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Seasonal and altitudinal variations of soil arthropods in *Abies nordmanniana* subsp. *bornmulleriana* forests

Variaciones estacionales y altitudinales de artrópodos del suelo en bosques de *Abies nordmanniana* subsp. *bornmuelleriana*

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SUMMARY

Seasonal and altitudinal variations in the abundance and diversity of soil arthropods were investigated in a pure *Abies nordmanniana* subsp. *bornmulleriana* (Uludağ fir) forest ecosystem. Sample plots were set at three different altitudes (1,200 m, 1,400 m and 1,550 m), and samplings were performed in four seasons in February, May, August and November in 2010. Soil properties varied significantly among the seasons; higher soil nitrogen (N) and carbon (C) concentrations were found in summer while C/N ratio and pH were higher in autumn. Litter mass decreased from winter to summer; however, litter nitrogen concentration was inversely correlated with litter mass. Litter C/N, potassium and magnesium concentrations were different among the seasons although litter pH, carbon, phosphorus and calcium concentrations did not show significant differences. Soil pH, phosphorus, calcium and magnesium concentrations mainly showed a decreasing trend with altitude; however, soil nitrogen and carbon concentrations had a significantly increasing trend. Litter mass did not have any significant difference although litter pH, calcium and magnesium concentrations showed a significantly decreasing trend with altitude. In total, 54,348 individual soil arthropods were counted, identified and classified from 144 litter and soil samples collected in the study. The arthropods that were identified belonged to 90 different taxa within six classes and 28 orders, which were significantly different depending on habitats (soil or litter), altitudes and seasons throughout the year.

Key words: abundance, Aladağ, CCA, litter, Uludağ fir.

RESUMEN

Las variaciones estacionales y de altitud en la abundancia y diversidad de artrópodos del suelo fueron investigadas en un ecosistema forestal puro de *Abies nordmanniana* subsp. *bornmuelleriana* (abeto Uludag). Se establecieron parcelas de muestreo en tres altitudes (1.200, 1.400 y 1.550 m) y se muestrearon en cuatro temporadas (febrero, mayo, agosto, noviembre, 2010). Las propiedades del suelo variaron significativamente entre las estaciones; en verano se encontraron en el suelo concentraciones superiores de nitrógeno y carbono, mientras que la relación C/N y el pH fueron mayores en otoño. La masa del mantillo disminuyó de invierno a verano y su concentración de nitrógeno correlacionó inversamente con la masa. En el mantillo, la relación C/N y las concentraciones de potasio y magnesio fueron diferentes entre estaciones del año, pero el pH y las concentraciones carbono, fósforo y calcio no mostraron diferencias significativas. En el suelo, el pH y las concentraciones de fósforo, calcio y magnesio mostraron tendencia decreciente con la altitud; sin embargo, las concentraciones de nitrógeno y carbono tuvieron una tendencia creciente significativa. La masa del mantillo no se diferenció significativamente, aunque el pH y las concentraciones de calcio y magnesio mostraron tendencia significativa a la baja con la altitud. Se contabilizaron 54.348 individuos de artrópodos del suelo, identificados y clasificados desde 144 muestras de mantillo y suelo. Los artrópodos identificados pertenecían a 90 taxones dentro de seis clases y 28 órdenes, que fueron significativamente diferentes en función de los hábitats (suelo o mantillo), altitudes y estaciones a lo largo del año.

Palabras clave: abundancia, Aladag, CCA, mantillo, abeto de Uludag.

INTRODUCTION

Soil arthropods can be used as bio-indicators in soil. Determining the constancy and variability of arthropod communities is very important in order to establish their predictability power for ecosystem processes. The significance of arthropods for ecosystem functions and soil has been determined regarding their biodiversity and abundance. Body sizes, forms and some organs of the soil arthropods allow them to live in various layers and depths of the soil (Razo-González *et al.* 2014). Arthropods can live on the forest floor, in the pores of litter and soil. Physiographic factors such as altitude, topography, aspect and slope; climatic variables including temperature, humidity and precipitation; site characteristics, habitat changes, forest floor and soil nutrients are important factors that may affect the abundance and diversity of arthropods (Townsend *et al.* 2008).

Forest soil and litter covering up the mineral soil represent the most important sources of biological diversity, and harbor a diversity of animals of varying sizes from protozoa to nematode and from microscopic acarina to small mammalian decomposers, except bacteria and fungi. In the soil ecosystem, the food chain containing arthropods is the basic linkage for food web, and it also includes macro fauna. All of these animals are heteropagus living at various trophic levels. Arthropods within the soil fauna play important roles in ecosystem processes such as litter decomposition, control of decomposers, nutrient cycling and contribution to biodiversity (Faber and van Wensem 2012). Besides their other fundamental functions, they are favorable soil quality regulators; furthermore, they are important for sustainable forest management (Sackett *et al.* 2010).

Ecological differences such as temperature and moisture regulate the life cycle of arthropods. Community structure and abundance of soil arthropods in a site may show seasonal variations; in particular, they are significantly affected by conditions such as the formation of different soil microclimates; alterations in the resource availability and changes in the food web (Logan *et al.* 2006). The climatic changes can occur in a wide range depending on the altitude, lead to alterations in the community structure of arthropods and can affect the activity rates of some species. However, the species that have tolerance to the changing climatic conditions depending on the altitude can be found at different altitudes, whereas the less tolerant species can only be found at a certain altitude (Pennings and Silliman 2005).

The aim of this study is to investigate the seasonal and altitudinal variations in the abundance and diversity of soil arthropods in the pure and full-canopy covered *Abies nordmanniana* subsp. *bornmulleriana* Mattf. (Uludağ fir) ecosystem that is an important forest tree species in Turkey. Therefore, the following research subjects are tested: (1) variations in the abundance and diversity of soil arthropods depending on the altitudinal zones and seasons, (2) relations between the properties of soil –litter and abundance-diversity of soil arthropods depending on different seasons and altitudes throughout the one-year research period.

METHODS

Site description. The study was conducted in a pure *A. nordmanniana* subsp. *bornmulleriana* forest on Aladağ montainous mass extending in east-west direction in the south of Bolu Province-Turkey. The study site is located on the latitudes of 40°37′05″ N - 40°39′36″ N, longitudes of 31°35′33″ E- 31°37′40″ E, and altitudes from 1,200 to 1,550 m. The overall mean stand characteristics of the sample plots are as follows: tree density = 500 tree ha^{-1}, tree height = 19.8 m, basal area = 53.6 m^{-2} ha^{-1} and tree diameter at breast height = 34.3 cm (Duyar 2014).

The parent material of the study site is andesite and the soil type is Luvisol. Average soil bulk density (< 2 mm) is 474 g L^{-1} in the top soil (0-5 cm). The clay content of soil ranges from 18 % to 24 %, while the soil reaction is 5.4-6.0 pH changing at the different altitudes (Duyar 2014).

Mean annual precipitation is 555 mm, and mean annual temperature is 10.5 °C, the hottest (> 16 °C) period is between the 6th and 9th months. Similarly, precipitation is minimum between the 7th and 9th months according to the long-term (1960-2012) measured data of Bolu meteorology station (Duyar 2014).

Sampling and sampling design. Nine sample plots (20 x 20 m) were selected in total in three replicates at three different altitudes (1,200 m, 1,400 m and 1,550 m). These altitudinal zones were selected by taking account of a former research of Kantarcı (1979), conducted in the same study area. Samplings were performed in four seasons in February, May, August and November in 2010. Two sampling sets were taken from each sample plot in each sampling time. Each sampling set contained as follows; one litter and one soil sample for analysis, one core sample to determine the soil moisture, one litter and one soil sample via steel soil corers for micro arthropods. In each sampling, 18 sampling sets were taken in two occasions from a total of nine sample plots; thus, 72 samples in total were collected throughout the research period. Soil temperatures were recorded by steel-tipped digital soil thermometer at five cm depth in each sampling period. Soil moisture was determined by wet and dry weight difference after dried at 105 °C for 24 h.

Sampling of arthropods from litter and soil. For sampling of arthropods in the field, steel cylinders with a diameter of 5 cm were used for undisturbed litter and soil samples. Litter samples were taken by pressing the steel cylinder in a vertical position down to the mineral soil level at the same points, while the soil samples were also taken from the mineral soils at a depth of 0-5 cm (Coleman *et al.* 2004).

Litter and soil samples for chemical analyses. Litter samples were taken from quadrats (20 x 20 cm) at every sampling point by collecting the entire litter on the mineral soil surface at the same sampling point, soil samples were also taken from the mineral soils at a depth of 0-5 cm. For other analyses, extra soil samples were taken from the same locations.

Extraction of the arthropods from the litter and soil samples. Samples in the steel cylinders were placed in Tullgren funnels to extract the arthropods; the samples were kept under 25-watt light bulbs providing heat for six days. Consequently, using the natural channels, arthropods gathered in the sample container contained 70 % ethyl alcohol and 2 % glycerin (Coleman *et al.* 2004).

Litter and soil analyses. Litter mass was determined by weighing the dried samples up to the constant weight at 65 °C. Carbon (C) and nitrogen (N) analyses were performed by the dry combustion method with CN analyzer (Leco Truspec 2000). The distribution of the soil particle size was determined by the Bouyoucos hydrometer method. International soil texture triangle was used to classify the soil texture. Soil acidity (pH) (1:2.5 soil/water ratio) and litter reaction (1:10 litter/water ratio) were measured using a glass electrode digital pH meter. Phosphorus (P) was determined in Spectronic 20D colorimeter. Soil samples were prepared by the ammonium acetate method for potassium (K), calcium (Ca) and magnesium (Mg). Litter samples were prepared by wet digestion using nitric-perchloric acid. In the prepared filtrates, potassium concentration was determined using flame photometry, while calcium and magnesium were measured by atomic absorption spectrometer (Duyar 2014).

Identification and classification of the arthropods. Since the arthropods are macroscopic organisms, not easily visible, we used stereo binocular microscope (Leica S8 APO) to identify, classify and count them. Classification was performed at suborder and family level based on the functional groups. However, rare taxa were assessed at order or class level. Identification keys were used for the classification of arthropods (Duyar 2014).

Statistical analyses. The number of arthropods in the extracted samples was counted and they were determined as individuals in a square meter (m^{-2}). Correlations among the variables were evaluated statistically ($P < 0.05$) through the correlation analysis. The differences among the variables due to the independent variables such as season and altitude were compared through the analyses of variance (ANOVA). Significant differences ($P < 0.05$) in ANOVA were found with Duncan test. The canonical correspondence analysis (CCA) using the ordination techniques was performed to reveal the variations in arthropods due to the investigated variables.

RESULTS

Seasonal and altitudinal changes in the investigated characteristics. Soil pH, nitrogen and carbon/nitrogen ratio (C/N) were significantly different across seasons. Soil nitrogen and carbon concentrations were particularly higher in summer while higher C/N ratio and pH were in autumn. Investigated soil chemical properties (carbon, phosphorus, potassium, calcium and magnesium were not significantly different among seasons (table 1).

Table 1. Seasonal changes of soil properties and litter characteristics.

Cambios estacionales de las características del suelo y mantillo.

Properties/ Characteristics	Winter	Spring	Summer	Autumn	Mean ± Sd.	*P*
			Soil			
Temperature (°C)	1.5 a	7.0 b	16.2 c	7.7 b	8.1 ± 5.4	0.0001**
Moisture (%)	53 c	41 ab	36 a	45 b	44 ± 12	0.0001**
pH	5.5 a	5.7 a	5.8 ab	6.1 b	5.8 ± 0.5	0.0040**
N (%)	0.79 ab	0.82 b	0.90 b	0.68 a	0.8 ± 0.2	0.0040**
C (%)	9.6 ab	9.1 a	11.2 b	9.5 ab	9.9 ± 2.9	0.1430
C/N	11.9 b	10.7 a	12.4 b	13.9 c	12.2 ± 1.9	0.0001**
P (mg kg^{-1})	46 a	43 a	44 a	41 a	44 ± 25	0.9570
K (mg kg^{-1})	426 a	402 a	395 a	374 a	399 ± 156	0.8050
Ca (mg kg^{-1})	3,890 a	4,122 a	4,415 a	4,127 a	4,138 ± 1,062	0.5390
Mg (mg kg^{-1})	266 a	253 a	265 a	246 a	258 ± 59	0.6940
			Litter			
Mass (g m^{-2})	6,172 c	5,182 b	3,519 a	3,843 a	4,679 ± 1,676	0.0001**
pH	6.0 a	5.8 a	6.1 a	6.1 a	6.0 ± 0.4	0.1390
N (%)	0.97 a	1.22 b	1.45 b	1.30 b	1.23 ± 0.4	0.0001**
C (%)	30.6 a	30.0 a	33.0 a	30.7 a	31.1 ± 5.8	0.4370
C/N	35.0 b	26.3 a	22.9 a	23.9 a	27 ± 8.3	0.0001**
P (mg kg^{-1})	922 a	997 a	992 a	917 a	957 ± 185	0.4020
K (mg kg^{-1})	1,868 b	1,584 a	1,906 b	2,011 b	1,842 ± 390	0.0060**
Ca (mg kg^{-1})	13,365 a	12,630 a	15,282 a	14,416 a	13,923 ± 6,565	0.6450
Mg (mg kg^{-1})	2,095 b	1,922 ab	1,752 a	1,774 a	1,886 ± 323	0.0030**

Sd: standard deviation, means within rows following by the same letter are not statistically different at 0.05 significance level in Duncan post hoc test.
** *P*-values are significant ($P < 0.01$).

Litter mass was significantly higher in winter after litter fall in autumn while it decreased in summer season. Litter nitrogen concentration was inversely correlated with litter mass. Litter C/N ratio, potassium and magnesium concentrations varied across the seasons although litter pH, carbon, phosphorus and calcium concentrations did not have any significant differences (table 1).

Soil temperature, C/N ratio, calcium and potassium did not have any significant altitudinal differences. Soil moisture at the altitude of 1,200 m was significantly lower than those presented by the other altitudes. General soil texture was loamy-clay; however, soil particle sizes were significantly ($P < 0.01$) different across the altitudes with an increasing trend in clay ratios from 1,200 m (18 %) to 1,550 m (24 %). Soil pH, phosphorus, calcium, and magnesium concentrations mainly showed a decreasing trend, whereas soil nitrogen and carbon ratios had a significantly ($P = 0.0001$) increasing trend with altitude (table 2).

Litter pH, calcium and magnesium concentrations had a significantly decreasing trend with altitude, although other litter characteristics did not show significant altitudinal differences (table 2).

Relations between arthropods' abundance and soil - litter characteristics. According to CCA, the explanation rates of axes for the variance in taxa-soil properties were cumulatively determined as: first axis = 34.0 %, second axis = 57.5 %, third axis = 73.9 % and fourth axis = 84.9 %. Ordination graph is presented in figure 1A, demonstrating the correlation between soil properties and abundance of arthropods. Soil temperature was positively correlated with Tomoceridae, Isotomidae and Diplura taxa and negatively

Table 2. Altitudinal changes of soil properties and litter characteristics.
Cambios altitudinales de las características del suelo y mantillo.

Properties/ Characteristics	1,200 m	1,400 m	1,550 m	Mean ± Sd.	*P*
			Soil		
Temperature (°C)	9.5 a	8.1 a	7.4 a	8.3 ± 5.4	0.3110
Moisture (%)	35 a	46 b	51 b	44 ± 12	0.0001**
Sand (%)	60 b	54 a	58 b	58 ± 6	0.0010**
Silt (%)	22 b	24 b	18 a	21 ± 4	0.0001**
Clay (%)	18 a	22 b	24 b	21 ± 4	0.0001**
pH	6.0 b	5.9 b	5.4 a	5.8 ± 0.5	0.0001**
N (%)	0.69 a	0.76 a	0.94 b	0.8 ± 0.2	0.0001**
C (%)	8.6 a	9.1 a	11.9 b	9.9 ± 2.9	0.0001**
C/N	12.2 a	11.7 a	12.8 a	12.2 ± 1.9	0.1390
P (mg kg^{-1})	44 b	65 c	22 a	44 ± 25	0.0001**
K (mg kg^{-1})	440 a	350 a	408 a	399 ± 156	0.1270
Ca (mg kg^{-1})	4,332 a	4,253 a	3,830 a	4,138 ± 1,062	0.2150
Mg (mg kg^{-1})	291 b	252 a	230 a	258 ± 59	0.0010**
			Litter		
Mass (g m^{-2})	4,665 a	4,338 a	5,033 a	4,679 ± 1,676	0.3610
pH	6.4 c	5.9 b	5.6 a	6 ± 0.4	0.0001**
N (%)	1.31 a	1.17 a	1.21 a	1.23 ± 0.4	0.4250
C (%)	31.1 a	30.9 a	31.1 a	31.1 ± 5.8	0.9970
C/N	24.4 a	28.1 a	28.6 a	27.0 ± 8.3	0.1610
P (mg kg^{-1})	902 a	950 a	1,019 a	957 ± 185	0.0880
K (mg kg^{-1})	1,755 a	1,776 a	1,996 a	1,842 ± 390	0.0580
Ca (mg kg^{-1})	17,817 b	15,101 b	8,851 a	13,923 ± 6,565	0.0001**
Mg (mg kg^{-1})	2,090 c	1,938 b	1,628 a	1,886 ± 323	0.0001**

Sd: standard deviation, means within rows following by the same letter are not statistically different at 0.05 significance level in Duncan post hoc test. ** *P*-values are significant ($P < 0.01$).

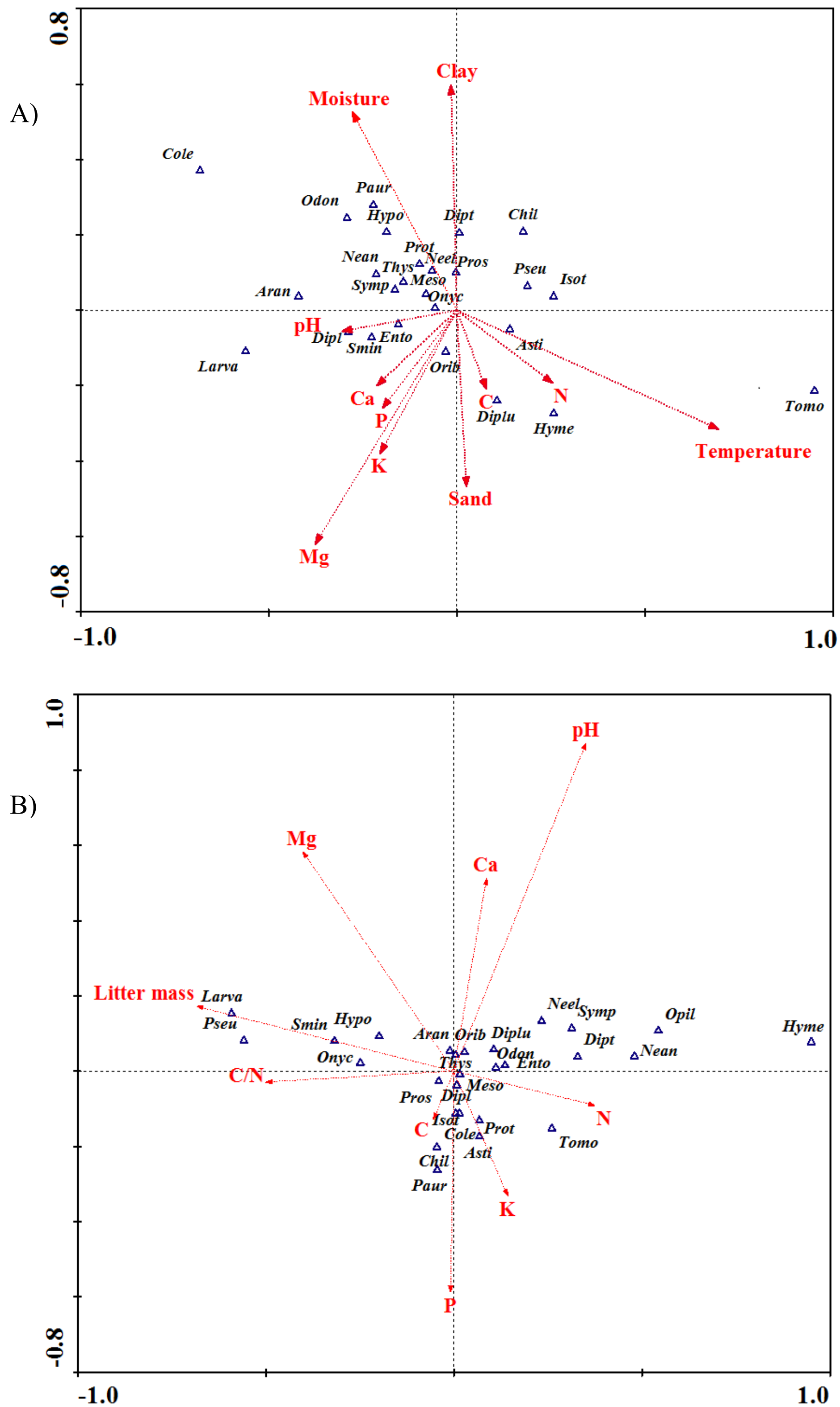

Figure 1. The CCA chart on the relationship of the arthropod with A) soil properties and B) litter characteristics.

Mapa del análisis de correspondencia canónica sobre las relaciones de los artrópodos con las características del suelo (A) y mantillo (B).

correlated with Odontellidae taxon. Soil moisture was negatively correlated with Oribatida and Hymenoptera taxa and positively correlated with Odontellidae taxon. The soil sand ratio was in positive correlation with Oribatida taxon despite soil clay ratio was negatively correlated with Oribatida, Diplura and Hymenoptera taxa. Soil calcium and magnesium concentrations were in positive correlation with Oribatida taxon (figure 1A).

As a result of the CCA analysis, the explanation rates of axes for the variation in taxa due to litter characteristics were cumulatively determined as: first axis = 41.4 %, second axis = 65.6 %, third axis = 82.9 % and fourth axis = 90.1 %. According to the relationships between arthropod abundance and litter characteristics; the litter mass was in positive correlation with insect larvae, Sminthuridae, Onychiuridae and Hypogastruridae, and it was negatively correlated with Tomoceridae, Neanurinae and Neelidae taxa. Litter nitrogen concentration and pH had a positive correlation with Hymenoptera, Entomobryidae, Symphyla and Diptera. Furthermore, litter phosphorus concentration was positively correlated with Astigmata and Pauropoda (figure 1B).

In total, 54,348 individual soil arthropods were counted, identified and classified from a total of 144 litter and soil samples throughout the study period. The identified arthropods belonged to 90 different taxa within six classes and 28 orders. The abundance of these taxa was significantly different across habitats, altitudes and seasons throughout the year. The annual mean individual number of arthropods per square meter was found to be 97,914 in soil, 175,822 in litter amounting to 273,736 in total (table 3).

Acarina and Collembola were the most abundant taxa in both soil and litter. The number of Acarina per square meter was 64,391 (66 %) in soil and 118,013 (67 %) in litter; however, the number of Collembola was 26,827 (27 %) in soil and 54,086 (31 %) in litter (table 3).

In both soil and litter habitats, the abundance of the families in Acarina was in descending order in Oribatida, Prostigmata, Mesostigmata and Astigmata. Similarly, abundances of Collembola families were in descending order in Isotomidae and Odontellidae. Other arthropod groups were also found to be in various abundances and ratios (table 3).

As regards the seasonal variation in arthropods; soil-dwelling arthropods such as Mesostigmata, Oribatida, Prostigmata, Symphyla, insect larvae, Diptera, Onychiuridae, Entomobryidae and Isotomidae showed a significant ($P < 0.05$) seasonal difference. Mesostigmata, Oribatida, Onychiuridae and Isotomidae were more abundant in summer while Prositigmata was less abundant (20 %) especially in winter compared to other seasons. The abundance of soil-dwelling arthropods in litter such as Mesostigmata, Oribatida, Prostigmata, insect larvae, Onychiuridae, Odontellidae, Entomobryidae, Isotomidae, Tomoceridae, Neelidae, Sminthuridae and Protura taxa was also significantly different among seasons. Acarina families such as Mesostigmata, Oribatida and Prostigmata with Onychiuridae and Sminthuridae from Collembola were in minimum abundance in summer. On the other hand, an overall seasonal comparison revealed that the number of arthropods in soil (individuals m^{-2}) was the maximum (158,655) in summer and the lowest (61,249) in winter, whereas the number of litter arthropods was the highest (232,093) in autumn and the minimum (137,452) in summer (table 3).

Regarding the variation in arthropods depending on altitude, only Diptera and Isotomidae taxa of soil-dwelling arthropods in mineral soil showed a significant difference. Furthermore, Oribatida, Isotomidae, Tomoceridae and Neelidae taxa in litter had significant altitudinal differences. As regards the variation in arthropods between soil and litter, only Tomoceridae showed a significant ($P = 0.029$) difference, all other arthropods in soil and litter except Tomoceridae had a similar distribution and did not have statistically significant differences. The altitudinal distribution of soil arthropods (individuals m^{-2}) was the maximum at 1,550 m (101,797) and the minimum at 1,400 m (93,717), although the abundance of litter arthropods was the highest at 1,200 m (190,793) and similar to the soil results, the lowest litter arthropod were detected at the altitude of 1,400 m (166,880) (table 4).

Regarding the preference of litter or soil habitats; Mesostigmata, Oribatida, Prostigmata, Symphyla, insect larvae, Onychiuridae, Isotomidae, Entomobryidae, Tomoceridae and Sminthuridae taxa showed significant differences depending on the seasons. Although the results in habitat preferences were not significantly different, mineral soil was more preferable for Pauropoda, Thysanoptera, Odontellidae, Neelida and Protura taxa, while the others preferred the litter (tables 3 and 4).

DISCUSSION

Seasonal and altitudinal changes in soil properties and litter characteristics. Soil moisture and temperature were significantly different among seasons. Soil moisture changed significantly whereas soil temperature did not change significantly across altitudes. Contrary to soil sand contents, soil clay contents showed a significantly increasing trend with altitude. Possibly because particle separation and clay formation are faster in the relatively more humid and more extreme climatic conditions that prevail at higher elevations and in the north aspect. Moreover, significantly changing clay content of soil at different altitudes may influence the altitudinal variations in soil moisture. Consistently with our results, Griffiths *et al.* (2009) demonstrated that soil moisture was significantly different depending on both altitude and season.

Litter characteristics that had significant differences across seasons included litter mass, pH, nitrogen, C/N, potassium and magnesium. Furthermore, pH, phosphorus, calcium and magnesium were the altitudinal litter characteristics that differed significantly. Significant seasonal changes in the soil properties were found to be in pH, nitrogen and C/N; furthermore, soil properties such as sand, silt, clay,

Table 3. Seasonal arthropod abundance under fir forest in different habitats.

Abundancia estacional de artrópodos en diferentes hábitats del bosque de abetos.

Taxa	Codes	Soil habitat					Litter habitat					Soil	Litter	
		Winter	Spring	Summer	Autumn	P	Winter	Spring	Summer	Autumn	P	Mean ± Sd.	Mean ± Sd.	P
		Individuals m^{-2}					Individuals m^{-2}					Individuals m^{-2}		
Araneae	Aran	61	0	0	61	0.272	111	61	92	276	0.577	31 ± 127	135 ± 490	0.764
Opiliones	Opil	0	0	0	0	.	0	31	0	0	0.399	0 ± 0	8 ± 65	0.395
Pscorpionida	Pseu	0	31	0	0	0.399	28	0	0	0	0.056	8 ± 65	7 ± 36	0.141
Mesostigmata	Meso	7,181 ab	5,370 a	9,574 b	6,014a	0.015*	9,451 a	9,022 a	6,720 a	13,380 b	0.008**	7,035 ± 4,419	9,643 ± 6,033	0.000**
Oribatida	Orib	25,042 a	32,837 a	66,257 b	28,325 a	0.000**	66,049 a	69,234 a	53,736 a	110,940 b	0.000**	38,115 ± 34,867	74,990 ± 37,425	0.000**
Astigmata	Asti	153	1,074	1,104	245	0.162	1,368	1,381	1,135	2,025	0.601	644 ± 1,664	1,477 ± 2,086	0.169
Prostigmata	Pros	4,265 a	19,947 b	23,108 b	27,067 b	0.000**	34,688 b	36,519 b	18,290 a	38,115 b	0.001**	18,597 ± 15,396	31,903 ± 19,213	0.000**
Chilopoda	Chil	31	31	153	92	0.264	63	276	123	123	0.175	77 ± 213	146 ± 298	0.121
Diplopoda	Dipl	92	215	61	61	0.611	97	31	123	123	0.599	107 ± 389	94 ± 240	0.331
Symphyla	Symp	153 a	797 b	215 a	491 ab	0.001**	35	61	123	92	0.510	414 ± 577	78 ± 187	0.002**
Pauropoda	Paur	245	2,884	1,197	890	0.453	417	460	491	399	0.994	1,304 ± 5,056	442 ± 1,105	0.486
Larvae	Larva	337 b	0 a	0 a	0 a	0.001**	924 b	0 a	0 a	0 a	0.000**	84 ± 316	231 ± 558	0.000**
Diptera	Dipt	0 a	153 ab	245 ab	399 b	0.039*	42	184	368	245	0.302	199 ± 484	210 ± 532	0.641
Coleoptera	Cole	61	61	0	61	0.801	104	184	123	123	0.917	46 ± 222	134 ± 347	0.915
Hymenoptera	Hyme	0	0	61	0	0.068	76	92	1,105	0	0.396	15 ± 91	318 ± 2,216	0.447
Thysanoptera	Thys	460	245	491	337	0.517	90	31	123	61	0.471	383 ± 583	76 ± 176	0.820
Neanurinae	Nean	92	0	153	92	0.561	69	31	1,074	123	0.209	84 ± 330	324 ± 1,720	0.300
Onychiuridae	Onyc	5,738 ab	3,897 a	8,316 b	4,480 a	0.005**	15,361 c	8,009 b	2,639 a	6,168 ab	0.000**	5,608 ± 4,284	8,044 ± 7,283	0.000**
Hypogastruridae	Hypo	2,670	2,148	1,565	1,688	0.805	5,674	7,211	5,125	4,879	0.904	2,018 ± 3,878	5,722 ± 10,089	0.940
Odontellidae	Odon	245	31	31	215	0.056	42 a	0 a	0 a	276 b	0.001**	130 ± 314	80 ± 262	0.195
Entomobryidae	Ento	3,161 ab	1,442 a	3,437 b	1,534 ab	0.041*	6,826 a	5,892 a	15,620 b	7,027 a	0.000**	2,393 ± 2,839	8,841 ± 7,664	0.001**
Isotomidae	Isot	6,782 a	6,137 a	37,041 b	9,360 a	0.000**	22,743 a	25,287 a	26,699 a	42,135 b	0.001**	14,830 ± 18,729	29,216 ± 20,456	0.000
Tomoceridae	Tomo	0	0	31	0	0.399	83 a	31 a	583 b	368 ab	0.013*	8 ± 65	266 ± 606	0.018*
Neelidae	Neel	1,258	1,595	1,994	1,994	0.630	160 a	1,013 a	1,012 a	2,547 b	0.002**	1,710 ± 1,986	1,183 ± 1,964	0.232
Sminthuridae	Smin	31	92	0	61	0.289	903 b	522 ab	61 a	153 a	0.034*	46 ± 154	410 ± 988	0.037*
Diplura	Diplu	61	31	215	31	0.091	139	123	522	337	0.061	85 ± 256	280 ± 514	0.413
Protura	Prot	3,130	4,020	3,406	5,217	0.424	306 a	2,209 b	1,565 ab	2,178 b	0.012*	3,943 ± 3,989	1,564 ± 2,014	0.771
Total		61,249	83,038	158,655	88,715	-	165,849	167,895	137,452	232,093	-	97,914	175,822	-

Sd: standard deviation, Ind.: individuals, means within rows following by the same letter are not statistically different at 0.05 significance level in Duncan post hoc test. Significant P-values: $*P < 0.05$, $**P < 0.01$).

Table 4. Altitudinal arthropod abundance under fir forest in different habitats.

Abundancia altitudinal de artrópodos en diferentes hábitats del bosque de abetos.

Taxa	Codes	Soil habitat				Litter habitat				Soil	Litter	
		1,200 m	1,400 m	1,550 m	*P*	1,200 m	1,400 m	1,550 m	*P*	Mean ± Sd.	Mean ± Sd.	*P*
		Individuals m-2				Individuals m-2				Individuals m-2		
Araneae	Aran	23	46	23	0.780	146	231	28	0.376	31 ± 127	135 ± 490	0.475
Opiliones	Opil	0	0	0	n/a	0	23	0	0.374	0 ± 0	8 ± 65	0.371
P.scorpionida	Pseu	0	0	23	0.374	5	10	5	0.847	8 ± 65	7 ± 36	0.379
Mesostigmata	Meso	6,973	7,434	6,697	0.817	10,667	8,804	9,459	0.510	7,035 ± 4,419	9,643 ± 6,033	0.506
Oribatida	Orib	47,943	31,647	34,755	0.110	95,909 b	64,190 a	64,870 a	0.000**	38,115 ± 34,867	74,990 ± 37,425	0.219
Astigmata	Asti	552	414	966	0.483	1,276	1,087	2,069	0.221	644 ± 1,664	1,477 ± 2,086	0.826
Prostigmata	Pros	18,666	15,444	21,681	0.238	35,009	25,188	35,511	0.050	18,597 ± 15,396	31,903 ± 19,213	0.529
Chilopoda	Chil	46	115	69	0.527	51	215	171	0.148	77 ± 213	146 ± 298	0.576
Diplopoda	Dipl	23	207	92	0.276	46	190	44	0.051	107 ± 389	94 ± 240	0.866
Symphyla	Symp	483	437	322	0.541	113	97	23	0.200	414 ± 577	78 ± 187	0.903
Pauropoda	Paur	368	851	2,693	0.254	181	354	791	0.146	1,304 ± 5,056	442 ± 1,105	0.477
Larvae	Larva	69	138	46	0.529	380	125	188	0.259	84 ± 316	231 ± 558	0.050
Diptera	Dipt	161 ab	368 b	69 a	0.043*	361	171	97	0.199	199 ± 484	210 ± 532	0.118
Coleoptera	Cole	0	92	46	0.374	49	249	102	0.147	46 ± 222	134 ± 347	0.619
Hymenoptera	Hyme	46	0	0	0.091	814	56	85	0.414	15 ± 91	318 ± 2,216	0.457
Thysanoptera	Thys	345	414	391	0.907	74	82	72	0.978	383 ± 583	76 ± 176	0.929
Neanurinae	Nean	69	161	23	0.327	161	681	131	0.458	84 ± 330	324 ± 1,720	0.626
Onychiuridae	Onyc	5,201	5,846	5,777	0.816	8,644	9,402	6,087	0.071	5,608 ± 4,284	8,044 ± 7,283	0.141
Hypogastruridae	Hypo	1,058	3,268	1,726	0.117	5,957	4,957	6,253	0.900	2,018 ± 3,878	5,722 ± 10,089	0.538
Odontellidae	Odon	46	138	207	0.169	51	164	23	0.089	130 ± 314	80 ± 262	0.103
Entomobryidae	Ento	2,485	2,762	1,933	0.537	10,273	8,213	8,038	0.404	2,393 ± 2,839	8,841 ± 7,664	0.480
Isotomidae	Isot	8,101 a	17,584 b	18,804 b	0.004**	16,564 a	38,653 b	32,431 b	0.000**	14,830 ± 18,729	29,216 ± 20,456	0.078
Tomoceridae	Tomo	0	0	23	0.374	23 a	453 b	323 ab	0.028*	8 ± 65	266 ± 606	0.029*
Neelidae	Neel	1,841	2,278	1,012	0.088	1,986 b	954 ab	609 a	0.025*	1,710 ± 1,986	1,183 ± 1,964	0.157
Sminthuridae	Smin	92	46	0	0.108	561	195	473	0.367	46 ± 154	410 ± 988	0.393
Diplura	Diplu	138	23	92	0.280	392	167	281	0.298	85 ± 256	280 ± 514	0.789
Protura	Prot	3,498	4,004	4,327	0.775	1,100	1,969	1,624	0.285	3,943 ± 3,989	1,564 ± 2,014	0.875
Total		98,227	93,717	101,797	-	190,793	166,880	169,788	-	97,914	175,822	-

Sd: standard deviation, Ind.: individuals, means within rows following by the same letter are not statistically different at 0.05 significance level in Duncan post hoc test.
Significant *P*-values: $*P < 0.05$, $**P < 0.01$).

pH, nitrogen, carbon, phosphorus, calcium and magnesium varied significantly across altitudes. Similarly, Zhao *et al.* (2014) reported that the distribution and the presence of soil and litter arthropods substantially depended on physical and chemical properties of soil and litter such as temperature, moisture, pH, etc. in the temperate forest ecosystems.

The average annual litter mass was 4,679 g m^{-2}. In different studies conducted in fir stands and supporting the results of this research, litter mass was found close to our value as 3850 g m^{-2} by Kantarcı (1979) in the same region. Moreover, similar to our results, they did not find significant differences at different altitudes. On the other hand, contrary to our results, some researchers found that altitude had a significant effect on litter mass alterations (Güner 2006). There was a high variation among seasons regarding litter mass, which is consistent with our results; whereas several researches demonstrated different forest floor-litter changes in different seasons depending mostly on decomposition processes (Akburak and Makineci 2013).

Values of pH in both soil and litter are inversely related with altitude. In other words, the reactions of soil and litter are acidified with increasing altitude. Different results are reported in literature in this context. Güner (2006) stated that soil reaction changed significantly at different altitudes. Bolat (2011) found significant seasonal changes in pH of fir litter; however, no significant changes were found in soil pH.

Litter and soil C/N ratios were significantly different across seasons. Litter nitrogen concentrations did not change significantly depending on the season, whereas contrary to our results, significant seasonal variations were found in the litter nitrogen ratios in fir stands (Bolat 2011) and in oak stands (Çakır 2013). Similar to our findings at the altitude steps; Kidanemariam *et al.* (2012) found a significant variation in litter or soil nitrogen depending on the altitude; while contrary to these results, Güner (2006) did not detect a significant change.

In this study, soil phosphorus ratio had a negative correlation with altitude. The soil phosphorus concentrations found by Kidanemariam *et al.* (2012) in forest soils were very close to the ones revealed in this present study.

Although calcium concentrations of litter and soil were not significantly correlated with season, they had a significantly negative correlation with altitude. Similarly, Yılmaz (2004) found a significantly negative correlation between altitude and soil calcium concentration. Contrary to these results, Güner (2006) found no significant correlation between soil calcium and altitude but a significantly positive correlation between litter calcium and altitude.

In this present study, magnesium concentrations of litter and soil differed considerably between seasons and altitudes. Moreover, Kantarcı (1979) highlighted a significant difference at the altitude steps in the same research area. Similar to our results, Yılmaz (2004), found a significantly negative correlation between the soil magnesium and altitude; in contrast, Güner (2006) reported a significantly positive correlation between altitude and litter magnesium.

Variation in arthropods. The distribution of arthropods in different habitats (soil and litter) showed significant variations. As mentioned above, differences in soil properties and litter characteristics due to altitudinal and seasonal changes were the possible causes of such variations. In this context, Antunes *et al.* (2008) stated that distribution of arthropods was not random, and strongly depended on chemical, physical and ecological conditions. Furthermore, they demonstrated that factors such as climatic, geomorphological, physical and chemical conditions in addition to the processes related to the distribution, growth and development of flora and fauna as well as the relationships between competition and predation were the main effects on the distribution of soil arthropods.

Litter mass and depth or structural features of micro habitats can influence the life cycle of arthropods. Many groups of arthropods are sensitive to the structure of litter; especially Araneae and Acarina are sensitive to litter features (Hansen 2000). In our study, Hypogastruridae, insect larvae, Onychiuridae and Sminthuridae taxa were positively correlated and Tomoceridae taxon was negatively correlated with litter mass.

Biological activities can only be initiated under the available temperature and moisture conditions. The temperature and moisture of soil have a major impact on the life of arthropods. Medianero *et al.* (2007) demonstrated that the rising temperature under the available moisture conditions increased the abundance of arthropods, and the water loss of both litter and soil due to the increased evaporation at higher temperatures decreased the abundance of arthropods. This may also be relevant for the interpretation of the results of the present study.

Soil sand content had a significantly positive correlation with taxa of Oribatida, Hymenoptera, and Diplura. On the other hand, soil clay content had a significantly positive correlation with Diptera and Prostigmata and negative correlation with Oribatida, Hymenoptera and Diplura. Sandy soil might be specifically preferred by saprophagous taxa because of its large porous structure for feeding and sheltering. Similarly, Gutiérrez-López *et al.* (2010) found that Isotomidae, Sminthuridae, Actinedida and Macropylina taxa had a positive correlation with clay and silt contents of soils; however, Poduromorpha and Entomobryidae taxa had a higher correlation with sand content and porosity of soil.

The reactions (pH) of soil and litter and nutrients showed significant correlations with some of arthropod taxa. Phosphorus, potassium, nitrogen and sodium are important nutrients related to soil arthropod fauna (Razo-González *et al.* 2014). Furthermore, taxa that have well-developed external skeletons such as Oribatida contain high amounts of calcium compounds such as calcium carbonate, calcium oxalate and calcium phosphate in their external skeletons (Coleman *et al.* 2004). Oribatida and Coleoptera had significantly positive correlations with calcium and magnesium in our study. Gutiérrez-López *et al.* (2010) found a positive correlation between soil pH and

Isotomidae, Sminthuridae, Actinedida and Macropylina taxa. On the other hand, Abbas (2012) demonstrated that the abundance of Collembola had a significantly negative correlation (r > -0.708) with soil pH in both the natural and degraded sites under monsoon climate. In the acid soil in coniferous forests, arthropods feeding on litter such as Collembola and Oribatida were the dominant groups. The addition of nutrients with nitrogen to the site directly influences microbial communities; therefore, it also causes an increase in the number of consumers of microbial bacteria and fungi such as Collembola and Acarina (Cole *et al.* 2008). Moreover, the diet of some macro-arthropods such as spiders and ants that are predators and omnivore largely depends on the presence of Collembola and mites, while their abundance may also increase (Halaj and Wise 2002).

In addition to the changing soil and litter characteristics, the changes in soil temperature or moisture arising from altitudinal and seasonal differences influence both some ecological characteristics and the life cycle of arthropods (Logan *et al.* 2006). Because of these alterations, the abundance and community structure of the arthropods in the environment also show seasonal and altitudinal changes. Acarina and Collembola taxa were the most affected arthropod groups. Significant changes in the distribution of soil arthropods due to the season are mainly controlled by the interactions between soil temperature and soil moisture. Arthropods living in the litter are more sensitive to seasonal changes than soil micro-arthropods and they can migrate into deeper soil layers in different seasons (Medianero *et al.* 2007). Abbas (2012) showed that the number of Collembola individuals was significantly different in seasons in the monsoon climate region while the cause of this was observed to be large-scale seasonal variations in soil temperature and moisture.

Önen and Koç (2011) reported that Oribatida and Mesostigmata taxa were observed to be the most abundant in the winter; however, Prostigmata and Astigmata taxa were the most abundant in spring. Similar to our results, they stated that the abundances of all taxa were the lowest in summer, possibly resulting from summer drought in the soil. The wide range of climatic changes due to altitude can alter the structure of the arthropod community and can affect the activity rate of specific species. Arthropods response to the changing environmental conditions due to altitude. In forestlands, local climate variations resulting from altitudinal changes lead to the taxa-specific variations. However, it is difficult to generalize all variations depending on the altitudinal differences. Due to rising seasonal temperature and declining soil moisture, some arthropod taxa migrated from the litter to the mineral soil in summer. The number of individuals was found to be the highest in soil and the lowest in litter. Similar to our findings, Önen and Koç (2011) reported that arthropods could migrate vertically into the soil layers due to the seasonal conditions in addition to the seasonal and altitudinal changes.

CONCLUSIONS

In conclusion, arthropods have different variations in abundance and diversity depending on the altitudinal and seasonal features. Besides, we have shown that abundance-diversity of soil arthropods were not random, and strongly depended on chemical and physical properties of soil and litter in different seasons and altitudes throughout the one-year research period. The local factors in the research area such as spatial variation in resource availability in different habitats (soil and litter) and microclimate may further influence the abundance and individuals of particular taxa. Moreover, the contribution of these organisms to the ecosystem processes may also vary depending on these alterations. However, the sampling was performed at each altitude in four seasons, and the study period was one year. A bigger number of samplings may give clearer results and repeated ongoing surveys would help clarifying the patterns.

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