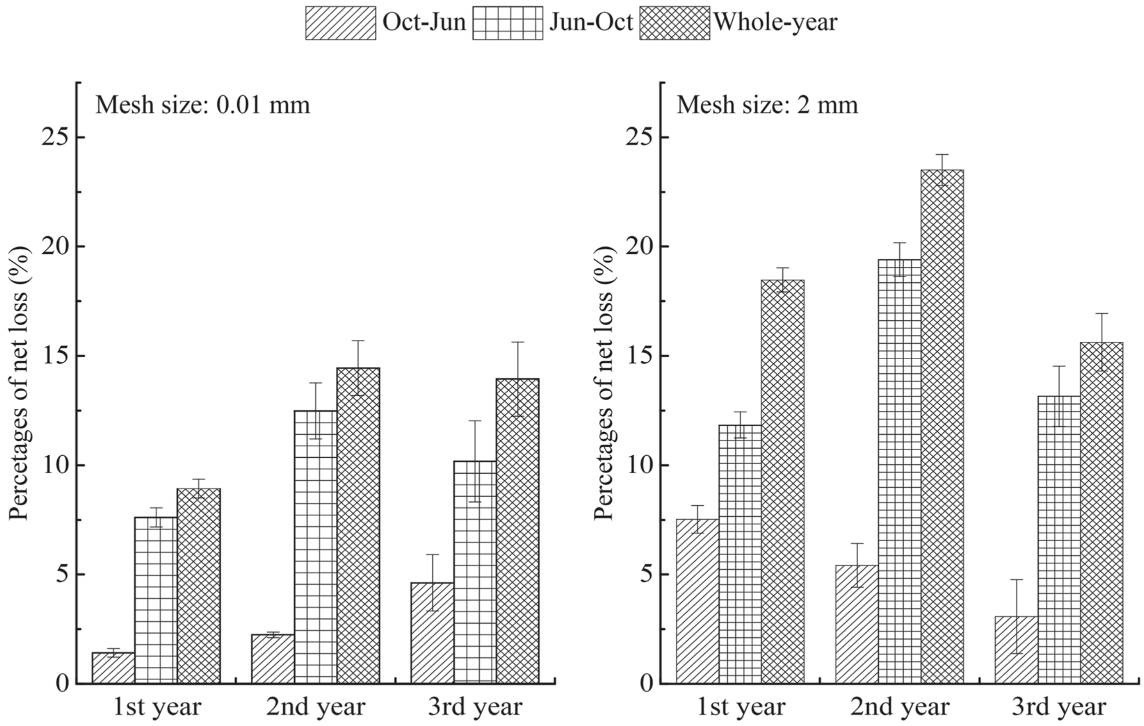

Fig. 2 Percentage of net loss of *Dryas octopetala* litter in different years. The lower case letters indicate the significant differences between the years within the same mesh size at the $p < 0.05$ level. Means ± SE of four replicates

was found to decrease year by year during the winter and spring seasons (7.52%, 5.42%, and 3.08%, respectively) (October–June), and significant differences were discovered each year ($p < 0.05$). The annual variations of the percentage during the summer and autumn seasons (June to October) were similar to those of the fine mesh (0.01 mm) litterbags. Overall, the percentage of the net loss in the winter and spring seasons (October–June) was found to be significantly less significant than that during the summer and autumn seasons (June to October), in both the fine and coarse mesh litterbags.

In addition, regardless of the mesh-size of the litterbags, the percentage of net loss during the second year was determined to be the highest. In the fine mesh (0.01 mm) litterbags, the percentage of net loss during the first year (8.93%) was significantly less than the other years ($p < 0.05$), and the percentage of the third year (15.62%) was found to be significantly less than the second year (23.50%) for the coarse mesh (2 mm) litterbags ($p < 0.05$).

Soil fauna in litterbags

During the experiment, a total of 439 individuals belonging to 17 different groups (orders) were collected from the litterbags, as shown in Table 2. There were five dominant groups in the litter, and these fauna were Gamasida, Isotomidae, Oribatida, Actinedida, and Pseudachortidae, which together comprised 87.93% of the total individuals. At the same time, three common groups were found during the decomposition, namely the Enchytraeidae, Entomobryidae, and Coccoidea, which comprised 8.42% of the total individuals. In addition, nine rare groups comprised 3.65% of the total individuals. The individual soil fauna were found to be different in each of the years. During the first year, 81 individuals were collected, which comprised 18.45% of the total, the smallest amount. Then, 200 individuals were collected in the second year, which comprised 45.56% of the total individuals, and this was the highest found during the duration of this study's experiment. In the third year, 158 individuals were found, which comprised 35.99% of the total.

The abundance (individuals per gram of the dry litter) and richness (orders per gram of the dry litter), as well as the Shannon–Wiener diversity index of the soil fauna, are shown in Table 3. When compared with other time periods of the experiment, the abundances of the soil fauna in the first year (0–12th months) were much less, or the soil fauna was not found, especially in the 8th month. During the second year (13th–24th months), the abundances of the soil fauna began to increase. The abundances were observed to decrease in the third year (25th–36th months). However, they increased suddenly to the maximum value of the experiment in the 36th month. There were no significant differences observed in the abundances of the soil fauna during the experiment ($p > 0.05$).

Table 2 All soil fauna taxa found in the *Dryas octopetala*, the total number of individuals found during the 3 year period of decomposition, and the percentage of soil fauna

Soil fauna	First year		Second year		Third year		Total		Abundance
	Ind.	%	Ind.	%	Ind.	%	Ind.	%	
Gamasida	45	10.25	6	1.37	66	15.03	117	26.65	+++
Isotomidae	14	3.19	31	7.06	30	6.83	75	17.08	+++
Oribatida	2	0.46	25	5.69	43	9.79	70	15.95	+++
Actinedida	7	1.59	56	12.76	2	0.46	65	14.81	+++
Pseudachortidae	9	2.05	44	10.02	6	1.37	59	13.44	+++
Enchytraeidae	0	0.00	23	5.24	0	0.00	23	5.24	++
Entomobryidae	0	0.00	5	1.14	2	0.46	7	1.59	++
Aphididae	2	0.46	1	0.23	4	0.91	7	1.59	++
Tomoceridae	0	0.00	1	0.23	3	0.68	4	0.91	+
Sminthuridae	0	0.00	3	0.68	0	0.00	3	0.68	+
Lithobiidae	0	0.00	2	0.46	0	0.00	2	0.46	+
Psocoptera	1	0.23	1	0.23	0	0.00	2	0.46	+
Hypogastruridae	0	0.00	0	0.00	1	0.23	1	0.23	+
Staphylinidae	0	0.00	1	0.23	0	0.00	1	0.23	+
Staphylinidae larva	0	0.00	0	0.00	1	0.23	1	0.23	+
Formicidae	0	0.00	1	0.23	0	0.00	1	0.23	+
Tipulidae	1	0.23	0	0.00	0	0.00	1	0.23	+
Total	81	18.45	200	45.56	158	35.99	439	100	

$^{+++}$dominant groups (percentages > 10%)

$^{++}$common groups (1% < percentages < 10%)

$^{+}$rare groups (percentages < 1%)

Table 3 Abundance [individuals (Ind.) per gram dry litter] and richness (order per gram dry litter) and Shannon–Wiener Index of the soil faunal communities in *Dryas octopetala* during the 3 year experiment

Time of litter exposure (Month)	Abundance ($\text{Ind.}\cdot\text{g}^{-1}$ dry litter)	Richness ($\text{Orders}\cdot\text{g}^{-1}$ dry litter)	Shannon–Wiener Index
6	1.27 ± 0.76	0.32 ± 0.11 cd	0.49 ± 0.28bc
10	0.08 ± 0.08	0.08 ± 0.08d	0.17 ± 0.17c
12	1.80 ± 0.65	0.42 ± 0.1bcd	0.47 ± 0.21bc
20	4.36 ± 1.05	1.00 ± 0.17a	1.32 ± 0.18a
22	3.40 ± 0.43	0.93 ± 0.07a	1.28 ± 0.11a
24	2.13 ± 1.05	0.40 ± 0.17bcd	0.39 ± 0.25bc
32	1.49 ± 0.37	0.60 ± 0.16abc	0.69 ± 0.25abc
34	1.94 ± 0.59	0.87 ± 0.24ab	0.96 ± 0.23ab
36	7.48 ± 4.56	0.55 ± 0.19abcd	0.39 ± 0.23bc

Lower case letters indicate the significant differences in each stage within the same richness and Shannon–Wiener Index at the $p < 0.05$ level. (Mean ± SE)

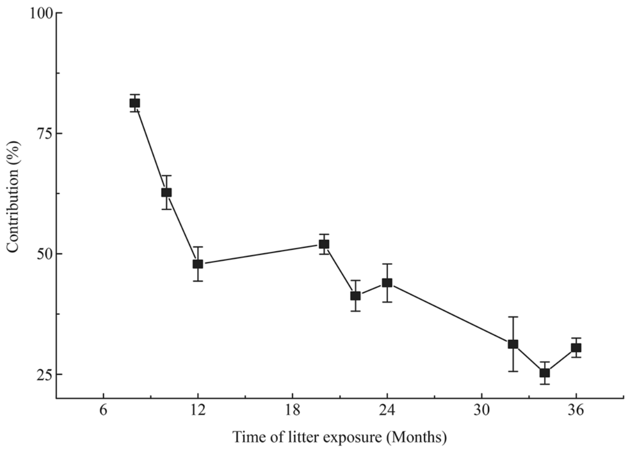

Fig. 3 Contribution rates of soil fauna to litter mass loss of *Dryas octopetala* during the time of litter exposure. Means ± SE of four replicates

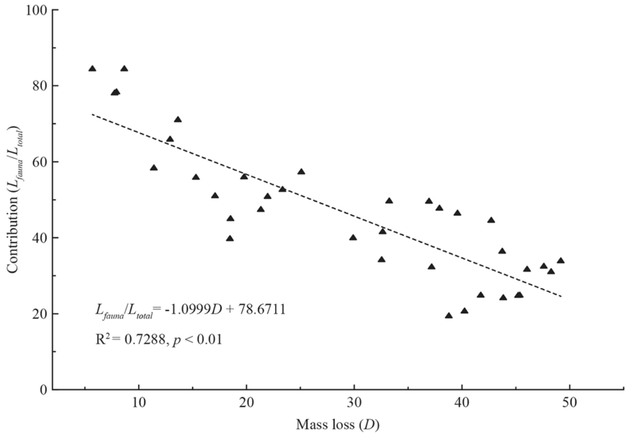

Fig. 4 Relationship between the soil fauna contribution ($L_{\text{fauna}}/L_{\text{total}}$) and mass loss of litter. The data represent individual samples ($n = 36$)

The richness of the soil fauna exhibited some annual differences. The second year had the greatest richness of soil fauna during the decomposition, and the richness was found to be at a lower level during the first year of the experiment. There were no significant differences found in the richness between the months ($p > 0.05$), with the exception of the 24th month, in which the richness was significantly lower than those of the 20th and 22nd months ($p < 0.05$). It was also found that the variations of the Shannon–Wiener diversity index of the soil fauna were similar to those of the richness.

3.3. Influence of the soil fauna on the decomposition

The influence of the soil fauna on the decomposition could be calculated by the $L_{\text{fauna}}/L_{\text{total}}$, as shown in Fig. 3. At the 8th month, the soil fauna contribution ($L_{\text{fauna}}/L_{\text{total}}$) reached this experiment's maximum level (81.26%). Then, the $L_{\text{fauna}}/L_{\text{total}}$ showed a trend of fluctuating downward. When the experiment was completed (36th month), the $L_{\text{fauna}}/L_{\text{total}}$ was 30.50%. In addition, we found significant negative relationship ($R^2 = 0.7288$, $p < 0.01$) between soil fauna contribution ($L_{\text{fauna}}/L_{\text{total}}$) and mass loss of litter (Fig. 4).

Discussion

Decomposition of *Dryas octopetala*

In this study, the time periods of the litter decomposition were longer than in the previous research regarding the *Pinus koraiensis* mixed broad-leaved forest, coniferous forest, and *Betula ermanii* forest of the Changbai Mountains. Some of the characteristics of the litter may have been key factors which influenced the rate of the litter decomposition (Wang et al. 2015a, b; Jiang et al. 2014; Li et al. 2014).

The previous research had shown that the hardness, toughness, and tensile strength of leaves all could potentially have important effects on the litter decomposition (Pérez-Harguindeguy et al. 2000; Cornelissen et al. 1999; Gallardo and Merino 1993). The research results of Vitousek et al. (1994) showed that the textures of leaves are rougher at high elevations, and their thicknesses are relatively larger. These factors tend to restrict decomposition at high elevations. In this study, the leaves of *Dryas octopetala*, which had a higher content of lignin (411.3 mg/g), were collected as experimental objects. This may have been the cause of the slower rate of decomposition. In addition, environmental factors play important roles in the litter decomposition (Ferreira et al. 2016), and the colder tundra environment in the Changbai Mountains also might have caused to slow decomposition rates.

We found that the decomposition rates of the coarse mesh (2 mm) litterbags were faster than those of the fine mesh (0.01 mm) litterbags. Some previous studies revealed that soil fauna could increase the decomposition rates of plant litter via breakdown, consume, and digest litter, as well as stimulate microbial activities (David 2014). In this study, the coarse mesh (2 mm) litterbags allowed most of the soil fauna species to be active within the bags. Consequently, higher decomposition rates were observed in the coarse mesh litterbags. In addition, there was a better aeration in coarse mesh litterbags, and thus, this increased the decomposition rates of *Dryas octopetala*.

In this study, it was found that the decomposition of the *Dryas octopetala* had obvious seasonal variations. For example, the percentages of the net losses during the winter and spring seasons were significantly less than the percentages during the summer and autumn seasons. Climate is an important factor influenced the litter decomposition (García-Palacios et al. 2016), and is also directly influenced by the temperatures and precipitation levels (Thakur et al. 2018). In line with these findings, the decomposition of the *Dryas octopetala* displayed seasonal variations. Since aeration played an important role in the litter decomposition (Knacker et al. 2003), the snow cover could also have influenced the decomposition by changing the gaseous environment. Wu et al. (2013) reported that different depths of the seasonal snow cover may cause seasonal variations of litter decomposition. Therefore, due to the fact that the tundra of the Changbai Mountains was covered with snow, obvious seasonal variations in the decomposition of the *Dryas octopetala* were found to be evident due to this environmental factor.

The results of this study showed that there were differences in the decomposition of the *Dryas octopetala* during the different years. The percentage of net loss first appeared to increase, then decrease, and reached the maximum level in the second year of this study. The research results indicated that the factors which affected the litter decomposition were different during each period (Aerts and de Caluwe 1997). The previous study found that the carbohydrates and water-soluble substances quickly decomposed, and then leached at the beginning of the decomposition, and this caused immediate mass losses in the litter (Swift et al. 1979). As the decomposition continued, the content of some of the easily decomposed materials became continuously reduced, and the content of the materials which took longer to decompose, such as lignin, cellulose, hemicellulose, and polyphenols continuously increased (Pérez-Harguindeguy et al. 2000; Thomas and Asakawa 1993). These difficult-to-decompose materials caused a slower rate of decomposition. This study was begun in the winter, which may have caused the percentage of the net loss during the first year to be lower than the second year.

Contributions of the soil fauna to decomposition

When compared with the study of the soil fauna communities in the tundra of the Changbai Mountains conducted by Wang et al. (2014), it was determined that, regardless of the abundance or richness, this study's results were at a lower level. The coarse mesh (2 mm) litterbags were selected during this study's experiment, and these litterbags allowed, in principle, that most of the soil fauna species were active in the bags. However, in the actual application, they may have had some effects on the soil fauna. Therefore, the litterbags may have potentially had decreases in the numbers of individuals and groups of soil fauna. Moreover, for imitating the litter decomposition naturally, the litterbags were set up on the surface of the tundra, and were exposed to cold temperatures and wind. These factors may have resulted in fewer numbers of individuals and groups of soil fauna in this study.

It was determined in this study that the contributions of the soil fauna to the litter decomposition appeared to at first increase. These results agreed with the research results proposed by Wang et al. (2015a, b) regarding the coniferous forest of the Changbai Mountains. The increase in soil fauna contribution was due to the seasonal pattern. Due to the fact that this experiment began during the winter, the soil fauna activity was inhibited by the long winter season and lower ground temperatures, and no positive soil fauna effect the decomposition. Some previous studies have determined that winter is important for litter decomposition (Dang et al. 2009; Sinsabaugh 1994). In winter, leading roles are being played by other factors, as well, such as the freezing-and-thawing actions, species of the litter, soil physicochemical properties, and activations of microorganisms (Aerts and de Caluwe 1997; Aponte et al. 2012; Lemma et al. 2007; Groffman et al. 2001). Therefore, the soil fauna in this study were found to have no apparent effects on the litter decomposition during the initial stage.

We found a significant negative relationship ($R^2 = 0.7288$, $p < 0.01$) between soil fauna contribution ($L_{\mathrm{fauna}}/L_{\mathrm{total}}$) and mass loss of litter, and it indicated that soil fauna contribution decreased with litter decomposition. The previous research has revealed that litter fragmentation and compaction into faecal pellets by soil fauna can lead to substantially enhanced decomposition (Joly et al. 2018). Due to the fact that the litter is chewed and converted by soil fauna, the microbial activity in these faeces is assumed to be increased (Joly et al. 2015). As a result, litter decomposition is enhanced (Coulis et al. 2016). The previous study has revealed that the concentration of recalcitrant compounds will increase as the decomposition continues (Austin and Ballaré 2016). The greater concentration of recalcitrant compounds weakens the effects of soil fauna on litter decomposition (Yan et al. 2016). Consequently, the contribution of soil fauna showed a downward trend with litter decomposition.

Conclusions

In conclusion, the decomposition rates of the coarse mesh (2 mm) litterbags were faster than those of the fine mesh (0.01 mm) litterbags, which indicated that soil fauna could promote the decomposition of *Dryas octopetala* litter in the alpine tundra ecosystem. The characteristics of litter decomposition exhibit some seasonal and annual differences, which net loss in the winter and spring seasons was always found to be significantly less than that in the summer and autumn seasons. Compared with other regions of the Changbai Mountains, the abundance and diversity of soil fauna were relatively lower in the alpine tundra. The diversity of the soil fauna in the litterbags was found to be different in each year of the experiment. However, there were no significant differences observed in the same year. Soil fauna contribution had a significant negative relationship with mass loss of litter. Overall, soil fauna can promote the decomposition of *Dryas octopetala* litter, but soil fauna contribution decreased with litter decomposition in the alpine tundra ecosystem. The findings of this study have implications for the relationship between soil fauna and litter decomposition in the alpine tundra ecosystem, and also can provide some help to better understand the mechanism of this relationship for future studies.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest in relation to this article.

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