BOSQUE 39(3): 441-447, 2018 DOI: 10.4067/S0717-92002018000300441

Richness and diversity of litter and soil fauna as affected by differences in three fir species

Riqueza y diversidad de la hojarasca y la fauna del suelo afectado por las diferencias en tres especies de abeto

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SUMMARY

The main objective of this study was to evaluate the relationships between soil and litter properties and the distribution and diversity of microarthropods in Atatürk Arboretum (Turkey). Soil and litter samples were collected from three fir species: Taurus fir (T_F – *Abies cilicica* Carr.), Uludağ fir (U_F – *Abies nordmanniana* ssp. *bornmuelleriana* Mattf.) and Caucasian fir (C_F – *Abies nordmanniana* ssp *nordmanniana* Mattf.). Microarthropods were sampled bimonthly using steel soil corers from May 2012 to March 2013. Redundancy analysis (RDA) detected clear relationships between microarthropods and litter mass and soil moisture. Litter mass at site C_F was significantly larger than that at sites U_F and T_F. The mean annual density of microarthropods per square meter was 62,888 individuals.m^{-2} for site T_F, 57,246 individuals.m^{-2} for site U_F, and 59,959 individuals.m^{-2} for site C_F. Shannon-Wiener diversity index (*H′*) values were significantly different among the study sites. Species diversity of soil arthropods was higher at site C_F than at sites T_F and U_F. Results show that soil pH, litter mass and soil moisture are the principal attributes determining richness and diversity of microarthropods found under three different fir species.

Key words: Microarthropods, fir, litter, biodiversity, Atatürk Arboretum.

RESUMEN

El objetivo principal de este estudio fue evaluar las relaciones entre las propiedades del suelo y la hojarasca en relación con la distribución y la diversidad de microartrópodos en Atatürk Arboretum (Turquía). Se tomaron muestras de suelo y hojarasca de tres especies de abeto: abeto Taurus (T_F - *Abies cilicica*), abeto Uludağ (U_F - *Abies nordmanniana* ssp.*bornmuelleriana*) y abeto caucásico (C_F - *Abies nordmanniana* ssp *nordmanniana*). Los microartrópodos fueron muestreados bimestralmente, utilizando cilinderos de acero de suelo de acero desde mayo de 2012 hasta marzo de 2013. El análisis de redundancia (RDA) detectó claramente relaciones entre los microartrópodos y la masa de la hojarasca y la humedad del suelo. La masa del suelo del bosque en el sitio CF fue significativamente mayor que la de los sitios U_F y T_F. La densidad media anual de microartrópodos por metro cuadrado fue de 62.888 para el sitio T_F, mientras que 57.246 para U_F y 59.959 para C_F. Los valores del índice de diversidad de Shannon-Wiener (*H'*) fueron significativamente diferentes entre los sitios de estudio. La diversidad de especies de artrópodos del suelo fue mayor en el sitio de C_F que en los sitios de T_F y U_F. Los resultados mostraron además que el pH del suelo, la masa de la hojarasca y la humedad del suelo fueron los principales atributos que determinaron la riqueza y la diversidad de los microartrópodos bajo tres especies diferentes de abeto.

Palabras clave: microartrópodos, abeto, hojarasca, biodiversidad, Arboreto de Atatürk.

INTRODUCTION

Tree species affect ecosystem properties and soil structure through the chemical and physical effects of their roots and improve the nutrient content of soils through the decomposition of their litter (Binkley and Giardina 1998). Biologically, trees affect almost all organisms in forest ecosystems. Differences in the chemical composition of litter may have considerable effects on the community structure of arthropods (Çakır and Makineci 2018). Thick litter layers also increase the available habitat space (Scheu *et al.* 2003) and regulate microclimate for soil fauna. Humus forms and litter quality may affect the abundance and diversity of microarthropods (Cakir and Makineci 2013).

Previous studies have shown that microarthropods are non-randomly distributed and reported that their abundance and diversity are strongly related to the chemical, physical and ecological properties of their environment (Antunes *et al.* 2008). Important factors determining microarthropod composition include vegetation type, soil structure and chemistry, organic matter, soil microflora, and soil moisture and temperature (Gutiérrez-López *et al.*

2010). The relationships among microarthropod species can also determine the spatial distribution of microarthropods (Wardle 2002). Previous studies have shown that predator relationships are an important factor in determining the distribution of microarthropods (Birkhofer *et al.* 2011).

The relationship between soil biodiversity and forest trees has been previously investigated. Previous studies have shown that the effect of tree species on microarthropod diversity can be positive (Sabais *et al.* 2011), negative (Alphei *et al.* 1996) or neutral (Wardle 2002). Only a few studies have shown how trees species affect soil microarthropod diversity. However, the effect remains unknown in these fir species.

The genus *Abies* (Pinaceae) includes 48–49 species spread throughout the world. This genus is represented by two species and six subspecies in Turkey. The most common fir taxa in Turkey are Taurus fir (T_F – *Abies cilicica* Carr.), Uludağ fir (U_F – *Abies nordmanniana* ssp. *bornmuelleriana* Mattf.) and Caucasian fir (C_F – *Abies nordmanniana* ssp *nordmanniana* Mattf.). The total area of Turkey covered by firs is 626647 ha (Yaltırık and Akkemik 2011). These tree species are found in different locations in Turkey, specifically the Mediterranean and Black Sea regions. In addition, these tree species were planted in Atatürk Arboretum in 1960. These stands have the same soil types and almost the same site characteristics, such as climate and hydrology.

All possible responses – positive, negative and neutral – have been found when examining the effect of tree species on the abundance and diversity of microarthropods; although, it is not clearly known which factors influence these changes in the community structure (Wardle 2002). Microarthropod abundance and diversity were investigated under three fir species in Atatürk Arboretum to determine the effect of tree species on the community structure of microarthropods and some litter and soil properties. The aims of this study are to (1) determine how tree species affect the physicochemical characteristics of litter and soil, and (2) compare soil microarthropod abundance and diversity found under three different fir species.

METHODS

The study area, Atatürk Arboretum, is located in Belgrad Forest in Istanbul, Turkey, between 41°09′48″–41°10′55″ N latitudes and 28°57′27″–28°59′2 7″ E longitudes. The altitude is 140 m, the slope is 10–15 %, and the area is southerly exposed. According to the long-term data from the Bahcekoy Meteorology Station, the nearest meteorology station to the study area, the mean annual precipitation is 1121 mm, the mean annual temperature is 13.0 °C, the mean highest temperature is 17.8 °C and the mean lowest temperature is 9.0 °C. Belgrad Forest has a maritime climate with moderate water deficiency in summers. According to the World Reference Base for Soil Resources (WRB), the soil group in the research area is Luvisol. The soil texture is loamy and well drained. The vegetative period lasts for 7.5 months (230 days) on average. Atatürk Arboretum (~296 ha) was established in 1949 and is home to over 2,000 plant species, as well as a variety of insects and birds.

Microarthropods were sampled bimonthly from May 2012 to March 2013. At each site (U_F, C_F, and T_F), a 40 × 40 m plot was established and divided into three 4 × 4 m subplots. Microarthropods were collected (5 cm diameter, 5 cm length) from each subplot using a soil core. Abundance and diversity of total microarthropods were obtained from three samples at each sampling plot on each sampling date. A total of 54 samples (3 sites × 3 plots × 6 months) was collected. Microarthropods were extracted using Tullgren funnels (Coleman *et al.* 2004). The extraction process was completed (± 72 h) when the soil was completely dried. All extracted arthropod samples were preserved in 70 % ethanol and identified up to the order or family level, then counted under a stereoscopic microscope (Leica S8 APO; Leica Microsystems, Germany).

Soil samples (5 cm diameter, depth 5 cm) were collected bimonthly from three blocks at each site from 2012 to 2013, using steel soil cores. Soil temperature was measured with a soil thermometer at 5 cm depth at each sampling point. The soil was homogenized by hand kneading the sampling paper bags. Stone, macrofauna and plant roots were removed carefully. Soil samples were oven-dried at 105 °C for 48 h, and afterwards, finely ground (< 2 mm) for analyses. Soil pH and electrical conductivity (EC) were determined with a combination electrode using 1:2.5 and 1:5 ratios of soil to deionized water, respectively. Litter samples were collected from three sampling points, using 0.25-m² at approximately 4-m intervals, under each of the tree species. Litter samples were oven-dried at 75 °C for 48 h to determine the dry weight and, subsequently, finely ground (< 0.5 mm) for analyzing carbon and nitrogen. Soil and litter carbon and nitrogen contents were determined using a CN analyzer (LECO, St. Joseph, MI, USA).

Physical, chemical and biological data were analyzed by one-way analysis of variance (ANOVA). The difference among groups was determined by Tukey's HSD, using $P < 0.05$ level of significance. The same test was performed to assess the difference in taxa abundance between months. Most of the variables were not normally distributed and therefore were log transformed. Diversity (Shannon-Wiener), richness (Margalef) and evenness (Pielou) indices were calculated for each sampling area (Shannon and Weaver 1949). The relationship between microarthropods and explanatory variables was analyzed using redundancy analysis (RDA). The effect of tree species on microarthropod community composition was analyzed using CANOCO, version 5.0 (ter Braak and Šmilauer 2012). Statistical significance of RDA was evaluated with a Monte Carlo test with 999 permutations.

RESULTS

Most litter and soil variables and some of the arthropod related variables were significantly different among fir species (table 1). The mass of the litter at site C_F was significantly higher ($P < 0.01$) than that at sites U_F and T_F. Carbon and nitrogen concentrations of litter were significantly higher at site U_F ($P < 0.01$) than at sites T_F and C_F (Table 1). There was no significant difference in the C/N ratio of litter among study sites. Soil carbon and C/N ratios at site T_F were significantly higher ($P < 0.01$) than those at the other two sites, while soil pH was significantly higher ($P < 0.01$) at site C_F. Non-significant differences were recorded for other soil parameters (moisture content, soil temperature, nitrogen concentration and electrical conductivity) among sampling sites. Shannon diversity index (H′) was significantly different among the study sites. Species diversity of microarthropods was higher at site C_F than at sites T_F and U_F. Evenness values were not significant among the three fir species ($P > 0.05$) (table 1).

Microarthropods were distributed among 31 taxa (table 2). Microarthropod abundance varied between 62,888 individuals m^{-2} (T_F) and 57,246 individuals m^{-2} (U_F) across the fir species sites. Collembola and Acari were the dominant groups, accounting for 97 % in T_F, 96 % in U_F and 95 % in C_F of the total soil microarthropods. Among these, Isotomidae (Collembola), Oribatida, Prostigmata and Mesostigmata (Acari) were the most abundant groups in the soil samples.

Some microarthropods were significantly different across the firs. Entomobryidae, Tomoceridae, Sminthuridae, Neelidae (Collembola), Chordeumatida (Diplopoda), Oniscidae (Isopoda) and Pseudoscorpionida were found in significantly superior abundance at site C_F (table 2). Prostigmata was the only group that differed significantly in abundance among firs that was not found in the highest abundance at site C_F. Hypopus, which is a unique nymphal stage of some astigmatic mites, Polidesmida, Chordeumatida, Lithobiomorpha and Scutigerella taxa did not occur at site U_F, while Isopoda taxa (Oniscidae and Armadillidiidae) occurred only at site C_F; Polyxenidae (Diplopoda), however, occurred only at sites T_F and U_F. Pauropoda, Araneae, Geophilimorpha and Japigidae were absent at site T_F.

Seasonal changes in the abundance of some taxa found under the three different fir species are shown in figure 1. Oribatida, Prostigmata and Isotomidae are the most abundant taxa in the study area. There are significant differences among mean values for microarthropod taxa over time (months). This can be attributed to increase in humidity in spring and autumn and decrease in humidity during summer and winter drought periods (figure 1).

Table 1. Chemical, physical and biological properties of the study area in Atatürk Arboretum.
Propiedades químicas, físicas y biológicas del área de estudio en Atatürk Arboretum.

	Variable	Taurus fir (T_F)	Uludağ fir (U_F)	Caucasian fir (C_F)	*P*
Litter	Mass (g m^{-2})	1,005.04±285.46 a	1,027.02±211.99 a	1,452.86±358.95 b	0.000
	N (%)	1.19±0.11 a	1.57±0.10 b	1.39±0.11 c	0.000
	C (%)	41.92±3.74 a	42.96±1.96 a	37.09±5.80 b	0.000
	C/N	28.26±3.49 a	27.32±1.76 ab	26.45±3.07 b	0.026
Soil	W (%)	34.95±13.03	28.74±11.92	31.59±13.13	0.348
	T (°C)	16.68±5.45	16.08±5.24	16.01±5.34	0.918
	N (%)	0.19±0.02 a	0.17±0.03 b	0.18±0.02 ab	0.007
	C (%)	6.91±1.86 a	5.28±2.32 b	4.65±1.59 b	0.003
	C/N	35.37±5.07 a	29.57±6.03 b	25.33±7.31 c	0.000
	pH-H_2O	5.08±0.35 a	5.14±0.32 a	5.58±0.12 b	0.000
	EC (µSM cm^{-1})	185.52±58.96	178.72±83.07	198.41±49.14	0.658
Micro-arthropods	H′	1.72±0.22 a	1.62±0.28 a	1.96±0.17 b	0.000
	S	11.11±2.94 a	10.22±2.73 a	13.00±3.59 b	0.002
	J′	0.52±0.07	0.53±0.13	0.57±0.10	0.340
	N (individuals m^{-2})	62,888.25±8,384.81	57,246.20±9,102.29	59,959.11±8,172.23	0.897

Values are the mean ± standard deviation. W, moisture content at sampling; T, temperature at soil sampling; N, nitrogen concentration; C, carbon concentration; EC, electrical conductivity; H′, Shannon-Wiener diversity index; S, Richness; J′, Pielou's Evenness; N, Abundance. Means with different letters in the same line are different ($P < 0.05$).

Table 2. Mean annual abundance and percentage of microarthropod groups (individuals per square meter) found under three different fir species.

Abundancia anual media y porcentaje de grupos de microartrópodos (individuos por metro cuadrado) en tres espesies diferentes de abetos.

Subclass/Order/Family		Code	Taurus fir (T_F)		Uludağ fir (U_F)		Caucasian fir (C_F)		*P*
			Mean	%	Mean	%	Mean	%	
Acari	Oribatida	Ori	16,002.20	25.45	13,092.71	22.87	13,800.42	23.02	0.716
	Astigmata	Ast	1,258.16	2.00	1,395.77	2.44	1,847.92	3.08	0.264
	Prostigmata	Pro	15,766.30 a	25.07	10,989.23 ab	19.20	6,919.87 b	11.54	0.001
	Mesostigmata	Mes	8,256.66	13.13	10,792.64	18.85	5,111.27	8.52	0.114
	Hypopus	Hyp	275.22	0.44	-	-	39.32	0.07	0.204
Collembola	Entomobryidae	Ent	4,030.04 a	6.41	1,926.56 a	3.37	9,219.94 b	15.38	0.000
	Tomoceridae	Tom	275.22 ab	0.44	157.27 a	0.27	982.94 b	1.64	0.035
	Isotomidae	Iso	12,050.80	19.16	14,665.41	25.62	11,323.43	18.89	0.735
	Sminthuridae	Smin	963.28 ab	1.53	609.42 a	1.06	2,850.52 b	4.75	0.027
	Neelidae	Nee	530.79 a	0.84	314.54 a	0.55	3,754.82 b	6.26	0.001
	Neanuridae	Nea	727.37	1.16	235.90	0.41	216.25	0.36	0.177
	Onychiuridae	Ony	432.49	0.69	196.59	0.34	314.54	0.52	0.523
	Hypogastruridae	Hypo	629.08	1.00	648.74	1.13	943.62	1.57	0.766
Diplopoda	Polidesmida	Poli	19.66	0.03	-	-	58.98	0.10	0.157
	Chordeumatida	Chor	19.66 a	0.03	-	-	294.88 b	0.49	0.035
	Polyxenidae	Poly	196.59 a	0.31	98.29 b	0.17	-	-	0.010
Chilopoda	Lithobiomorpha	Lith	58.98	0.09	-	-	39.32	0.07	0.223
	Geophilimorpha	Geo	-	-	98.29	0.17	58.98	0.10	0.336
Isopoda	Oniscidae	Onis	-	-	-	-	98.29	0.16	0.020
	Armadillidiidae	Arma	-	-	-	-	19.66	0.03	0.375
Protura		Prot	275.22	0.44	334.20	0.58	589.76	0.98	0.700
Pauropoda		Paur	-	-	196.59	0.34	294.88	0.49	0.127
Arachnida	Araneae	Arac	-	-	19.66	0.03	19.66	0.03	0.609
Diplura	Campodeidae	Camp	39.32	0.06	19.66	0.03	216.25	0.36	0.061
	Japygidae	Japi	-	-	39.32	0.07	19.66	0.03	0.361
Pseudoscorpionida		Pscr	216.25 ab	0.34	19.66 a	0.03	275.22 b	0.46	0.023
Sympyla	Scolopendrellidae	Scol	235.90	0.38	157.27	0.27	137.61	0.23	0.737
	Scutigerella	Scut	39.32	0.06	-	-	19.66	0.03	0.553
Hymenoptera	Formicidae	Form	58.98	0.09	747.03	1.30	58.98	0.10	0.354
Oligochaeta	Lumbricina	Lumb	117.95	0.19	176.93	0.31	216.25	0.36	0.632
Other		Oth	412.83	0.66	314.54	0.55	216.25	0.36	0.463
Total			62,888.26	100	57,246.21	100	59,959.11	100	0.897

Means with different letters in the same line are significantly different ($P < 0.05$).

Redundancy analysis (RDA) conducted using the forward selection method showed that litter mass (Litter; $P = 0.018$), litter carbon (LitterC; $P = 0.038$), soil acidity (pH; $P = 0.031$), soil temperature (T°; $P = 0.042$), Shannon diversity (H′) and evenness (J′) were the only variables that had a significant effect on the distribution of the different taxa (according to Monte Carlo permutation test with $P < 0.05$ for all these variables). The abundance of microarthropods was affected by tree species and some environmental variables (figure 2). RDA axis 1 represents an environmental gradient and axis 2 represents a tree species gradient among microarthropods. Eigenvalues of RDA axis 1 (0.196, $P \leq 0.001$) and 2 (0.079) explained 50.9 % of the total microarthropod-environment variance. Microarthropod-environment correlations were both axis 1 (0.97) and 2 (0.79). Our results also showed that the abundance of microarthropods depended on the litter mass, litter carbon, soil pH and soil temperature (figure 2).

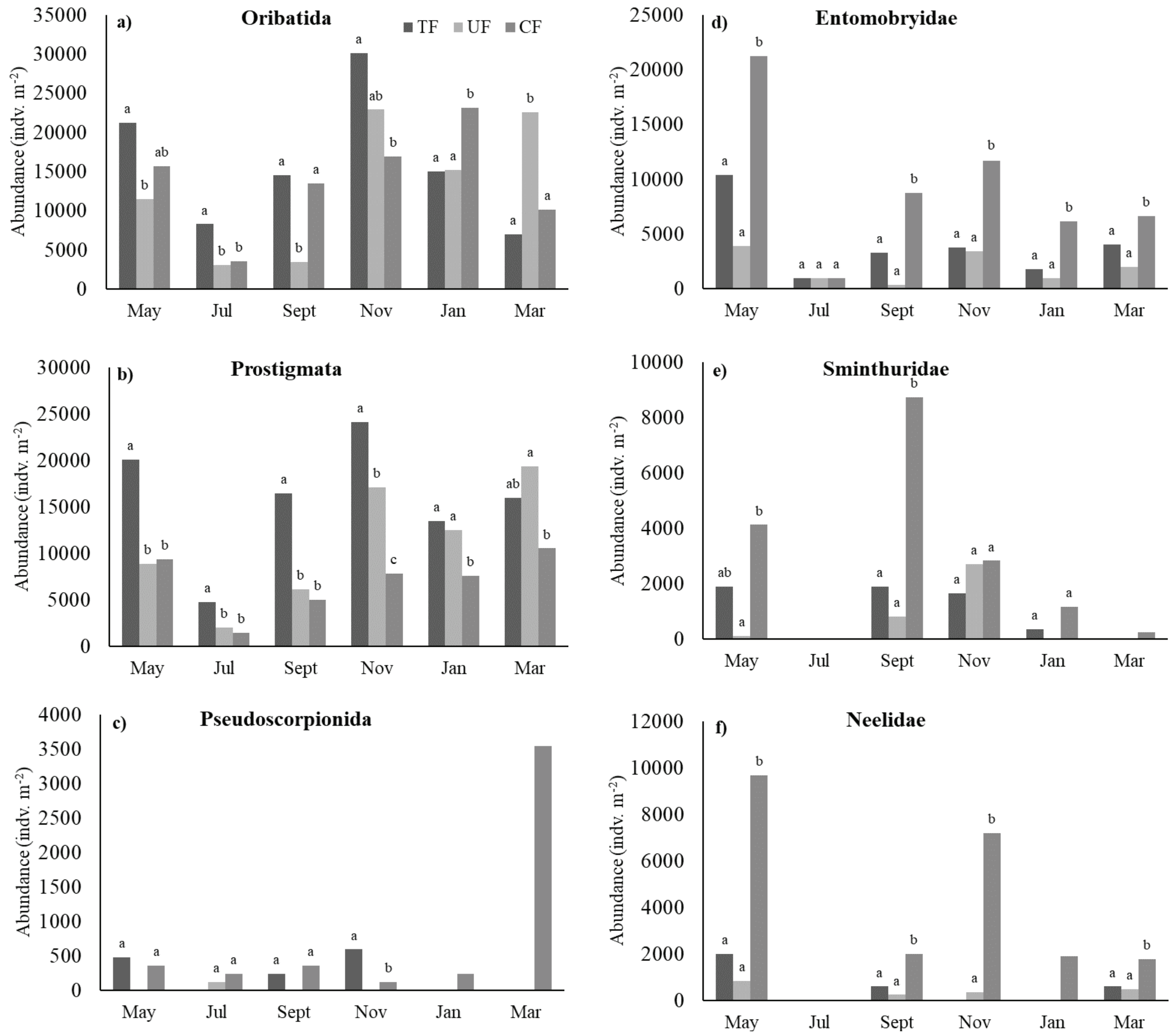

Figure 1. Seasonal changes in abundance of some taxa found under three fir species during the study period. Means with different letters are significantly different at $P < 0.05$.

Cambios estacionales de abundancia de algunos taxones en tres especies de abeto diferentes durante el período de estudio. Medias con letras diferentes son significativamente diferentes ($P < 0,05$).

DISCUSSION

In the present study, C_F is clearly statistically separated from other sites in terms of litter mass, litter carbon and litter nitrogen and microarthropod diversity (table 1 and figure 2). In addition, Monte Carlo tests of RDA were used to evaluate relationships between microarthropods and litter mass, litter carbon, soil pH and temperature, which revealed that fir species may induce changes in biotic and abiotic variables (Augusto *et al.* 2002).

The total abundance of microarthropods ranged from 57,246 to 62,888 indviduals m^{-2} and was not significantly different ($P > 0.05$) among the three fir species. Some taxa were significantly higher at site C_F where soil pH, litter mass, soil carbon, nitrogen and C/N ratio were significantly different from those at the other sites (table 1). The highest biodiversity of microarthropods was found at site C_F (H':1.96; $P = 0.000$) compared to T_F (1.72) and U_F (1.62) (table 1) sites. These results indicate that litter mass, litter carbon, soil pH and temperature significantly influenced the abundance and diversity of some taxa (figure 2). Some studies (Gongalsky *et al.* 2008, Sharon *et al.* 2001) conducted in Mediterranean forests show that soil parameters were more important for explaining differences among soil animal communities than among plant communities. Moço *et al.* (2010) showed that invertebrate diversity was affected by soil quality components; soil pH in particular had a direct positive effect on the diversity of microar-

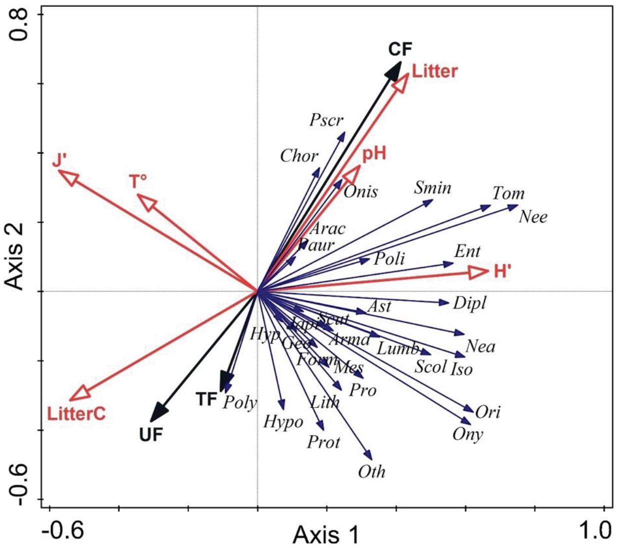

Figure 2. RDA ordination diagram showing quantitative community composition in relation to the fir species. Species are represented by blue arrows and environmental variables are represented by red arrow (T_F, Taurus fir; U_F, Uludağ fir; C_F, Caucasian fir; Litter, litter mass; LitterC, litter carbon; pH, soil acidity; T°, soil temperature; H′, Shannon-Wiener diversity; and J′, Pielou's evenness). For the abbreviations of the soil arthropod code, see table 2.

Diagrama de ordenación RDA que muestra la composición cuantitativa de la comunidad en relación con los sitios de abeto. Las especies están representadas por flechas azules y las variables ambientales flechas rojas (TF, abeto Tauro; UF, abeto Uludağ; CF, abeto Caucásico; hojarasca, masa de hojarasca; LitterC, carbono de hojarasca; pH, acidez del suelo; T °, temperatura del suelo; H', diversidad de Shannon-Wiener; y J', índice de Pielou). Para ver las abreviaturas del código de artrópodos del suelo, consulte el cuadro 2.

thropods. In general, increase in soil acidity decreases the abundance of microarthropods (Gillet and Ponge 2004, Loranger-Merciris *et al.* 2001). Compared to other sites, acidic T_F soils had high carbon and nitrogen content (table 1). This suggests that soil pH affects the rates of decomposition of organic matter, changing the carbon and nitrogen content of the soil. This pH-mediated increase in carbon and nitrogen content has a negative effect on the diversity of microarthropods. The lowest soil carbon content can be expected in forest soils with a pH range 5.0–6.0. Below pH 5.0, biological activity is reduced, which may lower the decomposition rates of organic matter, leading to increase in carbon content (Motavalli *et al.* 1995). Our results show that pH positively affected microarthropods at C_F site, which had the highest pH among the three sites. Similar results on the effect of pH on microarthropod communities have been reported elsewhere (Lavelle *et al.* 1995). Soil pH has been identified as a factor strongly influencing Collembola communities (Gillet and Ponge 2004, Loranger-Merciris *et al.* 2001). The results of the present study show that Collembola was the second most abundant arthropod identified at all the three fir sites. This is in agreement with the results of (Fountain and Hopkin 2005) who reported that Collembola was the most abundant hexapod in soil and can reach high densities up to 100,000 individuals per square meter. In the present study, Entomobryidae, Tomoceridae, Sminthuridae and Neelidae were found in significantly higher abundance at C_F site (table 1, figure 1).

Thick litter layers form a preferred habitat for microarthropods (Hasegawa and Takeda 1996, Ponge 2003). Several studies have reported about the relationship between the abundance of microarthropods and amount of litter (Cakir and Makineci 2013). In the present study, the highest litter mass was measured at C_F site; this explains the larger richness of saprophagous taxa such as Isopoda and Diplopoda at this site. David and Gillon (2002) stated that diplopods do not feed on fresh and phenolic-rich litter. Litter consists of three layers: litter, fermentation and humus. As Entomobryidae and Tomoceridae (Collembola) are relatively large microarthropods, they require a thick litter layer for shelter. A thick litter layer supports an abundance of Collembola, which leads to a large fermentation layer comprised of rich, decomposing organic matter, which promotes diplopod abundance. This may explain the higher abundance of Entomobryidae (Collembola) and Chordeumatida (Diplopoda) at site C_F.

The diversity of microarthropods was also affected by carbon and nitrogen content, low C/N ratio and decomposition rate. Cakir and Makineci (2013) reported a positive correlation between the quality of litter and the diversity of microarthropods. Similarly, low C/N ratio and high diversity and richness were found at site C_F.

CONCLUSIONS

Fir species were found to significantly affect soil microarthropod diversity and abundance. The distribution of microarthropod taxa was significantly affected by the pH and temperature of soil and carbon content and mass of litter, which are all influenced by fir species. For example, some arthropod species were found only at C_F. There was no significant difference among fir species in the abundance of arthropods, while their richness and diversity were significantly different. The most important diversity and richness occurred at site C_F and lowest at U_F. The amount of litter mass varied with fir species. This was attributed to the differences in the litter decomposition rate, which is affected by dissimilarities in the amount and chemical composition of litter falls. In addition, these differences in litter had a major influence on carbon and nitrogen content and pH of the study soils. Mean abundance of some arthropod taxa was significantly different between fir species and seasons. The thick litter layer at C_F compared to T_F and U_F indicated that neither the ecological niche nor the amount of organic matter was the driving force that determined the structure of the microarthropod community. Results showed that variation in soil arthropods was affected by the properties of soil and litter under three different fir species. Further studies are required to better understand and generalize the relationship between soil arthropods and plants.

ACKNOWLEDGMENTS

I especially thank Prof. Dr. Sabit Erşahin and Dr. María del Carmen Fernández Lago for their help and support on the manuscript.

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Recibido: 22/11/17
Aceptado: 16/10/18